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A feasibility study of a residential photovoltaic system in Cameroon

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ABSTRACT

This paper presents a feasibility study of stand-alone solar photovoltaic (PV) systems for the electrification of three residential case study buildings (T4, T5 and T6) in the capital city of Yaoundé, Cameroon. The system was sized taking into account the load of the buildings and the available energy from the sun. The power, area of PV modules and daily energy generated by the PV for T4, T5 and T6 were respectively determined as: 2103 W, 14 m^2 and 9.8 kW h/day; 3779 W, 25.2 m^2 and 17.6 kW h/day; and 2766 W, 18.4 m^2 and 12.9 kW h/day. The battery bank capacity, size of inverter and controller were respectively obtained as: 40,323 W h, 635 W and 93 A for T4; 72,433 W h, 795 W and 156 A for T5; and 53,017 W h, 826 W and 114 A for T6. The life cycle cost and annualized life cycle cost (ALCC) of the systems were respectively found to be: €15,714 and €1039 for T4; €27,227and €1800 for T5; and €20,006 and €1322 for T6. The average unit electricity cost for T4, T5 and T6 was respectively determined to be €0.52 kW h^{-1}, €0.50 kW h^{-1} and €0.51 kW h^{-1}, higher than the unit cost of residential grid electricity in Cameroon.

Background

Greenhouse gas (GHG)[1] emissions emanating from anthropogenic and natural activities since the onset of the industrial age have led to their increased concentration in the atmosphere. The absorption of radiations by these gases alters the amount of solar radiation reaching the earth and the amount of infrared radiation that goes into space. The result is the disruption of the earth-atmosphere energy balance leading to cooling or warming of the climate depending on the radiating forcing being negative or positive [20]. The change in the global climatic parameters have in recent times raised serious global concerns and is currently one of the most worrisome problem faced by the contemporary world. Energy security is yet another issue of global concern precipitated by the unprecedented depletion of oil wells and a concomitant increase in the demand of energy to drive national economies [17]. The built environment is recognised for its high energy use. As reported by the IPCC [29], the global building sector accounted for about 32% of final energy use and over 8.8 $GtCO_2$ emissions in 2010, with energy demand from this sector projected to double by mid-century. The consumption of energy by this sector is not without environmental impacts [51] and implications on security of energy supply [7]. The impacts of conventional or fossil energy sources coupled with recent reduction in cost has led to an increase in the demand of PV-systems in most countries. It is now common to find that small scale PV-systems installed on rooftop for the onsite generation and use of electricity in buildings is cost competitive compared to electricity generated from conventional power plants [50]. This is the case for countries like: Germany and India which proved to be the best of 16 countries for the investment of a 1 kW PV-system; and Italy and the United States which are the best countries for the investment of a 5 kW PV-system out of 16 countries. In some parts of Africa like Kenya, the high connection cost to the grid, unreliability of grid supply and corruption has resulted in many financially viable individuals to shun the national grid and resort to the use of solar home systems to meet their electricity needs [45]. It is anticipated that once 100% electrification rate is achieved in the Kendu Bay of Kenya, only 26% of residents will have their energy needs met by the national grid alone while 38% will be electrified through PV-based communal grids, 36% through PV home systems and communal grids. However, while PV-system costs have witnessed a decrease globally, the prevailing PV-system cost in Sub Sahara Africa is much higher when compared to the world average and this could be attributed to the political, financial and

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[1] All other abbreviations have been included in Appendix III.

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technological risks [11]. Despite this, in developing countries, PV-systems provide a solution to electricity especially in areas with lack of access to the grid [66]. In Tunisia for instance, hybrid renewable energy system applications that entails solar and wind is considered a viable option for meeting high electricity demands [33].

In Cameroon, the residential sector is the second highest electrical energy consumer after the industrial sector, accounting for 30% of total energy consumed [19]. The building sector constitutes an important developmental sector in Cameroon through its role in the provision of shelter and contribution to economic growth [64]. This sector has grown tremendously, boosted by the housing boom and public construction sites observed in recent times. Based on the International Futures statistics (http://www.ifs.du.edu/ifs/frm_CountryProfile.aspx?Country=CM), the population of Cameroon is projected to increase from 23.22 million in 2015 to 32.96 million in 2030. Hence, to cater for this expected population increase, the expansion or growth of the housing sector is imperative. The expected increase in housing will put pressure on the country's energy infrastructure which currently, is inadequate in meeting the nation's electricity demand. This is further exacerbated by the low rates of electrification and access to the electricity grid [9]. Improvement in energy efficiency and the employment of renewable energy technologies in buildings play an important role in reducing energy demand and GHG intensity [23]. Other than the role of renewable energy in climate change mitigation, they are important in meeting the basic energy needs (heating and lighting among others) of communities thereby contributing to the alleviation of energy poverty which in turn reduces economic poverty [31]. Energy poverty refers to the "absence in sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development" [48].

Energy use in buildings constitutes a large part of energy demand at the global and regional levels [59] contributing a major share to global environmental concerns [60]. Environmental pressures related to the quality and quantity of energy consumed in buildings includes energy insecurity, indoor and outdoor air pollution and related health risks and damages. The consumption of energy in buildings has consequences that impede the attainment of sustainable development goals [59]. Such consequences include among others deaths attributed to the use of traditional energy sources like fuel wood for indoor cooking, lack of access to modern energy services for all, and inadequate energy resources to fuel economic growth. The efficient use of energy in buildings is yet another issue of global concern. Low-income households often have high energy cost as result of poor structural conditions and energy inefficiency in their dwellings [26]. Energy inefficiency in buildings results in excessive consumption of energy therein putting pressure on the grid electricity supply which is often generated from conventional fuel associated with GHG emission that drives global climate change. The deployment and integration of renewable energy technologies into buildings and the existing energy infrastructure have potentials to lessen climate change through the reduction in GHG emissions. So far, efforts to assess renewable energy potential in Cameroon have largely been descriptive [1,2,62]. Based on the literature review, very few studies have examined the feasibility of renewable technologies in Cameroon. Nfah et al. [41] investigated the technical feasibility of solar/diesel/battery hybrid power systems for the electrification of rural households in the Far-North region of Cameroon. Nfah [38] conducted an economic analysis of photovoltaic hybrid systems for remote villages in Far-North of Cameroon. Nfah and Ngundam [40] investigated the technical feasibility of wind/diesel/battery hybrid power systems for Far-North Cameroon. Mbaka et al. [35] conducted an economic assessment of different types of PV-systems by comparing the net present value (NPV) between photovoltaic hybrid systems (PVHS), standalone photovoltaic (PV) and standalone diesel generator options. While these studies have been detailed on an either technical or economic feasibility, there are limited in scope and failed to take into account simultaneously the technical, environmental as well as economic dimension. Furthermore, the studies often assess only the PV-array without including significant components such as battery, charge controller and inverters. In Nfah and Ngundam [40], the effect of battery systems has not been investigated as well as the unit cost of energy produced by the wind/diesel system [40]. In Nfah et al. [41], an economic analysis of power supply options involving grid extension, a conventional diesel generator plant, and solar/diesel/battery hybrid power system was not considered for the feasibility study in the Far-North of Cameroon.

The aim of this study is to conduct the technical, environmental and economic feasibilities of residential buildings in Cameroon. The inclusion of the technical, environmental and economic dimensions in this study is novel, given most studies have often considered one or at most two dimensions as discussed in the preceding paragraph. Another novelty is the consideration of four PV-system components: PV-module, battery, charge controller and inverter in the assessment. Most studies usually consider only the PV-module because of its large size and the fact that it is the component directly in contact with the external environment. Three dwellings, representing typical homes in Cameroon will be employed as cases for the assessment.

Energy use in Cameroon

The energy production in the country in 2010 was estimated at 8521 kilotonne of oil equivalent (ktoe) of which biomass, oil and electricity contributed 53%, 42.7% and 4.3% respectively [55]. In 2012, electricity contributed only 7% to the country's energy demand [28]. Cameroon's final energy consumption per capita in 2010 was 0.12 toe [58], below the African and world average of 0.49 and 1.26 respectively. The supply of electricity, which plays an unequivocal role in the growth of any modern economy by virtue of its diverse end uses is inadequate in the country, exacerbated by the frequent power cuts mostly experienced during the months of January to June [39]. During the period of drought, the output power generated by back-up thermal plants is usually insufficient to meet demand and the rationing of electricity does not guarantee the day-to-day operation of industries especially those connected to networks of low voltage. Regarding electricity access in the country, about 3,000 out of 14,000 localities are electrified amounting to a national electrification rate of 22% while rural electrification rate stands at 3.5% [9]. This low access to electricity especially in the rural areas of the country where the situation is acute implies that the population in these areas rely on traditional energy sources and appliances like fuel wood and kerosene lamp respectively to meet their basic energy needs. The use of fuel wood does not only results to indoor air pollution that causes respiratory diseases but its extraction culminates in the degradation of the nation's forest resources [24] which contributes to climate change, with the Northern Region of the country already under the likelihood of experiencing desertification. This prevalence of energy poverty in the country contributes to economic poverty since the lack of access to modern energy actually limits the capacity of the energy poor to embark on income generating activities, making it difficult for them to come out of poverty. According to the Government of Cameroon's Growth and Development Strategy Paper [25], this structural weakness that rocks the energy sector of the country has resulted to the slow economic growth witnessed over time. To this end, the government of Cameroon is committed to tripling the electricity production