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Research Article

Valuation of CO_2 Emissions Reduction from Renewable Energy and Energy Efficiency Projects in Africa: A Case Study of Burkina Faso

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ABSTRACT. Burkina Faso like many other African countries hosts many renewable energy (RE) and energy efficiency (EE) projects that are not registered to the clean development mechanism (CDM), but which could represent potential CDM opportunities. This study seeks to determine these projects' impact on the level of CO_2 emissions in the country, and to determine their CDM potential by quantifying their carbon emissions reduction, using approved CDM methodologies adapted to the projects. 21 RE projects and 7 EE projects were considered, and all proven to be additional. Results revealed that, 68,709.424 MWh and 9,430.446MWh were saved and displaced by the EE and RE projects respectively annually, accounting for 48157.668 tCO_2e emissions reduced annually. This accounts for a 63.12% emissions reduction from the baseline scenario and represents a huge potential for the CDM, ready to be harnessed. The total amount of emissions reduced could generate about 4,8157.668 Certified Emissions Reduction (CERs) yearly. Considering a carbon price of $10/$tCO_2e$ and a 10-year fixed crediting period starting from 2020 would imply a total revenue of $4,815,766.8 in 2030 from the CERs, which will increase the sector's attractiveness to investors. Policies promoting the registration of these projects to the CDM are essential to boost the development of more of such projects in the country/ region, which will benefit from the sustainable development the CDM offers, while contributing to the achievement of its Intended Nationally Determined Contributions.

Keywords: Africa, Burkina Faso, CDM, Certified emissions reduction, CO_2 emissions reduction, Energy efficiency, Renewable energy, Sustainable development.

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1. Introduction

The desire for a better living standard and the rising global population has led to growing energy consumption over the last decades (Bose, 2010). Rapid global economic growth also contributed to increase the global energy demand, and consequently adding carbon dioxide (CO_2) emissions, since most of the energy needs for the past 100 years have been met through conventional energy sources. This led to an increasing global energy related CO_2 emissions from 20.5 $GtCO_2$ in 1990 to 33.1 $GtCO_2$ in 2018 as shown in Fig 1 (IEA, 2019b). Although Africa has contributed about 2% to these emissions, it remains the most vulnerable region worldwide so far as the impacts of the universe's changing climate are concerned (IEA, 2019a). The low level of emissions in Africa is due to the low economic activities, low level of industrialisation and poor access to electricity in the region (Calvin *et al*., 2013). In case of global failure to prevent the climate catastrophe, Africa will pay the highest price meanwhile it has the most underpowered, inefficient and unequal energy systems (Africa Progress Panel, 2015).

Energy production and use account for about two third of global greenhouse gas (GHG) emissions. This places the energy sector at the centre of the struggle to keep global average temperature rise below 2 °C above the pre-industrial values, in line with the Paris Agreement goals. The International Renewable Energy Agency (IRENA) emphasises that EE and RE quick deployment can account for about 90% of the decarbonisation required to remain within the requirements of the Agreement (IRENA, 2017).

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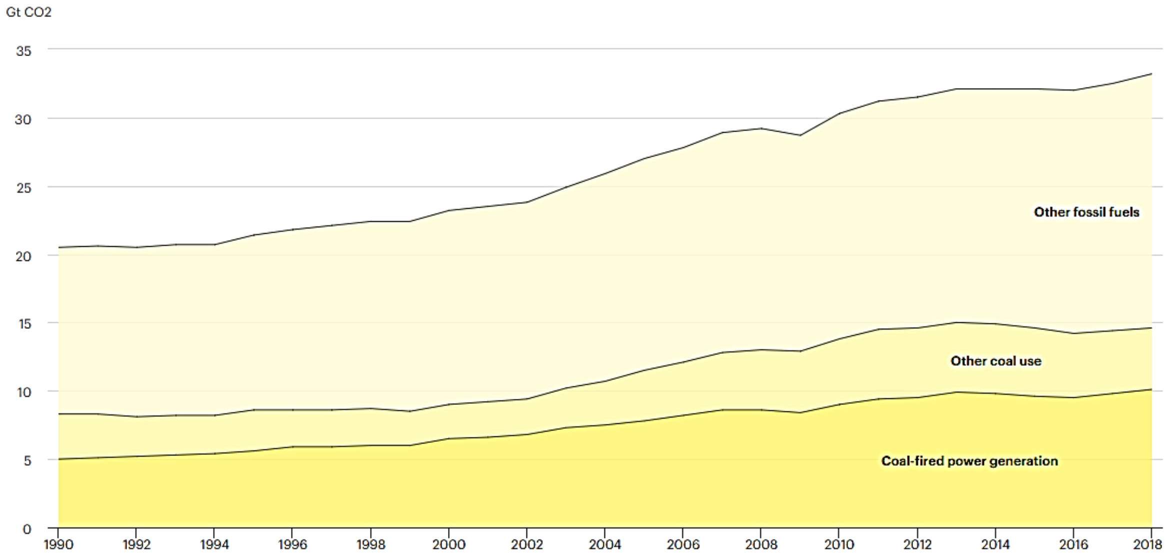

Fig. 1 Global energy-related CO_2 emissions by source, 1990-2018 (IEA, 2019b)

Recent analysis by Gielen *et al.* (2019) show that with the Business as Usual (BaU) scenario (current and planned policies), energy related CO_2 emissions would rise to 35 Gt by 2050, from 33 Gt in 2015, meanwhile these emissions need to decline to 9.7 Gt by 2050 to remain within the 2°C limit. It also reveals that, a 63% share of renewables in the total energy supply by 2050 from 15% in 2015, added to improved EE can account for over 90% of the emission curbs needed. However, enabling policy and institutional frameworks have to be put in place or amended for the accelerated transition required to occur. Additionally, an analysis of the mitigation of GHG emissions through EE, carried out for the period between 1995 and 2016 with datasets of 29 European countries indicated EE as a potential mechanism for long term reduction of GHG emissions (Akdag & Yıldırım, 2020). Moreover, Özbuğday & Erbas (2015) investigated on the effect of industrialisation, RE and EE on carbon emissions in 36 industrialised and developing countries between 1971 and 2009 and confirmed the significant impact they have on carbon curbing. About 0.55% and 0.11% of emissions was reduced for every single percentage of increase in EE and of RE in the total energy used respectively. As for Africa particularly, Prince & Okechukwu (2019) explored the effects of renewable and non-renewable energy consumption on CO_2 emissions in 19 African countries for the period between 1990 and 2014. This revealed that even though both energy types have varying effects on CO_2 emissions across countries, the tendency is that RE consumption slightly reduces carbon emissions, while non-renewable energy consumption highly increases the emissions in Africa. Inglesi-Lotz & Dogan (2018) also analysed the link between these three parameters in the ten biggest electricity generators of sub-Saharan Africa (SSA) for the period between 1980 and 2011; they also confirmed that CO_2 emissions decrease with an increase in RE consumption and increase with increasing consumption of non RE.

Despite the expansion of the global economy, the emissions were stable from 2014 to 2016 (Fig 1) due to the deployment of low carbon technologies, and some improvements in EE measures. However, the low carbon alternatives did not scale fast enough to meet the rising energy demand over the last 2 years. Consequently, for every 1% addition in global economic output, the emissions rise by ~0.5%, compared to an average increase of 0.3% in 2010. Nonetheless, the implementation of renewables and nuclear energy has had a positive impact as at 2018, with the rate of emissions growth being 25% slower than energy demand (IEA, 2019b). While the world population rose from 1.6 billion in 1900 to 7.2 billion in 2016, the total energy production worldwide rose from 23 million to 548 million Tera joules. This energy demand will continue to grow as the population is projected to rise to 10.9 billion by 2100 (Jones & Warner, 2016), with about 25% living in Africa (Calvin *et al.*, 2013).The rapid increase in the African urban population will result in growing need for industrial production, cooling, heating and mobility. This will unfailingly require more energy, and if unrestrained, increase CO_2 emissions. How Africa tackles its rising energy demand is crucial for its energy and economic future, and for worldwide trends (IEA, 2019a). A serious and concerted effort of humanity is the way to significantly diminish CO_2 emissions and save the world from the consequences of global warming. In an effort to curb greenhouse gas (GHG) emissions, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1997 and entered into force in 2005. This protocol shares the same objectives as the UNFCCC, but goes further by committing industrialised countries to reduce their carbon emissions (UNFCCC, 2011b). 192 parties have so far ratified the protocol. Burkina Faso ratified it in 2005 and is a non-Annex 1 party (UNFCCC, 2020a). One of the three tools put in place by this Protocol to achieve its objectives is the CDM. This mechanism enables industrialised countries with emission reduction targets to either finance or develop GHG mitigation projects in non-Annex 1(developing) countries in exchange for CERs (Pillay, 2016). This promotes sustainable development in the projects' host countries through the CDM's multiple benefits; for instance, technology transfer, financial support from CER sales, contribution to the achievement of country's intended nationally determined contributions (INDCs), economic development and poverty reduction. However, even though 52 African countries ratified the protocol, Africa currently hosts only 253 registered CDM projects, representing only about 3% of such projects globally (UNEP DTU Partnership, 2020).

Burkina Faso, like other Sahel countries is highly vulnerable to climate change. It is actually suffering from increasing temperatures , with irregularities in rainfall distribution over time and an increase in the occurrence of extreme climatic events like periods of droughts and floods (Dayamba *et al*., 2019). This threatens strategic sectors of the country like water, agriculture, livestock and forestry (Sawadogo, 2007). There is need for action to mitigate these impacts. Furthermore, the country has a 20.3% access to electricity, with less than 2% and about 58% in the rural and urban areas respectively. About 84% of the installed capacity is fossil fuel based, and the rest comes from hydro and solar energy (Power Africa, 2019). All the fossil fuel used in the country relies on imports, as Burkina Faso does not produce any of them. Almost 80% of the energy consumed consist of solid biomass such as firewood, charcoal and agricultural residues (inefficient and highly emits CO_2), accounting for close to 100% of energy supply in the rural areas (Moner-Girona *et al.*, 2016). Moner-Girona *et al.* (2016) recommends distributed mini grids powered by RE resources for the country's rural electrification plan; for a quick connection of more people to power, while mitigating fossil fuel consumption and carbon emissions.

In order to promote the use of local energy resources and boost efficient energy consumption, the government, in line with the Sustainable Energy for All (SE4ALL) country action put in place the RE and EE Action Plans. The targets are achieving 50% access to electricity in rural areas and 95% country wide, bringing RE (without biomass) in the electricity mix to 50% and reaching a 100% access to clean cooking energy in urban areas, and 65% in rural areas, all by 2030 (SE4ALL, 2019). This will also help the country to meet its INDCs and reduce its dependency on fossil fuel imports. Some RE and EE projects in line with these targets have already been implemented in partnership with the government through some national agencies like the National Agency of RE and EE (ANEREE), the National Utility company (SONABEL) and the Rural Electrification Agency of Burkina Faso (ABER). It is therefore imperative to assess these projects' impacts on CO_2 emissions levels, as they could be highly contributing to the reduction of emissions, making them potential opportunities for the CDM. Even though renewable energy technologies (RET) are gradually becoming competitive with the conventional technologies, high upfront cost and lack of access to technology still remain barriers to RE deployment in Africa. Therefore, capitalising the emission reductions resulting from these projects, through the CDM is important to attract private investments, boost the implementation of more RE and EE projects in the country, and consequently to mitigate carbon emissions and climate change impacts.

The main aim of the study is to investigate how the RE and EE projects implemented from 2012 to 2020[1] have impacted the level of carbon emissions; to determine their CDM potential (emissions reduction) which could be capitalised and contribute to the implementation of identified project opportunities, thereby contributing to improving the country's energy infrastructure. According to the project type, the CDM methods used to quantify these emissions are AMS-II.C., AMS-II.L., AMS-I.A., AMS-I.F., AMS-I.D. and AMS-III.AR. Moreover, some scholars identified low carbon project opportunities in Burkina Faso (UNEP RISØ, 2013) and in Africa (Burian & Christof, 2014; Christof *et al.*, 2011; Timilsina *et al.*, 2010), which if implemented could represent potential projects for the CDM. However, from the literature explored, no such study has been done for already implemented and operational projects. Therefore, the main contribution of this paper to the literature is to determine the CDM potential of existing and operational RE and EE projects in Burkina Faso, which are not registered to the mechanism; this is done using approved CDM methodologies.

This research is structured in 5 major sections. The introduction is followed by a concise and relevant literature review on the research topic. The methodology section showcases the methods used in collecting the data and quantifying the emissions reductions. The results of the study are then presented and discussed in the next section, followed by a conclusion, study limitation and some policy recommendations.

2. Literature review

2.1. Access to electricity in Africa and some countries' energy policies for electrification

The current energy needs in Africa are predominantly met by biomass and fossil fuels. Almost half of the continent's total primary energy supply (TPES) is covered by biomass. Oil, natural gas and coal account for about 22%, 14% and 14% respectively. Hydropower represents only about 3% of this TPES, leaving less than 1% for the other renewables and electricity (IRENA, 2015).

About 44.7% of Africa's population lack access to electricity; this challenge differs per region. This concerns less than 2% of the Northern African population, meanwhile in SSA, almost half of southern and western African population, and about three quarter of the eastern and central African population are still deprived of electricity (IRENA, 2015). Nevertheless, as presented in Table 1, some African countries have put in place energy policies with set targets for sustainable increase in access to electricity for their populations. Most of the measures set to achieve these targets involve the use of RET and the improvement of EE applications, which are implemented progressively. This also promotes the implementation of more RE and EE projects on the continent. Both the implemented projects and those to be could be potential sources of carbon reductions, which could be valued through CERs under the CDM.

[1] Willing to share data set of 2012-2020 in Excel format with those who wish to replicate the results of this study.

Table 1
Selected energy policies and targets in some SSA countries.

Country	Sector	Policies, targets and implementation measures
Angola	Access	Rate of electrification increase from 30% to 60% by 2025
	Integration	Transmission lines Establishment with Namibia and Congo
	Power	Implementation of a new power market model with only one power purchaser and equal rights for public and private power purchasers.
Côte d'Ivoire	Access	National program of rural electrification: All towns of over 500 inhabitants connected by 2020, all regions by 2025, with reduced tariffs for poor households. Program of electricity for all: Electrification of a million households.
DR Congo	Access	Rate of electrification increase from 9% to 14% by 2015 and 26% by 2020.
	Power	Firmer standards for electric motors
Ethiopia	Access	Total access by 2025 Program of electrification (2017): Public-private off-grid programs for six million households; accelerated grid extension and decentralised systems to cover respectively 65% and 35% of the population by 2025.
	Renewables	Targets put in place for new renewables' (hydro, geothermal, wind) capacity.
Ghana	Efficiency	18% reduction of transmission losses by 2018; set labels and standards for air conditioners and lighting.
	Renewables	Establishment of Feed-in tariff (2011 Renewable energy act)
Kenya	Access	Total access by 2022. National electrification strategy (2018): $2.8 billion investment from 2018 to 2022. Off-grid solar access project: 250 000 solar home systems distributed to schools, households, agriculture and health facilities by 2030
	Buildings	Requirements for the installation of solar water heaters in buildings served by the grid; elimination of kerosene as household fuel by 2022.
	Efficiency	Set energy efficiency obligations for utilities and standards for electrical appliances; 2014 energy bill provides for the establishment of an Agency of energy efficiency and conservation to enforce the standards.
Mozambique	Access	Electrification rate increase from 39% to 85% by 2035
	Renewables	Installation of 2000 televisions powered by solar PV/wind turbine system, 100 000 solar water heaters, 50 000 lighting systems and 5000 refrigeration systems in off-grid regions by 2025.
Nigeria	Access	Provide reliable electricity to 75% of the population by 2020 and 100% by 2030, from 45% in 2014. Connecting averagely 1.5 million households annually.
	Buildings	Announced the design and implementation of minimum energy performance standards for appliances and industrial equipment.
	Power	According to the Roadmap for power sector reform, continue sector-wide reforms to enable private sector investment, establish a competitive market and achieve stable power supply.
Rwanda	Access	Full access by 2024. Rural electrification strategy and energy sector strategic plan: By 2024, 52% of households connected to the grid and 48% to decentralised systems; energy standards for appliances introduced; frequency and duration of interruptions reduced by 50%; all productive users connected.
	General	Share of bioenergy in primary energy consumption reduced to 50% by 2020; transmission network expanded by 2100 km by 2017.
Senegal	Access	Total access by 2025 National electrification program: 95% of rural clients electrified via grid extension; 4% via solar or hybrid solar-diesel mini-grids; and the remaining via solar home systems.
	Renewables	20% renewables in the total energy supply mix was target for 2017.
	Energy prices	

Source: IEA (2014, 2019a)

2.2. Energy Situation in Burkina Faso

2.2.1. Energy Resources and Electricity Mix

Burkina Faso is a landlocked and low income Sahelian country in West Africa with limited natural resources. With an estimated annual growth rate of 2.9%, the country's population stood at 19.75 million inhabitants in 2018, with over 70% living in rural areas (World Bank, 2019). In 2008, the energy consumed was derived from biomass at about 84%, petroleum products at about 10%, hydropower at about 6% and other renewable sources, particularly solar at less than 1% (REEEP, 2012). Almost 90% of the population still relies on biomass (firewood and charcoal) energy mostly for cooking (REEEP, 2012; Tatsidjodoung Parfait, Marie-Hélene Dabat, 2012). However, in urban Ouagadougou (capital city), about 44% of households cook with firewood, meanwhile approximately 16% and 40% use charcoal and gas respectively (Sana et al., 2019). Nevertheless, as fuelwood consumption is gradually overweighing the production capacity, there is an increasing pressure on the already fragile forest ecosystem to meet the demand, making the system unsustainable (Tatsidjodoung Parfait, Marie-Hélene Dabat, 2012). It is therefore essential to harness this renewable resource in a sustainable way, and to diversify the energy resources used in Burkina Faso.

The lack of crude oil refineries and fossil fuel resources, which represent the 2nd most consumed energy type in Burkina Faso makes it totally dependent on the importation of all the hydrocarbons required to fuel different sectors of the country. Petroleum products are imported from neighbouring countries, especially Ivory Coast, 62% of which is used for transport, 21% for electricity production, 5% lighting and 5% cooking (Tatsidjodoung Parfait, Marie-Hélene Dabat, 2012). Oil consumption keeps increasing over the years in Burkina

Faso, in 2016 for example, it was at 23000 barrels per day, from 6574 barrels per day in 2000 (Worldmeter, 2016).

Hydroelectric power in Burkina Faso comes from both local plants and imports (about 20%) from neighbouring countries like Ivory Coast, Ghana and Togo. The installed capacity of hydroelectric power production is at 34.56 MW, totally connected to the national grid, and contributes for an average of 100GWh annually. Hydropower accounts for about 10% of the total installed electricity generation capacity (MEMC/MINEFID, 2016). The adverse hydro meteorological conditions in the country limit its hydropower potential.

Solar energy is the most abundant endogenous energy resource in Burkina Faso, and it is uniformly distributed across the country with an average specific yield of 620kWh/kWp (MEMC/MINEFID, 2016). On an annual basis, it receives 3000 to 3500hours of peak sunshine, which has the potential to generate an average of 5.5 kWh/m^2/day. In spite of this high solar potential, it is still poorly harnessed with most of the installations been of low capacity; beneath 250 kWp. Nonetheless, there are increasing numbers of installations of hybrid PV-diesel mini grids and solar kits (individual or collective) in the framework of the decentralised rural electrification program. The Zagtouli solar photovoltaic (PV) power plant with an installed capacity of 33 MW, with a planned extension of 17MW, is one of the most recent solar PV projects implemented in the country (MEMC/MINEFID, 2016; Moner-Girona *et al.*, 2016).

The key electricity operator which was vertically integrated, with a national monopoly on the generation and distribution of electricity in urban centres is the National Electricity Company of Burkina Faso (SONABEL). In 2014, its electricity supply reached 1125GWh (ADF, 2015) from 755GWh in 2008 (Tatsidjodoung Parfait, Marie-Hélene Dabat, 2012), generated in fossil fuelled thermal power plants. This very expensive source of electricity generation dominates the electricity mix with a share of 57%, followed by imported electricity at 36% (32% from Côte d'Ivoire and 4% from Ghana) and finally 7% from hydropower (ADF, 2015). Solar energy still accounts for less than 1% of the energy mix despite the annual growth rate of 30% in solar PV installed capacity since 2014 (Moner-Girona *et al*., 2017). The Yeleen solar PV project of 208MWp that would be implemented under the African Development Bank's Desert to power Initiative, between 2020 and 2024 would highly increase the % of solar power in the mix. The Yeleen is projected to reduce emissions by 48000 $tCO_{2}e$ yearly; a potential opportunity for the CDM (AfDB, 2019). The increasing economic and mining activities in addition to the fast growing population led to an annual average of 13% increase in electricity demand, compared to 8% increase in the supply over the past decade. In 2015 for instance, the total available capacity was at approximately 200 MW, for a peak demand of about 250MW, resulting in a deficit of 50 MW. Additionally, the yearly consumption of electricity per capita of about 35 kWh is amongst the least in Africa (ADF, 2015). Nonetheless, the cost of electricity which is currently at 0.22-0.25 USD/kWh in Burkina Faso remains amongst the most expensive in the region (Power Africa, 2019). It is therefore essential for Burkina Faso to consider an alternative energy mix that will extensively increase the national power supply to satisfy the rapidly growing demand, while reducing its dependence on imported petroleum products for power generation

Table 2
Regulations, Incentives and legislative energy framework at national level.

Policy/Sector	Reference document	Description
Production and distribution of energy	Law 014-2017/AN General regulation of the Energy sector.	Electricity production and distribution opened to private sector; transportation network remains under the monopoly of SONABEL.
Electricity	Decree 089/PRES/PM/MCE (2003)	Establishment of the Rural Electrification Fund [Fond de Développement de l'Electrification Rurale (FDE)]
Electricity	National White Paper (LBN) (2006)	Envisaged the provision of modern energy services to the population of the whole country by 2020.
Energy efficiency	Energy savings National Action Plan (2013)	Short term measures to promote sustainable use of energy and improve energy efficiency.
Renewable energy	Inter-ministerial decree N°2020-033/ME/MINEFID/MCIA	Eligibility and modalities for the exoneration of value added tax on importation and sales of solar equipment.
Electricity (Renewable Energy Technology-RET)	Bidding for a target of 225MWp of grid connected solar PV by 2020	Construction started in 2016 of 33 MWp being extended to 50MWp (Ministry of Energy). A tender was launched and 5 operators recruited for the installation of 68.25MWp in 5 settlements. Development of 26 MWp (WINDIGA energy) Plan for another tender to recruit 5 other operators in 2017 for a total of 80 MWp.
Energy sector reform	Lettre de politique sectorielle de l'énergie (LPSE), 2016.	Renewable energy and energy efficiency identified as crucial axes for the development of the energy sector. Energy law voted 2017.
Renewable energy	Decret N°2016-1200/PRES/PM/MINEFID/MEMC for the establishment of the (Agence Nationale des Energies Renouvelables et de l'Efficacite Energetique-ANEREE)	Establishment in 2016 of the new agency (ANEREE) dedicated to the development of renewable energy Technologies and the implementation of energy efficiency measures in the country.
Energy efficiency	Decree N°2017-1014/PRES/PM/ME/MCIA/MINEFID	Focus on setting energy efficiency obligations/standards applicable to electrical appliances and equipment.

Source: Compiled by author from ANEREE (2020), ARSE (2017) and Moner-Girona et al. (2017)

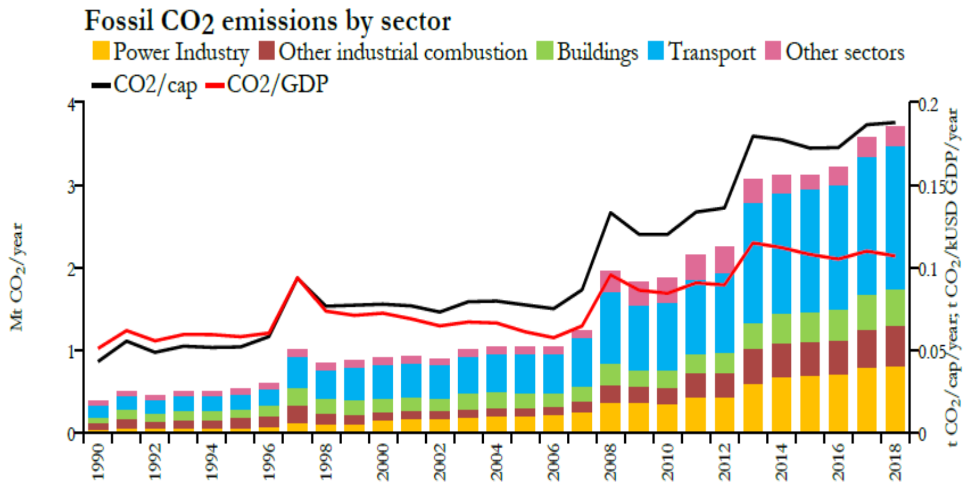

Fig. 2 Fossil CO_2 emissions by sector Burkina Faso (Crippa et al., 2019)

2.2.2 Institutional, Legislative and Regulatory Framework for the Energy Sector

Moner-Girona *et al.* (2017) confirm electricity as a significant factor in Burkina Faso's socio-economic development. However, the country's electricity sector is challenged amongst others by the need to provide electricity to its population and to improve the quality and reliability of its services. The government, through its Ministry of Mines and Energy (MMCE) put in place a number of policy instruments and strategies to alleviate these challenges (Moner-Girona *et al.*, 2017). There is not one regulatory framework that defines the country's strategy for electricity access; it is however enclosed in several sustainable development policies as presented in Table 2 (Moner-Girona *et al.*, 2016).

2.2.3 Fossil CO_2 emissions in Burkina Faso

The country GHG inventory conducted by the National Institute of Statistics and Demography showed that, CO_2 accounts for over 99% of the GHG emitted by the energy sector; with only traces of the other gases like CH_4 and N_2O (MEDD Burkina Faso, 2014). As shown in Fig.2, from about one million tonnes of CO_2 emissions estimated for Burkina Faso in the late 90s, in 2018, they were at about 3.7 million tonnes, with an average yearly increase rate of about 8.8%. This yearly amount of CO_2 emissions ranks Burkina Faso 128th out of 180 countries worldwide (Knoema, 2020). The fossil CO_2 emissions considered are those resulting from fossil fuel combustion, flaring and in industrial processes (steel, cement, and chemicals) (Crippa *et al.*, 2019). The transport sector, energy industries, manufacturing/construction industries and the residential sector; account respectively for about 60%, 27%, 9% and 4% of CO_2 emissions from the energy sector (MEDD Burkina Faso, 2014). The carbon emissions mitigation potential of the energy, transport, agriculture, waste and forestry sectors in the country were estimated at about 15 million tons between 2007 and 2015 (UNEP RISØ, 2013).

2.2.4. Emissions reduction scenarios for INDC targets achievement in Burkina Faso

According to the country's INDC document, by 2030, the conditional and the unconditional mitigation scenarios project a total emissions reduction of about 21 574.63 $MtCO_2e$, accounting for 18.2% reduction of emissions of the BaU scenario. The Agricultural, energy and waste sectors account for 15%, 3.1% and 0.1% of this reduction, but the cost of implementation of the projects in the energy sector are way higher than that of the others. About 40% of the total investment cost (about $1.8 billion) of mitigation actions falls under the conditional category (MEEVCC, 2015). However, all the adaptation scenarios with a total implementation cost estimated at about $5.8 billion are conditioned by international provisions of implementation means (World Bank, 2016). Therefore, the achievement of both mitigation and adaptation targets highly depends on the obtainment of international investments.

2.3 Benefits of the CDM and its effectiveness in carbon curbing and sustainable development

The two main purposes of the CDM are to enable developed countries (carbon credit buyers) to meet their emission reduction targets and contribute to the achievement of sustainable development in developing countries (host country). These carbon credits are called CERs and each represents one ton of CO_2 equivalent (tCO_2e) emission reduced (UNFCCC, 2020a). The CDM provides opportunities to developing countries to be attractive to commercial investments, which will locally abate poverty and promote socioeconomic development through the implementation of local infrastructure, technology transfer and job creation in an environmentally friendly approach (UNFCCC, 2020c). The concept of sustainable development involves economic, social and environmental factors. CERs account for about 40% of the GDP in Africa, meanwhile in 2015, only about 2.5% of emissions reduction in Africa was covered by the CERs (Pillay, 2016).

2.4 Registered CDM projects distribution by region and by sectoral scope

CDM projects have so far been very inequitably distributed worldwide (Table 3). The Asian and Pacific region alone host about 81% of these projects, while Africa is still at about 3% (UNEP DTU Partnership, 2020). Unlike many Asian and Latin American countries, most countries in sub-Saharan Africa deeply rely on foreign support to design and implement such projects (Michaelowa, 2007); and they remain very poorly represented globally in carbon markets despite their huge unharnessed and attractive financial and environmental CDM potential. This should urge Africa to take action to harness this potential; a way forward is the valuation (through the CDM) of the emission reductions resulting from the implemented RE and EE projects in the region. Additionally, regarding the distribution of registered CDM projects by sectoral scope, Fig. 3 shows that the energy industry dominates, as it accounts for over three quarters of all the registered projects (UNFCCC, 2020b).

2.5 The CDM potential and state of the CDM in Africa

Timilsina *et al.* (2010) investigated the technical potential of the energy sector in SSA to reduce GHG emissions, focusing on 22 selected technologies in 44 SSA countries. They found that 3227 CDM projects including 361 programs of activities could be developed in SSA. Using approved CDM baseline and monitoring methods, they estimated these projects' mitigation potential at 740.7 million tCO_2e annually and about 9.8 billion tCO_2e through the CDM project life. South Africa presents the highest potential with 2325.1 $MtCO_2e$ and Cape Verde the list with 0.7 $MtCO_2e$. According to this study, these projects could significantly boost the economic development of the region if implemented, as they could attract a total investment of over $200 billion. Added to that, $7.4 billion and $98 billion is what could be generated respectively yearly and through the project life from the sales of the CERs generated, considering a carbon price of $10/$tCO_2e$. In addition, 21.5 GW of generation capacity addition could be avoided by the energy efficiency CDM projects, meanwhile 149 GW of clean electricity generation capacity could be added by the other projects. However, the realisation of this CDM potential entails setting strategies to overcome some technical, financial, institutional and regulatory barriers. Christof *et al.* (2011) also researched on the CDM project technical potential in SSA focusing on 11 countries, namely Zambia, Uganda, Rwanda, Senegal, Tanzania, Mozambique, Mali, Malawi, Ethiopia, Democratic Republic Congo (DRC), and Burkina Faso.

The sectors considered for the CDM potential evaluation include waste potential, renewable energy, energy efficiency, transportation and potentials in mining, charcoal and cement production. They found a total annual emission reduction potential of these countries of about 128.6 $MtCO_2e$, representing 128.6 million CERs generated annually. Ethiopia tops the list with a potential of about 32 million CERs yearly, and Rwanda presents the least potential of about 2.3 million CERs yearly. They also pointed out lack of finance, limited technical and human resources as well as lack of institutional capacity as constrains that need to be alleviated to enable the exploitation of this potential. Burian & Christof (2014) also confirm Africa's huge potential to abate CO_2 emissions, and places emphases on the weakness of the institutional framework as a factor that slows down the development of CDM projects in the continent. Although Africa has a very significant GHG abatement potential, Africa will account for only 3.5% of the CERs issued by 2020, given that they would yield a total of about 280.3 million CERs by the end of 2020 (UNEP DTU Partnership, 2020).

2.6 RE and EE projects implemented in other African countries, but not registered to the CDM

Many African countries other than Burkina Faso host unharnessed CDM potential. There are RE and EE projects with great CDM potential, but not registered to the CDM in most of these countries. For instance, the 50MW Garissa solar PV power plant in Kenya with an annual emissions reduction capacity of about 64190tCO_2e (REREC, 2020); the 22 MW Malicounda solar PV plant in Senegal (ECREEE, 2018) and the 20 MW Gomoa Onyoadze solar PV plant in Ghana (Ngounou, 2018). The 5 MW Djounou solar PV plant in Benin (ECREEE, 2017), 54 MW Bangweulu solar PV plant in Zambia (Takouleu, 2019), the 90 MW High plateau East Adrar and the 90 MW High plateau Centre Adrar solar PV plants in Algeria (USC Africa, 2016) and the 1.3 hybrid solar PV – Genset power plant in DRC (Takouleu, 2020) are also potential CDM projects. The replacement of 172800 compact fluorescent lamps (CFL) by LED lamps in the framework of the "National CFL exchange program" (Amoah *et al.*, 2018), and the replacement of 8150 inefficient fridges by more efficient ones in the framework of the "Refrigerator rebate and exchange scheme" (Graphic Online, 2016; UNDP, 2015) in Ghana are also unharnessed potential opportunities for the CDM. These are just to name a few of such projects in African countries.

Table 3
Regional Distribution of CDM Projects.

Region	Number of projects	Proportion per Region
Asia and Pacific	6817	81.4%
Latin America	1111	13.3%
Africa	253	3.0%
Middle East	112	1.3%
Europe and Central Asia	84	1.0%
Total	**8377**	**100%**

Source : UNEP DTU Partnership (2020)

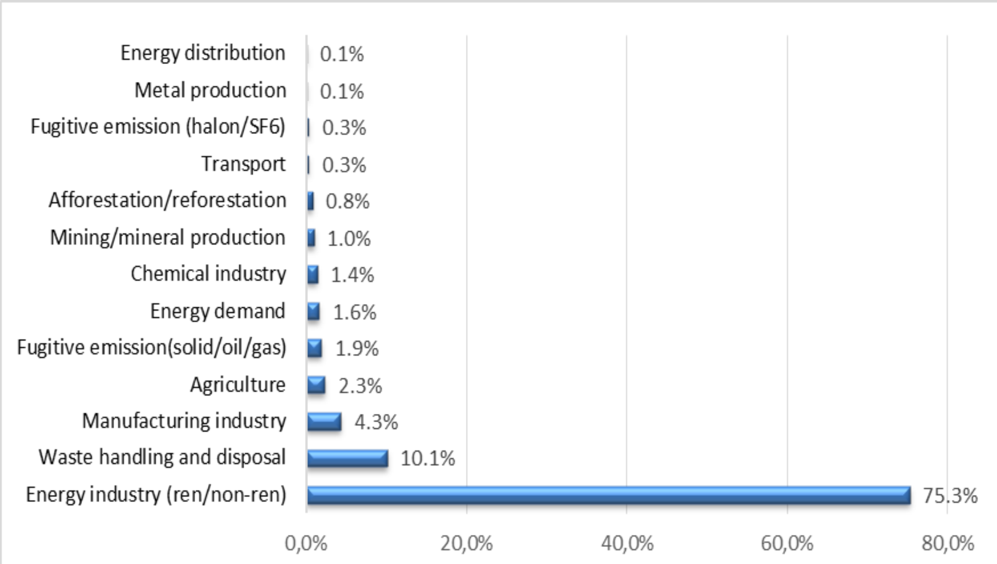

Fig. 3 Registered CDM projects distribution by sectoral scope (UNFCCC, 2020b)

2.7 The CDM potential and state of the CDM in Burkina Faso

UNEP RISØ (2013) estimated the CDM potential of a number of sectors/technologies in Burkina Faso at about 108. emissions reduced annually (Table 4), which reflects the country's relative attractiveness for carbon finance. Some of the technologies considered are: Solar PV, Improved stoves, biodiesel, Afforestation/Reforestation, solar lighting and gold mining, with Afforestation/Reforestation presenting the highest potential. Nevertheless, Burkina Faso currently hosts only three CDM registered solar photovoltaic power plant projects; the Zagtouli, the Zina, and the IAMGOLD Essakane SA Gold Mine with respective installed capacity/annual emission reduction potential of 17 MW/14,696 MtCO_2e, 22 MW/13,236 MtCO_2e and 15 MW/19,904 MtCO_2e. Burkina Faso is also among the host countries of program of activities (PoA) related to the promotion of efficient stoves dissemination and use in West Africa, the West African bio digester and the landfill gas capture, flaring and utilisation program in Africa (CDM, 2020b, 2020g, 2020d, 2020e, 2020f, 2020c).

Table 4
Emission reduction potential per technology type, Burkina Faso.

Technology type	Emission Reduction Potential per year (tCO2e)	Baseline Methodologies
REDD + / avoided deforestation	9, 672,652	Historical baseline
Afforestation/Reforestation	96, 726,520	AR-AM1, AR-AM3, AR-AM4, AR-AM5, AR-AM9, AR-AM10, AR-AMS1, AR-ACM1, AR-ACM2
Charcoal	455,525	AMS-I.C., AMS-III.K., AM41
Biodiesel	3,600	ACM0017, AMS-III.AK., AM0041
Bagasse	17,390	ACM2, ACM6, AM36, AMS-I.D., and AMS-I.C.
Liquid Waste (manure)	242,488	AMS-I.A,C,D. AMS-III.H. AMS-III.D., AMS-III.F., AMS-III.I., ACM14, AM25, AM80
Solid Waste	15,700	AM36, ACM6, ACM2, AMS-I.C., AM36, ACM6, ACM2, AMS-I.D., AMS-I.C., ACM6, ACM2, AMS-I.D. and AMS-I.C.
Hydro	68,250	ACM2, AMS-I.D., AM26, AMS-I.A., AM5, AM26, AMS-II.B., ACM11, ACM12, AM52
Solar lighting	180,000	AMS-I.A., AMS-II.J.
Solar PV	42,000	ACM2, AMS-I.A., AMS-I.C., AMS-I.D.
Improved stoves	1, 000,000	AMS-I.C., AMS-I.E., AMS-II.G.
Cement	5,300	ACM12
Mining (gold)	100,000	AM64 ACM8
Brewery	3,600	Depends
TOTAL	**108533025**	

Source : UNEP RISØ (2013)

3 Methodology

3.1 Scope

This study focuses on RE and EE CDM projects types. An inventory of such projects implemented in Burkina Faso from 2012 to 2020, but not registered to the CDM was done. The secondary data about the projects and some country data were provided by the 2iE and different national entities, including the Ministry of Energy through the ANEREE and the ABER. Other information was directly gotten online from open access journals, reports and different websites.

A key criterion for a project to be registered to the CDM is a proof of its additionality. This entails amongst others, showing the emissions savings are solely a result of the project's activities and would not have occurred without the implementation of the project concerned (CDM, 2020a). For each of the selected projects, the additionality, the baseline emissions (BAU scenario), the actual emissions with the projects (project scenario) and the quantity of annual emission reductions were determined, enabling to estimate the number of CERs which could be generated if they were registered to the CDM. The crediting period of a proposed CDM activity can either be a fixed (non-renewable) period of ten years or a period of seven years, renewable at most two times (UNFCCC, 2011a). In this study, a fixed crediting period of 10 years will be considered for all the projects to estimate the number of CERs they could generate within that timeframe. It is worth noting that the list of RE and EE projects implemented in Burkina Faso, which is presented in this study is not exhaustive, due to difficulties in obtaining data. The confirmation that these projects are not registered to the CDM was done by searching on the UNFCCC CDM project search, and also through information gotten from the institutions which provided the data.

Given that the present study is meant to encourage projects' registration to the CDM, approved CDM methodologies are those considered herein to determine the emission reductions and the proof of additionality of the projects selected. The CDM methodologies considered, which will be specified in each case are:

- For EE projects:
  - AMS-II.C.: Small-scale Methodology, Demand-side energy efficiency activities for specific technologies -Version 15.0.
  - AMS-II.L.: Small-scale Methodology, Demand-side activities for efficient outdoor and street lighting technologies -Version 02.0.
- For RE projects:
  - AMS-I.A.: Small-scale Methodology, Electricity generation by the user -Version 17.0.
  - AMS-I.F.: Small-scale Methodology, Renewable electricity generation for captive use and mini-grid -Version 03.0.
  - AMS-I.D.: Small-scale Methodology, Grid connected renewable electricity generation - Version 18.0.
  - AMS-III.AR.: Small-scale Methodology, Substituting fossil fuel-based lighting with LED/CFL lighting systems -Version 06.0

The calculation approaches applied are provided for individual projects, given that the parameters to be considered vary with different factors like project type and data available. The grid emission factor of the country's electricity system used is of 0.7 tCO_2e/MWh (Moner-Girona et al., 2017; UNEP RISØ, 2013). The emission factors used in other cases are default values proposed by the CDM method applied.

3.2 State of Project Additionality and Calculation of Project Emission Reductions

3.2.1 Energy Efficiency Projects

I. AMS-II.C (UNFCCC, 2016)

i) State of Additionality

All the projects considered under this method were deemed additional according to its 15th article.

ii) Calculation of CO_2 emission reductions

The project activity's emission reduction is calculated as follows:

$$ER_y = \left(BE_y - PE_y\right) - LE_y \quad (1)$$

Where:

- ER_y is the emission reductions during year y (tCO_2e)
- BE_y is the baseline emissions during year y (tCO_2e)
- PE_y is the project emissions in year y (tCO_2e)
- LE_y is the leakage emissions in year y (tCO_2e)

No refrigerants are involved in the project activities considered; therefore LE_y=0 all through.

- Calculation of Baseline Emissions

For this calculation, Option 1 (Constant load equipment) of the AMS-II.C tool is applied. The baseline emission is calculated as follows:

$$BE_y = E_{BL,y} \times EF_{CO2,ELEC,y} + Q_{ref,BL} \times GWP_{ref,BL} \quad (2)$$

$$E_{BL,y} = \sum_i \left(n_i \times \rho_i \times o_i/(1 - l_y)\right) \quad (3)$$

Where:

- $E_{BL,y}$ is the energy consumption for the baseline during year y (MWh)
- $EF_{CO2,ELEC,y}$ is the grid emission factor (tCO_2e/MWh) during year y
- $Q_{ref,BL}$ is the average annual quantity of refrigerant used in the baseline to replace the refrigerant that has leaked (tonnes/year)
- $GWP_{ref,BL}$ is the global warming potential of the baseline refrigerant (tCO_2e/t refrigerant)
- n_i is the number of pieces of equipment of the group of i baseline equipment replaced or that would have been replaced.
- ρ_i is the electrical power demand (W) for the group of i baseline equipment (e.g 20W incandescent lamp)

- o_i is the average annual operating hours for the group of *I* baseline equipment.
- l_y is the average annual technical grid losses (transmission and distribution) for year *y*.
- $\sum_I$ is the sum over the group of *i* baseline equipment replaced or that would have been replaced.

$Q_{ref,BL}$ and $GWP_{ref,BL}$ are not applicable in this case, since refrigerants are not involved.

➢ Calculation of project emissions

The project emission is determined as follows:

$$PE_y = EP_{PJ,y} \times EF_{CO2,y} + PE_{ref,y} \quad (4)$$

Where:

- $EP_{PJ,y}$ is the energy consumption of project activity in year *y* (MWh)
- $EF_{CO2,y}$ is the grid emission factor (tCO_2e/MWh) during year *y*
- $PE_{ref,y}$ is the project emission from physical leakage of refrigerant from the project equipment in year *y* (tCO_2e/y)

For the energy consumption of the project activity in year *y* ($EP_{PJ,y}$) , the same formula used for the baseline energy consumption **Error! Reference source not found.** in year *y* is applied, but with project activity data. Also, due to the lack of reliable data concerning the grid technical losses, the default value of 0.1 proposed by the method is applied.

II. AMS-II.L (UNFCCC, 2013)

i) State of Additionality

This method refers to the CDM methodological tool 19, version 09.0, for additionality demonstration. According to article 12 of this tool, all the projects considered here are deemed automatically additional (UNFCCC, 2018a).

ii) Calculation of CO_2 emission reductions

The project activity's emission reduction is calculated as follows:

$$ER_y = NES_y \times EF_{CO2,ELEC,y} \quad (5)$$

Where:

- ER_y is the emission reductions during year *y* (tCO_2e)
- NES_y is the net electricity saved in year *y* (kWh)
- $EF_{CO2,ELEC,y}$ is the grid emission factor (tCO_2e/MWh) during year *y*

➢ Calculation of net electricity saved (NES)

$$NES_y = \sum_{i=1}^{n} ES_{i,y} \times \frac{1}{(1 - TD_y)} \quad (6)$$

$$ES_{i,y} = \left(Q_{i,BL} \times P_{i,BL} \times O_{i,BL} \times \left(1 - SOF_{i,BL}\right)\right) - \left(Q_{i,p} \times P_{i,p,y} \times O_{i,y} \times \left(1 - SOF_{i,y}\right)\right) \quad (7)$$

$$SOF_{i,BL} = AFR_{i,BL} \times OF_{i,BL} \quad (8)$$

$$SOF_{i,y} = AFR_{i,y} \times OF_{i,y} \quad (9)$$

Where:

- $ES_{i,y}$ is the estimated yearly electricity savings (kWh) for lamp type *i* in year *y*
- TD_y is the average annual technical grid losses (transmission and distribution) for year *y*
- *Y* is the year considered
- *I* is the counter for lamp type
- *N* is the number of lamps
- $Q_{i,BL}$ is the quantity of baseline lamps of type *i* that were replaced
- $Q_{i,p,y}$ is the quantity of project lamps of type *i* installed year *y*
- $P_{i,BL}$ is the rated power of type *i* baseline lamps
- $P_{i,p,y}$ is the rated power of type *i* project lamps, year *y*
- $O_{i,BL}$ is the annual operating hours for the baseline lamps
- $O_{i,p,y}$ is the annual operating hours of project lamps, year *y*
- $SOF_{i,BL}$ is the system outage factor for type *i* baseline equipment
- $SOF_{i,p,y}$ is the system outage factor for type *i* project equipment
- OF_i is the outage factor; the average time in hours elapsed between failure of type *i* lamps and their replacement, divided by annual operating hours ($O_{i,y}$). $OF_{i,BL}$ for baseline values and $OF_{i,p,y}$ for project values in year *y*.
- AFR_i, is the annual failure rate of type *i* lamps, calculated as a fraction of *Q*. $AFR_{i,BL}$ for baseline values and $AFR_{i,p,y}$ for project values, year *y*. In ex-post estimations, AFR_i =actual fraction of lamps that fail annually, while in ex-ante estimations, AFR_i = annual operating hours divided by rated average life for project equipment (lamp). The ex-ante approach is applied in this study due to lack of data regarding the ex-post approach.

3.2.2 *Renewable Energy Projects*

I. AMS-I.F (UNFCCC, 2014b)

i) State of Additionality

This method refers to the CDM methodological tool 19, version 09.0, for additionality demonstration. According to article 11a of this tool, all the projects considered here are deemed automatically additional (UNFCCC, 2018a). This equally applies to projects under methods AMS-I.A and AMS-I.D below.

ii) Calculation of CO_2 emission reductions

Equation (1) also applies here for the calculation of emission reductions. However, since the *PE=0* and *LE* is not applicable for this category of projects, *ER=BE*.

$$BE_y = E_{BL,y} \times EF_{CO2,y} \quad (10)$$

Where:

- $E_{BL,y}$ is the quantity of net electricity displaced due to the implementation of the project activity in year y (kWh). This is considered as the quantity of electricity generated by the project activity during the same year.
- $EF_{CO2,y}$ is the grid emission factor

$$E_{BL,y} = \sum_i (EG_{i,y} \times CF_B)/(1 - TDL) \quad (11)$$

$$EG_{BL,y} = (P_P \times I_s \times K \times 365)/1kWm^{-2} \quad (12)$$

Where:
- $EG_{i,y}$ is the electricity generated by project activity units type i in year y (kWh).
- CF_B is the correction factor of total annual energy production by a project unit, adapted to the type of project beneficiary (end-user) B.
- P_p is the peak power of the project production unit (kWp)
- I_s is the average annual daily solar insolation (5.5 kWh/m^2/d in Burkina Faso)
- K is the coefficient of losses in the system (0.55 – 0.75)
- $1Kw/m^{-2}$ is the solar irradiation in Standard Test Conditions (1000 W/m^2; Air Mass: 1.5; cell temperature: 25°C)

Given that $EG_{i,y}$ obtained for the project activities takes into consideration all the 365 days of the year, a correction factor is applied for facilities considered not to be operational 7/7 throughout the year. Regarding the TDL, a default value of 10% is applied.

II. AMS-I.A (UNFCCC, 2019b)

i) State of Additionality

See method AMS-I.F above.

ii) Calculation of CO_2 emission reductions

The same steps for the determination of the project emissions reduction in method AMS-I.F. are applicable in this method, but with the peculiarities mentioned hereafter:

The baseline emissions are calculated using option 2, article 22 of this method, which is based on the annual electricity generation by the project activity. Since the end-users are not connected to the grid, it is assumed that they would have used a diesel generator to produce electricity in the absence of the project activity. For the baseline calculation, the method provides a default emission factor of 0.8 kgCO_2e, which is derived from diesel generation units. Also, since before project implementation the diesel generators were used at the consumption site, there was neither electricity transmission nor distribution, therefore, TDL=0.

III. AMS-I.D (UNFCCC, 2014a)

i) State of Additionality

See method AMS-I.F above.

ii) Calculation of CO_2 emission reductions

Equation (1) also applies here for the calculation of emission reductions. However, since the $PE=0$ and LE is not applicable for this project activity, $ER=BE$.

$$BE_y = EG_{PJ,y} \times EF_{grid,y} \quad (13)$$

Where:
- $EG_{PJ,y}$ is the quantity of net electricity generation that is produced and fed into the grid as a result of the implementation of the project activity in year y (kWh). This is considered as the quantity of electricity generated by the project activity during the same year.
- $EFgrid_{,y}$ is the grid emission factor

IV. AMS-III.AR (UNFCCC, 2018b)

i) State of Additionality

This method refers to the CDM methodological tool 19, version 09.0, for additionality demonstration (UNFCCC, 2018a). According to article 13b of this tool, all the projects considered here are deemed automatically additional.

ii) Calculation of CO_2 emission reductions

This method provides a default annual baseline emission factor of 0.092 tCO2e/ year for each of the lamps.

➢ Calculation of baseline emissions

Equation (14) enables to calculate the baseline emissions:

$$BE_y = DV \times GF_y \times DB_y \times N \quad (14)$$

Where:
- BEy is the baseline emissions per project lamp in year y (t CO2e)
- DV is the lamp Emission Factor (default is 0.092 tCO_2e per project lamp)
- GFy is the grid Factor in year y:
  - Equal to 1.0 when charging is done with a renewable energy source like solar PV;
  - Equal to 1.0 if the project activity is for off-grid households/communities (defined as no grid access or less than 12 hours grid availability per day on an annual average basis);
  - Otherwise it is equal to 1.0 minus (the fraction of time grid is available to the target households and communities/users in the region of project activity).
- DBy is the dynamic Baseline Factor (change in baseline fuel, fuel use rate, and/or utilization during crediting period) in year y. Calculated as either:
  - Option 1: default of 1.0 in the absence of relevant information;
  - Option 2: value of 1.0+FFg where FFg is the documented national growth rate of kerosene fuel use in lighting from the preceding years (use the most recent available data for three or five years average (fraction))

Table 5
RE and EE projects considered/unconsidered and CDM methods applied.

	ENERGY EFFICIENCY PROJECTS	Method	C	UC
1	600 LED lamps installed to replace fluorescent lamps in University Hostels (2020).	AMS-II.C	✖	
2	1500000 LED lamps installed to replace fluorescent lamps in 500000 households connected to the grid.	AMS-II.C	✖	
3	10500 LED lamps for street lighting to replace high pressure sodium and mercury lamps in rural and urban localities.	AMS-II.L	✖	
4	4500 LED lamps for street lighting in Ouagadougou and Bobo Diolasso.	AMS-II.L	✖	
5	1400 solar street lights with LED lamps installed in rural localities. (Project 175 rural localities)	AMS-II.L	✖	
6	1926 solar street lights with LED lamps installed in Ouagadougou.	AMS-II.L	✖	
7	Acquisition and installation of 3500 smart meters for high and medium voltage customers. 1778 installed as at 2020			✖
8	Installation of energy efficient air conditioners in public buildings in replacement of the old inefficient ones.			✖
	RENEWABLE ENERGY PROJECTS			
1	385 Infrastructures; installation of off-grid solar PV systems in schools and health facilities in different regions across the country.	AMS-I.F	✖	
2	Installation of grid-connected solar PV systems in 25 medical centres with surgical antenna (CMA) in different regions across the country (2018 & 2019).	AMS-I.F	✖	
3	Installation of grid-connected solar PV systems in 12 public buildings in different regions across the country (2019).	AMS-I.F	✖	
4	Installation of off-grid solar PV kits in 30 City Halls in different regions across the country.	AMS-I.F	✖	
5	Off-grid Solar Back up project, installation of solar kits in households and small and medium enterprises in different regions across the country.	AMS-I.F	✖	
6	On-grid solar PV systems (200kWp) installed at the presidency of Burkina Faso.	AMS-I.F	✖	
8	On-grid solar PV systems (62kWp) installed at the country's First Ministry.	AMS-I.F	✖	
9	On-grid solar PV systems (40kWp) installed at the Ministry of energy.	AMS-I.F	✖	
10	On-grid solar PV systems (20kWp) installed at Koupéla hospital.	AMS-I.F	✖	
11	On-grid solar PV systems (75kWp) installed at the Ministry of the environment.	AMS-I.F	✖	
12	On-grid solar PV systems (42kWp) installed at the research institute in applied sciences and technologies (IRSAT).	AMS-I.F	✖	
13	On-grid solar PV systems (35kWp) installed at the national centre for scientific research and technology (CNRST).	AMS-I.F	✖	
14	On-grid solar PV systems (40kWp) installed at société générale Burkina Faso (SGBF).	AMS-I.F	✖	
15	On-grid solar PV systems (3MWp) installed in other institutions across the country.	AMS-I.F	✖	
16	Installation of off-grid solar PV systems in 297 schools and colleges and in 152 CSPS in 175 rural localities.	AMS-I.A	✖	
17	Rural electrification with solar PV micro grids installed in 20 villages (2018&2019).	AMS-I.A	✖	
18	Ziga solar PV power plant 1.1MW, connected to the grid.	AMS-I.D	✖	
19	Bilgo hybrid solar PV-diesel generator power plant, connected to the grid.	AMS-I.D	✖	
20	Distribution of 25000 certified solar lamps, Lighting Africa, in 400 primary schools in off grid rural areas (2016-2020).	AMS-III.AR	✖	
21	Distribution of 8500 solar lamps to primary school pupils in off-grid rural areas	AMS-III.AR	✖	
23	Decentralised rural electrification of 45 localities in the provinces of Ziro and Gourma (ERD-ZIGO). 36 localities electrified as at 2020.			✖
24	Installation of 343 solar water heating (SWH) systems in maternities of the same areas. 201 SWH installed as at 2020			✖
25	150 solar water heating systems (SWH) installed in CSPS in rural localities. (Project 175 rural localities)			✖
26	60 localities electrified as at 2020 in the framework of the electrification of 41 rural localities with solar PV systems.			✖

C: Considered, UC: Unconsidered.

4 Results and Discussion

4.1 Results

A total of 34 projects were identified, but suitable data could be obtained for 28 of them (Table 5), including 21 RE projects and 7 EE projects all proven to be additional. The total annual energy saved by the EE projects is 68709.424 MWh, accounting for 36871.701 tCO_2e emissions reduced annually (Table 6), while the total energy displaced by the RE projects is 9430.446 MWh, accounting for 11285.967

tCO_2e emissions reduced annually (Table 7), giving a total of 48,157.668 tCO_2e emissions reduced annually by all the selected projects (Table 8). This represents a shift in emissions from 76,300.098 tCO_2e in the baseline scenario to 28,142.430 tCO_2e in the project scenario, accounting for about 63.12% emission reduction. The total amount of emissions reduced could generate about 48,157.668 CERs per year and 481,576.68 CERs in 10 years (Table 8), assuming a fixed 10-year crediting duration for all the projects, and a constant quantity of annual emission reduction for each project throughout this period.

Table 6
Annual energy savings and emission reductions by EE projects.

Project	Annual energy savings (MWh/year)	Baseline annual emissions (tCO2e/year)	Project annual emissions (tCO2e/year)	Annual emission reductions (tCO2e/year)
600 LED lamps in University Hostels	35.689	28.698	11.353	17.345
1500000 LED lamps in 375000 households	60,225.000	53,217.000	23947.650	29,269.350
10500 LED lamps for street lighting	5,746.829	7,036.928	3014.147	4,022.781
4500 LED lamps for street lighting	1,492.820	3,319.432	1169.279	2,150.153
1926 solar street lights with LED lamps installed in Ouagadougou.	700.150	817.695	0.000	817.695
1400 solar street lights with LED lamps installed in rural localities. (Project 175 rural localities)	508.936	594.780	0.000	594.378
TOTAL	**67,500.339**	**65,014.131**	**28,142.430**	**36,871.701**

Table 7
Annual energy displaced and emission reductions by RE projects.

Project	Annual energy displaced (MWh/year)	Baseline annual emissions (tCO2e/year)	Project annual emissions (tCO2e/year)	Annual emission reductions (tCO2e/year)
385 Infrastructures, off-grid solar PV systems in schools and health facilities	465.474	325.832	0.000	226.220
On-grid solar PV systems in medical centres and public buildings	2.154	1507.985	0.000	1046.973
Off-grid solar PV kits in City Halls	71.668	50.167	0.000	34.831
Solar Back up project, off grid	1851.331	1295.931	0.000	899.747
On-grid solar PV systems installed in different institutions	4376.686	3063,680	0,000	2127,070
Off-grid solar PV systems in rural schools and CSPS	274.067	219,.54	0.000	219.254
Rural electrification with solar PV micro grids	687.709	550.167	0.000	550.167
Ziga solar PV power plant	1656.188	1159,331	0.000	804.907
Bilgo hybrid solar PV-diesel generator power plant	45.169	31.618	0.000	21.952
Distribution of 25000 certified solar lamps, Lighting Africa, in 400 primary schools in off grid rural areas (2016-2020).	0.000	2300.000	0.000	2300.000
Distribution of 8500 solar lamps to primary school pupils in off-grid rural areas	0.000	782.000	0.000	782.000
TOTAL	**9,430.446**	**11,285.967**	**0.000**	**11,285.967**

Table 8
Total energy saved, energy displaced, emissions reduced and CERs generated by the projects considered.

Energy saved/year	68,709.424 MWh
Energy displaced/year	9,430.446 MWh
Emission reduced/year	48,157.668 tCO_2e
Percentage of emissions reduction	63.12%
Number of CERs/year	48,157.668
Number of CERs for a 10years crediting period	481,576.68

4.2 Discussion

The aim of this study was to investigate on how the low carbon projects implemented in Burkina Faso have impacted the level of CO_2 emissions, in order to capitalise the emission reduction and improve the country's energy infrastructure where required while accelerating the achievement of the country's INDCs and contributing to its sustainable development.

As per the study's findings, the EE projects presented a way more attractive CDM potential (36,871.701 tCO_2e, Table 6) than the RE energy projects (11,285.967 tCO_2e, Table 7); this may be explained by the fact that the scale of the projects identified in the EE sector are way bigger than those in the RE sector. An annual emissions reduction of 48,157.668 tCO_2e (Table 8), resulting from all the projects considered account for 63.12% of what would have been emitted without these projects. This is a huge reduction which concurs with the results of several studies which showed the potential or RE and EE in GHG emissions abatement (Akdag & Yıldırım, 2020; Gielen et al., 2019; Inglesi-Lotz & Dogan, 2018; IRENA, 2017; Özbuğday & Erbas, 2015; Prince & Okechukwu, 2019) This total annual emissions reduction represents about 1.3% of Burkina Faso's total carbon emissions from fossil fuel combustion, flaring and industrial processes, which amounted to about 3.7 MtCO2e in 2018 according to (Knoema, 2020). It is also way less than 82.7 MtCO2e/ year, for low carbon project opportunities in the energy sector in Burkina Faso identified by (Timilsina *et al.*, 2010). Moreover, the GHG emission reduction potential we found could yield about 48,157.668 CERs annually, which is also less than a total of 2.96 million CERs per year found by (Christof *et al.*, 2011). They considered project opportunities in different sectors including waste potential, renewable energy, energy efficiency, transportation and potentials in mining, charcoal and cement production. UNEP RISØ (2013) obtained 180000 tCO_2e and 48,000 tCO_2e as the annual emission reduction potential of solar lighting and solar PV technologies respectively in Burkina Faso. All the RE projects considered in this study fall under these groups but the annual emission reduction potential we obtained is of 11,285.967 tCO_2e. The total annual emission reduction obtained is also less than that of the different scenarios predicted to achieve the INDC targets; nevertheless, it shows that these projects should not be neglected in the struggle to achieve these targets.

Different reasons could justify the huge difference between the CDM potential of already implemented and operational RE and EE projects obtained in this study, and that of potential project opportunities in Burkina Faso identified by other authors. Some of which could be the scope of the sector of projects considered; the number and size of the project opportunities they considered and that of those actually implemented and included in this study; the CDM methods and tools used to quantify the emission reductions as well as their version, given the fact that these methods and tools are improved and updated as years go by. This however shows that there is still enough CDM potential to be harnessed in the country.

The emission reduction potential of RE and EE projects obtained in this study is less than the reality in Burkina Faso for several reasons. Firstly, not all the projects identified were taken into consideration for the quantification of emission reduction because of lack of data for some projects as shown in Table 5, which could highly increase the results found. Secondly, in addition to the fact that there are planned projects yet to be implemented, most of the implemented projects identified are part of bigger national programs which are still ongoing, with more projects progressively being implemented. Lastly, the list of the projects identified may not be exhaustive, as there could be relevant unidentified projects which may possibly reveal a higher total emission reduction potential of such projects implemented in the country.

Like (Timilsina *et al.*, 2010), considering a carbon price of \$10/ tCO_2e would imply a yearly yield of \$481,576.68 by the projects considered, giving a total of \$4,815,766.8 for a crediting period of ten years (Table 8). Assuming this crediting period started in 2020, this will represent the total revenue from CERs sales in 2030. This could be way more and will rise with time for the above mentioned reasons, providing a considerable source of revenue, which could be used for the expansion of the projects and the quick deployment of more of such projects across the country. This is also a factor that could make the sector more attractive for private investors.

As presented in Table 8, the total annual energy savings by the EE projects considered is 68709.424 MWh, which can serve to satisfy other consumers. In addition to reducing emissions, such energy savings could contribute to the avoidance of extra capacity installation, enable quick access to electricity, reduce electricity imports and increase the country's energy security.

All the selected projects were proven to be additional; an essential and indispensable criterion for a project activity to be registered to the CDM; since it ensures that the credits (CERs) would not be awarded for emissions that would have occurred with or without the project activity.

Some of the main reasons of the slow development of RE and EE projects in the country, and the non-registration of implemented projects to the CDM were also identified. There exist national regulations, incentives and legislative energy frameworks Table 2 in Burkina Faso that encourage the development of such projects in the country, however, the socio-political and security context of the country could hinder their implementation. Additionally, the lack of finance for such projects is the major constraint to their development. Added to the high transaction cost involved in the registration of projects to the CDM, the lack of awareness regarding the CDM generally; its benefits and the registration procedure are factors that hinder project registration to the CDM. The lengthy administrative procedures at the level of the DNA that could be a result of inadequate expertise is also one of these disfavouring factors. Apart from Burkina Faso, RE and EE projects were identified in Kenya, Senegal, Ghana, Benin, Algeria, DRC and Zambia, which are not registered to the CDM, and there are many other such cases across the continent.

5 Conclusion and Recommendations

5.1 Conclusion

RE and EE projects actually contribute to the reduction of GHG emissions in Burkina Faso and in Africa in general. Those implemented in Burkina Faso and considered in this study account for an annual decrease in carbon emissions of about 48,157.668 tCO_2e, which represents a 63.12% decrease from the baseline emissions. This is a great CDM potential, as they could generate about 48,157.668 CERs yearly, and 481,576.68 CERs for a crediting period of 10 years fixed for each project. With a carbon price of $10, these CERs will provide a total revenue of $4,815,766.8 in 10 years; thereby increasing the sector's attractiveness to more investments. Moreover, 48,157.668tCO_2e is less than the emission reduction potential in reality on site, since the list of inventoried projects is not exhaustive.

All the projects considered are not registered to the CDM, the main reasons being the lack of awareness regarding the CDM generally; its benefits and project registration procedure. The high transaction cost involved in the registration process of projects to the CDM, and the slowness of the administrative bureaucracy at the level of the Designated National Authority (DNA), which could result from inadequate expertise are also disfavouring factors.

The RE and EE projects implemented in Burkina Faso represent a huge potential for the CDM, ready to be harnessed. Like Burkina Faso, many other African countries are hosts to similar projects. Policies promoting the registration of these projects to the CDM are essential for individual countries and the region in general to benefit from the sustainable development this mechanism provides. This will also escalate Africa's representation which is currently poor in the CDM, despite its endowment with enormous CDM potential.

5.2 Recommendations

In Burkina Faso, some of the main barriers to the registration of projects to the CDM are lack of awareness and expertise, lengthy and complex registration process and high transaction cost involved; given that most of the projects are small scale projects. In order to tackle these constraints, firstly, project developers or governments could use the option of Programs of Activities (PoA) proposed by the CDM. The PoA is favourable for less developed countries as it simplifies the registration process, saves time, extends the access to the CDM to small projects which could not be viable as a regular project. It also reduces the transaction cost, the investment risks and uncertainties of participants; Component Program of Activities (CPA) (Burian & Christof, 2014; UNFCCC, 2019a). Secondly, Burkina Faso already has a DNA, however, there is still need for capacity building and awareness enhancement about the CDM to the different stakeholders, especially the local ones; as this will enable the country attract more CDM projects, with the capacity to develop and manage them. The implementation of Programs like the CDM Assist program is a way forward to achieve this goal. Thirdly, like China, the government can go further to establish a CDM management centre to work in collaboration with the DNA, and that will amongst others have the following responsibilities:

- Assist project owners to register their project to the CDM.
- Organise experts to review CDM projects and offer evaluation opinions.
- Offer CDM project development and management information.
- Monitor and supervise the implementation of CDM projects.

Furthermore, it was noticed that the reporting of low carbon projects in the country is done by different entities, which provided similar information and at times with some divergences due to failure to update data by some parties. The CDM centre if established could also be responsible to consolidate all the data regarding these projects, as well as ensuring their timely update, and facilitating access to reliable and accountable data for different stakeholders. Moreover, potential CDM opportunities may not be harnessed in some cases due to lack of awareness of their existence by potential investors; therefore, the government, through this centre could publicly make available country CDM statistics (online for example) regarding successful CDM projects hosted by the country and the CERs generated, the country's CDM potential and opportunities, in order to promote the sector, attract private investors and boost the implementation of such projects in the country. This is also applicable across the continent. Lastly, the implemented EE projects considered in this study appear to have a more attractive CDM potential than the RE projects, they could therefore be prioritised when registering these low carbon projects to the CDM.

5.3 Future Research

This study could be duplicated in other African countries, as it has been proven that Burkina Faso is not the only country in the region with such unharnessed CDM potential. Additionally, all the RE projects considered fall under the solar PV technology, other studies could look at biomass which represents a huge carbon sink and whose sustainable exploitation is encouraged by the implementation of efficient cook stoves projects across Africa. Projects under CDM sectoral scopes other than RE and EE could also be considered in future studies to optimise the quantification and exploitation of these countries' CDM potential.

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