Techno-economic feasibility of a remote PV mini-grid electrification system for five localities in Chad

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ABSTRACT
This study presents a techno-economic analysis of a mini-grid solar photovoltaic system for five typical rural communities in Chad while promoting renewable energy systems adaptation and rural electrification. The assessment techniques include the establishment of the socio-economic state of the rural communities through a field survey. The costs of system development, electricity tariff and sizing of energy production are realized via the Levelized Cost of Electricity (LCOE) technique. Sensitivity analysis was carried out to identify the parameters that affect the evolution of the LCOE during the life cycle of the project. The results have shown that the annual energy production at all sites varies between 233 MWh/year and 3585 MWh/year. The highest amount of energy production is estimated at Guéiendeng at a rate of 3218 MWh/year and a capacity of 2041 kW, while the lowest is predicted at Mombou at a rate of 211 MWh/year and a capacity of 134 kW. The standard LCOE for the system during the 25-year lifespan in the five villages is estimated at 0.30 €/kWh except at Mailo which was 0.31 €/kWh. This cost per kilowatt-hour is more attractive and competitive compared with the current rate charged by the national electricity company.

1. Introduction

Today, access to an adequate, reliable power supply system is indispensable in shaping the sustainable economic development of a nation. While the rate of access to electricity is high among the developed nations and a gradual transition to a cleaner and sustainable energy structure is envisioned, Africa remains one of the least continents to have access to a reliable electricity supply system. Over the years, the rate of people gaining access to electricity in the African continent has improved from as low as nine million per year back in 2000 to about twenty million per year in recent years. However, the majority of the developing sub-Saharan African nations are still struggling to establish a reliable, consistent power supply system and the electrification rate remains very low despite significant investments in many countries. According to the recent data from the International Energy Agency (IEA), nearly 600 million people in the sub-Saharan region still do not have access to uninterrupted electrical energy (EIA 2019). This accounts for about 50% of the population in the African continent. However, in Chad, despite the country being endowed with lots of potential in both conventional and renewable energy resources, the country is considered one of the most concerned counties by the Global Sustainable Energy Goal (GSEG7) that has been set by the United Nations (UN) to achieve global access to electricity, with the current access to electricity of about 10% only as of 2018, according to IEA. Such a percentage is measured among the lowest share of energy in the region and also one of the most expensive. Thus, the consistent power outage is an everyday norm that lives across the country in a nation where the majority (75%) of the population live in rural areas (Hassane et al. 2018; Didane et al. 2017a, 2016b).

Higher costs of power from renewable energy sources have been the leading cause hindering the promotion and dissemination of renewable energy technologies worldwide. Today, however, small-scale off-grid energy systems such as solar photovoltaics (PVs), wind turbines, small hydropower plants, batteries, diesel generators, and so on, are being adopted globally due to their emerging economic competitiveness, particularly in the remote rural areas. This has resulted from the advancement in materials technologies and mass production of components (Duman and Güler 2018; Didane et al. 2016a; Al-Ghriyabah et al. 2019). Given that the majority of the population who lacks access or have limited access to electricity are the inhabitants of the remote rural areas, exploring grid electricity may be expensive and thus could be priced above the means of the rural communities (Lee et al. 2016). Recent data have indicated that the combination of off-grid renewable
energy systems and conventional systems could be a more appropriate approach to unravel the recurring issues of electricity supply while resolving the intermittent nature of renewable energy resources such as wind and solar (Ould Bilal et al. 2015). Hence, using a single renewable energy source may not be feasible for a community in terms of reliability and cost-effectiveness while promoting a low-carbon society, due to these seasonal variations of sunshine and wind speed (Saheb-Koussa, Haddadi, and Belhamel 2008). As a result, a combination or integration of more than one source of energy is suggested by a great number of researchers including (McNeil, Karali, and Letschert 2019; Isa et al. 2016; Sen and Bhattacharyya 2014; Olatomiwa, Mekhilef, and Ohunakin 2016; Agyekum and Nutakor 2020; Colle, Luna Abreu, and Rüther 2004).

Although hybrid systems could potentially be reliable and cost-effective, the best combination and integration of renewable energy-based components with fossil fuel-based components is highly dependent on the geographical and climatic conditions of the particular site under study (Aziz et al. 2019). The main objective of this paper is to study the technical and economic feasibility of solar photovoltaic mini-grids in five localities in Chad. As scientific publications on mini-grid renewable energy systems are limited in Chad and most of the existing studies are limited to the optimisation of a single site by a single software such as HOMER, in this study, two software programmes (PVGIS and PVSYST) are combined to find more robust and accurate solutions in the calculation of the LCOE of five localities in Chad. In addition, an on-site survey to assess the actual electrical needs of these different communities was conducted. This successful optimised model of mini-grid in Chad could serve as an example and contribute to the development of a rural electrification plan to make electricity available and accessible to the population, especially in rural areas of Chad and in the region.

The main problem is to know how to estimate the electricity demand of a locality in Chad, then, what kind of PV mini-grid can satisfy this demand and, lastly, at what level is the cost of the kilowatt-hour reasonable for the population. To answer these questions, this paper is structured as follows: Section 1 covers the introduction, section 2 presents the literature review, and section 3 presents the context and the energy scenario in Chad. Sections 4 and 5 describe the methodology for identifying typical villages and the method of calculating the cost of energy (LCOE). The LCOE calculation results and discussion are presented in section 6. Finally, section 7 presents the conclusion of the present study.

2. Literature review

Nowadays, the quest for cleaner energy to satisfy energy demands, particularly in remote areas is receiving attention all over the world. Several studies have demonstrated that a hybrid off-grid system is far more favourable on many levels such as cost-effectiveness, reliability, sustainability, and technical and environmental performance (greenhouse gas emission minimisation) than a single-source energy system for remote rural electrification (Al Garni, Awasthi, and Ramli 2018; Baneshi and Hadianfard 2016). Ogunjuyigbe, Ayodele and Akinola (Ogunjuyigbe, Ayodele, and Akinola 2016) studied five different scenarios of combinations between renewable and non-renewable resources using the genetic algorithm technique and found that the PV/wind/split-diesel and battery system was the most feasible system. Esan et al. (Esan et al. 2019) assessed the reliability of an off-grid hybrid system for rural communities in Nigeria and it was observed that a hybrid system consisting of PV-diesel-battery is highly reliable and economically feasible, and it has the potential to reduce emissions by 97% compared to a conventional diesel-generated system. A similar reduction in CO2 emission was also achieved while reducing battery requirement by almost 70% in a study conducted in the rural areas of Benin (Odou, Bhandari, and Adamou 2020).

Furthermore, Ghorbani et al. (Ghorbani et al. 2018) studied the optimisation of the best sizing of an off-grid house in the suburbs of Tehran, Iran, while using the genetic algorithm method found that the PV/Wind turbine and battery system combination was the most feasible option. Similarly, the best configurations for PV and wind turbine combination were found in micro-grid projects in the United States (US) by using both the genetic algorithm method in (Nagapurkar and Smith 2019) and the hybrid optimisation of multiple energy resources (HOMER) software in (Nacer, Hamidat, and Nadjiemi 2015) for a cattle farm in the desert of Algeria. Meanwhile, Bhattacharyya (Bhattacharyya 2015) revealed that the combination of solar, wind and diesel system is advantageous for a design of an off-grid village in Bangladesh, and further classified that the energy from the diesel generator should be for the basic energy demands and the energy from the hybrid system for the high-level energy demands. Likewise, Maleki and Askarzadeh (Maleki and Askarzadeh 2014) and Olatomiwa et al. (Olatomiwa et al. 2015a) also found that the hybrid solar PV/wind/diesel/battery system is effective for rural applications, while the solar PV panels alone were suggested in (Jeyapraba and Selvakumar 2015; Ismail, Moghavvemi, and Mahlia 2013). Olatomiwa, Mekhilef and Ohunakin (Olatomiwa, Mekhilef, and Ohunakin 2016) showed that the PV, diesel and battery integration is more feasible in some parts of Nigeria, and the PV-battery-wind-diesel in other parts of the country. In addition, the PV panels, diesel and battery combination was found to be the most economically viable option for a remote mobile base transceiver station in Nigeria (Olatomiwa et al. 2015b).

Meanwhile, a hybrid configuration that comprises only solar PV and diesel was found to be the optimal in studies conducted by (Akinyele 2017; Suresh Kumar and Manoharan 2014). Raji and Luta (Raji and Luta 2019) and Yilmaz and Dincer (Yilmaz and Dincer 2017) suggested the combination of solar PV, generator, converter and batteries as the optimal system configuration. A similar configuration while including a wind turbine in the system was proposed in (Adaramola, Agelin-Chaab, and Paul 2014; Hossain, Mekhilef, and Olatomiwa 2017). A hybrid of hydropower, biomass and biogas, including the solar PV and wind turbine, was also utilised and found to be optimal (Kanase-Patil, Saini, and Sharma 2010). While in some cases, PV/battery and inverter were found useful (Bhakta and Mukherjee 2017).
As such, the effectiveness of the number of hybrid component combinations and the percentage share from each resource depends highly on the availability of the resources in the particular location under study as well as the level of CO₂ emission reduction required. However, despite the consensus of the majority of the available literature on the superiority of hybrid systems compared to the cost of grid electricity, some studies such as Duman and Güler (Duman and Güler 2018) found that the cost of electricity production from renewable energy systems could also be higher than the conventional grid electrical energy, in a study conducted in coastal regions of Izmir, Turkey, for seasonal vacation homes. The hybrid system adopted was a combination of PV/wind/fuel cells, and it was suggested the use of battery storage instead of hydrogen storage for cost reduction. It is noted from the literature review conducted that having fuel cell components within the combined hybrid system is not economically feasible since fuel cell technology is not a mature technology yet, and thus its design components are still expensive, as shown in Table 1. However, the design, optimisation, performance, simulation and sensitivity analysis of the hybrid systems are typically performed using numerous methods and techniques as seen in the literature. Among the most common and reliable methods are by using the renowned HOMER software, artificial intelligence (AI) technique, or the analytical technique. Given that scientific publications on mini-grid renewable energies are limited in Chad (Hassane et al. 2022; Didane et al. 2017b), we have been interested in literature in other regional countries such as Algeria, South Africa, Nigeria, Cameroon, and so on. However, the gap in most of these studies is limited to the optimisation of a single site by a single software such as HOMER, whereas in the present study, a combination of two software programs (PVGIS and PVSYST) was used to find more robust solutions in the calculation of the LCOE of five localities in Chad. In addition, an on-site survey to assess the actual electrical needs of these different communities was also conducted where a decentralised solar energy could contribute to increasing the rate of rural electrification in Chad. As such, this study aims to perform a techno-economic feasibility analysis of a mini-grid solar PV system in the rural areas of Chad while seeking to satisfy energy requirements and promote renewable energy adaptation in the region.

3. Energy scenario in Chad

The electrical power sector in Chad remains heavily dependent on fossil fuels. The country’s energy balance is distributed as follows: 96.5% from wood fuel, 3% from

| Authors | PV-diesel-batteries | PV-wind-batteries | PV-wind-diesel-batteries | Wind-diesel-batteries | Methodology/Software used | Research gap |
|---------|---------------------|-------------------|--------------------------|-----------------------|---------------------------|--------------|
| (Dufo-López and Bernal-Agustin 2005) | x | | | | Artificial intelligence | Algorithm optimisation of a hybrid PV-diesel system. There is, however, a risk of error in the estimated data. |
| Koutroulis et al. 2006 | | x | | | Artificial intelligence | Optimisation of a hybrid PV/wind system by genetic algorithm. However, the estimated data may be erroneous. |
| (Diaf et al. 2008) | | | x | | Artificial intelligence | Use of a probabilistic model to minimise production loss in a hybrid PV/wind system. However, estimated data may not be accurate. |
| (Sinha, Chandel, and Malik 2021) | | | | x | Analytical method | An experimental study with low capacity (6 kWp) which may not be applied in sites with high demand |
| (Shahid and El-Amin 2009) | x | | | | Analytical method | A comparative study of the performance of a fixed and variable tilt angle and the tracking system of a solar power plant in India. This is an interesting study, but it may not be duplicated elsewhere because of the characteristics of the plant and the materials used. |
| (Shafullah et al. 2010) | | | | x (Without diesel) | HOMER | Saudi Arabia Specific Study for Arid Regions with Significant Wind Potential |
| (Shoeb et al. 2016) | | | | x | HOMER | Optimisation of a hybrid PV-wind system with data collected on sunlight and wind speed over a few days. For the optimal robustness of the solution, data of at least one year must be introduced to obtain good results. |
| (Shafullah 2016) | | | | x | HOMER | Optimisation of the PV/wind system by algorithm prediction of meteorological data on wind speeds and sunlight. However, the data used are not real and can be flawed for a system connected to the network. This study could interest us, except that the data used are not real and may be tainted with errors. Also, in the case of our study, the electricity sites are far from the national grid. |
| (Yadav et al. 2021) | | | | x (Without diesel) | HOMER | The authors studied the influence of the tilting angle of solar panels on the efficiency of the installation. But the tilting angle of the solar panel affects the efficiency of the electricity production. This angle varies from place to place. Feasibility of a hydraulic/p/diesel/battery hybrid system applied to Chipendeke, a remote village located in Zimbabwe. The authors studied three evaluation criteria, namely: the net present value, the cost of energy and the fraction of renewable energies. It appears from this study that the project has a competitive cost estimated at $0.165/kWh. Moreover, it can be duplicated anywhere in the world. |
petroleum products and only 0.5% from electricity (Hassane et al. 2019). However, Chad has significant potential in renewable energies, particularly solar energy. The Chadian government is planning to increase the rate of access to electricity to 30% throughout the country and 25% in the rural areas compared to the current 2%, by adopting renewable energies as a part of Chad’s vision for 2030 (Ministry of Economy and Development Planning, Republic of Chad 2017). To achieve such goals, substantial investments and sustainable energy policies are needed to boost this sector.

The current electricity network is concentrated mainly in the capital city of the country (N’Djaména) and also in the regional capitals which are supplied by thermal power stations (generators running on diesel) by the national electric company (SNE). This network is made up of a 90 kV loop around the city of N’Djaména, a 66 kV overhead line from the Djermaya refinery and a 15 kV cable line distribution network, supplying the city with HV/LV distribution stations. In addition to this national network, an interconnection with the neighbouring country, Cameroon, is possible via the Lagdo hydraulic dam in Cameroon (72 MW). As part of Chad’s electrification plan for 2030, the Ministry of Petroleum and Energy has identified three possible interconnection lines between the two countries in the near future which are a 13 MW line through Warak-Moundou, a 10 MW line through Maroua-Bongor and a 13 MW line through Maroua-N’Djaména.

Moreover, the investigation of the current condition of the Chadian electric energy production system based on fossil fuels has enabled us to observe substantial issues, such as maintenance problems of electrical installations, lack of availability of electric power in isolated villages, lack of skilled labour, barriers to renewable energy system development, lack of support for investment in green electricity and low level of demand in isolated sites (Hassane, Hauglustaine, and Tahir 2017). Thus, the present study will identify the solar energy potentials for rural electrification in Chad while optimising electricity production from local sites to meet its energy demand. Thus, it is important to identify how to estimate the energy demand profile for typical villages in Chad, when and what type of mini-grid can meet this energy demand and at what level is the reasonable kilowatt-hour (kWh) cost for the rural population.

3. Materials and methods

In this study, five typical community villages in the province of Chari-Baguirmi, N’Djamena, in the Sahelian region in Chad are studied. They are, namely, Mombou, Mailao, Douguia, Gelendeng and Dourbalvi village. The methodology of the present study consists of understanding the socio-economic development of each village by interviewing the chief of each village and collecting the data concerning the energy needs of each household. The

![Rural electrification methodology for mini-grid in Chad.](image)
Table 2. Characteristics of the selected villages.

| Characteristics of the village | Mombou: small village | Mailao: medium village | Douguia: large town | Gelierdeng: small rural commune | Dourbal: large rural commune |
|-------------------------------|-----------------------|------------------------|---------------------|--------------------------------|-----------------------------|
| The geographical situation with respect to N'Djamen | <1000 inhabitants | (1000 to 3000 inhabitants) | (3000 to 5000 inhabitants) | (10,000 to 15,000 inhabitants) | (15,000 to 20,000 inhabitants) |
| Population | 707 | 2272 | 4038 | 12,000 | 16,782 |
| Average number of people/households | 6.8 | 7.6 | 6 | 4 | 6.7 |
| Total number of households per village | 104 | 300 | 673 | 3000 | 2500 |
| Number of households surveyed | 21 | 51 | 60 | 510 | 425 |
| Estimated energy for the households surveyed (kWh/d) | 47.32 | 114.6 | 135.8 | 1194 | 995 |
| Estimated energy for all households (kWh/d) | 234.3 | 674.1 | 1523.7 | 7023.5 | 5852.9 |
| Energy demand per village (kWh/d) | 472 | 1342 | 2248 | 7744 | 6517 |
| Growth margin of estimated demand (10%) | 47 | 134 | 225 | 774 | 652 |
| Total energy demand per village (kWh/d) | 520 | 1476 | 2473 | 8519 | 7169 |

The type of the habitat (grouped or dispersed) and the nature of the structure (cement, earth) of the households have been taken into consideration.

3.1 Site selection criteria

The choice of the sites is justified by the potential of solar energy, diversification of socio-economic activities, the distance from the central network office of the SNE and the number of inhabitants of village size, as shown in Figure 1.

3.2 Village size

The size of the villages must be considered in order to have a more successful rural planning. Of the five villages investigated, three categories of villages and two types of rural communities have been distinguished as shown in Table 1. The present approach is to install mini-grids in the villages with small professional structures (craftsmen, mechanics, cuckunisers, etc.), in order to facilitate maintenance of the panels and to avoid additional maintenance costs by involving experts from overseas or outside the village. However, over 20,000 inhabitants are characterised as towns as they are equipped with their own network and thus, they are automatically excluded from this study. Other villages in the Sahelian zone, which are further away, are considered under medium, large villages and small rural communities. Table 2 summarises the characteristics of the villages covered in the study, including the estimate of their daily energy needs.

3.3 Solar energy potential

During the field survey conducted on the issue of access to renewable energy in Chad, 95% of the interviewed populations responded favourably to the use of or shifting to renewable energy systems. In addition, the average wind speed is less than 5 m/s, while the solar radiation is 6 kWh/m²/day on average in the areas studied, as shown in Figure 2. As a result, the sites considered present a very good solar potential, with low wind energy, which justifies the choice of solar PV energy project. Another renewable energy resource that could have favourable potential is biomass residues. Studies indicate that the exploitation of 5% of residues of the two most cultivated bowls of cereal in Chad (sorghum and millet) can produce electric power of up to 23 MW. The yields of these residues per hectare are, respectively, 2 tonnes for millet and 2.5 tonnes for sorghum.

Figure 2. Solar irradiation and clearness index for the selected sites.
3.4. Daily energy demand profiles

First, the load profiles of the energy demand of the different villages based on the electrical devices used for the energy needs of households (lighting, telephone charging, television, etc.), community uses (school, mosque, church, water pumping, public lighting, etc.) and productive (supplies, shops, phone booths) were estimated. Secondly, for each village, we grouped the households into 3 types according to their consumption: lighting + telephone charging socket for low-income type 1 households, lighting + telephone charging + television for middle-income type 2 households and lighting + telephone charging socket + television + ventilation + refrigeration for type 3 households with average income, as shown in Table 3.

Beyond this current demand, it is necessary to consider its evolution on average and long term, so that the sizing of a mini-grid continues to meet the demand during its lifetime. The annual growth margin thus takes into account the expansion of the village and the increase in the number of electrical appliances used by the residents. A margin of 10% of daily energy needs is suggested by numerous authors including (Muh and Tabet 2019).

On the other hand, the World Bank in its 2012 report on the sustainability of solar photovoltaic energy projects for community facilities and services in sub-Saharan Africa recommends a 20% margin. We surveyed the field to estimate the annual growth margin in electricity demand for long-term Chadian households (10–20 years). Hence, we choose as an assumption to take a margin of 10%. Meanwhile, the interest rate, inflation rate, discount rate and the degradation rate are taken, respectively, as 8%, 3%, 5% and 1% for the 25 years of the project lifespan.

4. Method of calculating the cost of a mini solar PV power plant

There are several methods of cost evaluation in the feasibility study of energy projects nonetheless the Levelized Cost of Electricity (LCOE) is the most used in the choice of technologies or the development of renewable sectors such as solar photovoltaic (Branker, Pathak, and Pearce 2011). Its particularity is to allow the evaluation of the cost of production of energy during the life of the project, while the other methods generally calculate the annual cost only. The general formula for calculating the LCOE (Equation 1) is defined by (Branker, Pathak, and Pearce 2011; Ouedraogo et al. 2015)

\[
LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,c}}{(1+i)^t}}
\]

where:

- LCOE: Levelized Cost of Electricity in EUR/kWh
- \( I_0 \): Initial investment in Euro
- \( A_t \): Total annual cost in Euro for year \( t \)
- \( M_{t,c} \): Quantity of electricity produced in kWh per year
- \( i \): Discount rate in%
- \( n \): Project life in years
- \( t \): Number of years (1, 2, ..., \( n \))

4.1. Energy cost (LCOE) calculation parameters

4.1.1. Meteorological data

To make the micro-grid simulations adaptable to these villages according to the scenario of satisfaction of household energy demand, community uses and productive uses, it is necessary to choose the nearest weather station from the database provided by the PVSYST. Thus, the weather data are obtained for the N’Djamena station and illustrated as shown in Figure 2.

4.1.2. System component costs

The photovoltaic mini-grid is made up of solar panels, converters, inverters, batteries, and so on. Given the abundance of solar radiation, the chosen option is to supply each village with solar energy, initially considered at 100% including battery storage. The prices of different components shown in Table 4 are based on current market conditions available in Chad.
### Table 5. LCOE for the different photovoltaic mini-grids (O&M = operation and maintenance costs).

| Sites      | Installed capacity (kWp) | Area (m²) | Initial investment cost (€) | O&M costs (€/year) | Annual production (kWh/year) | LCOE (€/kWh) |
|------------|--------------------------|-----------|------------------------------|--------------------|-------------------------------|--------------|
| Mombou     | 134                      | 1089      | 581,560                      | 4824               | 233,047                       | 0.30         |
| Mailao     | 385                      | 3092      | 1,670,900                    | 13,860             | 659,593                       | 0.31         |
| Douguia    | 633                      | 5181      | 2,734,560                    | 22,788             | 1,093,644                     | 0.30         |
| Dourbali   | 1787                     | 15,018    | 7,719,840                    | 64,332             | 3,161,247                     | 0.30         |
| Guelendeng | 2041                     | 17,846    | 8,817,120                    | 73,476             | 3,584,656                     | 0.30         |

### Table 6. Energy production for the various sites using the PVSYST (in MWh).

| Energy produced | Mombou | Mailao | Douguia | Dourbali | Guelendeng |
|-----------------|--------|--------|---------|----------|------------|
| January         | 24.1   | 68.3   | 113.3   | 324.4    | 367.6      |
| February        | 20.6   | 58.3   | 96.6    | 278.0    | 315.2      |
| March           | 21.0   | 59.6   | 98.7    | 285.3    | 323.7      |
| April           | 18.5   | 52.4   | 86.8    | 252.6    | 286.5      |
| May             | 17.2   | 48.7   | 80.8    | 235.8    | 267.3      |
| June            | 14.7   | 41.6   | 69.0    | 202.3    | 229.3      |
| July            | 13.8   | 39.2   | 65.0    | 190.3    | 215.9      |
| August          | 15.7   | 44.4   | 73.6    | 214.4    | 243.4      |
| September       | 17.0   | 48.2   | 79.8    | 231.5    | 262.8      |
| October         | 22.1   | 62.5   | 103.5   | 298.4    | 338.5      |
| November        | 23.9   | 67.6   | 112.1   | 321.0    | 363.7      |
| December        | 24.4   | 68.9   | 114.4   | 327.4    | 370.9      |
| Total annual production (in MWh) | 233    | 660    | 1094    | 3161     | 3585       |

### 5. Results and discussion

#### 5.1. Annual energy production

The sizing or scaling of the amount of energy production is achieved through the PVSYST and PVGIS software apart from using the LCOE technique. The overall simulation results are shown in Figures 3–7, while the comprehensive and detailed results for all parameters including the peak power to be installed, the storage capacity of batteries, the cost per kilowatt-hour, and so on, are shown in the Appendix (Table 9–13 and Appendix A).

Table 5 summarises the results of the pre-sizing of the amount of energy produced for an isolated system with a battery using the PVSYST software. It is observed that with the average sunshine of about 6 kWh/m²/day, the energy produced at the five different sites varies between 233 MWh/year and 3585 MWh/year. The highest amount of energy production was found at Guelendeng community village at a rate of 3218 MWh/year and a capacity of 2041 kW; meanwhile, the lowest amount of energy was obtained at Mombou village with a rate of 211 MWh/year and a capacity of 134 kW. Accordingly, the initial investment cost at Guelendeng community village was higher compared to the other sites since the installed capacity was the highest on this site. Similar trends are observed in the operation and maintenance costs as expected. However, the LCOE tends to be similar among all stations with the exception of one site which is the Mailo village where the LCOE differs slightly with 0.31 €/kWh as compared to 0.30 €/kWh at the other community villages.

Moreover, the simulation results of the energy production annually at each site at different times or seasons of the year are presented in Table 5 and Table 6 by using PVSYST and PVGIS, respectively. It is clear that all sites produce more energy in the months between November and January and the lowest is seen in July using both methods (PVSYST and PVGIS) with Guelendeng having the highest capacity of 3585 MWh/year using the PVSYST software and 3218 MWh/year using the

Figure 3. Difference in annual electricity production between PVGIS and PVSYST.
Table 7. Energy produced for the different sites using the PVGIS (in MWh).

| Energy produced | Mombou     | Mailao   | Douguia | Dourbali | Guelendeng |
|-----------------|------------|----------|---------|----------|------------|
| January         | 21.2       | 60.8     | 100     | 282      | 322        |
| February        | 18.6       | 53.5     | 88      | 248      | 284        |
| March           | 21.3       | 61.1     | 101     | 284      | 324        |
| April           | 17.1       | 49.3     | 81      | 229      | 261        |
| May             | 15.8       | 45.4     | 74.6    | 211      | 241        |
| June            | 13.6       | 39.2     | 64.5    | 182      | 208        |
| July            | 13.3       | 38.1     | 62.6    | 177      | 202        |
| August          | 13.6       | 39.1     | 64.2    | 181      | 207        |
| September       | 16.1       | 46.3     | 76      | 215      | 245        |
| October         | 19.4       | 55.7     | 91.6    | 259      | 295        |
| November        | 20.0       | 57.4     | 94.4    | 267      | 304        |
| December        | 21.3       | 61.3     | 101     | 285      | 325        |
| Total annual production (in MWh) | 211       | 607     | 998     | 2820     | 3218       |

PVGIS method. Meanwhile, the lowest production is estimated at 211 MWh/year at the Mombou while using the PVGIS technique.

Furthermore, the comparisons of the results obtained by the PVSYST software with those provided by the PVGIS database are illustrated in Figure 3. It is observed that the annual energy produced using PVSYST data has shown higher values compared to the PVSYST software. Thus, it can be seen that the results of the total electricity production obtained by PVGIS are relatively low compared to those provided by PVSYST. The observed deviation varies by 5% at the site from Mombou and 11% to the Dourbali site. Since the results with PVSYST are relatively favourable for the different sites, we chose the latter for our simulations.

With regard to the annual energy produced, we note that the use of two software programs (PVGIS and PVSYST) gives similar results in terms of the favourable solar energy potential over the entire national territory (6 kWh/m²/day).

Table 8. LCOE sensitivity analysis parameters of different mini-grid projects (€/kWh).

| Parameters                  | Discount rate (%) | Investment bonus (%) | LCOE Mombou | LCOE Mailao | LCOE Douguia | LCOE Dourbali | LCOE Guelendeng |
|-----------------------------|-------------------|----------------------|-------------|-------------|--------------|--------------|-----------------|
| Better scenario, low LCOE  | 0%                | 100%                 | 0.02        | 0.02        | 0.02         | 0.02         | 0.02            |
| Basic scenario, standard LCOE | 5%            | 0%                   | 0.30        | 0.30        | 0.30         | 0.30         | 0.30            |
| Bad scenario, High LCOE    | 10%               | 0%                   | 39.0        | 40.0        | 39.0         | 38.0         | 39.0            |

Table 9. LCOE of the PV mini-grid at Mombou site.

| Year | Discount rate (%) | Production (kWh) | Sum of Electrical Energy Produced over Lifetime (kWh/Lifetime) | Investment Cost (€) | O&M Cost (€) | Sum of Costs over Lifetime (€/Lifetime) | LCOE (€/kWh) |
|------|-------------------|------------------|---------------------------------------------------------------|---------------------|--------------|----------------------------------------|--------------|
| 0    | 5%                | 233.047          | 581.56                                                        | 4.824               | 586.384      | 2.52                                   |              |
| 1    |                   | 233.047          |                                                               |                     |              |                                        |              |
| 2    |                   | 221.950          |                                                               |                     |              |                                        |              |
| 3    |                   | 211.380          |                                                               |                     |              |                                        |              |
| 4    |                   | 201.315          |                                                               |                     |              |                                        |              |
| 5    |                   | 191.728          |                                                               |                     |              |                                        |              |
| 6    |                   | 182.598          |                                                               |                     |              |                                        |              |
| 7    |                   | 173.903          |                                                               |                     |              |                                        |              |
| 8    |                   | 165.622          |                                                               |                     |              |                                        |              |
| 9    |                   | 157.735          |                                                               |                     |              |                                        |              |
| 10   |                   | 150.224          |                                                               |                     |              |                                        |              |
| 11   |                   | 143.071          |                                                               |                     |              |                                        |              |
| 12   |                   | 136.258          |                                                               |                     |              |                                        |              |
| 13   |                   | 129.769          |                                                               |                     |              |                                        |              |
| 14   |                   | 123.590          |                                                               |                     |              |                                        |              |
| 15   |                   | 117.705          |                                                               |                     |              |                                        |              |
| 16   |                   | 112.100          |                                                               |                     |              |                                        |              |
| 17   |                   | 106.762          |                                                               |                     |              |                                        |              |
| 18   |                   | 101.678          |                                                               |                     |              |                                        |              |
| 19   |                   | 96.836           |                                                               |                     |              |                                        |              |
| 20   |                   | 92.225           |                                                               |                     |              |                                        |              |
| 21   |                   | 87.833           |                                                               |                     |              |                                        |              |
| 22   |                   | 83.650           |                                                               |                     |              |                                        |              |
| 23   |                   | 79.667           |                                                               |                     |              |                                        |              |
| 24   |                   | 75.873           |                                                               |                     |              |                                        |              |
| 25   |                   | 72.260           |                                                               |                     |              |                                        |              |
| Total|                   | 3.448.779        | 53.374.094                                                  | 175.879             | 16.225.387   | 0.30                                   |              |
5.2. Energy cost (LCOE)

The economic evaluation of mini-grids in the five localities studied by the LCOE method has enabled us to obtain a cost of around 0.31 €/kWh, which is competitive with the cost of the national electricity company (SNE) of around 0.45 €/kWh. This decrease is due to the substitution of diesel units which are expensive in terms of diesel consumption and often require maintenance by photovoltaic solar panels.

Tables 9, 10, 11, 12 and 13, shown in the Appendix, illustrate the results of LCOE calculations, obtained for the various mini-grid projects during their 25-year lifespan. It emerges from these results that the standard LCOE for these projects is, respectively, estimated at 0.30 €/kWh for the Mombou, Douguia, Dourbali and Guelendeng sites, and at € 0.31/kWh at the Mailao site. This cost per kilowatt-hour is competitive with the rate charged by the SNE, which is around 0.45 €/kWh (= 252 F CFA/kWh).

5.3. Sensitivity analysis

The sensitivity analysis allows us to identify the parameters that influence the evolution of the LCOE during the life cycle of the project. Table 7 and 8 illustrates the sensitivity analysis of the LCOE compared to the evolution of the discount rate which varies from 0% to 10% and the investment bonus varies from 10% to 100% of the initial investment. It is necessary to validate the results obtained through the analysis of the variables that can influence the cost of energy. In order to compare the

| Year | Discount rate (%) | Production (kWh) | Sum of Electrical Energy Produced over Lifetime (kWh/Lifetime) | Investment Cost (€) | O&M Cost (€) | Sum of Costs over Lifetime (€/Lifetime) | LCOE (€/kWh) |
|------|------------------|------------------|---------------------------------------------------------------|---------------------|-------------|----------------------------------------|-------------|
| 0    | 5%               | 659.593          | 659.593                                                       | 1.670.900           |             | 1.670.900                              | 1.670.900   |
| 1    |                  | 628.184          | 1.287.777                                                    | 13.860              | 1.684.760   | 1.698.620                              | 2.55        |
| 2    |                  | 598.270          | 1.886.047                                                    | 14.726              | 1.697.960   | 1.845.926                              | 3.32        |
| 3    |                  | 569.781          | 2.455.828                                                    | 14.704              | 1.710.531   | 1.851.235                              | 0.91        |
| 4    |                  | 542.649          | 2.998.477                                                    | 15.145              | 1.748.841   | 1.864.986                              | 0.90        |
| 5    |                  | 516.808          | 3.515.286                                                    | 15.600              | 1.733.907   | 1.878.513                              | 0.88        |
| 6    |                  | 492.198          | 4.007.484                                                    | 16.068              | 1.744.767   | 1.892.834                              | 0.85        |
| 7    |                  | 468.760          | 4.476.244                                                    | 16.550              | 1.755.109   | 1.898.658                              | 0.84        |
| 8    |                  | 446.439          | 4.922.683                                                    | 17.046              | 1.764.959   | 1.898.918                              | 0.84        |
| 9    |                  | 425.180          | 5.347.862                                                    | 17.557              | 1.774.340   | 1.899.897                              | 0.84        |
| 10   |                  | 404.933          | 5.752.795                                                    | 18.084              | 1.783.274   | 1.900.358                              | 0.84        |
| 11   |                  | 385.650          | 6.138.446                                                    | 18.627              | 1.791.783   | 1.901.406                              | 0.84        |
| 12   |                  | 367.286          | 6.505.732                                                    | 19.185              | 1.799.887   | 1.902.072                              | 0.84        |
| 13   |                  | 349.796          | 6.855.528                                                    | 19.761              | 1.807.605   | 1.902.370                              | 0.84        |
| 14   |                  | 333.139          | 7.188.667                                                    | 20.354              | 1.814.955   | 1.902.310                              | 0.84        |
| 15   |                  | 317.276          | 7.505.943                                                    | 20.964              | 1.821.955   | 1.902.310                              | 0.84        |
| 16   |                  | 302.167          | 7.808.110                                                    | 21.593              | 1.828.622   | 1.902.330                              | 0.84        |
| 17   |                  | 287.778          | 8.095.888                                                    | 22.241              | 1.834.971   | 1.902.330                              | 0.84        |
| 18   |                  | 274.075          | 8.369.963                                                    | 22.908              | 1.841.019   | 1.902.330                              | 0.84        |
| 19   |                  | 261.023          | 8.630.986                                                    | 23.596              | 1.846.778   | 1.902.330                              | 0.84        |
| 20   |                  | 248.594          | 8.879.580                                                    | 24.304              | 1.852.263   | 1.902.330                              | 0.84        |
| 21   |                  | 236.756          | 9.116.336                                                    | 25.033              | 1.857.486   | 1.902.330                              | 0.84        |
| 22   |                  | 225.482          | 9.341.817                                                    | 25.784              | 1.862.461   | 1.902.330                              | 0.84        |
| 23   |                  | 214.745          | 9.556.562                                                    | 26.557              | 1.867.199   | 1.902.330                              | 0.84        |
| 24   |                  | 204.519          | 9.761.081                                                    | 27.354              | 1.871.712   | 1.902.330                              | 0.84        |
| 25   |                  | 194.081          | 10.060.601                                                   | 28.175              | 1.876.009   | 1.902.330                              | 0.84        |
| Total|                  | 9.761.081        | 151.064.714                                                 | 505.325             | 46.617.716  | 185.031                                | 0.31        |
cost of solar PV with the diesel cost at SNE which is around 0.45 €/kWh, we have issued the following three scenarios:

- Best scenario: low LCOE (0.02 €/kWh);
- Base case scenario: average LCOE (0.30–0.31 €/kWh);
- Worst scenario: high LCOE (0.38–0.40 €/kWh).

The first scenario is unrealistic, but we get an average energy cost of € 0.25/kWh for a discount rate of 2% and an investment bonus rate that rises at 20%, respectively, for all sites as shown in Figure 4 and Figure 5.

Figures 4–7 show the evolution of the LCOE over the entire life period of the project as well as the sensitivity of the LCOE to the variation of certain factors such as the
discount rate and the investment bonus. The rates of change of these parameters vary, respectively, from 0% to 10% for the interest rate and from 0% to 100% for the investment bonus. It can be seen that the discount rate and the investment bonus follow a linear evolution ($R^2 = 0.9996$ for the discount rate and $R^2 = 0.9998$ for the investment bonus). Depending on the discount rate, the minimum value of the LCOE varies

![Figure 5. Evolution of the average LCOE compared to the discount rate.](image)

![Figure 6. Sensitivity of the LCOE of the 5 mini-grids in relation to the investment premium.](image)
between 0.22 €/kWh and 0.30 €/kWh. The LCOE varies from 0.02 €/kWh to 0.40 €/kWh compared to the variation of the investment bonus. When the discount rate reaches 10%, the LCOE reaches 0.39 €/kWh. The LCOE decreases to 0.02 €/kWh when the investment bonus reaches 100%. It can be concluded that the LCOE is very sensitive to the variation of the investment bonus, as well as the evolution of the discount rate.

6. Conclusion

In this study, the development of a solar photovoltaic (PV) mini-grid system and a techno-economic assessment of the energy needs of five typical villages in Chad is carried out through both an analytical technique and a field survey. The main aim of this study was to establish a reliable energy system while performing a techno-economic feasibility analysis of a mini-grid solar PV system in rural areas. The analysis involves the use of the Levelized Cost of Electricity (LCOE) technique and the PVGIS and PVSYST software. The demand load profile and sizing of the mini-grid system are established through the field survey data conducted at the five typical villages under study. The results have shown that the energy produced varies between 233 MWh/year at Mombou site and 3585 MWh/year at Guelendeng for a capacity of 134 kWp and 2041 kWp, respectively. The lowest production is estimated at 211 MWh/year at the Mombou while the highest amounts to 3218 MWh/year at Guelendeng. Moreover, the total electricity productions obtained by PVGIS are relatively low compared to those provided by PVSYST. The observed deviation varies between 5% (at Mombou) and 11% (at Dourball). The LCOE for all the villages over the 25-year lifespan of the project was estimated to cost between 0.30 and 0.31 €/kWh. This cost is already competitive compared to that of the National Electricity Company (SNE) which is around 0.45 €/kWh. It was also noticed that the LCOE is relatively more sensitive to the change in the investment bonuses than the increase in the discount rate. The choice and establishment of the demand load profiles were carried out at the Mailao site.

Other than that, this study allowed us to evaluate the annual energy produced and the calculation of the LCOE of mini-grid PV in five localities in Chad. Solar energy holds promise for rural electrification in Chad. The country has significant potential because the solar radiation is around 6 kWh/m²/day. The sensitivity analysis of the LCOE in relation to the discount rate and asks it for the investment has shown that the cost is very sensitive to the investment premium. As investment subsidies increase, the LCOE decreases. We recommend that the government encourage investors in the mini-grid by providing investment grants to make electricity available and accessible to the population, especially in rural areas. Also, a rural electrification plan in Chad must be developed to improve the low rate of access to electricity. This is because solar energy is promising in Chad due to the country’s potential and its production cost, which is competitive with that of diesel-based thermal energy.

The limitation of this study is that it has not generalised all the localities in Chad. Also, hybrid photovoltaic/wind systems have not been studied. This is because although there are wind potentials in the Sahara part of Chad, however, it is insignificant in other parts of the country, especially the southern part which is more populated.

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References

Adaramola, M. S., M. Agelin-Chaab, and S. S. Paul. 2014. “Analysis of Hybrid Energy Systems for Application in Southern Ghana.” Energy Conversion and Management 88: 284–295. doi:10.1016/j.enconman.2014.08.029.

Agyeikum, E. B., and C. Nutakor. 2020. “Feasibility Study and Economic Analysis of stand-alone Hybrid Energy System for Southern Ghana.” Sustainable Energy Technologies and Assessments 39 (March): 100695. doi:10.1016/j.seta.2020.100695.
McNeil, M. A., N. Karali, and V. Letschert. 2019. "Forecasting Indonesia’s Electricity Load through 2030 and Peak Demand Reductions from Appliance and Lighting Efficiency," *Energy for Sustainable Development* 49: 65–77. doi:10.1016/j.esd.2019.01.001.

Ministry of Economy and Development Planning, Republic of Chad. 2017. *National Development Planning 2017–2021* 1 (1): 128. Ndjamenas: Prime Minister’s Office.

Muh, E., and F. Tabet. 2019. "Comparative Analysis of Hybrid Renewable Energy Systems for off-grid Applications in Southern Cameroons." *Renewable Energy* 135: 41–54. doi:10.1016/j.renene.2019.11.105.

Nacer, T., A. Hamidat, and O. Nadjem. 2015. "Techno-economic Impacts Analysis of a Hybrid Grid Connected Energy System Applied for a Cattle Farm." *Energy Procedia* 75: 963–968. doi:10.1016/j.egypro.2018.11.072.

Nagarurkar, P., and J. D. Smith. 2019. "Techno-economic Optimization and Environmental Life Cycle Assessment (LCA) of Microgrids Located in the US Using Genetic Algorithm." *Energy Conversion and Management* 181: 272–291. doi:10.1016/j.enconman.2018.11.072. Feb.

Odou, O. D. T., R. Bhandari, and R. Adamou. 2020. "Hybrid off-grid Renewable Power System for Sustainable Rural Electrification in Benin." *Renewable Energy* 145: 1266–1279. doi:10.1016/j.renene.2019.06.032.

Ogunjuyigbe, A. S. O., T. R. Ayodele, and O. A. Akinola. 2016. "Optimal Allocation and Sizing of PV/Wind/Split-diesel/Battery Hybrid Energy System for Minimizing Life Cycle Cost, Carbon Emission and Dump Energy of Remote Residential Building." *Applied Energy* 171: 153–171. doi:10.1016/j.apenergy.2016.03.051. Jun.

Olatomiwa, L., S. Mekhilef, A. S. N. Huda, and O. S. Ohunakin. 2015a. "Economic Evaluation of Hybrid Energy Systems for Rural Electrification in Six geo-political Zones of Nigeria." *Renewable Energy* 83: 435–446. doi:10.1016/j.renene.2015.04.057.

Olatomiwa, L., S. Mekhilef, A. S. N. Huda, and K. Sanusi. 2015b. "Techno-economic Analysis of Hybrid PV–diesel–battery and PV–wind–diesel–battery Power Systems for Mobile BTS: The Way Forward for Rural Development." *Energy Science and Engineering* 3 (4): 271–285. doi:10.1002/ese3.71.

Olatomiwa, L., S. Mekhilef, and O. S. Ohunakin. 2016. "Hybrid Renewable Power Supply for Rural Health Clinics (RHC) in Six geo-political Zones of Nigeria." *Sustainable Energy Technologies and Assessments* 13: 1–12. doi:10.1016/j.seta.2015.11.001. Feb.

Ouedraogo, B. I., S. Kouame, Y. Azoumah, and D. Yamegueu. 2015. “Incentives for Rural off Grid Electrification in Burkina Faso Using LCOE.” *Renewable Energy* 78: 573–582. doi:10.1016/j.renene.2015.01.044. Jun.

Raji, A. K., and D. N. Luta. 2019. "Modeling and Optimization of a Community Microgrid Components." *Energy Procedia* 156: 406–411. doi:10.1016/j.egypro.2018.11.103.

Saheb-Koussa, D., M. Haddadi, and M. Belhamel. 2008. "Economic and Technical Study of a Hybrid System (wind–photovoltaic–diesel) for Rural Electrification in Algeria." *Applied Energy* 86: 1024–1030. doi:10.1016/j.apenergy.2008.10.015.

Sen, R., and S. C. Bhattacharyya. 2014. “Off-grid Electricity Generation with Renewable Energy Technologies in India: An Application of HOMER.” *Renewable Energy* 62: 388–398. doi:10.1016/j.renene.2013.07.028.

Shaahid, S. M., and I. El-Amin. 2009. "Techno-economic Evaluation of off-grid Hybrid photovoltaic-diesel-battery Power Systems for Rural Electrification in Saudi Arabia-A Way Forward for Sustainable Development." *Renewable and Sustainable Energy Reviews* 13 (3): 625–633. doi:10.1016/j.rser.2007.11.017.

Shafullah, G. M., A. M. T. Oo, A. S. Ali, D. Jarvis, and P. Wolfs. 2010. "Economic Analysis of Hybrid Renewable Model for Subtropical Climate." *International Journal of Thermal and Environmental Engineering* 1 (2) (Dec): 57–65. doi:10.5838/ijtee.01.02.001.

Shafullah, G. M. 2016. "Hybrid Renewable Energy Integration (HREI) System for Subtropical Climate in Central Queensland, Australia." *Renewable Energy* 96: 1034–1053. doi:10.1016/j.renene.2016.04.101.

Shafullah, G. M., T. Masola, R. Samu, R. M. Elavarasen, S. Begum, U. Subramaniam, M. F. Romlie, M. Chowdhury, and M. T. Arif. 2021. "Prospects of Hybrid Renewable Energy-Based Power System: A Case Study, Post Analysis of Chipendeke Micro-Hydro, Zimbabwe.” *IEEE Access* 9: 73433–73452. doi:10.1109/ACCESS.2021.3078713.

Shoeb, M. A., T. Jamal, G. M. Shafullah, and M. M. Rahman, "Analysis of Remote PV-diesel Based Hybrid Minigrid for Different Load Conditions," *IEEE PES Innovative Smart Grid Technologies-Asia (ISGT-Asia)*, 28 Nov.-1 Dec. 2016, IEEE, Melbourne Convention and Exhibition Centre, Melbourne, VI, pp. 1165–1170. 2016. doi:10.1109/ISGT-Asia.2016.7796550

Sinha, S., S. S. Chandel, and P. Malik. 2021. "Investigation of A building-integrated Solar photovoltaic-wind-battery Hybrid Energy System: A Case Study." *International Journal of Energy Research* 45 (15) (Dec): 21534–21539. doi:10.1002/er.7184.

Suresh Kumar, U., and P. S. Manoharan. 2014. "Economic Analysis of Hybrid Power Systems (PV/diesel) in Different Climatic Zones of Tamil Nadu." *Energy Conversion and Management* 80: 469–476. doi:10.1016/j.enconman.2014.01.046. Apr.

Yadav, A. K., H. Malik, S. S. Chandel, I. A. Khan, S. Al Otaibi, and H. I. Alkhammash. 2021. “Novel Approach to Investigate the Influence of Optimum Tilt Angle on Minimum Cost of Energy-Based Maximum Power Generation and Sizing of PV Systems: A Case Study of Diverse Climatic Zones in India.” *IEEE Access* 9: 110103–110115. doi:10.1109/ACCESS.2021.3102153.

Yilmaz, S., and F. Dincer. 2017. "Optimal Design of Hybrid PV-Diesel-Battery Systems for Isolated Lands: A Case Study for Kilis, Turkey." *Renewable and Sustainable Energy Reviews* 77: 344–352. Elsevier Ltd. doi:10.1016/j.rser.2017.04.037.
APPENDIX A: Estimation of daily energy needs for 5 localities

| Domestic uses | Small village (<1000 inhabitants) (Mombou) | Medium village (1000 to 3000 inhabitants) (Maïao) | Large village (3000 to 5000 inhabitants) (Dougui) | Small community (10,000 to 15,000 inhabitants) (Guelendeng) | Large town (15,000 to 20,000 inhabitants) (Dourball) |
|---------------|------------------------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|
|               | Energy demanded per day (Wh) | Amount | Total energy required (Wh) | Energy demanded per day (Wh) | Amount | Total energy required (Wh) | Energy demanded per day (Wh) | Amount | Total energy required (Wh) | Energy demanded per day (Wh) | Amount | Total energy required (Wh) |
| Type 1 households | 760 | 7 | 5,320 | 760 | 18 | 13,680 | 760 | 21 | 15,960 | 760 | 180 | 136,800 |
| Type 2 households | 2,040 | 8 | 16,320 | 2,040 | 18 | 36,720 | 2,040 | 21 | 42,840 | 2,040 | 180 | 367,200 |
| Type 3 households | 4,280 | 6 | 25,680 | 4,280 | 15 | 64,200 | 4,280 | 18 | 77,040 | 4,600 | 150 | 690,000 |
| Subtotal 1 | 21 | 47,320 | 7,080 | 51 | 114,600 | 60 | 135,840 | 510 | 1,194,000 | 425 | 995,000 |
| Energy demanded by households | 104 | 234,347 | 300 | 674,118 | 673 | 1,523,672 | 3,000 | 7,023,529 | 2,500 | 5,852,941 |
| Community uses | Energy demanded per day (Wh) | Amount | Total energy required (Wh) | Energy demanded per day (Wh) | Amount | Total energy required (Wh) | Energy demanded per day (Wh) | Amount | Total energy required (Wh) | Energy demanded per day (Wh) | Amount | Total energy required (Wh) |
| Public lighting | 9,600 | 1 | 9,600 | 19,200 | 1 | 19,200 | 19,200 | 1 | 19,200 | 19,200 | 1 | 19,200 | 28,800 | 1 | 28,800 |
| Supply of water drinking | 3,000 | 1 | 3,000 | 3,000 | 1 | 3,000 | 1,600 | 1 | 1,600 | 1,600 | 1 | 1,600 | 1,600 | 1 | 1,600 |
| Centre Health | 3,000 | 1 | 3,000 | 3,000 | 1 | 3,000 | 1,600 | 1 | 1,600 | 1,600 | 1 | 1,600 | 1,600 | 1 | 1,600 |
| Schools | 1,200 | 3 | 3,600 | 1,400 | 2 | 2,800 | 1,400 | 2 | 2,800 | 1,200 | 2 | 2,400 | 1,200 | 8 | 9,600 |
| Colleges | 1,400 | 1 | 1,400 | 800 | 1 | 800 | 800 | 1 | 800 | 800 | 1 | 800 |
| Gendarmerie | 1,400 | 1 | 1,400 | 1,440 | 1 | 1,440 | 1,440 | 1 | 1,440 | 1,440 | 1 | 1,440 |
| Customs office | 1,440 | 1 | 1,440 | 1,440 | 1 | 1,440 | 1,440 | 1 | 1,440 | 1,440 | 1 | 1,440 |
| Mosques | 960 | 6 | 5,760 | 960 | 6 | 5,760 | 960 | 8 | 7,680 | 960 | 8 | 7,680 |
| Churches | 320 | 2 | 640 | 320 | 2 | 640 | 320 | 1 | 320 | 320 | 15 | 4,800 |
| Centre cultural | 1,600 | 1 | 1,600 | 1,600 | 1 | 1,600 |
| High school | 1,400 | 1 | 1,400 | 1,400 | 1 | 1,400 |
| Townhall | 1,400 | 1 | 1,400 | 1,400 | 1 | 1,400 |
| Police station | 1,440 | 1 | 1,440 | 1,440 | 1 | 1,440 |
| Subtotal 2 | 13 | 22,600 | 29,160 | 15 | 35,680 | 17 | 87,440 | 33 | 94,520 | 44 | 340,120 |
| (Subtotal 1 + Subtotal 2) | 69,920 | 36,240 | 150,280 | 223,280 | 1,288,520 | 1,335,120 |