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THE POTENTIAL FOR ROOFTOP SOLAR PHOTOVOLTAICS TO MEET FUTURE ELECTRICITY DEMAND IN KHARTOUM, SUDAN

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ABSTRACT

Many sub-Saharan African cities, such as Khartoum - the capital of Sudan, suffer from frequent power outage due to insufficient power capacity. However, the electricity demand in that city is expected to increase by more than 30% from 2020 to 2030. This paper investigates the potential for widescale grid connected residential rooftop solar PV to meet electricity demand increase in Khartoum by 2030. Three different rooftop solar PV sizes were investigated, to represent low, medium, and high energy consumption households. These were 2kW, 4kW and 9kW. The energy software HOMER was used to find the annual energy generation from each system and the Cost Of Electricity (COE). With a 4kW rooftop PV system it was estimated that 420,500 houses would be needed to meet the full electricity demand increase by 2030. If using the 9kW system, then only 187,00 homes would be needed. However, if using a 2kW system then over 841,000 homes would be required. This is a significant challenge for the city. Therefore, to complement rooftop solar PV and to ease the burden on households unable to afford it, the government is recommended to install utility scale solar PV. The government is also recommended to incentivise households to install rooftop solar PV through energy policies such as feed-in tariff or net metering. The financial analysis shows the 4 kW PV system has the lowest COE value of $0.048 per kWh.

The COE values were higher than the subsidized grid electricity tariff but lower than the unsubsidized tariff.

KEYWORDS: Rooftop photovoltaics, Khartoum, Sudan, Solar Energy, HOMER, Sustainable Development Word Count: xxxx (excluding title, author names and affiliations, keywords, abbreviations, acknowledgments, and references).

1.0 INTRODUCTION

Energy poverty remains a major issue in sub–Saharan Africa countries including Sudan. This issue is not just restricted to rural areas, but also in many urban cities. Khartoum, the capital city of Sudan, consumes almost 70% of the electricity in the country (D. Ahmed, 2016), but only has 15% of the total population (United Nations, 2019). The city's increasing electricity demand has outpaced electricity capacity, leading to frequent blackouts (Dabanga, 2021; Reuters, 2021; The World Bank, 2019). Therefore, the city will need to urgently grow its electricity capacity to meet further demand from increasing urbanization and population growth (United Nations, 2019). By 2030, electricity demand in Khartoum is expected to reach 10 TWh from 7 TWh today (Ontario Tech University, 2020).

The main electricity source in Sudan is hydropower (Sudan Ministry of Energy and Mining, 2020). Although this power source has low carbon emissions, it is susceptible to drought which can drastically reduce its output (Falchetta et al., 2019). Also, placing more hydropower dams in the river Nile is controversial as it can destabilize local populations as well as affect water flow to Egypt (I. A. I. Ahmed, 2019). The rest of the electricity in the country is either imported or generated using fossil fuels. However, importing electricity and purchase of fossil fuels costs the government millions of dollars each year (D. Ahmed, 2016; The World Bank, 2019).

A power source that is currently inadequately utilized in Sudan is Solar Photovoltaics (PV). Less than 1 % of electricity in Sudan comes from this source (Sudan Ministry of Energy and Mining, 2020). Solar energy's zero carbon emissions during operation coupled with the country's high solar radiation potential (Prăvălie et al., 2019) make it a promising sustainable solution to the country's energy poverty. An added benefit is that the cost of solar PV has been decreasing over the years and is predicted to continue doing so in future, this will make it more affordable over time to countries in sub-Saharan Africa (Baurzhan & Jenkins, 2016; Kavlak et al., 2018). Some studies have looked at the potential of solar PV in Sudan (Abdeen et al., 2019; el Zein, 2017; Elzubeir, 2016a; Fadlallah & Benhadji Serradj, 2020; Omer, 2007a, 2012; Saeed et al., 2019) and with some focusing on Khartoum (Alrawi & Al-Ghamdi, 2020; Elhassan, 2012; Ismail & Hashim, 2018a). However, no studies were found looking at widescale distribution of rooftop solar PV in Khartoum. This paper attempts to fill this gap in literature.

The aim of this paper is to investigate the potential of widescale grid connected rooftop solar PV in Khartoum and its ability to supply future electricity demand. The intention is that the findings can be used to assess other sub-Saharan African cities, which typically also have high solar irradiation levels but insufficient electricity capacity. The focus is on the residential sector, as over 50% of the electricity consumed in the country is attributed to this sector (Rabah et al., 2016; Sudan Ministry of Energy and Mining, 2020). Theoretical calculations were used to size three rooftop solar PV systems based on low, medium, and high energy consumption households. The three rooftop solar PV sizes investigated are 2 kW, 4 kW and 9kW. The HOMER energy software was used to estimate the annual energy production and the levelized Cost Of Electricity (COE) for each system. The total number of each system required to meet the full electricity demand increase to 2030 was then found.

2.0 Khartoum and Solar PV

2.1 City Background

The climate of Khartoum is classified as hot desert (Koppen-Geiger classification). Its daily solar irradiation (GHI) is approximately 6 KWh/m^2 (SolarGIS, 2019), with daily hours of sunshine typically exceeding 9 hrs (Weather-Atlas.com, 2020), Figure 1. The solar Photovoltaic power potential in Khartoum is around 5 kWh/kWp (SolarGIS, 2019)), this means for every 1 kW of solar panel around 5 kWh in energy is generated per day on average. These numbers are comparatively high when compared to other regions (Prăvălie et al., 2019) and encourage solar PV use in Khartoum.

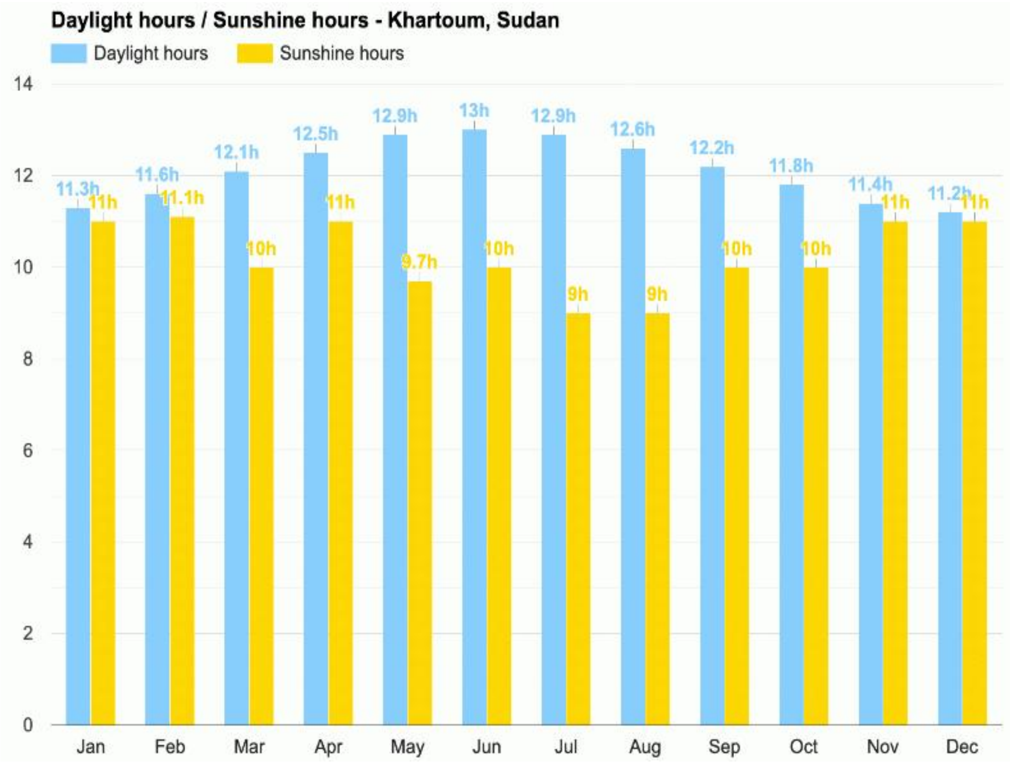

Figure 1: Annual Sunshine Hours, Khartoum, Sudan (Weather-Atlas.Com, 2020).

Khartoum residential areas are a favourable target for solar PV integration as the houses have relatively high plot areas of > 150 m^2 (Mohammed & Takaguchi, 2018), which allows rooftop space for solar panels. Also, most of the homes are of similar height to each other (UN Habitat, 2009). Such residential areas are better suited to rooftop PV as it results in less overshadowing of the solar panels from adjacent buildings. This means higher electricity yield compared to the denser commercial city centres (Kanters & Wall, 2018; Lau et al., 2017; Sarralde et al., 2015).

The number of households connected to grid electricity in Khartoum is estimated to be around 800,000 (The World Bank, 2019). A more up to date number for the housing stock was not found, however, this is taken as a 'least case' estimate as the rising population in Khartoum means the housing stock is likely much higher. It is acknowledged some homes may have low strength roofs that might be structurally unsafe for solar panels. However, these are expected to be the minority.

2.2 Electricity Usage

Sudan's electricity tariff is considered the lowest in sub-Saharan Africa (The World Bank, 2019), at ~$0.02 per KWh, even after the recent rise in electricity tariff (Dabanga, 2021).

This low rate may discourage people from spending money on another power source such as rooftop solar PV due to the high payback periods (Alrawi & Al-Ghamdi, 2020; Ismail & Hashim, 2018) . This low rate has also encouraged relatively high electricity consumption. It's estimated the average Sudanese households consume as much electricity as the average German household (The World Bank, 2019) (Figure 2). This high consumption puts pressure on the grid and can lead to blackouts due to insufficient electricity capacity to meet the demand. The average consumption for a household in Sudan was found to range from 177 kWh per month to 368 kWh per month (The World Bank, 2019).

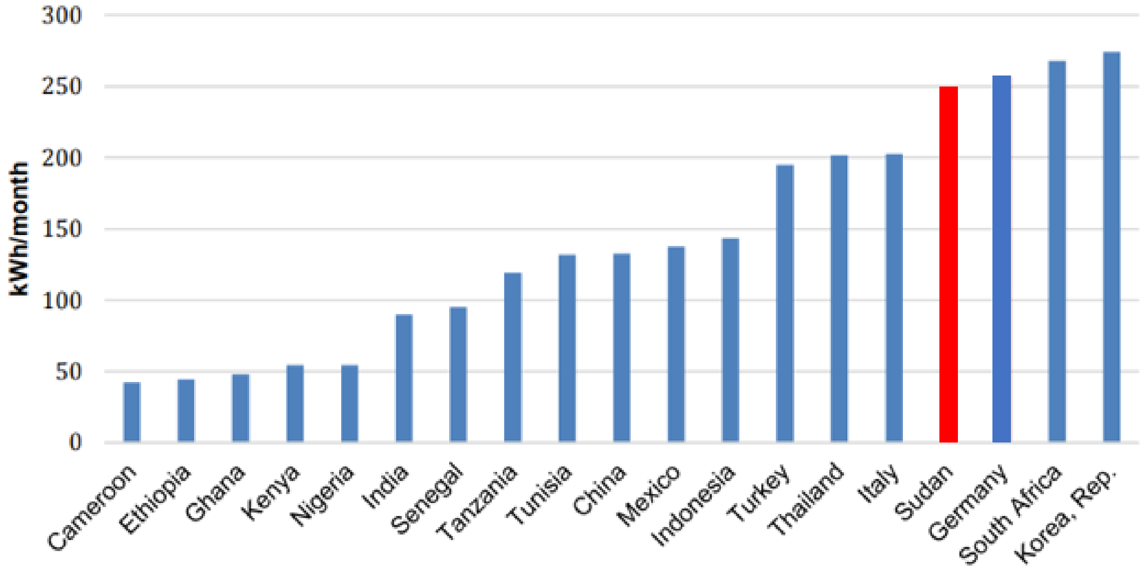

Figure 2: International Comparison Of Sudan's Residential Electricity Sector (The World Bank, 2019).

Regular power outages may sway people with higher incomes to invest in a back-up power source. Traditionally, in Sudan, this back up source has been diesel generators (el Zein, 2017; Elzubeir, 2016; Omer, 2007). However, these have been criticized for their high pollution, large fuel consumption (which is heavily subsided by the government) and susceptibility to fuel shortages (Reuters, 2020).

Solar PV are a sustainable alternative energy that aligns with the UN Sustainability Development Goals, SDG 7, and SDG 11. Khartoum can utilize solar energy through rooftop PV or large-scale solar PV farms (utility scale) to generate electricity (Figure 3). A benefit of utility scale solar farms is it can cost almost half that of rooftop PV per KWh generated (Tsuchida et al., 2015). This is mainly due to the economies of scale achieved with vast solar panel installations in one place, as is the case with solar farms, whereas rooftop PV has additional costs related to installation, transport, and maintenance (Gernaat et al., 2020).

(A) (B)

Figure 3: Examples Of (A) A Solar Pv Farm (Utility Scale), And, (B) Rooftop Pv (Residential Pv) (Equator Energy, 2021).

However, the high investment cost for solar PV is a barrier in Sudan and Khartoum (el Zein, 2017; Elzubeir, 2016). A benefit of rooftop solar PV from a government perspective is that the cost of the system is mainly met by the homeowner. This is advantagoues to Sudan since the government has low funds for investment in alternative energy sources (The World Bank, 2019). Although, the government can ease the financial burden upon the rooftop PV owner through energy incentives, such as feed-in tariffs or net-metering. These tariffs allow for energy exported to the grid from the solar PV systems to be refunded in cash to the homeowner or deducted from the utility bill. One study estimated the payback period for rooftop solar PV system in Khartoum can be reduced from 18 years to 9 years by using feed-in tariffs (Ismail & Hashim, 2018a). Unfortunately, Sudan is yet to fully implement such a policy (UNDP, 2020). Many international case studies prove the effectiveness of feed-in tariffs and net-metering in encouraging the wide-scale adoption of grid-connected rooftop PV (Biswas et al., 2014; Hoegh-Guldberg et al., 2018; Moosavian et al., 2013), particularly in regions with low uptake (Du & Takeuchi, 2020).

Overall, there are various strengths and opportunities for rooftop solar PV in Khartoum according to the literature. These are summarized on Table 1 based on the SWOT framework looking at the Strengths, Opportunities, Weakness and Threats present in Khartoum and

Sudan. These factors are categorized using the PESTLE (Political, Economic, Social, Technical, Legal and Environmental) framework.,

Table 1: Swot Analysis And Macro Economic Factors Relating To The Potential Of Rooftop Solar Pv In Khartoum.

Pestle / Swot	Strengths	Weaknesses	Opportunities	Threats
P – Political / L - Legal	There is interest from the government in supporting rooftop PV implementation, as seen from past laws, Nationally Determined Contributions (Hassan, 2021) and the Government's strategy report (Sudan Ministry of Energy and Mining, 2020).	The government budget for investment is low, because a large portion of the budget is spent on electricity subsidy and purchase of fuel for thermal power plants (The World Bank, 2019).	Opportunity to apply incentive schemes and policies (such as feed in tariffs) to reduce rooftop solar PV costs for users and increase uptake.	Internal political instability may delay implementation of investment and energy policies for rooftop PV.
E – Economic / S - Social	There is a strong social desire to have more energy independence due to the large number of power blackouts from the grid (Reuters, 2021). There is also a large labour force available to recruit as solar PV technicians due to the current high unemployment rate (CEIC, 2022).	The cost of the rooftop PV system is expected to be too high for the average Khartoum household. There is also likely a lack of awareness of the benefits of solar PV among citizens (Elzubeir, 2016).	Widescale rooftop PV installations can engage the private sector, creates jobs, and increase citizen welfare through reliable electricity connections.	Inflation and low economic output in future may further reduce the governments and citizen's ability to invest in rooftop PV (Statista, 2021). The low cost of grid electricity may discourage from uptake rooftop solar PV (The World Bank, 2019)
T – Technical / E – Environmental	Khartoum has high solar irradiation and long sunshine hours all year round meaning high power output from solar panels (Figure 1).	There is a large reliance on diesel generators for extra power (Renewable Energy Agency, 2016). This creates pollution and greenhouse gases.	Use of rooftop solar PV can lead to reduction of CO_2 emissions, air pollution, meet the governments climate mitigation targets and UN Sustainability Development Goals.	Extensive capital maybe needed to upgrade the utility grid to suite rooftop PV.

3.0 METHODOLOGY

3.1 Rooftop Solar PV Sizing

To size the rooftop solar PV energy system Equation 1 was used (Šúri et al., 2005). Three different household energy loads were considered: low electricity consumption, medium electricity consumption and high electricity consumption. These values were assigned as the 'E_{out}' in Equation 1. The energy loads were obtained from a study conducted by the Sudanese Industrial Association called '*Kahrabtak Eindak'* ('Have Your Own Electricity'*)* (M. E. Ahmed, 2020). The value '*P'* for the solar panel size was then found, a slight oversizing was done to ensure the solar panels covered the electrical load comfortably. The solar PV systems sized were 2 kW, 4 kW and 9 kW.

Equation 1 estimating size of rooftop solar pv system (šúri et al., 2005)

$$P = \frac{E_{out}}{365.r.H}$$

E_{out} = Energy Generated (KWh); P = *Solar power installed* (KWp); r = system performance ratio (typically 0.75); H = Daily PV power potential (5 KWh/KWp for Khartoum (SolarGIS, 2019)).

The system performance ratio '*r*' adjusts for losses such as fluctuation in temperature, dust accumulation and other losses. A value of 0.75 is recommended from literature (Šúri et al., 2005). This is separate to the conversion efficiency of the solar panel (already accounted for in *H*). The daily PV power potential (*H*) is an estimate of the amount of power generated from 1 kW of solar panel operating during the peak sunshine hours. The measured value for Khartoum is 5 kWh/kWp (*H*). This value is calculated from satellite data and PV modelling software. It takes into account solar radiation, air temperature, losses from the PV module and other components (e.g., cables, inverters etc) (SolarGIS, 2022).

The roof area occupied by the solar panels was estimated based on commercial panels occupying ~1 m^2 per 180 W of power (I.T.S Technologies, 2020). The most common area for a typical Khartoum residential roof was estimated to be 96 m^2 (Mohammed & Takaguchi, 2018). Roof obstructions, such as water tanks, satellite dishes, air conditioning units and their shadows are expected to reduce the roof area by ~40% combined (Khan et al., 2017). However, even with this considered, the average roof area available is still >50 m^2 and sufficient even for a 9 KW PV system (Table 2).

Table 1 Household energy consumption (M. E. Ahmed, 2020) and Suggested solar PV system size (using Equation 1).

Household User Group	Estimated Minimum Daily Consumption (kWh) by Household	Suggested Solar PV Size	Roof Area Occupied (m^2)
High Electricity Consumption	30	Large – 9 KW	50
Medium Electricity Consumption	12	Medium – 4 KW	25
Low Electricity Consumption	6	Small – 2 KW	11

3.2 Annual Energy Generation

Following the use of Equation 1 to estimate the solar PV size, the software HOMER (Hybrid Optimization Model for Multiple Energy Resources) was used to estimate the annual expected electricity output from the solar PV system. HOMER was also used to find the Cost Of Electricity (COE) of the systems in terms of $/kWh. The benefits of using HOMER compared to manual calculations is that it calculates values based on actual satellite data for the measurement of the GHI (Global Horizontal Irradiance) in Khartoum in the year. The GHI data is taken from NASA satellites and averaged over a 23-year period from Jul 1983 to Jun 2005(HOMER Energy, 2022). The system schematic used for the HOMER analysis is shown in Figure 4.

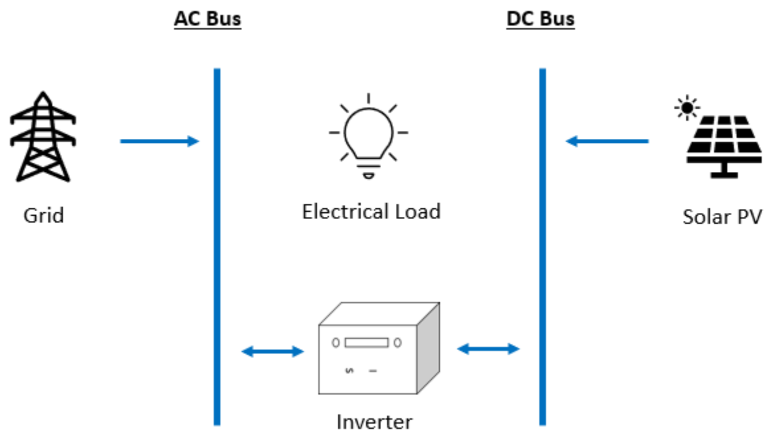

Figure 4: System schematic used in the homer analysis of the rooftop pv systems.

The forecast future electricity demand for Khartoum is 10 TWh by 2030, which is an increase of 3 TWh from 2020 (Ontario Tech University, 2020). The annual electricity output from each of the three systems (2kW, 4kW and 9kW) was then divided by this value to estimate the number of households required to install rooftop solar PV to meet the electricity demand increase by 2030.

3.3 Cost of Electricity (Coe)

The Cost of Electricity (COE) is used to find the cost of producing electricity per kWh. This method is normally used to assess the financial feasibility of an energy source and compare it with others (IRENA, 2020). The HOMER software was used to estimate the COE for the three PV system sizes (2 kW, 4 kW and 9 kW). The COE is summarized in Equation 2 but is described in detail on the HOMER website method (HOMER Energy, 2022).

Equation 1 Summarized Cost Of Electricity Equation (Homer Energy, 2022)

$$COE = \frac{C_{ann,tot}}{E_{served}}$$

The total annualized cost ($C_{ann,tot}$) consists of the initial capital cost of the solar PV system, plus operation and maintenance costs per year. The energy served (E_{served}) is the total amount of energy generated by the solar PV system and sent to serve primary and deferable (grid exported) loads during the year. The $C_{ann,tot}$ consists of other parameters are which are required to calculate it accurately, these are listed in Table 3.

Table 3: Cost of Electricity Parameters.

Parameter	Description
Investment cost	This is the estimated cost of the rooftop solar PV system (as given in Appendix 1).
Operation and maintenance costs	A value of $20 per kW is assumed for maintenance (IRENA, 2020).
Discount rate	10% rate is applied.
Annual electricity output	From the solar PV panels. This is calculated using HOMER and NASA satellite data
Economic life	25 years

The costs associated with the solar panels are summarized in Table 4. These were taken from a local solar PV contractor based in Khartoum. A quote from that contractor is found in Appendix 1.

Table 4: Estimated Cost per kw rooftop pv system in khartoum.

Item	Rate	Reason
Solar Panels	$462 / kW	Based on solar panels monocrystalline PERC type
Inverter	$250 / kW	Based on a standard hybrid convertor
Stand structure and accessories	$140 / kW	Stands, equipment, cabling and electrical connectors
Installation and Transport	$85 / kW	Labour work for installation and transport
Risk / other costs	10% of subtotal	Including risk due to transport issues or inflation.

The overall methodology used in this paper is summarized in Figure 5.

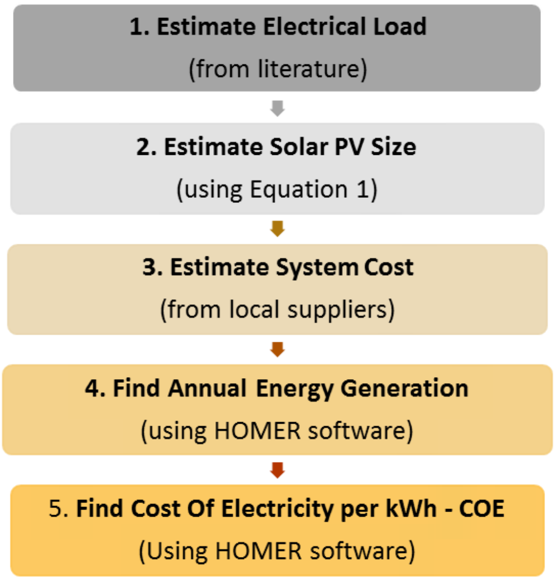

Figure 5: Methodology used to calculate the rooftop pv potential in khartoum state.

4.0 RESULTS AND DISCUSSION

4.1 Meeting Future Energy Demand

Using HOMER software the number of houses fitted with solar PV required to meet the future electricity demand to 2030 was estimated for the different rooftop PV sizes. This was found by dividing the annual expected energy output from each system by the expected energy demand increase. The results show to meet the full energy demand increase by 2030 then 420,500 houses would need to install an average of 4kW rooftop PV each (Figure 6). This reduces to 187,000 homes, if an average of 9kW is installed per home. However, over 841,000 homes are required when using a 2kW solar PV system. The number of grid connected homes in Khartoum is around 800,000 (The World Bank, 2019) so only relying on a 2kW system might be insufficient to meet all the expected electricity increase by 2030. This suggests alternative power sources would be needed in addition to the 2kW system. These can be in the form of utility scale solar PV farms, the use of higher solar PV sizes or alternative power sources.

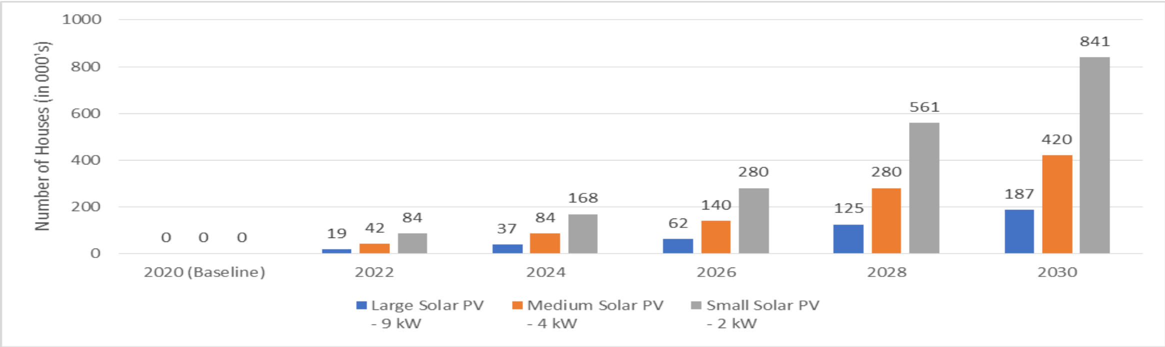

Figure 6: Number of rooftop solar pv systems required to meet electricity demand increase in khartoum.

The literature suggests the cost of the PV system would be a large factor when considering the uptake (Elzubeir, 2016a), so the 2kW system is likely to be the most popular option for most citizens in Khartoum. Ideally, each household should install rooftop PV system size based on their energy needs. To make it more affordable to citizens, the government should focus on introducing financial incentives in the form of energy policies such as net-metering, feed-in tariff or grants. In addition, the government can also install large utility scale solar PV farms to complement any shortages of rooftop solar PV. These are cheaper to install per kWh, as discussed in Section 2.2, and can help provide additional capacity. The estimated solar PV capacity required to meet the 2030 electricity demand increase in Khartoum is shown in Figure 7. This was calculated using Equation 1 and the expected demand by 2030.

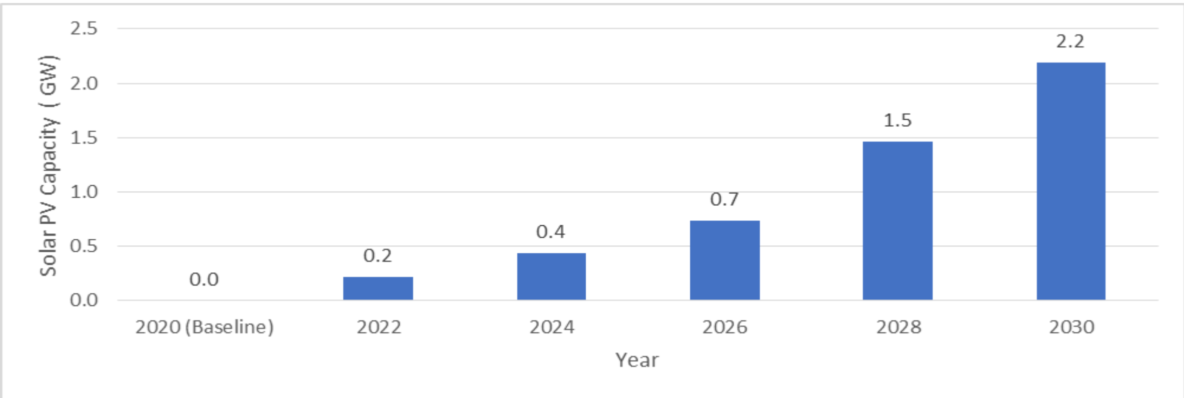

Figure 7: Solar Pv Capacity Required To Meet Increasing Electricity Demand In Khartoum.

Since solar PV generates energy during daytime then it can be used to meet the demand increase then and the night demand increase can be met by other power sources. In Sudan in the summer, around 70% of the electricity demand is from daytime consumption, whereas in the winter around 50% of electricity demand is from daytime consumption (The World Bank, 2019).

The method of estimating rooftop potential using a manual calculations and HOMER software in this paper has limitations. For example, it assumes all homes have access to the same sunlight potential whereas some rooftops might be obstructed by overshadowing from other structures. Other studies from the literature used more advanced methods to estimate rooftop PV potential for cities, such as computer 3D modelling of buildings with Geographic Information Systems (GIS) (Belmahdi & Bouardi, 2020; Huld et al., 2012) and LiDAR (Light Detection And Ranging) surveys of city rooftops using light aircraft (Assouline et al., 2018; Jurasz et al., 2020; Lukač et al., 2020; Madurai Elavarasan et al., 2020; Mangiante et al., 2020). However, these methods are novel and require specialist software and data which was lacking for Khartoum. Future studies are encouraged to build on these findings using such systems.

4.2 Cost of Electricity (COE)

The initial system cost was found based on the local market rates of solar PV contractor's (Appendix 1). Thereafter, the COE was estimated using HOMER energy software and was based on a 25-year lifetime assessment of the solar PV system. The COE and Initial costs for the three different rooftop solar PV systems is shown on Table 5:

Table 5: Comparison of costs and COE values for the three solar pv systems (over 25 years).

System Size	Annual Electricity Generation	Initial Capital Cost	Annual Operating Costs	COE (HOMER software)
2 KW	3568 kWh	$1,943	$77	$0.053/kWh
4 KW	7135 kWh	$3,993	$83	$0.048/kWh
9 KW	16,055 kWh	$7,886	$92	$0.05/kWh

The COE values for the three different rooftop PV systems were found to be much higher than the subsidized rate of electricity in Khartoum, ~0.02 $/ KWh (The World Bank, 2019) . However, the COEs are expected to be lower than the unsubsidized rate of electricity. The subsidised electricity rate is estimated to cover only 10% of the total cost the government pays for electricity generation and distribution (The World Bank, 2019), meaning the unsubsidized rate maybe as high as 0.2 $/ KWh. Overall, the 4 kW rooftop PV system appears to be the best value for money over 25 years due to its lower COE. The annual electricity generation expected from each system (Table 5) comfortably meets the daily demands for low, medium and high consumption household groups (Table 2). Therefore, much excess electricity is expected to be sent to the grid. If the government implements a financial incentive scheme such as feed-in tariff or net metering, then the cost burden is expected to be greatly reduced for the households.

A limitation with this COE method is it does not consider all costs associated with rooftop PV. For example, the cost of upgrading the grid networks to allow solar PV connection is unknown and unaccounted for. Increasing intermittent electricity to the grid could affect grid stability and therefore necessary mitigating measures through network upgrades would be needed. Also, the cost of battery packs is excluded, as it is assumed that electricity at night or during cloud cover would be taken from the grid. Although adding a battery pack can keep homes connected to electricity even during grid power outages, the overall cost of the system could increase by more than 50% (IRENA, 2017). This would make it even harder for households in Khartoum to afford it.

5.0 CONCLUSION AND RECOMMENDATIONS

The city of Khartoum is experiencing increasing electricity demand which sometimes exceeds supply and leads to load shedding and blackouts. This causes distress to citizens and harms businesses. Most of the electricity consumption is from the residential sector. This study investigated the potential of widescale residential rooftop solar PV to meet the city's future electricity demand and therefore reduce power shortages. Overall, the research findings indicate Khartoum has enough residential rooftop space for solar PV to meet all the electricity demand increase by 2030. Khartoum is also boosted by strong solar radiation and long shine hours year-round, as is the case with most sub-Saharan African cities.

Three solar PV sizes were considered for rooftop installations, a 2 KW, 4 KW and 9 KW solar PV system. These were chosen to represent the different energy consumption levels of households in Khartoum from low electricity consumption to high. To meet the full electricity demand increase by 2030 (3 TWH) then 2.2 GW of solar PV would need to be installed. For a 4kW system then 420,500 houses are required. This reduces to 187,000 homes, if an average of 9 KW is installed per home. However, over 841,000 homes will be required if only a 2 kW, solar PV system is used to meet demand to 2030. This might be more than the number of homes available in Khartoum state, as the grid connected homes count is around 800,000.

The solar PV systems can be utilised to only meet the daytime demand with the night-time demand coming from other energy sources, such as hydropower. The daytime demand is estimated to be 70% of the total daily demand during the summer months and approximately 50% of the total demand during the winter months.

The financial analysis shows the 4 kW PV system has the lowest COE value of $0.048 per kWh. Thereafter, the 9 kW had a value of $0.05 per kWh and the 2 kW PV system had a COE of $0.053 per kWh. All three values were much higher than the current subsidized rate of grid electricity of under $0.02 per KWh. However, the actual cost of grid electricity when removing subsidies and taking into account all costs associated with generation and distribution is thought to be 10 times this value.

A limitation of the estimated COE for rooftop PV is it did not consider any upgrade costs needed to the grid network or battery storage. A network study of the local grid infrastructure is recommended to evaluate the impact of large-scale rooftop PV connections to its stability and advise on upgrade costs.

Affordability of the rooftop solar PV systems is expected to be a major obstacle to uptake. The government is therefore encouraged to introduce incentive packages, such as a feed-in tariff or a net-metering policy to help lower costs of rooftop PV to homeowners and boost uptake. Further research is recommended to assess the most suitable energy policy for the city. The government is also recommended to complement rooftop solar PV with a utility scale solar PV farms. The COE for these is expected to lower than rooftop PV due to economies of scale. This can help cover the electricity demand for those homes unable to afford a rooftop solar PV system.

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