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TECHNICAL AND ECONOMIC ANALYSIS OF A PHOTOVOLTAIC-WIND-BIODIESEL HYBRID SYSTEM IN COMPARISON WITH ISOLATED PHOTOVOLTAIC-WIND-BIODIESEL SYSTEMS: CASE OF TOGO

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ABSTRACT

This article aims to study different configurations of renewable energy sources in order to propose viable power plants, with maximum power production that compensating for the country's energy deficit. To do this, first, after determining the appropriate software for our study, isolated systems are studied and compared with each other. Hybrid systems are then analyzed and compared with each other. Finally, a comparison between optimal hybrid and isolated systems is made. The simulation is performed with Lomé's site characteristics, located in the south of Togo. This simulation result of isolated and hybrid configurations using HOMER software, reinforced by a feasibility study of optimal systems using RETScreen Expert software, make it possible to conclude that the PV-biodiesel hybrid power plant is the best alternative energy production on this site. This power plant of 32 MW photovoltaic panel field coupled with a 30 MW biodiesel generator, can supply an electricity demand of 408 MWh per day (17MW) with a peak of 48 MW. The cost per KWh of electricity generated by this hybrid power plant is *0.185$*.It also comes out that, this systemis viable due to its internal rate of profitability(18.3%)higher than the discount rate (8%), the net present value is positive, and is strongly involved in the reduction of greenhouse gases.

KEYWORDS: Isolated power systems, hybrid systems, simulation, feasibility, comparison, greenhouse gases.

1. INTRODUCTION

The development of any human activity implies energy consumption [22].All human energy activities must face today to fossil fuel resources depletion and to greenhouse gases emissions challenge, responsible of climate change. Renewable energies are inexhaustible on a human scale and their conversion has a low impact on the environment. They are a relevant answer to the current and future energy problem[25]. It leads countries throughout the world to gradually move towards new and renewable energies [24]. Least developed countries in the world, endowed with renewable resources, are the most affected by the global energy crisis [23]. Togo is not spared from this.

The structure of Togo's electricity grid indicates that three different electricity systems supply the country with electricity [2]: the interconnected electrical system of Benin Electric Community (CEB); the electrical system connected to the border networks and the isolated electrical system for localities very far from the electrical distribution grid before distribution is provided by the Electrical Energy Company of Togo (CEET)[5][6]. The different contributions of these systems have evolved over the years according to needs and demand. Thus, a study of the CEB's electricity supply data, contained in the 2016 activity report of the Regulatory Authority for Electricity Sector (ARSE), illustrating electricity's part production and imports, reveals that Togo's electricity comes mainly from abroad, through imports estimated at 61.2%. In addition, the country's electrification rate is low at 35.81%, due to its high dependence on imports, mainly from Ghana, Ivory Coast and Nigeria.

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Thus, to improve Togo's electrification rate and thus the satisfaction rate of energy needs, inexhaustible sources of energy known as renewable energies appear essential. However, the exploitation of renewable energies still faces a relatively high cost per kilowatt-hour produced [19]

Among available renewable energy sources, photovoltaics is undoubtedly of great advantage, due to its easiness implementation and low maintenance it requires [4]. In addition, the use and production of solar equipment is increasing as the world is shifting to alternative and renewable energy sources and the use of solar appliances can save a lot of energy and make life easy for rural people who do not have access to electricity [26]. Butisolated systems, in this case photovoltaics, requiremany very expensive accumulators (batteries) [3] that must generally be replaced before the end of installations life to compensate for the intermittent nature of the deposits required for their exploitation. Unfortunately, its intermittency and unavailability at night require it to be combined with other renewable energy sources, including wind turbines, biodiesel generator, storage units, including batteries, or all four at once.

The construction and operation of an end-to-end wind power system is quite expensive compared to conventional sources with the added risk of profitability. It also shows that the installation of isolated wind systems often requires an oversizing of the necessary wind turbines [12] and this causes unnecessary additional costs.

Thus, hybrid systems with photovoltaic solar panels combined with wind turbines are therefore expected to be a solution capable of limiting the intermittency of resources, reducing the number of storage units required for system reliability and reducing the size of wind and photovoltaic systems installed. Hybrid systems are interesting solution for areas electrification where the electricity network does not exist, or its extension requires a relatively high cost[20]. That's why the development of hybrid electric systems requires that they become more economically attractive [21].But wouldn't this last solution be more optimal, with the association of biodiesel generator which contain is a "clean fuel", fuel without greenhouse gas emissions? It is within this framework that our theme's study, whose objective is to propose viable power plants of maximum power, reducing the country's energy deficit, is part of this idea.

2. TOGO'S ENERGY POTENTIAL

a. Solar energy

The various measurements taken at different latitudes of the country by the Solar Energy Laboratory of University of Lomé and the National Meteorological Office make it possible to estimate the global irradiation. It is 4.4 kWh/m^2/day in Lomé, 4.3 kWh/m^2/day in Atakpamé, 4.5 kWh/m^2/day in Mango [1] with powers up to 0.7kW/m^2, especially in dry season when the sky is clear with low humidity levels [10].The average sunstroke for the country is 6.62 hours per day. The total installed solar energy capacity in 2016 at the national level was estimated to 301.92kWp [1].Nevertheless, electricity supply, especially in rural areas, using solar energy remains very little or almost untapped in Togo for reasons sometimes linked to the cost of the equipment needed for deployment.

b. Wind energy

Togo's wind farm is not important, although there are instant peaks at moments. It is estimated at 20 Megawatts, mainly concentrated in coastal areas [1]. According to wind production indicators, an average wind speed of around 4.5 m/s is still sufficient to start wind energy production. But wind energy production is not developed for financial reasons and also because Togo is classified among quiet areas of the sub-region. Its average wind speed is estimated at 1.93 m/s. Salami et al [9] in their paper, have shown thatLomé site has a low wind potential that can, however, be optimally exploited through the use of low-power wind turbines, i.e. wind turbines of low nominal wind speed at high heights. According to this author, the coastal zone is the most exposed to the wind with a monthly average of less than 4 m/s to 10 m/s above the ground [8].

c. Biodiesel fuel

Alternative fuel, derived from various types of biomass such as vegetable oils, cooking oil derivatives or animal fats, Togo's biodiesel deposit is as small as that of wind energy. With the main task of replacing fuels from

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fossil energy sources, its use would undoubtedly require imports. According to final report of the potential development evaluation of bioenergy in Togo, produced in 2011 [7], liquid biofuels in Togo are all of agricultural origin and concern oilseeds: cotton seed, jatropha, oil palm, soya…and sugar or starched plants (sugar cane, manioc). However, Togo has a strong agricultural potential in terms of the number of arable land. This report estimated the quantity of biodiesel that could be produced at 10 000 tons per year, corresponding to 11 400 000 liters, on a surface area of 10 000 Ha whose raw material is Jatropha curcas [7].

3. MATERIALS AND METHODS

a. Method

For the technical and economic analysis, we choose to study the Correlation Coefficient (CC) between the daily wind and solar average energies for each month for certain sites across the country. This in order to choose appropriate site for our study. Then we estimate the load required to satisfy.

Correlation Coefficient method

The advantage of hybrid system lies in their possibility of using several energy sources to better meet a continuous energy's demand from the user or electrical grid. Indeed, the great variability of renewable sources requires, on the one hand, to oversize wind or photovoltaic generators and, above all, to introduce into the system's production an energy storage or at least an energy buffer that will make it possible to fill temporal and amplitude gaps between production and consumption [11].

Using a hybrid system will reduce the size of the system components, reduce waste energy, increase its reliability and make the use of renewable energy sources more economically attractive. All of these advantages will be as more important as solar and wind energy sources are complementary to each other and in line with the consumption curve.

To quantify monthly complementarily we have chosen to use two parameters: the first one quantifying temporal simultaneity [11]:

- The correlation coefficient CC between the daily average wind and solar energies for each month is given by the relationship (i):

$$CC = \frac{\sum_{i=1}^{N}(yi-y)(xi-x)}{\{[\sum_{i=1}^{N}(yi-y)^2][\sum_{i=1}^{N}(xi-x)^2]\}} \qquad (i)$$

Where yi and xi are the daily average values of the solar and wind energies for month i and y and x are respectively the annual average values of these energies;

- The second R quantifying energetic complementarily
R is the annual average of the daily solar irradiations and the daily wind energy ratio expressed by the relationship (2).

$$R=\frac{E_{wind}}{E_{Solar}} \qquad (ii)$$

Where E_{wind} and E_{solar} are annual average values of solar and wind energy for one m².

The closer CC is to "1" the more the two sources vary in the same direction; a good site will be in our opinion the one for which there will be a negative correlation between the two solar and wind sources as close as possible to "-1".

Table 1. CC and R coefficients of a number of sites

Region	City	CC	R
Savanes	Dapaong	0,409237213	0,071669224
	Mango	0,404216473	0,072877403
Kara	Kara	0,147695918	0,07093437

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	Bassar	0,287872645	0,069207221
Centrale	Sokodé	**-0,42515265**	0,076606249
Plateaux	Atakpamé	**-0,43855027**	0,101864632
	Kpalimé	**-0,415742394**	0,130232807
Maritime	Tabligbo	0,105428085	0,163334918
	Lomé	**-0,540480256**	0,22004613

The different correlation coefficients obtained in Table 1 allow us to deduce that the possible sites for hybridization are cities of Lomé, Atakpamé, Sokodé and Kpalimé. The last three cities have approximately equal coefficients, so we combine them into a single study area to estimate and determine the average characteristics of the facilities. We call this area "Cluster Atakpamé". In summary, two sites have been found:

- Lomé site;
- Cluster Atakpamé site.

But this paper presents the study carried out on Lomé site.

Estimate of the load on Lomé site.
Lomé is the capital of Togo. Located in the south of Togo, at 6.1372latitude and 1.2125 longitude, it has a population of nearly 850 000 on an area of 90 km^2.

On the basis of the available power produced by CEET in Lomé, around 24 MW subdivided in 12MW for the “Lomé siege” thermal power plant and 11.9 MW for the “Lomé B” thermal power plant, we ambitiously define the average electrical load of Lomé site at 20MW. Considering the relatively low wind at Lomé, the load will be considered as sensitive data that will be varied and decreased in simulations until the optimal load for each system is found.

b. Materials

These are mainly design, sizing, optimization and feasibility study software.

HOMER software presentation:
Homer means: Hybrid Optimization of Multiple Energy Resources. It is software for hybrid energy systems (PV, wind, grid, storage and diesel) optimization [13][15]. It performs the optimization task by performing an hourly simulation of the energy flow between the load and the other components of the system over a period of one year [14]. For each configuration of the hybrid system, Homer software performs a time analysis of the installation. At each time step, the software observes the consumption and compares it with the photovoltaic production which has priority. In the case of a lack of this energy, the Homer software must choose between use generator or Batteries. The main features of Homer software are: taking into account the hourly load profile as well as controllable loads, time simulation of a multi-source production system, production system economic optimization and sensitivity analysis. The operation of Homer is analyzed for hybrid systems comprising: photovoltaic installation, one or two generators, with or without an electrochemical storage unit. For parameters such as number of devices and powers, Homer software simulates the operation of the system for each of the parameterized values [13]. Homer software presents a financial analysis on project life cycle, based on comparison results of produced kWh costs by different sources [13]. Thus, for each architecture and configuration, it is possible to observe the following outputs: global cost of the updated kWh (LCOE: Levelized Cost of electricity), distribution of the items of expenditure, the detail corresponding to each source, daily charts over the life of the system, sensitivity analysis graphs, an economic analysis compared to a reference installation, sensitivity analysis presented in graphical form[15].

RET Screen Expert software presentation:
RETScreen Expert is a software tool for analyzing clean energy projects based on Microsoft Excel developed by the CANMET Energy Diversification Research Laboratory of Canada. It is used to help decision-makers quickly determine whether a renewable energy, energy efficiency and co-generation project is financially and technically viable [17][16]. The tool is a standardized and integrated software program that can analyze clean

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energy and energy efficiency projects around the world to improve energy production, life cycle costs and greenhouse gas emission reductions. Each clean energy technology model is developed in an individual Microsoft Excel workbook. Then, each workbook is composed of a series of spreadsheets. These spreadsheets have a common look and feel and follow a standardized approach. In addition to the software, the tool includes databases (products, costs and weather data), an online manual, a website, an engineering manual, case studies and a training course [18]. RETScreen Expert allows three main types of analysis for different types of installations. The possible analyses are: comparison, feasibility and performance. Each project analysis is done in 5 steps: establishment of the energy model, cost analysis, analysis of the emission rate of greenhouse gases, preparation of the financial summary, sensitivity and risk analysis.

4. RESULTS AND DISCUSSION
5.

a. Simulation result for photovoltaic, wind, biodiesel isolated systems

The architecture ofan example of isolated photovoltaic system is presented at figure 1.

Figure 1: Architecture of isolated photovoltaic system dimensioned in Homer software

Isolated systems (photovoltaic, wind and biodiesel generators) are first studied using HOMER software. The best optimization results are then submitted to a feasibility analysis using RETScreen Expert software. The results are shown in Table 1

Table 2. Simulation result for isolated systems

Lomé site			
Results from HOMER			
System Configuration	Photovoltaic	Wind Power	Biodiesel generator
Power Installed (MW)	54	24	8
Available Power (MW)	5	1	**5**
Number of Generator	27	8	1
Production (kWh/yr)	88 274 089	29 559 105	43 811 648
Net Present Cost (NPC) in USD	330 434 100	137 176 000	83 000 000
Cost of Energy (COE) in $/kWh	0,594	1,23	0,150
Results from RETScreen Expert			
Discount rate (%)	8	8	8
Internal rate of profitability (%)	13,1	-0,7	34,7
Equity payback (year)	12	>25	3

Autonomous photovoltaic, wind and biodiesel generator systems are studied and compared with each other. Technically, 88 GWh/yr would be produced for an installed capacity of 54 MW of photovoltaic power, 29GWh/yr for an installed capacity of 24 MW of wind turbine compared to 43 GWh/yr for an installed capacity of 8 MW of biodiesel generator. The respective Cost of Energy (COE) for each system is 0.594$/kWh for PV, 1.23$/kWh for wind turbine and 0.150$/kWh for biodiesel generator. Based on this cost and considering the total cost of each system (which evolves from $330 million for PV, $137 million for wind turbine to $83 million for biodiesel generator), installing a biodiesel generator would be beneficial. It is confirmed by the feasibility analysis done by using RETScreen Expert software, which shows that for the same production capacity of 5MW, the biodiesel generator is more advantageous than the photovoltaic. This, because the biodiesel generator system has a better internal rate of profitability of 34.7% than the photovoltaic system of 13.1% (rate higher than the discount rate of 8%) and an equity payback already in 3 years, while the wind system is economically unsustainable because of its equity payback longer than the estimated life of the project of 25 years.

b. Simulation result of hybrid photovoltaic-wind-biodiesel systems

The architecture of isolated photovoltaic-wind-biodiesel system is presented at the figure 2.

Figure 2: Architecture of hybrid system dimensioned in Homer software

The approach remains the same as for stand-alone systems. Hybrid system is first studied using HOMER software (Table 3). The best optimization results will then be submitted to a feasibility analysis using RETScreen Expert software.

Table 3. Simulation results of hybrid systems

Lomé's site	
Results from HOMER	
System Configuration	Photovoltaic-Biodiesel
Power Installed (MW)	62

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Available Power (MW)	17	
Number of Generator	16 (PV packs)	1 (Bio)
Production (kWh/Yr)	64 452 994	94 540 417
Net Present Cost (NPC) in USD	356 638 000	
Cost of Energy (COE) in $/kWh	0,185	
Results from RETScreen Expert		
Discount rate (%)	8	
Internal rate of profitability (%)	18,3	
Equity payback (year)	7	

The table 3 shows that the possible combination on this site is that of photovoltaics coupled with a biodiesel generator. This configuration will require 16 photovoltaic packs of 2 MW each and a 30 MW biodiesel generator for an annual production of 159 993 471 kWh/yr. The Cost of Energy (COE) from this production is 0.185$/kWh, which is very competitive by national standards and makes this system attractive. This assertion is confirmed by the feasibility analysis of this system using RETScreen Expert software. According to this analysis, the PV-biodiesel configuration is economically viable as its internal rate of profitability is higher than the discount rate (twice) and an equity payback already after 7 years over the project's life which is 25 years and strongly contributed to greenhouse gases reduction.

c. Economic performance and general results of the analyses

The performance of the facilities is the investor's first concern. It is clear from this fact that we draw up a balance sheet of the gains and benefits of each configuration in order to come out the most profitable (Table 4).

Table 4. Comparison between optimal isolated and hybrid power plant

Lomé site		
System Configuration	Biodiesel Generator	Photovoltaic-Biodiesel generator
Initial Cost (USD)	52 701 996	141 719 376
Carbon Credit (USD)	29 342 713	89 022 906
Free Energy (USD)	126 709 118	378 590 926
Total profits (USD)	156 051 831	467 613 832
Real Gain (USD)	103 349 836	325 894 456
Economic Ratio	1,96	2,3

From this table 4, it appears that for an investment of $52 million, a profit of $156 million would be realized, representing a real gain of $103 million for the biodiesel generator. As a result, a ratio of 1.96% emerges, which literally means that "for every dollar invested we would earn $1.96". On the other hand, for an investment of $141 million, a profit of $467 million would be realized, representing a real gain of $325 million for the PV-biodiesel hybrid system. As a result, a ratio of 2.3% emerges, which literally means that "for every dollar invested, we would earn 2.3 dollars".

From this analysis, the PV-biodiesel hybrid system is more cost-effective than the biodiesel generator. Investing in this system would be more beneficial.

6. CONCLUSION

Technical and economic analysis of various configurations (isolated or hybrid) using Homer software, reinforced by a feasibility study of the optimal systems using RETScreen Expert software, lead to the conclusion that the PV-biodiesel combination is the best alternative for energy production on Lomé site. This system makes it possible to satisfy an average load of 17 MW, contributes significantly to the reduction of greenhouse gases (GHGs) over the life of the project, estimated at 25 years, with an average rate of dissatisfaction of loads less

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than 1% per year. It also shows that this system is economically viable because the project's internal rate of profitability is higher than the discount rate and the net present value (NPV) is positive. It is on the basis of

these deductions and observations that this work is part of the rationale for the construction of a hybrid PV-biodiesel power plant to supply electrical power to communities for the above-mentioned site.

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