INTRODUCTION

Scientific evidences have shown that greenhouse gas (GHG) emissions, caused by fossil fuel–based energy sources, contribute to global warming and climate change. In particular, anthropogenic emissions of GHGs led, over the past 100 years, to a considerable increase in the concentration of these gases in the atmosphere. Indeed, since 1750, the atmospheric concentrations of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) have increased approximately 31%, 150%, and 16%, respectively. Population growth will continue to underpin rising energy demand and then GHG emission if the current energy policy scenario does not change. In fact, during the last 40 years, global energy demand increased from 5000 Mtep in 1970 to 12 000 Mtep in 2010 (2.24% of annual growth), and the demand is expected to double in 2050 compared with the 2010 level. Besides, energy prices will continue to have a major impact on future demand and supply patterns. In the New Policies Scenario of the International Energy Agency (IEA), crude oil import
price is assumed to approach $120/barrel (in year 2010 dollars) in 2035. Then, future energy strategies, which should form the base of future global energy structure, should put more emphasis on developing the potential of renewable energy resources.

The choice of diesel generation based on fossil energy resources has been considered for a long time as an economical and reliable alternative to provide electricity, in particular for countries of sub-Saharan Africa region. However, this option is not always the most profitable one and induces several technical and environmental problems for the users such as high operating and maintenance costs, relatively low power efficiency, sound nuisance, and GHG emissions. These countries cannot then afford to depend essentially on these fossil energy supply systems, especially nowadays with fluctuating fossil fuel prices in the global market. Furthermore, the ongoing regular energy shortages that characterize most of the African countries impose a rethink of integrated energy resource planning to increase access to electricity, especially for social, environmental, and economic growth. It is projected that the supply/demand gap will continue to rise exponentially in these countries unless it is met by some other means of power generation.

Besides, it is today widely accepted that renewable energies can play an important role in both the reinforcement of energy security and mitigation of climate change issues. Furthermore, energy production costs from such sources have been drastically reduced in the past decade leading to an acceleration of their development. The government of Burkina Faso has as one’s ambition to increase significantly the share of energy from renewable energies, especially from solar in its energy mix in the next few years. The achievement of this ambition will pass through the implementation of both off-grid renewable energy systems and the integration of renewable energy systems into the existing electric grid. Beyond the technical aspect concerning the integration of renewables into a grid, the issue of their impact on the electricity production cost should be carefully investigated, particularly in countries as Burkina Faso where the electricity price is very high (€ 0.20/kWh).

In this sense, an important question that could be raised is “what could be the optimal share of renewables into a grid?” The main purpose of this paper is then to assess the impact of solar photovoltaic (PV) integration into the grid on the electricity production cost in the context of Burkina Faso. The methodology used is mainly based on the levelized cost of electricity (LCOE) technique. Several levels of PV integration have been considered, and the simulations are conducted based on the estimated electricity consumption capacity of the country. This paper also outlines policies that could help policymakers reduce the burden of high investment cost for PV and how they could attract more investors for the solar energy sector in Burkina Faso.

## 2 | Brief Review on Grid-Connected PV Systems in Africa

Grid-connected PV systems have the fastest growth rate in the international energy industry, and this sector plays a dominant role in the global market. Grid-connected or on-grid PV systems only generate energy when the utility power grid is available. An inverter is used to convert electricity from direct current (DC) as produced by the PV array to alternating current (AC) that is then supplied to the electricity network. The typical weighted conversion efficiency of inverters is currently in the range of 95%-99%. Most inverters incorporate a Maximum Power Point Tracker (MPPT), which continuously adjusts the load impedance to provide the maximum power from the PV array. Besides, one inverter can be used for the whole array or separate inverters may be used for each “string” of modules. Because they avoid the cost of batteries, grid-connected PV systems significantly reduce system cost (installation cost), and therefore, the cost of electricity generated is lower than systems with battery storage. Small grid-connected systems mounted on rooftops have been responsible for powering the phenomenal growth of solar PV in Germany and other leading countries around the world. They have been stimulated by schemes such as (micro) feed-in tariffs (FiTs) and net-metering. Large-scale hybrid PV systems can also be used for large cities powered today by diesel generators and have been seen for instance in Central and West Africa for powering cities far from the grid with a base of utility-scale PV. The global PV installed capacity represented 403.3 GW of cumulative PV installations altogether, mostly grid-connected, at the end of 2017. Africa also sees PV deployment, with Morocco having installed 4.7 MW in 2017 which has brought the total installed capacity in the country to 14.6 MW. Algeria has installed 54 MW in 2016 and 80 MW more in 2017. South Africa installed around 13 MW after a rapid expansion in 2014, and others are already granted for the years to come.

Concerning West Africa, in 2010, the island of Cape Verde commissioned a 7.5 MW solar PV power plant, which was reputed to be Africa’s largest at the time. Senegal has installed 42, 60, and 40 MW, respectively, in 2016, 2017, and 2018. Niger installed 7 MW in 2018 and Burkina Faso 34 MW in 2017. Globally, in several African countries, the interest for PV is growing. Large-scale plants are under construction or planned to replace or complement existing diesel generators. Table 1 shows main solar PV projects across the West African Economic and Monetary Union (WAEMU) member states.

However, the implementation or evaluation of a project about a specific technology as solar PV requires especially a technical and economic analysis in order to assess and compare
its performances relative to the other types of technologies. In that purpose, the International Energy Agency (IEA) released a series of publications since 2008 about the assessment of the competitiveness of electricity generation technologies based on the LCOE technique. The eighth edition of this report published in 2015 examines in depth the LCOE generation for all main electricity generating technologies and reveals a number of interesting findings that have implications for policymakers. However, most of the cases addressed in this publication are those of OECD (Organisation for Economic Co-operation and Development) countries. The only African country that has been considered is South Africa. Nevertheless, some recent scientific publications tried to assess the techno-economic potential of grid-connected PV systems in some African countries. Rose et al.12 used an economic system-level optimization model for the case of Kenya to evaluate the potential to use grid-connected solar PV in combination with existing reservoir hydropower to displace diesel generation. Sako et al.13 made a comparative economic analysis of PV, diesel generator, and grid extension for the case of Ivory Coast. Ky et al.14 have studied the viability of grid-connected solar PV system in Ethiopia. Nyarko et al.15 developed a standard techno-economic procedure for the design of large-scale institutional grid-connected solar PV systems using the roofs of buildings and car parks in Ghana. The procedure developed was validated in the design of a 1 MW grid-connected solar PV system for Kwame Nkrumah University of Science and Technology (KNUST). It certainly exists other publications concerning some other African countries. Thus, in the line of these previous works, the present study is a contribution focused on the case of Burkina Faso. Such a study has not been conducted so far concerning this country.

In the following sections, the energy situation of Burkina Faso is briefly presented before addressing the techno-economic analysis in itself.

### 3 | ENERGY CONTEXT IN BURKINA FASO

#### 3.1 | General situation

Burkina Faso is a West African landlocked Sahel country. It is characterized by a semi-arid climate. It has around 274,000 square kilometers in size and a current population of about 16 million with approximately 77.3% of the population living in rural areas. The country has a high population growth rate estimated at 3.1% due to the high and early fertility rate with an average of 6.2 children per woman. Thus, the country is experiencing a high urbanization rate. This rate was estimated to about 3.7% in 1960 that increased to 14.5% in 1990 and 22.7% in 2007 with a forecast of 45% in 2030.16 This rapid urbanization is boosted in part by the so-called rural exodus, resulting in an urgent demand for housing and electricity.

### Table 1  Main solar photovoltaic projects across West African Economic and Monetary Union (WAEMU) states

| Country     | Project locality         | Funding | Capacity (MW) | Level of progress                                                                 |
|-------------|--------------------------|---------|---------------|-----------------------------------------------------------------------------------|
| Benin       | Onigbolo                 | Public  | 25            | Funding agreement signed with European Union (EU) and French Agency for Development (AFD) |
| Benin       | Natitingou/Djougou/Parakou/Bohicon | PPA 45  | Negotiations ongoing with the partner, Millennium Challenge Account (MCA)          |
| Burkina Faso| Zagtouli 2               | Public  | 17            | Approval of European Bank of Investment for the funding; Call for tenders in preparation. |
| Burkina Faso| Koudougou                | PPA 20  | Approval of World Bank for the funding; call for tenders in preparation.           |
| Burkina Faso| Kaya                     | PPA 10  | Approval of World Bank for the funding; call for tenders in preparation.           |
| Ivory Coast | Korhogo                  | PPA 25  | Negotiations ongoing with private partners                                    |
| Ivory Coast | Boundali                 | Public  | 37.5          | Under construction                                                                |
| Guinea Bissau| Gabu and Canchungo      | Public  | 22            | Agreement of the West African Bank of Development (BOAD) for the funding           |
| Mali        | Kita                     | PPA 50  | Negotiations ongoing with private partners                                   |
| Mali        | Sikasso                  | PPA 50  | Negotiations ongoing with private partners                                   |
| Mali        | Ségou                    | PPA 33  | Negotiations ongoing with private partners                                   |
| Mali        | Koutiala                 | PPA 25  | Negotiations ongoing with private partners                                   |
| Niger       | Agadez                   | Public  | 13            | Starting of construction expected during 2019                                    |
| Niger       | Gorou Banda              | Public  | 20            | Funding agreement signed in 2018 with European Union (EU) and French Agency for Development (AFD) |
| Senegal     | Kahone/Kael              | PPA 60  | Agreement signed with the private partner (Scaling Solar)                      |
| Senegal     | Diass                    | Public  | 23            | Under construction                                                                |
3.2 The power sector

At the end of 2018, the total installed capacity in Burkina Faso is 359 MW of which 292 MW from thermal, 32 MW from hydroelectricity, and 34 MW from grid-connected PV systems (See Figure 1). Thus, electricity production is mainly based on fossil fuels, which represents about 70% of the electricity generated per year in the country. Electricity is also imported from Ghana and Ivory Coast, while hydroelectricity is mainly provided from the Kompienga dam. The PV power plants are in operation only since the year 2017.

Among the Economic Community of West African States (ECOWAS), Burkina Faso is the second country after Guinea Bissau to have the highest cost of the kWh of electricity. Indeed, despite the high level of government yearly subsidy which is around €24 million, Burkina Faso still has one of the highest costs of electricity in the world, estimated at about €0.2/kWh. Comparatively, the average cost of kWh is estimated at 0.05€ and 0.11€, respectively, for Nigeria and Mali.

The exorbitant cost of the kWh in Burkina is widely criticized by the economic sector as well as industrial services and business sector. Direct and indirect costs associated with electricity cost contribute significantly to increased expenses for holding companies or industrial units with high electricity consumption and deteriorating their cash situation. According to the World Bank, these companies are spending about 12% of the budget on electricity.

The sky rocking cost of electricity leads to lower coverage of electricity in the country. As a result, mainly urban areas only have access to electricity with 112 urban localities or districts out of 350 that have access to electricity. Indeed, the electrification rate in Burkina Faso is only about 20%. A closer look shows that 95% of that electricity is consumed in urban areas, while electricity needs in peri-urban and rural areas remain uncovered.

Despite the high cost of fossil fuel leading to exponential increase in production cost, the cost of the kWh is kept constant based on government policy. Therefore, it surely will soon become unsustainable for Burkina Faso government to continue subsidizing electricity production and provide enough energy for most of its population. Thus, the government should look for alternative energy production systems, including solar energy. In this respect, the integration of solar PV into the existing electric grid could be a viable option to decrease the electricity cost in Burkina Faso.

Indeed, solar energy is the most promising of the renewable energy resources in Burkina Faso due to its apparent abundance. Like neighboring countries in the West Africa region, Burkina Faso enjoys abundant sunshine with 3000 hours/y and a daily average irradiation of 4.5-6 kWh/m².

4 METHODOLOGY

4.1 Country load assessment

Load assessment is an inescapable step for the design of any energy production system. Equation was used to estimate the peak load demand at year n.

\[ L_n = L_1 \times (1 + x)^n, \]

where \( L_1 \) is the peak load at the year 1, \( L_n \) the peak load at year \( n \), and \( x \) the annual rate of load's increase.

In the present case study, the modeling is done by considering an annual average rate of load's increase of 8.2% (average rate registered between 2006 and 2015 in Burkina Faso) as shown by Birizza and Felten and for year 5.

4.2 Resources assessment

The solar resource for Burkina Faso has been obtained from the NASA surface meteorology and solar energy database. The annual average solar radiation illustrated in Figure 2 shows a daily average radiation of 5.76 kWh/m² with average clearness index estimated at 0.605. Solar radiations are available throughout the year with about 12 hours of sunshine per day. Therefore, a considerable amount of PV power output can be expected.

4.3 System modeling

For the case of Burkina Faso, the electricity production system is mainly based on diesel generators. The integration of PV to the existing grid is done through inverters. Different levels of integration (20%, 40%, 60%, and 80%) have been considered. The mere availability of a renewable energy resource does not mean that resource can readily be used as an energy source. Therefore, to use efficiently the available resource several technical and economic factors need to be considered.
These factors will be outlined in detail in the following section through the LCOE methodology which is used in the present study to assess the economic performance of the different scenarios considered.

4.4 | Economic analysis

4.4.1 | The LCOE methodology

Various methods are available in the literature to assess the economic feasibility of electricity generation projects. However, the LCOE method is one of the most relevant and frequently used.\(^{16}\) Indeed, LCOE has become a very practical and valuable comparative method to analyze different energy technologies in terms of cost. The LCOE calculation method is internationally recognized as a benchmark for assessing the economic viability of different generation technologies as well as of individual projects and enables the comparison of different energy technologies with respect to their costs.\(^ {24-28}\) Besides, the LCOE method is able to reflect the key factors of the production cost throughout the lifetime of the power plant in just one number and it causes a great reduction in complexity and allows a quick and easy comparison of different alternatives.\(^ {29,30}\) According to Myhr et al.\(^ {31}\) from an economic point of view, the LCOE contains the most important factors contributing to the economic evaluation of a project.

Thus, for the above-mentioned reasons, the economic analysis conducted in this paper is based on the LCOE technique. The LCOE as illustrated in Equation (2) can be defined as the sum of all the discounted costs incurred during the lifetime of the project divided by the units of discounted energy produced.

\[
\text{LCOE} = \frac{\text{Life cycle cost of the system}}{\text{Lifetime energy production}}. \tag{2}
\]

The life cycle cost of the system includes the costs of components, installation costs, fuel and/or operating costs, maintenance costs, replacement costs, dismantling (decommissioning) cost, cost of carbon (carbon penalty), and salvage values of components.

The details of the LCOE methodology have been developed in previous works.\(^ {32,33}\)

4.4.2 | Economic inputs

Many papers have shown that PV modules which are the key component of PV systems are warranted for duration in the range between 25 and 30 years by most manufacturers.\(^ {34-36}\) Therefore, we will consider 25 years for the lifetime of PV modules as well as for the current project’s lifetime. It was assumed that the project was financed based on government own budget. Conservative discount rates between 6% and 10% for PV systems were assumed in the case of government loan.\(^ {37}\) Inflation and escalation rates have been estimated to be of about 1% and 3%, respectively. Therefore, for this paper a real discount rate of 8% has been estimated. Other discounts rates (4% and 0%) have been considered for the sensitivity analysis. Many countries do not have an explicit carbon price as it is the case of Burkina Faso. In these cases, the International Energy Agency (IEA) recommends to consider $30/tonne of CO\(_2\) as the shadow price of carbon.\(^ {11}\)

Table 2 illustrates the different values that have been considered for cost calculation in the present paper. The costs from Table 2 include shipping, tariffs, mounting hardware, control system, wiring, installation, and dealer markups.\(^ {11,32,38,39}\)

5 | RESULTS AND DISCUSSION

The following sections have covered the results of the LCOE calculations applied on the hypothesis of different electricity production scenarios for Burkina Faso. Various scenarios of PV integration into the grid have been considered, and the results are compared to show the best practices in terms of energy production configuration and possible policy implications. This paper considered two different main scenarios: with and without government subsidies in order to access its impact on the LCOE and how effective government subsidies are. The environmental aspect of the electricity generation has also been considered with the assessment of CO\(_2\) emissions for each of the scenarios studied. Finally, a sensitivity analysis has been considered in order to give different opportunities for policymakers to outline subsidies scenarios that will help the government increase the accessibility of electricity at a lower cost.

5.1 | Load to be supplied and diesel generator size

The country energy load requirement has been estimated based on existing load data provided by the national electricity
company (SONABEL). As of 2018, the total daily energy need for the country has been estimated to about 5 GWh with a peak load of 326 MW. The current maximum installed capacity is of 359 MW.17

By applying Equation with an annual average rate of load's increase of 8.2% (average rate registered between 2006 and 2015 in Burkina Faso) and for the year 5, one obtains a peak load of 540 MW. Then, by considering a load factor of 0.8, a total nominal capacity of about 600 MW for diesel generators was obtained.

## 5.2 LCOE assessment without subsidies

### 5.2.1 Diesel Generator (DG) standalone system

For this configuration, we assumed that 100% of the electricity produced in the country is fossil fuel–based. For optimization reason, the nominal power of the diesel generator obtained above (600 MW) is divided into three diesel generators of 250, 200, and 150 MW, respectively.

The results show that this configuration required an overall initial investment cost of about $901.2 million without subsidies. Based on Table 2 data and on Equation , the LCOE without subsidy is estimated to about $0.536/kWh. This represents the highest cost of electricity production among the scenarios studied as shown in Figure 3. The initial investment is quite low; however, when the 25 years lifetime of the project is considered, it results in a staggering $5.48 billion lifetime cost for the project. The total fuel consumption cost for the project lifetime is equal to about $2.51 billion. Since Burkina Faso is not an oil-producing country, with the continuous raising oil cost, it is projected that DG standalone production will result in huge spending on fuel in the long run. It is therefore suggested that other technologies such as PV be introduced in electricity production configuration in order to reduce the high cost of electricity.

### 5.2.2 20% of PV Integration to the grid

For this configuration, we design a mix electricity production configuration of 20% PV of the total power installed. In this configuration and for all the other hybrid scenarios which will follow, battery backup is eliminated and any shortage of power not supplied by solar PV field is covered by the diesel generators. Daytime demand is then supplied both by the solar PV production and diesel generators. Due to the absence of battery, the diesel generators should be able to produce electricity to fully supply the peak load demand.

By taking into account the above consideration, one obtains 120 MW of PV and three diesel generators of 250, 200, and 150 MW, respectively. We also consider a 126 MW total inverter capacity. In this configuration, the initial investment increases to $1.47 billion, and the net present value (NPV) is estimated to $5.02 billion for the project lifetime. This is a $0.48 billion NPV reduction when compared to the diesel standalone system. Moreover, the LCOE based on Table 2 assumptions is estimated to about $0.48/kWh.
5.2.3 | 40% of PV integration to the grid

In the hybrid configuration with 40% PV fraction, we considered a 240 MW PV plant combined with 250 MW, 200 MW, and 150 MW DG and with 252 MW as total inverter capacity. In this configuration, the initial investment increases to $2.04 billion and the NPV is estimated to $5.08 billion for the project lifetime. This is a $0.4 billion NPV reduction when compared to the diesel standalone system with a $0.49/kWh LCOE as shown in Figure 3.

5.2.4 | 60% of PV integration to the grid

In this configuration, a 360 MW solar array has been considered and combined with three diesel generators with, respectively, a 250, 200, and 150 MW of nominal power capacity, and with inverters of 358 MW as total capacity. The results have shown that this system needs about $2.59 billion initial investment which is a $1.12 billion increase when compared to the standalone diesel generator system. However, the results depict also a profitable scenario when compared to the base case scenario. The initial investment needed is about $3.18 billion with an $5.18 billion NPV for the project lifetime. This is, respectively, a $2.28 billion increase and a $0.3 billion decrease when compared to the base case diesel standalone scenario. Besides, this scenario results in about $580 million diesel consumption, which is a 76% decrease compared with the base case scenario. The LCOE is estimated to about $0.50/kWh. Here also, the increase in the initial investment for PV does not lead to an unsustainable electricity production cost compared with the base case diesel generator standalone.

5.2.5 | 80% of PV integration to the grid

In this configuration, a 480 MW solar park has been considered and combined with three diesel generators with, respectively, a 250, 200, and 150 MW of power capacity, and with inverters of 504 MW as total capacity. Here, the results depict also a profitable scenario when compared to the base case scenario. The initial investment needed is about $3.18 billion with an $5.18 billion NPV for the project lifetime. This is, respectively, a $2.28 billion increase and a $0.3 billion decrease when compared to the base case diesel standalone scenario. Besides, this scenario results in about $580 million diesel consumption, which is a 76% decrease compared with the base case scenario. The LCOE is estimated to about $0.50/kWh. Here also, the increase in the initial investment for PV does not lead to an unsustainable electricity production cost compared with the base case diesel generator standalone.

As it can be seen in Figure 3, the findings suggest that the integration of solar PV to a national grid is becoming increasingly an attractive scenario compared with the base case diesel generator standalone. Indeed, for all the scenarios of PV integration studied, it has been found that the electricity production is cost-effective (from $0.48/kWh to $0.50/kWh) compared with conventional fossil fuel electricity ($0.54/kWh). However, if we can conclude at this level that the PV integration to grid is a better scenario compared with diesel generator standalone, it is difficult to recommend an optimal share of PV due to the minor differences between the LCOE values. Other additional parameters to LCOE such as investment cost and CO2 emissions should be considered to make a decision. If one considers the investment cost as the additional decision parameter, the 20% PV would be the best scenario as it has the lowest capital cost ($ 1.47 billion) compared with the other PV integration scenarios ($ 2.04, 2.5, and 3.18, respectively, for 40% PV, 60% PV, and 80% PV). On the other hand, if the CO2 emission is considered as the additional decision parameter, the 80% PV would be the best scenario as it has the lowest amount of CO2 emission (135 563 tonnes of CO2/year) as shown in Figure 4.

Thus, in the view taken by many other researchers in the past years that solar PV in developing countries should remain limited to off-grid applications, due to its prohibitively high LCOE, most certainly needs to be updated in line with recent cost decreases for the technology. Therefore, this paper in the following section will investigate the impact of subsidies and different factors sensitivity impact on the LCOE.

5.3 | LCOE assessment with subsidies

Due to the high cost of electricity in Burkina Faso, the government is obliged to yearly subsidize electricity (up to about $44 and $60 million for the years 2016 and 2017, respectively). Based on data from SONABEL, we have estimated an average subsidy of about $0.057/kWh. The objective of
this section is to assess how subsidies could affect LCOE in the case of PV integration to grid.

The impact of subsidies on each case scenario is depicted in Figure 3. It shows the potential benefit for consumers if the government happens to subsidize different PV integration scenarios. The first observation that could be highlighted from Figure 3 is that the LCOE decreases in all scenarios with subsidies. Starting from the diesel standalone system to the 80% PV share, we found that the LCOE ranges from $0.43 to $0.48/kWh. Furthermore, we observe that as with the scenario without subsidy, the LCOE for scenarios with PV integration to grid is all cost-effective (between $0.43/kWh and $0.44/kWh) when compared to the base case diesel generator standalone ($0.48/kWh) in the scenario with subsidy. However, one can notice that here also, the LCOE varies weakly for the scenarios with PV integration to grid. As stated previously, other additional parameters such as investment cost or CO₂ emissions should then be considered to make a judicious decision.

As it could be also seen in Figure 3, the results suggest about an average of 11% decrease in the LCOE when the government is providing a subsidy of $0.057/kWh.

5.4 | Sensitivity of inputs

In order to test the robustness of the results, a number of scenarios have been analyzed and a sensitivity analysis has been carried out in this section. To assess the sensitivity of the results, one parameter is changed at a time, keeping all other parameters constant. This is followed by a small number of scenarios in which more than one parameter value is changed in order to test the model robustness further. Table 3 presents the scenario parameters that were changed in the first part of the scenario analyses, as well as their specific values in the different scenarios. As it can be seen in Table 3, there are about 27 possible combinations for each case scenario. The results for the sensitivity analysis of LCOE are depicted in Figures 5-10.

The results from the previous section have shown that all the scenarios with PV integration to grid are more

**TABLE 3** Different parameters considered for the sensitivity analysis

| Fuel price ($/L) | PV multiplier | Discount rate (%) |
|------------------|---------------|-------------------|
| 0.9              | 1.0           | 8                 |
| 1.2              | 0.8           | 4                 |
| 1.5              | 0.5           | 0                 |
cost-effective than the base case diesel generator standalone irrespective of subsidies with nevertheless a weak difference between the LCOE values of the different PV integration cases. Therefore, the sensitivity analysis will help to strengthen the study made in the previous section.

The results depicted in Figures 5 and 6 show the impact of PV technology cost on LCOE, respectively, for the scenarios without subsidy and with subsidy. As expected, one can notice that the lowest LCOE values are obtained with the PV price multiplier of 0.5. Indeed, the price multiplier of 0.5 compared to the base scenario lead to a reduction of LCOE by about 5% (from 0.48 to $0.46/kWh), 9% (from 0.49 to $0.44/kWh), 13% (from 0.50 to $0.43/kWh), and 18% (from 0.5 to $0.41/kWh), respectively, for 20% PV, 40% PV, 60% PV and 80% PV without subsidy. When subsidy is applied, as illustrated in Figure 6, the LCOE drops to 0.4, 0.39, 0.38, and $0.31/kWh, respectively, for 20% PV, 40% PV, 60% PV and 80% PV for a PV price multiplier of 0.5. One can then observe that the differences between the LCOE for the scenario 80% PV and the others are more considerable. This highlights clearly the cost-effectiveness of this scenario comparatively to the others. These results suggest that the development in PV technology leading to their cost reduction will induce a reduction in the LCOE cost giving additional incentive for policymakers to invest in solar technology.

Besides, a change in the discount rate significantly impacts the LCOE, as it would be expected with a power plant that is very capital intensive but has low operating costs. As illustrated in Figure 7, in the case of own investment for the state, we use the lower discount rate of 0% and that reduces the LCOE by almost 0.07, 0.09, 0.1, and $0.12/kWh or about 14%, 15%, 21%, and 25%, respectively, for 20% PV, 40% PV, 60% PV, and 80% PV. In addition, for an auto investment scenario, when the state subsidies electricity production, it further brings the LCOE at 0.31, 0.28, 0.25, and $0.22/kWh. This illustrates that in the case of own investment for the state irrespective to the subsidy, the scenario 80% PV appears clearly as the most cost-effective compared with the other ones. The results here also show the particularly high sensitivity of LCOE to the discount rate applied.

Finally, by considering the diesel generator standalone configuration, the cost summary of the system has shown that fuel consumption is the main expenditure. Therefore, for the sensitivity analysis, we have varied the parameter fuel cost over time while keeping all other parameters constant. As depicted in Figure 9, the increase in fuel cost significantly impacts the LCOE. An increase in fuel cost from $0.9/L to $1.5/L results in an increase of the LCOE from $0.48/kWh to $0.61/kWh, $0.40/kWh to $0.58/kWh, $0.50 to $0.57/kWh, and $0.50/kWh to $0.54/kWh, respectively, for 20% PV, 40% PV, 60% PV, and 80% PV; this corresponds, respectively, to a 20%, 16%, 11%, and 7% increase from the initial LCOE. Fuel cost is projected to continuously rise due to higher demand and decline in the offer. In addition, currently in Burkina Faso, electricity production is mainly based on fossil fuel. These results clearly show that it is not sustainable to continue on this path. The sensitivity analysis conducted here suggests once again that the scenario 80% PV is the most sustainable one as it is less impacted by the fluctuation of fuel price compared with the other ones. Thus, this configuration will help reduce the trend of high electricity cost and widen territory coverage. In addition, government subsidies will be well spent in the case of a grid-connected PV system.
6 | CONCLUSION

The results of this paper based on LCOE technique showed that integration of solar PV to the grid could be a viable option in the context of Burkina Faso. It has been shown that the PV integration to grid is more attractive and cost-effective compared with conventional diesel standalone electricity system whatever the share of PV considered (20%, 40%, 60%, and 80% PV). However, with the base data used for LCOE calculations, it was not evident to recommend a particular share of PV as the differences between the LCOE are minors. It was then necessary at this stage to consider other additional parameters as the investment cost or CO2 emission to make a decision. In that sense, 20% PV and 80% PV have appeared as the best scenarios, respectively, if the investment cost or CO2 emissions are considered as additional decision parameter. However, the sensitivity analysis conducted afterward shows clearly that the scenario 80% PV is the most cost-effective one whatever the parameter considered. This paper also shows that subsidies given by the government of Burkina Faso to its national electricity company (SONABEL) will be more effective for a grid with PV integration. The results of this paper can be of interest for energy policymakers, in the field related to financial subsidies for renewable energies in the form of tax deductions, preferential loans, etc. In addition, it is important to note that, due to the fact that solar PV is capital intensive, the discount or interest rates on the loans are essential for the right funding of the project, as we have proven in our sensitivity analysis. Therefore, a proper negotiation of the loans is essential for the financial success of the projects. The way the study has been conducted in this paper can serve as a guideline for assessing techno-economic aspects of PV integration in the electric grid for any given country.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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