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# Estimation and diminution of $CO_2$ emissions by clean development mechanism option at power sector in Oman

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**Abstract**
Carbon dioxide ($CO_2$) is one of the major pollutants among greenhouse gases emitted by fossil fuel based power plants and responsible for environmental tribulations. Therefore diminution of carbon dioxide level by Clean Development Mechanism (CDM) is now serious concern worldwide. This paper evaluates the emission factors of national electric grid in Oman and proposes a wind energy based CDM project to diminish the $CO_2$ emissions. Estimations show that operating margin emission factors of national grid during five years lies in the range of 0.74 to 0.69 kg $CO_2$/kWh. Further, proposed CDM project revealed the annual baseline emissions reduction of 45552 ton $CO_2$ and able to earn the revenue of US$ 61.49 million by certify emission reductions in the first crediting period of project. Paper also critically analyse the opportunities for CDM project, its lucrative aspect, barrier and challenges.


**Keywords:** Build margin; $CO_2$; Clean development mechanism; Emission factor; Operating margin.

## 1. Introduction

It is well known that six Gulf Cooperation Council (GCC) states i.e. Oman, United Arab Emirates, Saudi Arabia, Bahrain, Qatar and Kuwait are blessed with abundant renewable energy resources; however their economy is still heavily dependent on export of fossil fuel products. These countries hold around 23.5% of the world's natural gas and 40% proven oil reserves [1]. In present scenario the economical growths of GCC states are better represented by their gross domestic product and per capita energy consumption which are much higher compare to other developing countries [2]. Most of their domestic energy needs are served by the fossil fuels which eventually responsible for their higher per capita Greenhouse Gas (GHG) emissions. For instance only 0.61% of the world's population is residing in GCC countries but they are contributing about 2.4% of the total global GHG emissions [1]. Further it is significant to note that GCC states are standing at the top 25 countries of $CO_2$ emissions per capita on global ranking [3]. The oil and natural gas fields in Oman are more widely scattered and may be depleted in another 2 to 4 decades respectively [1] while the trend of its domestic energy consumption is ever increasing. Electrical power and transport sectors are largely operated by natural gas and oil respectively while the coal has proposed to generate electricity in near future. Combustion of fossil fuels are predominantly accountable to produce greenhouse gases consist of Carbon Dioxide ($CO_2$), Methane ($CH_4$) , Nitrous Oxide ($N_2O$) and other fluorinated gases along with considerable waste of energy. Since $CO_2$ is plying dominating role in climate change and emissions of other gases are comparatively minor, hence the subject matter of $CO_2$ is examined in this paper. Other than emissions, recycling of waste gases discharged by power plants in

Oman could also have the potential scope of study for environmental benefits under CDM projects. Sector wise contribution of $CO_2$ emissions in Oman, compiled from various sources [4, 5] during 2009 is shown in Figure 1. It can be depicted from Figure 1 that power sector is the highest contributor with 35% of total $CO_2$ emissions followed by transport sector with 26% while industries (particularly cement and steel industry) are stand at third place. Around 85% of total electricity in Oman is generated by natural gas based power plants which are largely connected to national grid known as Main Interconnected System (MIS) while 15% off-grid electricity is generated from widespread diesel and other sources particularly at Dhofar, Mashirah and Musandam area. Theses scattered diesel power plants may be part of national grid soon due to rapid development of Dhofar region and upcoming 1000 MW coal fired based power plant in the region.

The transport sector across the country is rapidly developing and estimated data of 2009 shows that 256 cars on each 1000 people were in operation [6] while additional 0.12 million new vehicles were registered during 2010 [7]. Major fuel used for transport sector is either petrol or diesel while Compressed Natural Gas (CNG) and electrically operated techniques are still waiting their ground to be explored at commercial level.

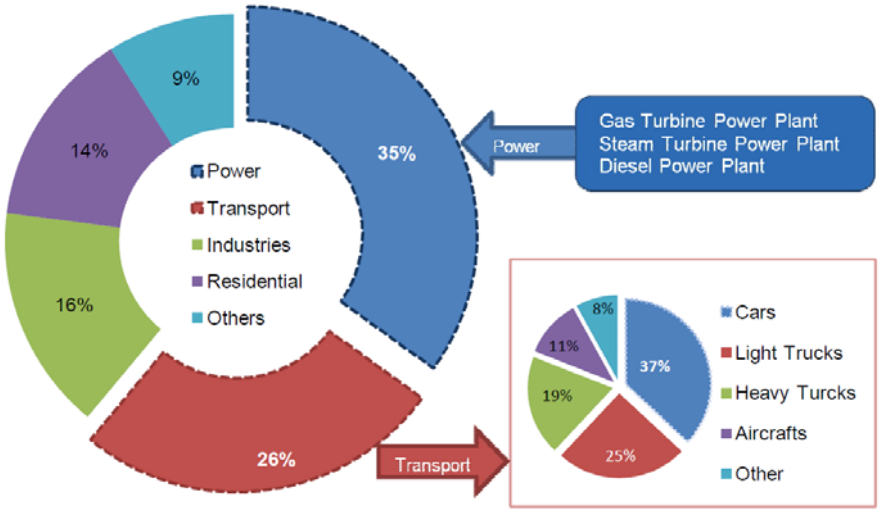


Figure 1. Sector wise $CO_2$ emissions during 2009

After the policy to diversify the economy from fossil fuel to other sectors and power sector reforms in 2005, the demand of electricity has increased by average 9% per year. The electricity demand is expected to rise further due to upcoming industrial and tourism projects. Hence to balance the demand and supply, additional power generation is inevitable which further mount pressure on the quantity of fossil fuel combustion. Moreover the country's natural gas supplies are largely committed [8] therefore gas based plants will shift to oil and coal fired power plants. For instance a proposed 1000 MW coal based power plant at Duqm in Dhofar region expected to be operational by 2015. It is obvious that if gas based power plants are replaced by oil and coal, the $CO_2$ emissions level will be much more than present level and this situation will put a big challenge to oblige the Kyoto protocol. To deal with such emissions problem, measures like CDM based projects need to be taken into consideration.

The CDM methodologies for diminution of $CO_2$ emission from fossil fuels have been looked into in a number of studies [9-14]. However estimation and diminution of $CO_2$ emissions in context to Oman under CDM activities is so far unexplored. As a member of United Nations Framework Convention on Climate Change (UNFCCC), Oman has ratified the Kyoto protocol in 2005 [15] to contribute in solution of global warming problem. Under Kyoto protocol various methodologies like approved methodology, approved methodology for small scale project and aforestation and reforestation approved methodologies are described to control the GHG emissions. Clean development mechanism is one of the key components to help developing countries to accomplish sustainable development and assist industrialized nations abiding with their anticipation of emission reductions [13]. There are various domains which could be explored under CDM such as energy efficiency, fuel switching, methane recovery, industrial process changes, cogeneration and agriculture etc. In context to Oman, fuel switching from oil/gas to

 

renewable energy, waste gases utilisation for combined cycle power plant, energy efficiency, demand side management in power sector [16], oil to compressed natural gas and use of electric vehicle in transport sector are more favourable.

In this paper, an attempt has made to estimate the $CO_2$ emissions factor by considering national grid as the electrical system and to evaluate the reduction in emissions by proposing wind power to displace the conventional power generation as a case of CDM project. The paper is organised in six sections. Section 1 introduces the general overview of $CO_2$ emissions and its contribution by various sectors in Oman. Section 2 describes the overall scenario of natural gas production, its consumption and per capita $CO_2$ emissions. Estimation of grid emission factor using operating, build and combined margin is discussed in section 3. Section 4 presents the diminution of primary energy input and $CO_2$ by introducing wind energy under CDM project. A critical analysis on opportunities and barriers for CDM project is described in section 5 while section 6 concludes the paper.

## 2. Energy and $CO_2$ scenario in Oman

Fossil fuels are playing leading role in the economic development of Oman. Since 2005, average 77.54% of government's revenue is generated from the export of petroleum products [17]. Now energy scenario in Oman is changing compare to a decade ago when most part of its natural gas and oil was exported and considerably small part was sufficient to cater the local needs. Also with respect to time its fossil fuels reserves have come down to saturation and domestic energy demands particularly in power, industrial and residential sectors are increasing considerably. It can be seen from Figure 2, the consumption of natural gas has increased by 152% in a span of one decade i.e. year 2000-2009. The crude oil production in 2009 was about 0.863 million barrels per day and its 13.5% had consumed to feed the local demands [18], which is largely shared by diesel power plants and transport sector across the country.

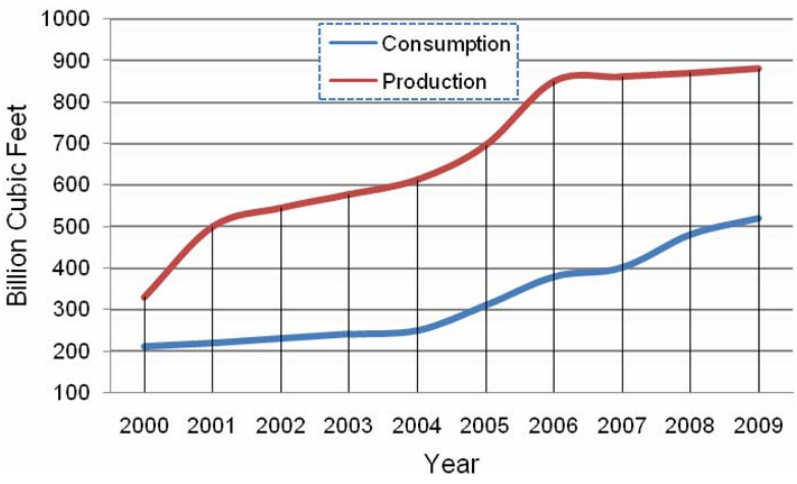


Figure 2. Gas production and consumption [18]

### *2.1 Fossil fuels and per capita $CO_2$ emissions*

It can be seen from the Figure 3 that $CO_2$ emission from the natural gas is higher than oil due to large quantity of gas used in power, industrial and residential sectors. The level of $CO_2$ emission resulted from the combustion of fossil fuels have increased about 140% in 2009 compare to the level of year 2000. Further it can be observed from Figure 3 the contribution in emissions by oil has maintained the similar pace with natural gas, however scenario may change soon when oil and other fossil fuel will supersede the use of natural gas due to more diversify upcoming power plants and mushrooming private and public motor vehicle density on the road.

It can be seen from the Figure 4 that average per capita $CO_2$ emission during 2005 to 2009 has increased 47% compared to the average value of 2000 to 2004. Further it can be seen that since 2001, the emission has been increased by 13% annually. According to the data revealed by United Nations Statistics Division [19] in 2009, the Oman has per capita $CO_2$ emissions more than 5 times the world average value and significantly higher than average value of developing countries. In the present circumstances when Oman is still among the less industrialised nations, high per capita emission level is alarming and essentially requires the diminution measures of carbon dioxide.

 

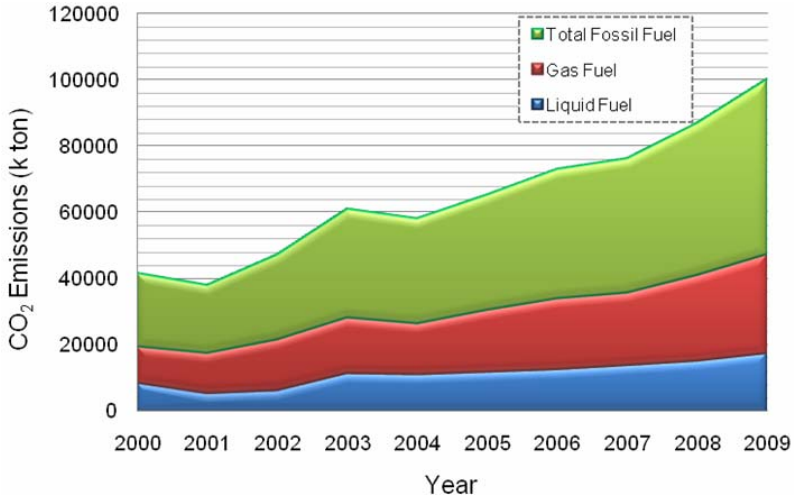


Figure 3. $CO_2$ emission by fossil fuels

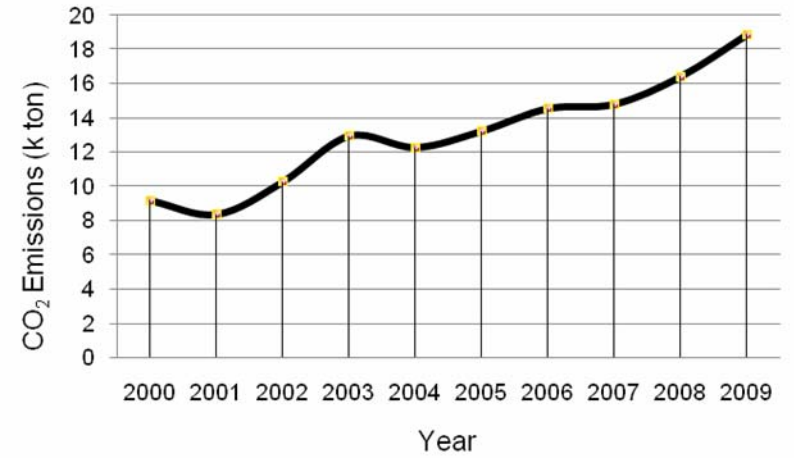


Figure 4. Per capita $CO_2$ emissions

## 3. Estimation of grid emission factor

In order to calculate the $CO_2$ emission factor of electricity generated or supplied by the electrical systems or national grid across the country, methodological tool i.e. "*Tool to calculate the emission factor for an electricity system*" [20] proposed by the CDM projects have implemented. The combined margin emission factor resulting from weighted average of operating and build margin represents the $CO_2$ emission factor of electricity system. The modus operandi to estimate the grid emission factor and reduction is shown in Figure 5.

The $CO_2$ emission factors of fossil fuels used for electricity generation are country-specific and depend on various factors [21]. As the sector-specific fuel emission factors are not readily available therefore values used for similar calculation by other CDM project is taken into account as 0.65 and 0.91 $tCO_2$ /MWh for natural gas and diesel respectively [22]. Some assumptions made for calculations are as follows:

- Though Dhofar Power Company is partially off-grid but taken into account to estimate $CO_2$ emissions due to rapid development of region and upcoming proposed large scale power station.
- Direct and indirect sources associated with $CO_2$ emissions during project construction as a result of transport of material and equipment to project site as well as emissions from manufacture of parts, supplies and machinery required for project are excluded.
- The CO2 emission factor for net electricity imports from GCC power grid [23] and total grid losses are considered as zero and same is applicable for water desalination plants and power produced by large industrial customers who have their independent power plants because of non availability of detailed data.

 

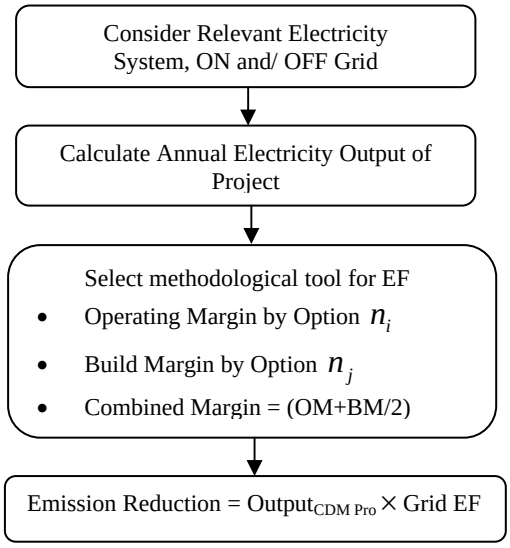


Figure 5. Flowchart to evaluate emissions and $CO_2$ reduction by CDM project [13, 24]

*3.1 Operating margin*

This refers to emission factor of a group of power plants that reflect the existing power plants whose output would be influenced by the proposed CDM activities [25]. There are number of options like simple, adjusted, dispatch data analysis and average through that Operating Margin (OM) can be determined. In context to Oman, simple adjusted and dispatch data analysis options are not meeting the eligibility criterion and hence not used. The most viable way is to consider the detailed load contribution of each type of generation unit under simple operating margin. Following equation is widely used to determine the average weighted emissions in producing the unit of energy from all generating sources connected to the national grid [25-27]

$$EF_{grid,OMsimple,y} = \frac{\sum_m FC_{i,m,y} \times NCV_{i,y} \times EF_{CO_2,m,y}}{\sum_m EG_{m,y}} \quad (1)$$

where, $EF_{grid,OM\ simple,y}$: Simple operating margin $CO_2$ emission factor in year $y$ ($tCO_2$/MWh), $FC_{i,m,y}$: The amount of $i$ type fossil fuel consumed by generating unit $m$ connected to grid in year $y$, $NCV_{i,y}$: The net calorific value (energy content in gJ/volume unit) of fossil fuel type $i$ in year $y$, $EF_{CO_2,m,y}$: $CO_2$ emission factor of power unit $m$ in year $y$ ($tCO_2$/gJ), $EG_{m,y}$: Quantity of electricity generated and delivered to the grid by power unit m in year $y$ in MWh, $m$: All power units serving the grid in year $y$ while $y$: Time frame in years, $i$: All types of fossil fuels brunt by the power unit $m$ in year $y$.

Using default values from IPCC guidelines for GHG inventories [26, 27, 35], the $CO_2$ emission coefficient of each fossil fuel type associated with national grid on 2009 is shown in Table 1.

It can be seen from the Table 2, the OM emission factor has improved since 2008 because the share of diesel based power plants in Oman have decreased due operation of LNG based Barka Power and Desalination Plant- II

Table 1. Average weight of emission factor for main interconnected system

| Fuel Type | kg $CO_2$/kWh | Generation Mix (%) | EF (kg $CO_2$/kWh) |
|---|---|---|---|
| Liquid Natural Gas | 0.65 | 84 | 0.55 |
| Diesel and Other | 0.91 | 16 | 0.14 |
| Weighted Emission Factor in 2009 ($EF_{grid,OMsimple,y}$) | | 0.69 | |

 

Table 2. Operating margin emission factor for main interconnected system

| Year | Emission Factor (kg $CO_2$/kWh) |
|---|---|
| 2005 | 0.74 |
| 2006 | 0.74 |
| 2007 | 0.71 |
| 2008 | 0.70 |
| 2009 | 0.69 |
| $EF_{grid,OMsimple,y_1-y_5}$ | 0.72 |

*3.2 Build margin*

This refers to emission factor of a group of recently built generating units whose construction would be affected by the proposed CDM project activity [25]. The Build Margin (BM) emissions factor is the generation-weighted average emission factor (in $gCO_2$/kWh or $tCO_2$/MWh) of all power units during the most recent year for which power generation data is available. This is calculated as follows [25-27]:

$$EF_{grid,BM,y} = \frac{\sum_m EG_{m,y} \times EF_{el,m,y}}{\sum_m EG_{m,y}} \quad (2)$$

where, $EF_{grid,BM,y}$ : Build margin $CO_2$ emission in year $y$, $EG_{m,y}$ : Net quantity of electricity generated and delivered to the grid by power unit $m$ in year $y$ (MWh), $EF_{el,m,y}$ : $CO_2$ emission factor of power unit in year $y$ ($tCO_2$/MWh), $m$ : Power units included in the build margin and $y$ : Time frame for most recent historical year for which power generation data is available.

According to AERO annual report [28] total MIS output of Oman in 2009 was 17,410 GWh. Therefore, 20% of the total system generation is 3482 GWh. The total system generation of power plants from 2005 to 2009 is about 3491 GWh from Barka Power Plant Phase-1 and II. The evaluation results a build margin emission 0.61 $tCO_2$/MWh for MIS as shown in Table 3.

Table 3. Baseline emission factor of national grid

| Tool | Weight | Emission Factor |
|---|---|---|
| Operating Margin | 0.5 | 0.69 |
| Build Margin | 0.5 | 0.61 |
| Combined Margin ($EF_{grid,CM,y}$) | 0.65 | |

*3.3 Combined margin*

This refers to weighted average of operating margin and build margin. Most of the methodologies approved by CDM projects to determine the coefficient of emissions in power generation proposed to use average weighted value estimated of OM and BM. This combined approach is used for assessment of the grid emission factor and calculated as follows [25-27]:

$$EF_{grid,CM,y} = W_{OM} \times EF_{grid,OM,y} + W_{BM} \times EF_{grid,BM,y} \quad (3)$$

where, $EF_{grid,OM,y}$ : Operating margin $CO_2$ emission factor in year $y$ ($tCO_2$/MWh), $EF_{grid,BM,y}$ : Build margin $CO_2$ emission factor in year $y$ ($tCO_2$/MWh), $W_{OM}$ : % weighting of the operation margin emission factor and $W_{BM}$ : % weighting of the build margin emission factor.

To calculate the Combined Margin (CM) of grid emission factor for year 2005 to 2008, data required to calculate the BM eligibility criterion is not available. Therefore simplification option under the purview of grid emission factor tool can waive the BM calculations, subjected to CDM project is situated in a country with less than ten registered CDM project activities at the commencing date of validation. This

 

check is satisfied for this study, as there is no registered CDM project in Oman till 2011. Counting above discussion, the CM may be evaluated by considering the average of OM for 2005 to 2008. The estimated $CO_2$ emissions of MIS along with baseline grid emission factor is summarised in Table 4.

Table 4. $CO_2$ emissions of electricity system

| Year | Baseline Grid Emission Factor | Annual Generation (GWh) | $CO_2$ Emissions (k ton $CO_2$) |
|---|---|---|---|
| 2005 | 0.74 | 12648 | 9359.52 |
| 2006 | 0.74 | 13258 | 9810.92 |
| 2007 | 0.71 | 14133 | 10034.43 |
| 2008 | 0.70 | 15721 | 11004.70 |
| 2009 | 0.69 | 17823 | 12297.87 |

## 4. $CO_2$ reduction by CDM based project

Geographically Oman is blessed with most favourable solar condition in the world and moderate to good wind speed to produce bulk electricity [29, 30]. The effective use of available abundant wind and solar energy potential could solve the local and regional energy problem and part of it can be export to energy deficient countries through GCC power grid. It can be seen from Figure 6, the solar energy potential is higher at north-west strip of Oman with annual average sunshine duration of 3708 hours while the south-east coastal strip is observing good wind energy potential [30]. The harnessing of solar energy is still expensive and less efficient compared to wind therefore wind energy based CDM project has proposed in paper. The environmental performance could be addressed by considering CDM project based on the electricity generated by wind energy which otherwise would have been supplied by fossil fuelled based power plants. Such CDM based projects may be beneficial in two fold to mitigate the $CO_2$ emissions as well as to diminish primary energy input required for conventional generation.


Figure 6. Higher wind and solar energy potential strips [Map source: www.maps.com]

 

*4.1 Wind energy and baseline emission*

It is proposed in this study that a wind energy project of 25 MW for its first crediting period of 10 years is located at Marmul in the southern part of Oman where moderate to high wind speed potential is available. The wind speed data of three years are collected [30, 31] to develop the average wind speed profile and shown in Figure 7.

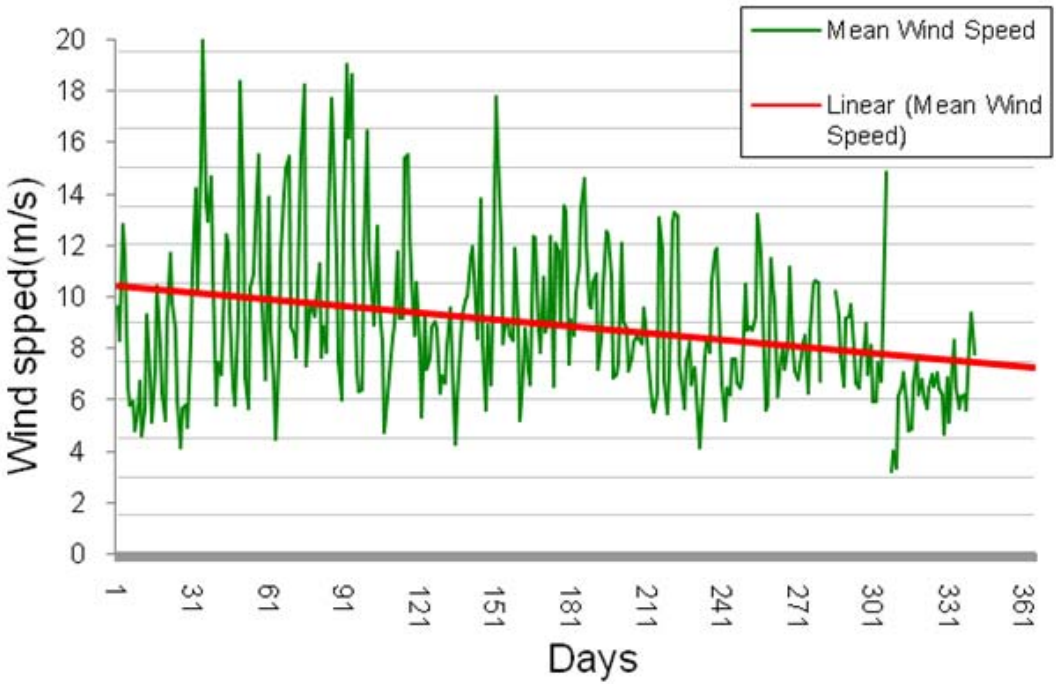


Figure 7. Average wind speed profile at Marmul

It is tangible to assume based on study carried out by COWI & Partner that wind turbine can operate at 32% plant factor which is also widely used in non-OECD and Middle East countries [30]. The annual electricity production of project is determined as 70 GWh using following expression.

$$Annual\ Project\ Output = Electricity\ Produced \times Plant\ Capacity\ Factor \tag{4}$$

The expected annual project emissions for generated output will be zero as input to plant is pollution free. The baseline $CO_2$ emission per year for this project can be determined by considering grid emission factor 0.65 kg $CO_2$/kWh, as emission factor for energy generated by wind turbine.

$$\begin{aligned} Baseline\ CO_2 Emission &= Output(MWh) \times Grid\ EF\ (tCO_2 / MWh) \\ &= 45552\ tCO_2 \end{aligned} \tag{5}$$

Using above calculation the net annual reduction in primary energy input and $CO_2$ emissions for the project are 70080 MWh and 45552 t$CO_2$ respectively. If $CO_2$ is emission is converted into credits known as certified emission reductions (CERs) to sale at average rate of $ 13.5 per ton [13, 32], it may earn about US$ 614952 per year or US$61.49 million in the first crediting period of project.

**5. Opportunities and barriers for CDM projects**

After ratification of the Kyoto protocol in 2005, the federal government of Oman had constituted the ministry of environment and climate change to deal the issues of climate change at administrative capacities. In late July 2009, government had announced the creation of a Designated National Authority (DNA) pursuant to its commitment as a 'non-Annex-I party to the Kyoto Protocol [33]. The creation of a DNA is a crucial step that will ultimately allow Oman to host projects, including renewable energy and clean technology that could reduce GHG under the Kyoto Protocol. It seems from the initial policies framed by DNA that Oman is taking seriously the opportunities in climate change and that many

 

entrepreneurs and petroleum field operators stand to benefit from these CDM based projects initiatives. These projects may provide economic benefits by revenue from emissions credits sales and developing the international carbon markets. However initiatives of CDM projects may also face some challenges due to immature policies which certainly need adequate time before details of DNA policies become effective.

*5.1 CDM opportunities in Oman*

- Study carried out by AERO revealed that Oman represents a potentially attractive market for investment in renewable energy and energy efficient initiatives that fall within the scope of the Kyoto Protocol's Clean Development Mechanism [30, 33]
- The ministry of environment and climate change is in the process of setting up the DNA, which must certify all candidate CDM projects before they are considered for registration as CDM initiatives under the UNFCCC.
- The CDM could be a principal driver for investors to develop energy efficient projects, especially in the context of current efforts to diversify economies away from fossil fuel into manufacturing and tourism industries. In power sector, energy efficiency and waste gases utilisation for combined cycle power plants represents a lucrative candidate CDM opportunity.
- The deployment projects leading to switching of electrical power generation from conventional fossil fuels to renewable energies will reduce the local demand of gas and oil and keep their fossil reserve intact for longer time. This will enhance the export capacity of country to earn hard currency for further development and also earned the CER credits which could be sold to industrialised or Annex-I countries.
- It is clear that the amount of $CO_2$ emission reduction is the main index for CDM, which are lucrative from the view point of ecologically and climate change. Two illustrations are given here to sense the benefits.

(i) If measures are not initiated to reduce $CO_2$, the rise in sea level resulting from global warming could submerge the 2092 km long coastline of Oman and will adversely hit to its marine life as well as the livelihood of thousands of inhabitants.

(ii) The drinking water in Oman is facilitated either by limited fresh water reserves or desalination of sea water. Rising temperature will soon dry out theses freshwater reserves and increase the salinity in seawater. Therefore the solutions to these problems are more beneficial to address today then to pay a heavy cost in future.

*5.2 Barriers and challenges*

- As of today the Oman is exempted from any essential obligations to reduce GHG emissions by international community. This discourages the political will to frame the strong policies to switching existing projects to low carbon power project under the umbrella of CDM.
- In order to apply the CDM methodologies and to develop the baseline, extensive data is required. For instance, in case of gas and diesel the data about the fossil fuel consumptions (excluding subsidies) at each level i.e. grid connected power plants, off grid plants, transportation etc. is needed which are not readily available.
- Insufficient bilateral $CO_2$ reduction programme with regional and industrialised countries, for instance Saudi Arabia is the first country among the GCC who had deployed Solar Energy Research American Saudi (SOLERAS) for 22 years (1975 to 1997) in collaboration with US Department of Energy to reduce the dependency of remote area on conventional power [34].
- Public or private entrepreneurs seeking to participate in CDM activities must comply with CDM rules in order to ensure that CERs are properly issued. CERs must be validated, registered, verified and certified by the proper national and international authorities and independent auditors before issuance. As of today there is no authorised body for carbon credit exchange to attract the emission trading market in the country.

## 6. Conclusion

The Kyoto protocol with its CDM activities provides a way to encourage Annex-I countries and highly industrialised countries to cultivate climate friendly projects in non-Annex-I and developing countries. However, while the CDM in general is expanding rapidly among developing countries, Oman has so far

 

hardly represented in the CDM project portfolio. There could be various reasons like lack of awareness to climate change and its long term effects, presence of abundant fossil fuel and exemption from any compulsory obligation from $CO_2$ reductions. However the rapidly increasing per capita $CO_2$ emissions and depleting fossil fuel reserves and abundant potential of renewable energy are major drivers to consider the CDM based projects for economic and environmental benefits. To foster the CDM projects activities, national grid is taken as main electrical system and emission factors are estimated. A case of 25 MW wind energy project at Marmul is consider to evaluate the diminution of $CO_2$. Following are the major findings of this study.

- Main interconnected system has the operating margin emission factor in the range of 0.74 to 0.69 kg $CO_2$ /kWh during 2005 to 2009 respectively. Since 2005 the emission factor has improved by 6.75% in 2009 due to commissioning of gas based low carbon plants.
- Annual primary energy input to MIS by the CDM project is 70.08 GWh and annual baseline emission reduction is 45.55 k $tCO_2$.
- In the first crediting period of project the revenue earned by CERs is US$ 61.49 million subjected to sale the CERs at US$ 13.5 per ton $CO_2$.

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