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Hybrid System for Electrification and Upliftment of Northern Rural Region of Togo

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Abstract*: Availability of abundant energy sources is one of the factors, which help in the socio-economic development of any country. Without energy sources, it is impossible for any country to produce, transport and transform products for general human activities. Togo, a country of West Africa, is a net importer of petroleum products and produces only 40% of its electrical energy requirements. At the level of rural electrification, the rate of access to electricity is 6.3% in 2016. Although Togo is a country with a high potential for bioenergy and solar energy production. Hybrid photovoltaic/biodiesel systems (PV/BG) could therefore contribute to reducing the country's energy dependence and increasing the rate of access to electricity in rural areas while reducing greenhouse gas emissions. This research presents the economic viability of a hybrid system (PV/BG from Jatropha Curcas) for the electrification of a village in the central region of northern Togo. The main objective of this research is to propose a model of electric energy production system in rural areas from renewable sources at a low operating cost while ensuring positive socio-economic impacts for the inhabitants of the environment. The analysis and optimization of the techno-economic performance of the proposed hybrid system is done using the hybrid optimization model for electric renewable (HOMER). The simulations has been carried out under various climate conditions and fuel price used as sensitivity variables. This research has proven that despite the high cost of biodiesel produced from Jatropha Curcas (1.6 USD/ litter) the hybrid (PV/biodiesel) system proposed for the production of electric energy in rural Togo is very economical. The electricity produced by the proposed system under various climate condition is always less than 0.21 USD/kWh with a capacity shortage of about 0.0999%, economical than the electricity produced by the largest thermal power plant of the country (ContourGlobal) which electricity costs 0.3 USD/kWh. The results shows that the proposed system can contribute in a sustainable way to the improvement of the economic and social conditions of the inhabitants of rural areas.

***Index Terms*: Biodiesel, HOMER, Hybrid system, Jatropha curcas.**

I. INTRODUCTION

The availability of power supply has been reported in many of the literature as the basic requirement for the development of any country. Togo is part of Sub-Saharan Africa, which has more than 950 million inhabitants and is the world's poorest region of electricity. Most of the countries in this region have an electricity access rate of about 20% and two out of three people do not have access to modern energy services [1]. In year 2016, Togo imports about 60% of the electricity to meet the national demand and the overall fuel energy is imported. The access rate to electricity is 35.6% nationally compared to only 6.3% for rural areas [2], [5]. As a net importer of petroleum products, Togo is vulnerable to changes in petroleum prices of global markets. Despite this dependence on petroleum products, the energy mix in Togo is dominated by more than 98% by thermal energy [2]. More than 95% of greenhouse gas emission (GHG) from the energy sector come from the combustion of fossil fuels and energy biomass. It becomes essential to take into account the climate component in the implementation of programs and projects in the energy sector in Togo [6]. This complex energy deficit represents an opportunity for Togo to design low-carbon energy systems focused on wind, geothermal, solar and biomass technologies and to use management strategies for flexible and effective demand. The renewable energy subsector is still embryonic in Togo. The part of renewable energies in the energy mix is less than 2% and if the part of micro-hydropower is subtracted the contribution of other renewable energy sources is less than 0.5%. For achieving the target value of renewable power generation (20% of the total generation) within 2030 [7], it is highly essential to investigate the economic and environmental issues of Togo to bring the higher percentage of renewable energy (RE) sources into the energy mix. Due to the benchmarks set by many international organizations, several countries have been encouraged to construct micro grid power generation facilities to power the remote locations that cannot be connected to the grid due to economic and technical constraints [3],[4]. If electricity appears as a fundamental vector of human development, the context of the predominantly rural populations (62.6% of rural population in 2016) in Togo encourages the search for adapted energy alternatives. According to the final report of the evaluation of the development potential of bio energies in Togo, published in 2011 [7], the amount of biodiesel that could be produced on an area of 10 000 hectares is estimated at 10 000 tons which correspond to 11,400,000 liters per year whose raw material is jatropha curcas.

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Jatropha oil, unlike other biodiesels, can be used without mixing and modification of engines while other biodiesels from oilseeds such as sunflower, soybean, rapeseed, castor and cotton for example are blended with conventional diesel up to a maximum of 30%.

Jatropha is currently the only biodiesel that can substitute the conventional diesel fuel [8]. As studies has shown that the wind generator, due to the low wind speed on the territory is not profitable for electrical energy production in Togo [10], the main objectives of this paper are:

- Analysis of the economic feasibility of biodiesel/PV systems for the production of electricity in rural areas
- Energy recovery of Jatropha Curcas sub-products
- Analysis of the impacts of the proposed electricity generation system on the rural socio-economic development

II. TOGO RENEWABLE ENERGY RESOURCES

The renewable energy subsector is still embryonic in Togo. Therefore, very little policies directly apply to renewable energies in terms of energy politics in the country. However, its potential remains considerable.

A. *Solar energy*

The commonly called solar energy represents, in fact, the share of energy from the sun captured by the earth (45%) in the form of electromagnetic radiation. The remainder of the energy provided by sun (55%) is either directly reflected in space (30%) or converted in the atmosphere or used for photosynthesis (25%), thus giving rise to other renewable resources such as wind and hydraulic energy, swell or biomass. Many systems exist to convert solar radiation into useful energy, although it has to be noted that before any active use of solar energy, man has used and still uses predominantly this energy passively. Conversely, conversion systems are active systems that use mechanical, optical or electronic elements to convert solar energy into thermal, mechanical or electrical energy. Several main types can be distinguished (Arvizu et al., 2011) [26]: photovoltaic module, solar thermal collectors, thermodynamic solar power plants, solar cookers, and solar air conditioners. In terms of electricity generation, two types of systems exist at the moment and use two different technologies, respectively the concentrating solar (CSP) and the photovoltaic conversion (PV). In this paper, photovoltaic system is used for solar energy conversion.

B. *Solar energy potential*

Solar energy remain very little exploited in Togo for reasons sometimes related to the cost of the operating equipment. The achievements in solar energy are increasingly popularized by civil society for pumping water, electricity supply especially in rural areas. The different measurements made at different latitudes of the country by the Laboratory of Solar Energy at the University of Lomé and the Directorate of National Meteorology allow estimating global sunshine. The average insolation for the whole country is 6.62 hours per day. The different measurements made at different latitudes of the country make it possible to estimate average global solar energy at 4.4 KWh/m^2/day in Lomé (capital city of the country), 4.3 KWh/m^2/Day in Atakpamé, 4.5 KWh /m^2/Day in Mango. The solar power is estimate to 0.7kW/m^2 especially in the dry season when the sky is clear with the humidity rate of the air low [9]-[11].

C. *Solar energy data for Djarkpanga*

The place considered in this research paper is Djarkpanga located at 8°99N 1°15E and situated in the central region of the country in the district of Mo. The data used for the analysis paper has been downloaded by HOMER software from NASA surface meteorology and solar energy database. The data present the global horizontal radiation, monthly averaged values over 22 years period. From the used data, it is seen that the annual average solar global horizontal irradiation is 5.01 Kwh/m^2/day. The monthly solar radiation and clearness index is shown in figure 1. The irradiation is considered as a sensitivity variable and for the analysis of the proposed system; the annual average solar global horizontal irradiation is varied from 4.0 to 5.02 Kwh/m^2/day so that we can determine the effect of solar irradiation on the economic viability of the system.

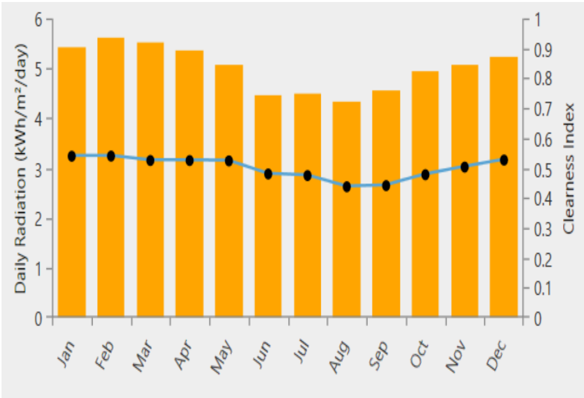


Fig 1. *Monthly average solar radiation and clearness index for selected site*

D. *Biomass resources: Production of biodiesel from Jatropha curcas*

Jatropha curcas is a very rustic and plastic species, resistant to climates semi-arid and can grow on poor soils. The productivity of Jatropha can be estimated in average to 5 tons per hectare from the fifth year [7]. The process of producing biodiesel from Jatropha curcas is shown in the figure 2.

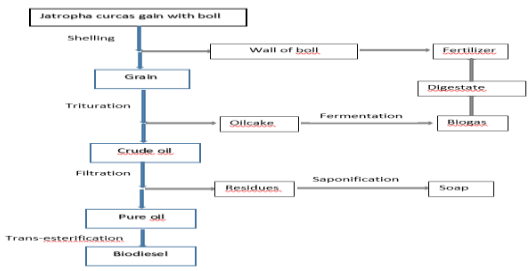


Fig 2. Chain of biodiesel production from Jatropha curcas

Jatropha is now the only biodiesel capable of replacing the classic diesel as it can be used without mixing and modification of engines. The heat of combustion for biodiesel is up to 95% by volume of conventional diesel, but biodiesel oxygenated provides the same fuel value as that of diesel. The parameters in table 1 approve Jatropha seed as an economically feedstock to produce biodiesel.

Table I: The characteristic of Jatropha oil in comparison with biodiesel oil

Name	Flash point (^{0}C)	Density at 20/40^{0}C	Viscosity	Octane number	Heating value (MJ/litre)
Diesel	32	0.82 – 0.86	2.0 – 7.5	42	34.5 – 36.0
Biodiesel (Jatropha curcas)	161	0.878	4.54	65	33.7

A study conducted by Jeremi B. et al (2012) [12] shows that the oil yield of Jatropha using the bielenberg type machine locally craft varies from 18% to 27%. The litter of Jatropha oil usable as biofuel is estimated at 1055 franc CFA(Togo currency). Taking into account the sale of the cakes the cost price of one litre is 928 franc CFA or about 1.66 USD. Wiliam F. et al (2012) have mentioned the cost of Jatropha oil bought from Agritech, a local enterprise of Burkina Faso, to 350 franc CFA. Considering the cost of filtration of the oil, the price of Jatropha oil would be estimated at 625 franc CFA or 1.12 USD per litter [13]. Since there is not yet the Jatropha oil processing company in Togo, the basic price of a litter of Jatropha oil for our study is taken as a sensitivity variable. Therefore, we simulate several scenarios with the price of biodiesel ranging from 1 to 1.66 dollars by step of 0.1 dollars USD.

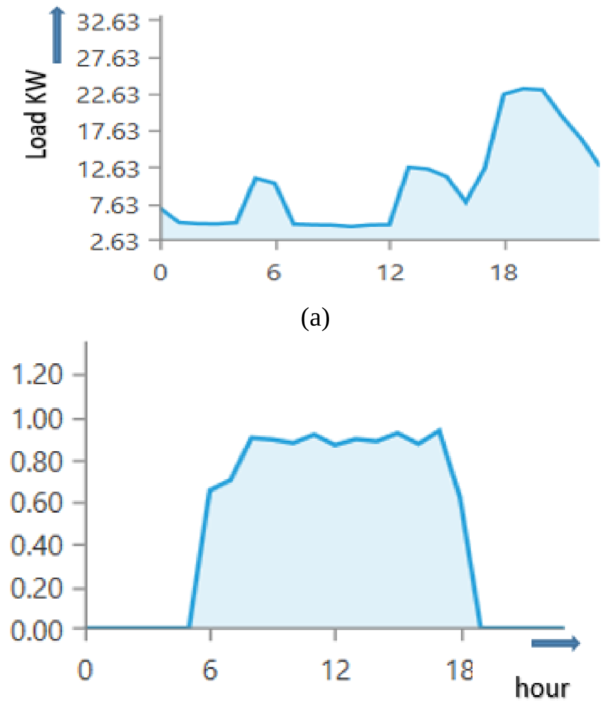
III. ENERGY REQUIREMENT OF DJARKPANGA

Djarkpanga is a village in the Centrale region of Togo. The economics of the population of that village is mainly based on agriculture. The village, like most of the country's villages, has a relatively high-energy intensity due to the large share of traditional energies such as firewood with very low utilization yields [14]. The load estimation is preliminary essential part of plant installation. The estimation of the power demand was done after analyzing the previously made case studies of rural electrification in some developing countries [15],[20,[21]. Therefore, the estimation of the load is made based on the data in the table 2. The number of households considered is 130.

Table II: Load estimation

		Lamp 15 W	TV 80 W	Fan 60W	Fridge 150W	Computer 40W
Estimated Domestic/household Load	Number of apparatus per household	03	01	01	00	00
Community loads	School	15	00	01	0	01
	Dispensary	03	01	01	01	01
Commercial Load	03 Shops	06	03	03	03	00
Load for water supply	4 DC motors for water pumping (3 KW)					

To get more accurate hourly load profile, a 10% hour-to-hour random variability and 10% day-to-day random variability has been considered. The total daily average electricity demand at the considered village is found as 249.18 KWh and the load factor is found as 0.32 where the peak load is 32.61 kW. Four DC motors assure water pumping and are connected to DC bus. The total daily average electricity demand for water pumping is found as 61.55 KWh and the load factor is found as 0.34 where the peak load is 9.02 kW. The daily load profile is shown in the figure 3.



(b)

Fig 3. Djarkpanga Daily load profile; a) AC daily load profile, b) DC daily load profile for water pumping

IV. HYBRID SYSTEM COMPONENTS

The optimization of electricity generation and the pluralism of energy sources, especially renewable sources, today require the association or combination of sources in order to increase efficiency and limit the effect of their intermittence. This system technically called "hybrid energy system" is identified with a system that simultaneously operates several energy sources with different properties to produce electrical energy [16]. According to Adefarati T. et al (2016) [4], the use of several energy sources for the production of electricity is beneficial because the weaknesses of a source can be filled by the forces of another.

The architecture of the hybrid system used is shown in the figure 5.

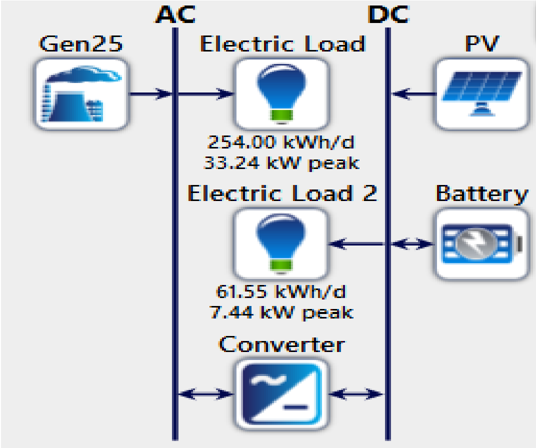


Fig 5. Hybrid power system

A. *Solar PV panel*

In order to make a reliable economic study of our hybrid system, the economics data is based on the costs given by a study conducted by Nurunnabi et al (2018). According to his study, the cost of the solar panel can be estimated at 1340USD/kWp with 20 years of warranty [17]. This cost includes all derivatives related to the transport and installation of the panels. The replacement cost of solar panel is estimated as 67% of the total capital cost and the operating and maintenance is estimated as 26USD/kWp per year.

B. *Biodiesel Generator*

In this work, the diesel generator is chosen from HOMER software library and the fuel characteristics is changed to have the same properties as biodiesel obtained from Jatropha. The biodiesel generator rating is 25 KW and its minimum load ratio is 25%. The initial capital cost is taken as $500/KW, the replacement cost is set to 440USD/KW and an operating and maintenance cost of 0.5/hr USD. The rate of the fuel consumption of the used biodiesel generator with its output power at time t can be expressed as per equation 1 [18]:

$$Fc = F_0.Y_{gen} + F_1.P_{DG} \tag{1}$$

Where F_0 is the fuel curve intercept coefficient (L/h/kw), F1 is the fuel curve slope (L/h/kW), P_{DG} is the electrical output of the generator (kW) and Ygen is the rated capacity of the generator (kW).

C. *Battery and converter*

A battery storage system and a converter are integrated in the supply system. Concerning this research paper, the capital cost including shipment cost of the inverter is taken as $214/kW [17]. The replacement cost is 93% of total capital and O&M cost is estimated as 1.2% of the capital cost.

V. ECONOMIC MODELLING OF THE HYBRID SYSTEM

In order to study the economic viability of a hybrid system, three economic parameters are particularly indispensable to take into account: The annualized cost of the system (ACS), the system net present cost (NPC), and the cost of electricity (COE) [19]. Therefore, for the economic analysis of the proposed system, we have used the economic criteria abovementioned.

Table III: main parameters of the battery and converter

Parameters	Battery	Converter
Initial capital cost	1000$	$214/kW
Replacement cost	870$	199.02$
O&M cost	1$	2.57$
Nominal voltage	240V	-
Maximum capacity	204 kWh	-
Efficiency	86	95
Lifetime	10000 cycles	15 Years

A. *Annualized cost of the system*

The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component. It is calculated using the following equations [22]:

$$ACS = \sum_{i=1}^{n}[\mathrm{ACC} + \mathrm{ARC} + \mathrm{AMC} + \mathrm{AFC}] \tag{2}$$

Where:
ACC is the annualized capital cost,
ARC is the annualized replacement cost,
AMC is the annualized maintenance cost and
AFC the annualized fuel cost
The annualized cost of each component can be calculated by first calculating the net present cost, then multiplying it by the capital recovery factor, as in the following equation:

$$C_{ann} = CRF(i, N).C_{NPC} \tag{3}$$

Where CRF is the capital recovery factor and is given by:

$$CRF(i, N) = \frac{i(1+i)^N}{-1+(1+i)^N} \tag{4}$$

i is the annual real discount rate, N the project lifetime and C_{NPC} the net present cost

B. *Net Present Cost (NPC)*

The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime.

C. *Cost Operating Energy*

The cost operating energy (COE) is a convenient metric with which to compare systems.
It can be defined as the mean value of cost per kWh of useful electrical energy produced by the plant [23].It is expressed by:

$$COE = \frac{C_{ann} - C_{boiler} * H_{served}}{E_{tot}} \tag{5}$$

Where C_{ann} is the total cost of the system [USD/yr], C_{boiler} is the boiler marginal cost in [USD/kWh], H_{served} is the total thermal load served [kWh/yr] and E_{tot} the total electrical load served [kWh/yr]

VI. RESULTS AND DISCUSSION

The analysis is performed for three-system configuration: PV alone, biodiesel generator alone and hybrid PV/Biodiesel under various sensitivity variables. After all input parameters associated with systems have been considered, the sensitivity analysis is performed. In this research, the sensitivity variables considered are biodiesel cost (USD/L), solar irradiation (kWh/m^2/day). Economic analysis is done by considering cost of electricity (COE), the net present cost (NPC), the initial capital cost and the system operating cost. For the system economic analysis under various climate condition, the solar irradiation considered as a sensitivity variable is varied from 4.0 kWh/m^2/ day (South-west climate condition) to 5.2 kWh/m^2/day (Northern climate condition).

A. *Fuel cost 1.0$ and solar radiation 5.2 KWh/m^2/day*

The results presented in this section corresponds to the optimal condition where the biodiesel fuel is the lowest and solar irradiation highest. The solar irradiation correspond to the central and northern region of the country. This scenario gives the lowest COE and NPC for all systems configuration. The result of this scenario is shown in table 4. It is observed that hybrid system is the economic configuration under this condition.

B. *Fuel cost 1.6$ and solar radiation 5.2 KWh/m^2/day*

The economic analysis results shown in the table 5 corresponds to the case that the biodiesel price is considered equal to the price given after implementation of the project base on biodiesel production from Jatropha curcas in Senegal [12]. The hybrid system PV/BG still being the most economical configuration.

C. *Fuel cost 1.6$ and solar irradiation 4.0 kWh/m^2/day*

The solar irradiation correspond to the southern region. The economic analysis results are shown in the table 6.

D. *Results under Djarkpanga climate condition*

The annual average solar global horizontal irradiation is 5.01 Kwh/m^2/day and the fuel cost is considered to be 1.2 $ as given by a Jatropha oil production enterprise in Burkina Faso and under Senegal oil refining project implementation condition [12],[13]. The economic analysis results under the given climate and fuel cost condition is shown in Table 7.

E. *Impact of fuel cost on the designed hybrid system NPC and COE*

The fuel cost is varied from 1.0 USD to 1.6 USD so that we can see the impact of the biodiesel price on the system economics especially on the net present cost and the cost of electricity. The result is shown in the figure 6.

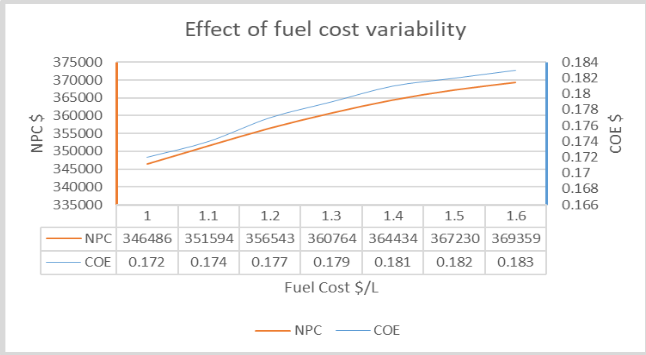


Fig. 6: *Effect of fuel cost on the system COE and NPC*

Discussion

In all the four cases studied, the electricity cost of the system hybrid remains the optimal. Its COE and NPC remain lower than those of other configurations in all cases do. This confirms the fact that hybrid systems are more suitable for the production of electricity in an isolated environment in Togo. In addition, in the three studied conditions, the cost of electricity (COE) of the hybrid system, which ranges from 0.168 to 0.208 USD, remains below the cost of electricity produced by the largest thermal power plant in the country (ContourGlobal) using heavy fuel oil and natural gas which electricity cost is 0.300$. The change in the cost of biodiesel obviously influences the cost of electricity in the system. At every cost, HOMER looks for the combination for the minimum NPC. When the cost of biodiesel ranges from 1.0 to 1.6 dollars, the NPC ranges from 346,486USD to 369,359USD and the COE from 0.172 to 0.183 USD which remains below the cost of electricity generated by the PV system alone (0.215USD) when the annual solar irradiation is 5.01 kWh/m^2/day as shown in table 7. Although the initial cost of the biodiesel system is low, this system is the least economical since the cost of the electricity it produces is still very high (above 0.380 USD). The PV system is the second economic choice according to study results. It is therefore inferred, according to table 4, 5, 6 and 7, that the cost of biodiesel obtained from the implementation of the Jatropha system in Senegal [12] remains acceptable to develop an energetic pathway from Jatropha Curcas.

VII. ENERGY, SOCIOECONOMIC AND ENVIRONMENT IMPACTS OF THE PV/BIODIESEL SYSTEM

A. *Socioeconomic impacts*

The analysis of the socioeconomic impacts of the hybrid system are based on the results obtained for the climatic conditions of the village of Djarkpanga i.e. the annual solar irradiation of 5.01 kWh/m^2/day and the cost of biodiesel at 1.2 USD. Considering the above parameters, the amount of biodiesel consumed is 2628 litters. Since the inhabitants of the village are essentially farmers based on the assumption that this quantity of biodiesel will be produced locally, many young people will therefore be employed in the fields for the cultivation of Jatropha and other will be able to work in the small production and refining plant of Jatropha oil.

In addition, several studies have shown that Jatropha cakes are very good fertilizers better than chemical fertilizers [12]. Generally, the poverty of the villagers is due to the low yield of their culture caused in part by the lack of financial means to purchase chemical fertilizers. Since farmers will be able to buy Jatropha cakes at a lower cost, this will enable them to improve the agricultural profitability of food crops. Jobs created and increased in agricultural profitability will participate in the braking of the rural exodus.

B. *Energy and environment impacts*

The proposed hybrid system produces 150,263 kWh/yr. According to the objectives for non-network renewable energies of Togo, which is to serve 8.92% of the rural population by non-network systems (mini-networks and autonomous systems) of electricity services based on renewable energies [10], if the hybrid system which is proposed is implemented in several villages, it would contribute in a meaningful way to the attainment of these objectives. This would therefore contribute in a direct way to the reduction of the country's energy dependence.

In the African context, Jatropha crop yields range from 0.5 to 1.5 tonnes/hectare and the pressing gives 25 to 30% oil and 45 to 75% of meal [7],[24]. For the analysis, we consider an oil yield of 28% and 70% of oilcake. The amount of biodiesel required by the system for annual electricity production is 2628 litres. The necessary space for the production of Jatropha is:

Mj = 2628 * 100/28 = 9385 kg. By considering a yield of one tonne per hectare, 10ha is sufficient for the production of this electricity. With 10ha, a production of 10 tons of Jatropha beans is ensured which after pressing gives 7 tons of Jatropha cakes.

According to studies conducted by Flaurant P. et al [25], 1 kg of biomass consisting of two doses of Jatropha meal and one dose of maize stem gives after methanation 0.17 m^3 of biogas. Seven tons of cake can therefore contribute to the methanation of 1776 m^3 of biogas which can be used directly for cooking. This will curb the excessive exploitation of woody resources that causes problems of deforestation and ecosystem imbalances.

According to the studies of William F. et al [13], the Jatropha oil fireplace yields 43% thermal yield compared to 35% for the improved wood burning fireplace, while allowing women to avoid certain chores related to the use of wood, in addition to exposure to the heat of the fire and the smoke.Biodiesel is neuter in carbon cycle since its combustion rejects approximately the same amount consumed by the plant from which it originates. Moreover, the combustion of biodiesel does not reject sulphuric gases and therefore much more eco-friendly.

Table IV: Economics for Fuel cost 1.0$ and solar irradiation 5.2 kWh/m^2/day

Description / Configuration	COE USD	NPC USD	Initial capital cost USD	Operating cost USD	Fuel consumption L/year
BG	**0.384**	**775541**	**20721**	**43064**	**38244**
PV	0.210	424396	275778	8479	-
Hybrid PV/BG	0.168	339430	339430	7997	2907

Table V: Economics for Fuel cost 1.6$ and solar irradiation 5.2 kWh/m^2/day

Description / Configuration	**COE $**	**NPC $**	**Initial capital cost $**	**Operating cost $**	**Fuel consumption L/year**
BG	0.583	1,177,405	19,319	66,071	38,222
PV	0.234	472,503	313,170	9,090	-
Hybrid PV/BG	0.179	361,516	227,218	7,662	1,367

Table VI: Economics for Fuel cost 1.6$ and solar irradiation 4.0 kWh/m^2/day

Description / Configuration	**COE $**	**NPC $**	**Initial capital cost $**	**Operating cost $**	**Fuel consumption L/year**
BG	0.583	1,177,405	19,319	66,071	38,222
PV	0.246	495,510	326,002	9,671	-
Hybrid PV/BG	0.208	420,795	263,083	8,998	1,635

Table VII: Economics for fuel cost 1.2 $ and under Djarkpanga climate condition (5.01 Kwh/m^2/day)

Description / Configuration	COE $	NPC $	Initial capital cost $	Operating cost $	Fuel consumption L/year
BG	0.450	909,309	20,741	50,695	38,237
PV	0.215	434,368	282,272	8,677	-
Hybrid PV/BG	**0.177**	**356,543**	**208,897**	**8,424**	**2628**

VIII. CONCLUSION

In this research paper, HOMER software is used to optimize the operation cost of the photovoltaic and biodiesel generator that served as a standalone power system. The comparison of the economic performance of the system was analyzed by using different case studies while considering various sensitivity variables such as solar irradiation and fuel cost. It has been observed that despite the high cost of biodiesel produced from Jatropha curcas, the electricity produced by hybrid system PV/BG is 0.038 USD/kWh economical than PV system alone and 0.273 USD/kWh economical than biodiesel generator alone. Moreover, the hybrid system based on PV/ biodiesel creates more employment and has more impact on agriculture than other autonomous electricity production system. To look very closely, Jatropha could be an alternative to energy problems in rural areas. With the Jatropha oil, by installing generator sets coupled with solar systems in villages, rural population can have electricity at an affordable cost; at the same time as the population have an electric power source, it would tend towards development by increasing food crops with the use of pumps and organic fertilizers obtained from the Jatropha cakes. This system of electricity generation, which combines agriculture and energy, can therefore be a response to fight against unemployment and poverty in rural areas.

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