Clean Development Mechanism Projects for Developing Countries: Potential for Carbon Emissions Mitigation and Sustainable Development

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Abstract—Energy shortage is one of the major impediments to social, industrial and economic growths in developing countries. For instance, only about 40% of Nigeria’s population (about 170 million) has access to electricity. Due to this, petrol/diesel generators are used for electricity generation in various sectors of the country, which are not eco-friendly. Though developing countries are thought to emit lesser greenhouse gases compared to industrialized nations, due to low industrial activities, a global cooperation is necessary to mitigate climate change.

The intent of this paper is to develop solar power generation systems through Clean Development Mechanism (CDM), which involves investments in clean technologies, in developing countries by governments, companies or agencies from developed countries, with the aim of reducing greenhouse gas emissions, at an optimum cost. This could offer a possible solution to energy poverty, and also lead to sustainable development in developing countries, including Nigeria. Case studies were conducted for Nigeria using small-scale PV systems for different applications. The paper also presents the modalities for CDM agreement between two parties, the benefits and challenges. The CO₂ emissions that could be avoided by adopting the proposed energy systems are also discussed.

Index Terms—Carbon emission, distributed generation, energy consumption, renewable energy, sustainable development

I. INTRODUCTION

Energy is an important component of a modern human society; it affects the social, industrial, economic and developmental aspects of any nation. Also, access to reliable and affordable energy services is crucial for better lifestyles, and poverty alleviation. For these reasons, energy is one of the potential factors for ascertaining whether a country is developed or less developed [1]. While developed countries are working towards diversifying their energy systems to achieve future energy security, many developing countries on the other hand, are battling with the challenges of reliability of the existing power networks, availability and poor access to electricity [2]. It is estimated that about 17% of the global population lives without access to electricity [3]; majority of these people are within sub-Saharan Africa and South Asia. The number of people in these two regions who are not connected to electricity network is 585 and 493 million respectively, out of a total of about 1.5 billion people in the world with no access to modern electricity [4]. For example, the available power generation capacity of Nigeria is less than 5GW; with only about 40% of its 170 million population having access to electricity [5][6]. The electricity supply is often not reliable, due to the wide gap between the users’ demands and the available generation capacity. The rural areas are mostly not connected to the electricity network, with around 90% without access to the network [5][7]. Due to this, fossil-fuelled generators are resorted to for meeting daily electricity demands in most sectors of the country, leading to increased air pollution, which is detrimental to health and also contribute to climate change. Nigeria is also amongst the world’s highest emitters of flare gas [8][9]. There is the need to address these issues to save the environment. Though developing countries are thought to emit lesser greenhouse gases compared to industrialized nations [10], due to low manufacturing and industrial activities, a global effort is necessary to mitigate climate change.

Nigeria operates a centralized power generation system with a total installed capacity of over 6GW, out of which about 4.522GW and 1.93GW of electricity are produced from thermal and hydro power systems respectively [5][11]. Electrical power is usually generated at the generation plants
at 14 –16kV, stepped up to 330kV and transmitted over long distances; it is stepped down to 132kV, and then to primary and secondary distribution level of 33/11kV and 0.415/0.22kV respectively. The country has huge primary energy resources such as oil and gas, solar, wind, hydro and biomass, which could help it in achieving energy security, if they are properly harnessed [5]. Currently, hydro, wind and solar PV power and geothermal systems have global total installed capacities of 1,000GW, 318GW, 139GW and 12GW respectively, based on REN21 2014 renewable energy global status report [4]. Renewable energy accounts for 22.1% of the global electricity production, as at the end of 2013. Solar PV system has increased by 28% over the 2012 capacity. This shows that PV technology is receiving increasing attention around the world. Therefore, the widespread application of distributed solar PV systems in Nigeria is expected to play a vital role in liberating its citizens from the energy poverty problem [12].

The remaining part of this paper is organized as follows: section II focuses on climate change issues and electricity generation in Nigeria; section III discusses distributed generation, the CDM process and the existing CDM projects in Nigeria; section IV centers on the case studies – simulations of PV generation systems for different applications; section V and VI concentrate on the results and discussion, and the future work respectively, and the paper is concluded in section VII.

II. CLIMATE CHANGE AND ELECTRICITY GENERATION IN NIGERIA

A. Impact of Climate Change

Though developing countries are assumed to emit lesser greenhouse gases (GHGs) compared to the developed countries [10], most developing countries are bearing the consequences of climate change, caused through the anthropogenic activities. Flash floods occurred in Lagos, and some other parts of the country in 2012, which led to displacement and death of people, and loss of properties e.g. Ibadan, Plateau etc. [13][14]. In 2011, a serious flooding was experienced in Lagos and Ibadan, southwest of Nigeria, due to unusual rainfall of 233.3mm and 88.2mm respectively [14]. Furthermore, Lagos state witnessed a rainfall of 237.3mm in 1997 [14]. Increased rainfall in the ‘very humid regions’ of southern part of Nigeria may still be expected in the future [15]. Fig.1 shows the common generators used in households in Nigeria.

B. Nigeria’s Electricity Generation

The installed generating capacity in Nigeria is presented in Table 1 [5][11][16]. Currently, out of the installed capacity of over 6,000MW, the available generating capacity is less than 5,000MW. Fig. 2 shows the voltage levels of the electricity system in Nigeria. While the industrial premises are fed at the primary distribution level, electricity is supplied to households at the secondary voltage level, with three-phase and single-phase, at 415V and 220V respectively.

<table>
<thead>
<tr>
<th>S/No.</th>
<th>Power Plant</th>
<th>Technology</th>
<th>Installed Capacity (MW)</th>
<th>Year Commissioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Jebba</td>
<td>Hydro</td>
<td>570</td>
<td>1985</td>
</tr>
<tr>
<td>2.</td>
<td>Shiroro</td>
<td>Hydro</td>
<td>600</td>
<td>1989</td>
</tr>
<tr>
<td>3.</td>
<td>Kainji</td>
<td>Hydro</td>
<td>760</td>
<td>1968</td>
</tr>
<tr>
<td>5.</td>
<td>Afam</td>
<td>Thermal</td>
<td>776</td>
<td>1963/2001</td>
</tr>
<tr>
<td>6.</td>
<td>Ughelli</td>
<td>Thermal</td>
<td>972</td>
<td>1966</td>
</tr>
<tr>
<td>7.</td>
<td>Sapele</td>
<td>Thermal</td>
<td>1,020</td>
<td>1978</td>
</tr>
<tr>
<td>8.</td>
<td>Egbin</td>
<td>Thermal</td>
<td>1,320</td>
<td>1986</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>&gt;6,000</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 1. EXISTING GENERATING STATIONS IN NIGERIA

![Fig1. Common generators used in households in Nigeria](image1)

![Fig. 2. Electricity voltage levels](image2)

III. DISTRIBUTED GENERATION

Distributed generation (DG) technologies are often referred to as small-scale energy generation systems that are located close to the electricity users [12]. This makes them a suitable option for off-grid areas and for other places where irregular electricity supply is experienced. The energy generated could be utilized for lighting, powering TVs, fridges, fans, battery charging, water pumping, street lighting; for electricity appliances in schools, health centers, agro-processing etc., and for promoting the commercial activities in rural areas of the country.

The ballpark figure for annual average solar radiation between the southern and northern parts of the country is 3.5-7.0 kWh/m²/day [17]-[19] respectively. Solar photovoltaic power is a promising option for addressing the energy shortage problem in households, communities, offices etc. in Nigeria. However, renewable energy systems have unstable outputs [20], and this will require the use of appropriate energy storage systems, especially for off-grid applications,
where there is no interaction with the grid system, so as to store energy at periods of high renewable energy generation, and then utilize it later.

A. Clean Development Mechanism

In a bid to tackle the global issue of climate change, the international community have adopted the United Nations Framework Convention on Climate Change (UNFCCC), and the Kyoto Protocol in 1992 and 1997 respectively [21]. The Kyoto Protocol sets target for the reduction of GHG emissions for 39 developed countries, and some other developing countries, between 2008 and 2012 [21]; CDM is one of the market mechanisms set up to satisfy the emissions reduction commitments. Therefore, it is essentially a partnership structure specified by Kyoto Protocol, with the goal of encouraging the implementation of projects that can lead to a reduction of GHGs. It involves two parties: an investor from a developed country, and the host country (developing country). The investment in clean technologies in developing countries has the potential to offer carbon emission reductions, at a relatively lower cost [22]. Apart from environmental benefits, CDM projects could also ensure the transfer of technologies and sustainable development in the host country [21]; however, a well-defined method of collaboration between the investors and the host countries is necessary for the adoption and success of CDM projects.

A number of conditions have to be satisfied for a project to be adopted as a CDM project. Of all these conditions, “additionality” is the most crucial, which implies that a project is required to achieve a reduction in GHG emissions that would be impossible if it were not in existence [21][22]; therefore, a project is considered additional if its emission reduction can be measured and verified based on data which is reasonable. The project must reduce any one of the following GHGs: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbon (HFC), perfluorocarbon (PFC) and sulphur hexafluoride (SF6). An approval has to be given by the government of the host country or the appropriate authority, usually represented by Ministry of the Environment, to ensure that the project complies with the country’s policies and regulations [21].

The potential barriers to CDM projects are high cost and accessibility of the technology, lack of skilled manpower to manage the continuous operation of the project, poor capacity by the designated authority in the host country; too much time for processing the project documentation, difficulty in evaluating the CDM’s “additionality”, lack of awareness and information etc. [8][21][22][26]-[28].

B. CDM in Nigerian Perspective

Nigeria agreed to the UNFCCC and also ratified the Kyoto Protocol in 1994 and 2004 respectively [26]. In 2006, the country instituted a CDM Designated National Authority (DNA). The Federal Ministry of Environment being the centre for UNFCCC, while the Department of Climate Change is the DNA for the implementation of CDM projects in Nigeria. Some of the roles of the country’s DNA include regulation, evaluation and endorsement, confirmation of approval, issuing letter of no objection (LNO) and letter of approval (LoA) for CDM projects, and ensuring successful registration and implementation of the intended projects [26]. To obtain LNO, the project idea note (PIN) has to be submitted to DNA by the proponent, specifying the participants, description and location of the project, quantity of emissions to be reduced or avoided, expected benefits etc. The LoA is awarded after visiting the site, assessing the project, submitting the Project Design Document (PDD) to DNA, and the review of PIN and Environmental Impact Assessment (EIA) document [21][22][26]-[28]. CDM projects have the potential to thrive in the following sectors in Nigeria: Integrated Waste and Compost Management (e.g. landfills), Energy Generation (e.g. solar PV, wind systems etc.), Industrial Production (e.g. oil and gas), Sustainable Land Management practices (e.g. agroforestry, afforestation, reforestation), Transportation [26]. Some of the existing registered CDM projects in the country are shown in Table II [28], as of Dec. 2012, 11 projects have been registered by the CDM executive, while 21 projects were approved by DNA.

<table>
<thead>
<tr>
<th>S/No.</th>
<th>CDM Project</th>
<th>Type</th>
<th>Annual CERs</th>
<th>Date of Registration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Recovery of Associated Gas that would otherwise be flared at Kwale Oil-Gas processing plant, Nigeria</td>
<td>Waste gas/heat utilization</td>
<td>1,496,934</td>
<td>Nov., 2006</td>
</tr>
<tr>
<td>5.</td>
<td>Municipal Solid Waste Composting in Borodou, Lagos</td>
<td>CH4 recovery and utilization</td>
<td>281, 781</td>
<td>Dec., 2010</td>
</tr>
</tbody>
</table>
In order to justify the existence of a CDM project, a baseline has to be set [27]. This allows the measurement and verification of the reduction in the emissions, in comparison with the baseline. For instance, a project receives 31,309 Certified Emission Reduction credits (CERs), when it has reduced 31,309 tons of CO$_2$, compared to the baseline. A baseline is a reference point which is used to envisage the GHGs that would have been emitted in the absence of the project [22][27]. The amount of emissions reduced by the project is represented by (1):

$$E = B - V$$  

where $E$, $B$ and $V$ are emissions reduction, baseline emissions and verified CDM project emissions respectively. $E$ is the number of CERs that will be received by the investor.

IV. CASE STUDIES

Some studies were conducted for the application of PV systems in Lagos (south-west) and Bauchi (north-east). The average daily solar irradiance for these locations for a period of 11 years is shown in Figs. 3 and 4, whose data have been sourced from the Nigerian Meteorological Agency (NIMET). It is obvious from the figures that Lagos has a lower solar energy potential compared to Bauchi. The values of the annual average daily solar radiation of the two sites is in the range of 9.9 – 12.2, and 16.5 - 20.3MJ/m$^2$/day respectively; these are 2.7 – 4.5 and 4.6 – 5.6kWh/m$^2$/day respectively. In this study, four scenarios were considered. Scenarios 1 and 2 represent PV systems for two households in Lagos, while scenarios 3 and 4 represent PV systems for remote household and street lighting applications in Bauchi.

A. Scenario 1

A load profile of a 3-bedroom residence in a housing estate in Ikorodu Lagos is shown in Fig. 5; it shows the consumption pattern of the house when electricity is supplied by the utility. The daily demand and the peak load are 16kWh and 1.64kW respectively. The loads include lighting bulbs, LCD, DVD, fans, fridge, electric cooker, and electric kettle. The load pattern has three peak periods, between 6 and 7a.m, 1 and 2p.m and 6 and 8p.m. The electricity consumption in the morning is due to lighting, cooking, water boiling, operation of TV and DVD. The peak demand in the afternoon is as a result of cooking. In the evening, most of the appliances are operated simultaneously. The use of electric fans in the midnight is common in most Nigerian homes, especially during the dry season. However, electricity supply from the utility is erratic, therefore, most households use diesel or petrol generators to provide electricity for lighting, refrigeration, operating TVs, DVDs, computers etc., while kerosene, LPG or natural gas is used for cooking [23]. Also, wood, charcoal, animal and crop residues are used for cooking in the rural areas. Kerosene is not only a means of lighting for homes without access to electricity, but also used in some urban homes for lighting during power outages, in the evening/night.

Fig. 6 (a) shows an energy configuration whereby a diesel generator is used to supply the appliances, excluding electric cooker and kettle, with the daily electricity consumption and the peak load reduced to 8kWh and 0.485kW respectively. A solar PV system for this home is represented by Fig. 6 (b). The different configurations have been simulated in HOMER environment. The L16P battery is 6V 360Ah, and with a system voltage of 12V.
B. Scenario 2

Another home is considered having similar electricity consumption with scenario 1, but with an additional load of 1.5h.p (1.125kW) for water pumping. The machine is operated daily to provide water for the household between 12 and 1p.m. The daily electricity demand and peak load are 10kWh and 1.6kW respectively. The configurations are represented by Fig. 7 (a) and (b).

![Fig. 7. The energy configurations for scenario 2](image)

C. Scenario 3

Most people dwelling in remote areas are believed to be peasants. They depend majorly on biomass wood for cooking [1][24], unlike the homes in urban settlements that have multiple energy options; but solid fuels not only emit pollutant gases, but also lead to lung diseases [24]. These people are assumed to consume less electricity compared to those in the urban areas. The appliances which they use include TVs, radio sets, fans, phone chargers etc. Fig. 8 represents the configuration for a remote household, with a demand of 1.8kWh/day, and a peak load of 214W. The electrical loads in other remote households could be higher than this, depending on their usage.

![Fig. 8. The energy configuration for scenario 3](image)

D. Scenario 4

A solar PV system is also considered for street lighting, operated from dusk till dawn (6:30p.m to 6:30a.m) every day. The lamp assumed for this application is a high-power LED, with excellent luminous output. The configuration for this system is shown in Fig.9. The daily demand and load of the system are 0.432kWh and 0.036kW respectively.

![Fig. 9. Energy configuration for LED lighting](image)

V. RESULTS AND DISCUSSION

The initial capital cost, sizes of components and the carbon dioxide emissions saved are shown in Table 3. The quantity of carbon dioxide emission by diesel generators falls in the range of 2.4 to 2.8kg per litre of fuel [25]. Therefore, if a diesel generator is used in scenario1, 1,519 litres of fuel will be consumed, and 4tons of CO2 will be emitted per year, based on the simulation. Also, the household in scenario 2 will utilize 2,247 litres leading to emission of 5.917tons of CO2. Furthermore, 1.238 and 0.196tons will be released by the configurations in scenarios 3 and 4 respectively. Powering scenarios 1 to 4 through solar electricity will require 4kW, 5kW, 0.6kW and 0.17kW PV systems respectively, which could help to avoid the carbon emissions, due to diesel-based system. The costs of 4kW, 5kW, 0.6kW and 0.17kW PV systems are $16,442, $20,115, $2,870 and $960 respectively, including the installation costs. The costs of generators for powering the systems in scenarios 1 to 4 are $344, $516, $172 and $34 respectively; the cost per litre of diesel in Nigeria is about $0.88. It is also observed from the simulation results that the initial capital costs of the generators are less than those of the PV systems. However, the volatility of prices of fuels, maintenance costs and the continuous reduction in the cost of PV modules will give solar power generating systems edge over diesel generation, thus making them a competitive option for addressing the energy shortage in Nigeria, in the nearest future. The cost per kW of a renewable energy system in a developed country could purchase a higher kW of the same system in a developing country, such as Nigeria. For instance, a total amount of USD$8,000 was spent on 1kW solar PV system in a house in Brooklyn Wellington, which generates its own electricity; this excludes the cost of batteries. Furthermore, the owner spent USD$40,000 on 2.5kW Wind turbine, and a 24V battery bank (12 units of 2V cells in series) configured in 2 parallel strings. Therefore, investments in CDM projects in developing countries, by project developers from advanced countries could lead to realizing emissions reduction at a relatively lower cost.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Demand (kWh/yr)</th>
<th>Gen (kW)</th>
<th>PV (kW)</th>
<th>Capital Cost(USD)</th>
<th>Emissions (tons/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,920.0</td>
<td>1</td>
<td>-</td>
<td>344</td>
<td>4.000</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>4</td>
<td>3,958.0</td>
<td>16,442</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>3,650.0</td>
<td>2</td>
<td>-</td>
<td>516</td>
<td>5.917</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>5</td>
<td>4,947.0</td>
<td>20,115</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>657.0</td>
<td>-</td>
<td>-</td>
<td>172</td>
<td>1.238</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.6</td>
<td>823.0</td>
<td>2,870</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>157.7</td>
<td>-</td>
<td>-</td>
<td>34</td>
<td>0.196</td>
</tr>
</tbody>
</table>

VI. FUTURE WORK

This work was based on the assumption of average solar irradiance data and a fixed load profile. However, a study of the PV system based on hourly irradiation data with considerations for different seasons, and variation of loads,
could lead to achieving better performance, that can compete with diesel systems. These tasks will be pursued in future research, with the goal of developing reliable and relatively low-cost PV electricity generation systems for off-grid houses and community-wide applications, giving them an edge over diesel systems. DlgSILENT PowerFactory and Fundamental PV Module Performance Analysis (FPVMPA) [29] tools, and life cycle cost analysis (LCCA) will be employed for the study.

VII. CONCLUSION

This paper has discussed the application of small-scale solar photovoltaic systems in two different locations in Nigeria – Lagos and Bauchi. It has investigated the cost implications of these systems, the carbon dioxide emissions that could be saved by utilizing them, and the possibility of deploying them through Clean Development Mechanism. Because of the poor energy system and low electricity access rate in Nigeria, diesel and petrol generators have become a primary source of electricity. The country is also a potential emitter of flare gas. All of these will together cause serious environmental problems in the future. Therefore, urgent attention is needed to address these problems. One of the possible ways of reducing the country’s carbon footprint is by promoting the utilization of renewable energy resources. Renewable energy systems could earn higher incentives (CERs), because they are clean technologies. CDM projects could also be implemented by one or two party in a developing country, without any other party from a developed country [8]. Therefore, independent power producers, private sector, individuals, community development association, local and state governments, could invest in renewable energy-based CDM projects, which in the long-term, will not only reduce greenhouse gas emissions, but also address the problem of energy shortage and lead to sustainable development.

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