Available online at www.ejournals.uofk.edu

UofKEJ Vol. 12 Issue 1 pp. 17- 22 (February 2022)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UofKEJ)

Economic Analysis and Policy-Related Recommendations to Promote Distributed Solar Photovoltaic Systems in Sudan

Abubaker Younis[1], Amro Khalafalla[2], Ismail Elgizouli[3], Ratiba Abdelgadir[1], Ali Omer[1], Mahmoud Onsa[4], Quosay Ahmed[5]*

1 National Energy Research Center, Khartoum, Sudan

2 Independent Energy Policy Analyst, Khartoum, Sudan

3 Independent Energy Planning Consultant, Khartoum, Sudan

4 Department of Mechanical Engineering, University of Khartoum, Sudan

5 Department of Petroleum and Natural Gas Engineering, University of Khartoum, Sudan

Sudan (Email: onsa@uofk.edu; a.younis@imresearch.sd)

Abstract*:* Distributed solar photovoltaic (DSPV) is a practical and reliable solution in the case of Sudan, considering the vast and remote off-grid rural areas and the insufficient electricity generation in the parts powered by the national provider. This research outlines the scientific processes to work out the economic appraisal of an off-grid PV system with and without storage units that could be deployed within Greater Khartoum. The provided financial assessment, which relies on the PV price, the annualized monthly bill savings, the Levelized cost of energy, the simple payback period, and the national and regional kilowatt-hour tariffs, delivers an insight into the cost affordability of solar-generated electric power in Sudan. Accordingly, the analysis concluded that approximately 1.6 $/W$_p$ is the PV price for a system with a battery bank and 1.2 $/W$_p$ for the on-grid option, both to be fixed in the residential sector. However, the designed system here will not pay back the initial cost, considering the low local electricity price. Also, considering the status quo, the investment will not attract investors in the energy sector, although it compensates for the frequent power deficiency in times of need. On the other side, the effort presents local experts and leaders in energy research and planning recommendations to encourage the governmental facilitation of DSPV use as viable renewable energy (RE) technological option. These recommendations hover around the issuance of country-level PV energy policies and are categorized into financial, policy, social, and technical. This work's novelty is its contribution to developing and supporting the Sudanese literature in the energy field, in which the lack of resources and content specific to the republic, especially RE, is evident.

Keywords*:* Photovoltaic Performance; National Energy Policy; Distributed Energy System; Sudan; Payback period; LCOE.

1. INTRODUCTION

Sudan is an attractive case study regarding renewable energies, as the country meets a considerable part of its power need, with an average household electricity consumption of 308 $kWh/month$ in 2014 [1], through renewables, precisely hydropower [1,2]. Likewise, the East African country has excessive solar energy potential, with an average daily global horizontal irradiance reaching 6.8 $kWh/m^2/day$ in some parts [3,4] and a high annual wind energy yield verified by GIS analysis [5]. In 2020 renewables' share in the country's total electricity capacity was 2124 MW$_p$, mainly hydropower and 18 MW$_p$ of solar PV [2].

Khartoum state, or as it is locally called the *Triangular Capital*, is the most densely populated region of Sudan, with over seven million residents [6]. The state with the best infrastructure across the country will have a projected electricity consumption reaching 7.9 TWh in 2025, accounting for 17.7% of the country's total consumption [6]. Due to shortage and hefty intake, the national electric power supplier enforces scheduled blackouts all over the country, emphasizing the summertime, in which around 40% of the demand is subjected to load shedding [1], annually-averaged accounts for 4.3 hours of outages per month [7].

These Planned power-offs force many locals, especially those in the capital, to turn to alternative energy sources, including conventional small-scale diesel generators, the Newly Introduced battery-inverter backup system, and small-Capacity standalone PV systems. Access to electricity is yet another aching issue, with only 55.4% of the population covered by the national grid in 2020 [8]. A principal aim of this study is to provide local engineers and professionals with the financial information, which is publicly absent and only a few studies that include cash flows have been reported [3,9], needed to prepare pro forma costings of an off-grid roof-mounted PV system for a household in Khartoum. It is worth mentioning that the financial analysis here relies on currently operating PV system data obtained through personal communications with expert engineers, which is the only way to gather reliable performance data for now.

Focusing on the energy production component, distributed energy systems (DES) are a viable solution to the domestic energy dilemma. DESs refer to energy generation units (i.e., electricity, cooking, cooling) that are decentralized or not part of a central generation plant. In other words, the generation is next to the demand or the end-user (i.e., residential, commercial) [10–12]. DESs are highly acknowledged for enhancing energy access in developing countries [13], while renewable energy-based DESs are considered innovative solutions that help many countries meet their carbon dioxide goals [14].

Moreover, DESs prominent advantages are the flexibility to combine renewable and conventional technologies in their design and the reduced power losses because of the short transmission lines [15–17]. In this research, we emphasize the distributed solar PV (DSPV) systems, a DES technology, because of the likelihood of their various technologic models (e.g., mini-grids, pico-grids) to alleviate the escalating need for electricity in the cities and help in the electrification of remote rural areas. Besides, if proper energy management is applicable, this technology can become a lasting resolution to the renewed urge to meet the growing demand for electric power in Sudan. The country generally offers excellent weather conditions for designing and employing different size PV systems because the quantity of received solar radiation supports constant energy production over the entire year [18], as illustrated in Fig. ***1*** [19].

1. Electricity generation business as usual scenario for Sudan

The domestic business as usual (BAU) scenario for electricity generation on a utility-scale is a mixture of hydropower and thermal power generations, with the domination of renewable resources [2,20]. In 2020, the installed hydro capacity was 51% (i.e., 2124 MW_p), and the thermal power plants capacity count for 49% (i.e., 2013 MW_p) [2]. In 2016, Sudan consumed 5.1 million tons of oil products, of which 40% was for electricity production. While the demand is expected to grow by 10% annually, the new investments in the power sector will prioritize thermal generation, according to a declared plan of the government [1]. Fig**. 2** shows historical data for Sudan's annual electricity production per source in GWh [1]. At the other end of the electricity supply chain, the end-user also produces his power to make up for the frequent outages or to create his electric energy due to a deficiency in the national grid coverage. In either case, the BAU scenario depends on conventional technologies, mainly diesel generators. Nowadays, the battery backup system is popular among apartment residents within the capital. Fig. **3** pictures a backup system installed inside an ATM service room. The lack of awareness and some technical issues related to appliances' compatibility with DSPV or DES technologies hinder the diffusion of RE among the public as a power source. Through its electricity authority, the government of Sudan introduced solar home systems (SHSs) and distributed around 15,000 locally manufactured units. Fig ***.4*** shows these assembled devices [1]. Also, a local PV encapsulation plant was established in the National Energy Research Center (NERC) in 2003, which commenced the manufacture with a 2 MW_p annual capacity manual line until 2010, in which a second fully automated line was added. Unfortunately, the plant is now working at a minimal capacity due to a scarcity of production inputs.

In general, the local electricity sector faces numerous challenges:

1. Anticipated financial losses due to slow capacity upgrades and increasing grid connections.
2. Policy and planning frameworks are weak.
3. The sector cannot create an attractive environment for private investment.
4. Macroeconomic factors (e.g., domestic inflation, fluctuating exchange rate) create a barricade for foreign investment.

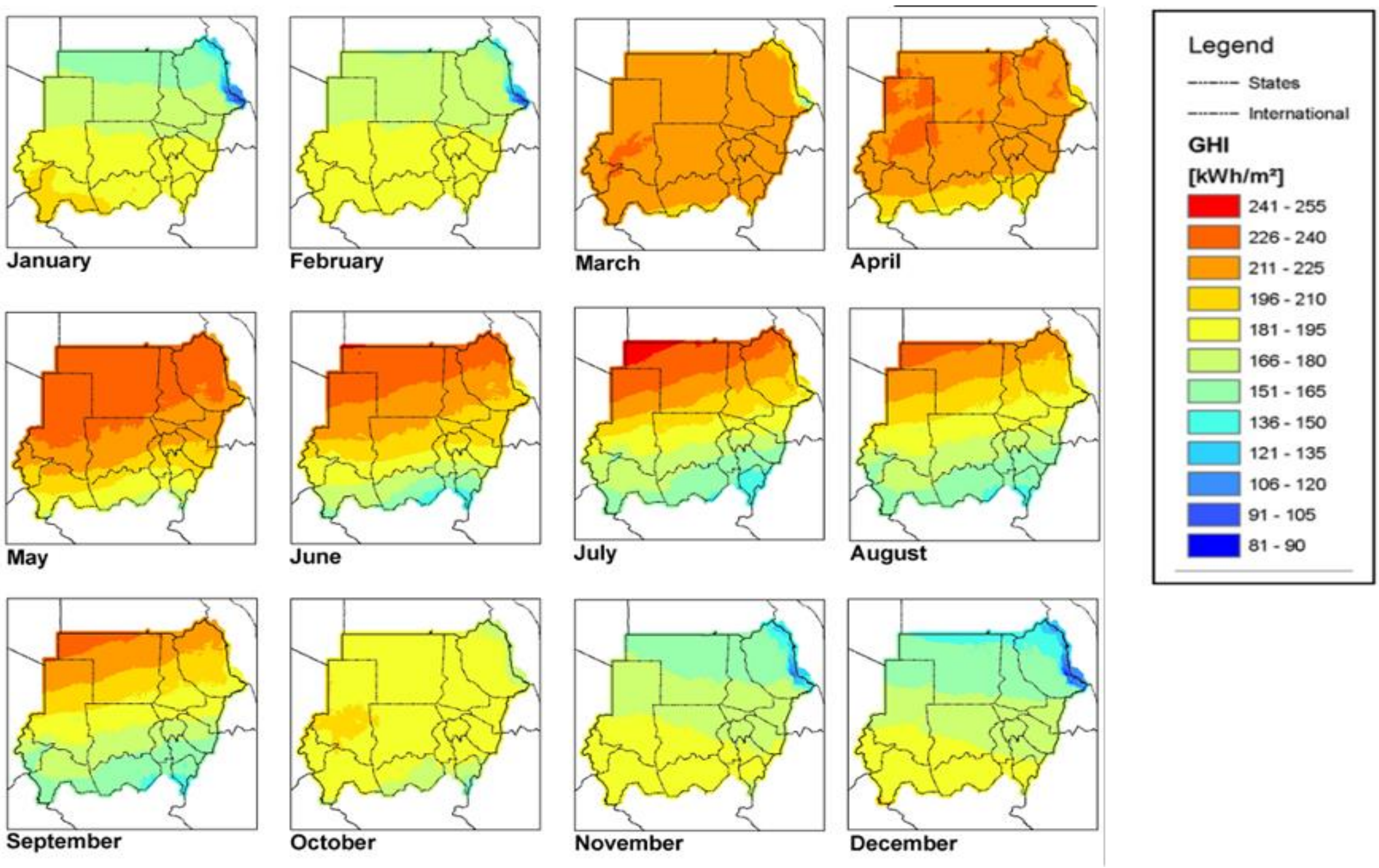


Fig. 1. Monthly-accumulated Global Horizontal Irradiances for Sudan [19]

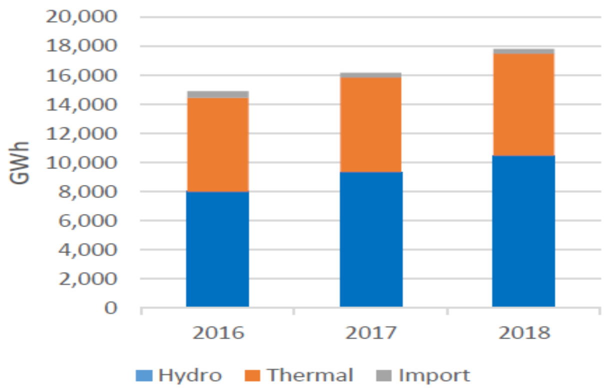


Fig. 2. Sudan's annual electricity generation [1]

Fig. 3. 1kVA Inverter-battery backup system during installation inside Bank of Khartoum ATM service room

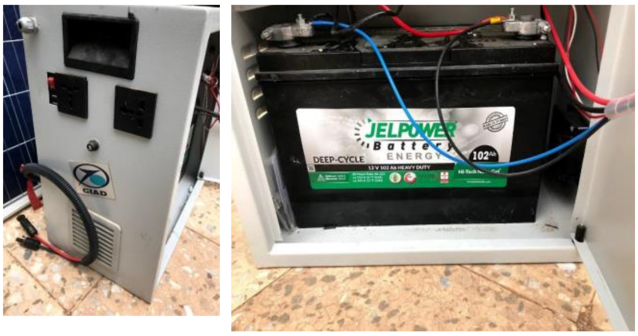


Fig .4. SHS model developed by the Sudan government [1]

1. DSPV overview

The use of PV panels is rapidly growing around the globe. In 2020, the world generated a record of 821 TWh of solar PV power [21]. In 2021, Africa had an 8.7 GW_p installed PV capacity, with only a 5 MW_p large-scale on-grid PV plant in Sudan [22]. The international energy agency (IEA) reported that 70% of the population without electricity access is better served with PV mini-grids (51.5%) and standalone PV systems (17.5%), all are variants of DSPV [23]. DSPV power is the electricity produced by rooftop PV or small-scale PV systems or PV plants that are off-grid or sent to a local network instead of the high-voltage one [24]. This power has become a visible source of electricity in China, Germany, the USA, and Japan [24]. Fig ***.5*** shows the worldwide DSPV capacity growth in GW_p per sector between 2007 and 2024 [25]. In 2018, China raised its installed capacity of DSPV to 50.61 GW_p [26], showcasing this renewable solution's high reliability.

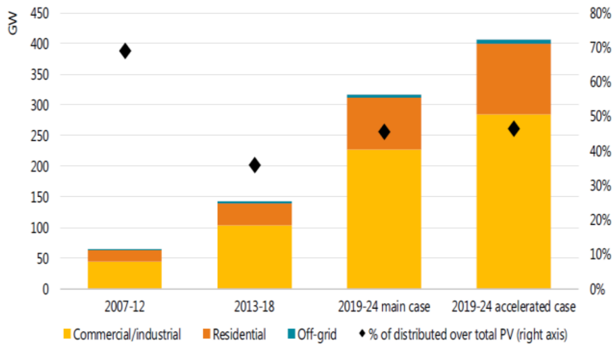


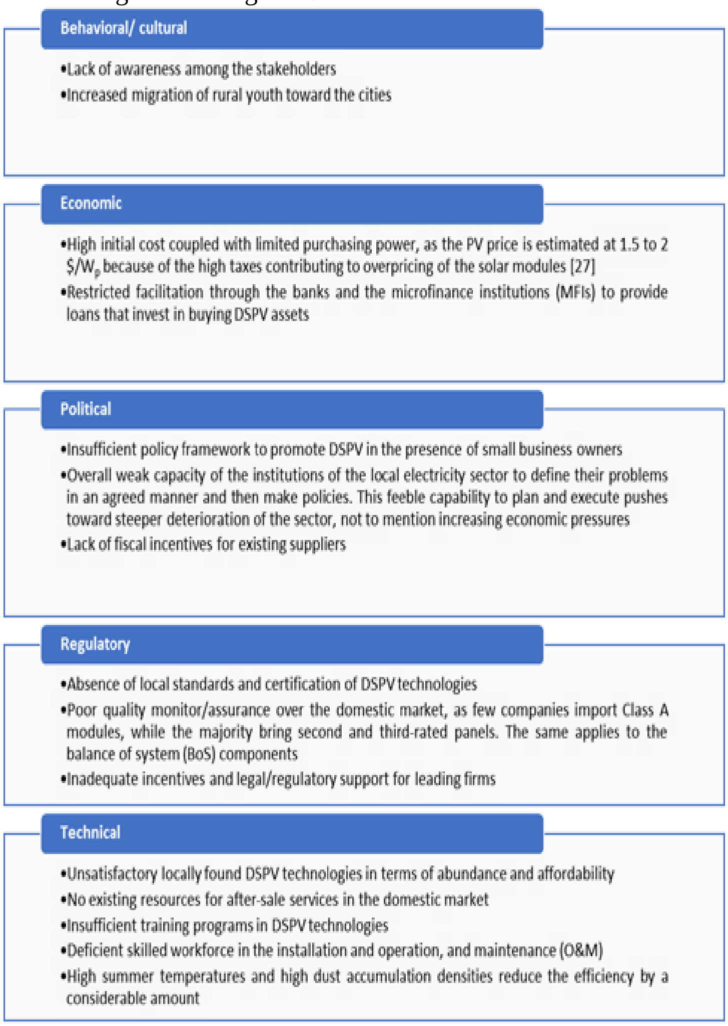
Fig .5. Distributed PV capacity growth by segment, 2007-2024 [25].

1. Barriers to DSPV diffusion

Different barriers delay the diffusion of solar panels as a DES solution. We can summarize them, listing the most common and globally recognized obstacles [12,27]:

A. Awareness and behavioral
B. Company resources
C. Financial and profitability
D. Regulatory, institutional, and policy
E. Technological

In Africa, where more than half of the energy poor reside, the same difficulties are present, while most countries did not either work hard enough to attract investors or commit to the policies that develop renewables as a source of energy [28]. Again, the major intracontinental hurdles are the same poor institutional framework, the high initial cost, and the lack of a skilled workforce [28]. For Sudan, we performed a general barriers analysis that complies with the global trend according to the categories:



2. Sudan plans and policies for DSPV integration

In Sudan's first Intended Nationally Determined Contribution (INDC) document submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, the government outlined its mitigation plans in the energy sector by utilizing more renewable resources by 2030 to eventually make up for 20% of the total energy mix [29]. The projected 2030 share of DSPV in the national electricity generation, as mentioned in the INDC report [29]:

1. 1000 MW_p, on and off-grid, will be applicable across the country.
2. Rural electrification by installing 1.1 million SHSs.

However, basic information like the solar PV cost is officially unavailable/inaccessible, making the task even harder for policymakers to set sensible policies [7]. Moreover, energy policymaking faces complex challenges ranging from incoherent policy processes (i.e., planning, governance, and implementation) to inconsistent policy objectives and a lack of comprehensiveness. All of these lead to weak designs of policy instruments causing setbacks and increased resistance to change. Nevertheless, the government endorsed a 0% policy on BoS components, including the import duty and the VAT, authorized law amendment to allow private companies to invest in the electricity generation sector, and plans to launch Net-metering within 2022 [22].

3. Rooftop PV system technical specifications and cost data

Building houses in residential areas of the capital, Khartoum, particularly the city of Umm Durman, is characterized by large roof surface areas, as shown in Fig .**6**. On the power generation mechanism of this roof-mounted system, the conventional standalone PV scheme comprises PV modules, storage units or batteries, a charge controller, which is embedded in many modern models of inverters, an inverter, and the electric load, as shown in Fig .**7**.

Fig .6. A satellite image of housing topology in El-Thawra district, Umm Durman, captured by Google Earth (15°40'55" 32°28'48", imagery date:01/28/2021).

Usually, most people in the traditional residential districts of Khartoum come from a comparable economic or income level and use similar electric appliances, including the basic ones with few luxuries. The list of most common home appliances used locally is given in **Table 1**.

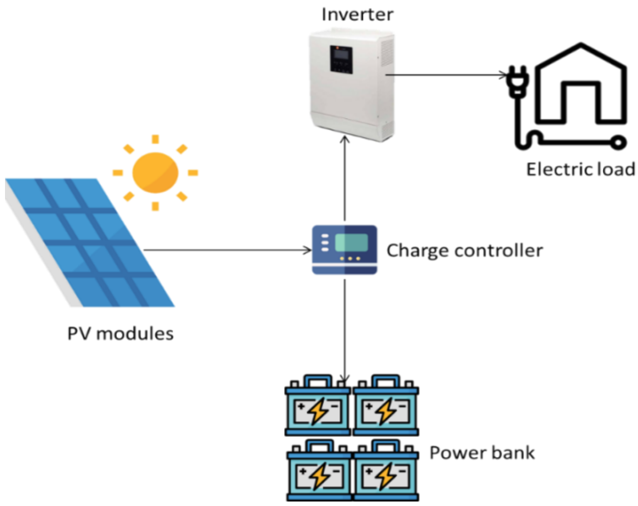


Fig .7. Typical standalone PV system with storage units

Table 1. Typical appliances and their wattages of an average income household in Khartoum

Appliance	Wattage (W)
Domestic water pump	300 [30]
Ceiling fan	65 – 175 [31]
Iron	1000-1800 [31]
Refrigerator	195 [32]
LED light bulb	10 [30]
32 Inch LCD TV	60
Mobile phone charger	7 [30]
Evaporative air cooler	250

Mosab Hamed (personal communication, March 5, 2022) provided the authors with data regarding a 1.82 kW_p roof-mounted off-grid PV system fixed in the *Abo-Adam* district, Khartoum, shown in Fig .**8**; we constructed our financial analysis based on this data, which is listed in **Table 2** and **Table 3**. Likewise, *Abeer Aladdin* (personal communication, March 14, 2022) supplied the authors with data regarding battery storage unit prices, listed in **Table 4**.

Fig .8. 1.82 kW_p off-grid rooftop PV system without power bank during installation in the Abo-Adam district, Khartoum

Table 2. Technical specifications of a reference PV system installed in the Abo-Adam district, Khartoum

Installed Capacity	1.82kW_p
Module Capacity	455W_p
Total load	900 W
PV technology	Monocrystalline silicon
Number of Modules	4
PV system total cost	$2100
Exchange rate (at time of installation)	(1 USD=470 SDG)
Installation Date	19-Feb-2022

Table 3: Reference data for the Abo-Adam system without battery bank

Initial cost (without batteries)	\$2,100.00
Initial cost (with batteries)	\$2,874.00
Annual battery bank cost	\$774.00
Electricity tariff for the first 100kWh in the residential sector	\$0.01[33], \$0.015 [22]
Annualized average electricity rate	\$0.03
PV performance degradation	0.74%/year[34]
Duration of economic analysis	25[35]
Discount rate	16.7%[36]
Battery bank backup duration	≥613 min
Annualized operation and maintenance cost	1%[37,38]
Daily PV power potential in Khartoum	5 kWh/kWp[39]
Average daily global tilted irradiance	5.6 kWh/m2/day[3, 4]
Annualized power potential	3322 kWh

4. PV System Economics

A. Economic metrics

PV systems are installed by many sectors in the market, starting from the commercial and agricultural sectors and ending with the industrial sector and utilities.s Each segment often uses different economic performance criteria to describe the PV value, an approach to looking for revenues from their investment [40]. Among the various financial metrics, we chose PV price, annualized monthly bill savings (MBS), Levelized cost of energy (LCOE), and simple payback period (SPB) as the most applicable criteria for evaluating the finances of PV systems to be installed in the residential sector and thus in Khartoum's houses. **Table 4** lists these criteria and their corresponding mathematical expressions [40]. The results presented in **Table 5** are based on Sudan's electricity rate or tariff for February 2022.

It is challenging to conduct reliable analyses or calculations built on national electricity tariff forecasts due to the volatile domestic economic situation. However, the average electricity tariff for low and middle-income countries was \$0.15/kWh in 2020 [41]. Accordingly, we also exhibit the results of the economic analysis derived from the regional electricity price in Table 6.

Table 4. Economic metrics frequently used for the residential segment [40]

Metric	Equation	Unit
PV price	$\frac{Initial\ cost}{PV\ capacity}$	$\$/kW_p$
Annualized MBS	$MBS = \frac{1}{N \times 12}\sum_{t=1}^{N}\frac{PV\ generation_t \times (Electricity\ tariff_t - LCO}{(1+d)^t}$	$\$/month$
LCOE	$LCOE = \frac{\sum_{t=0}^{N}\frac{Total\ cost_t}{(1+d)^t}}{\sum_{t=0}^{N}\frac{PV\ generation_t}{(1+d)^t}}$	$\$/kWh$
SPB	$SPB = \frac{Initial\ cost}{Annual\ PV\ revenue - Annual\ O\&M\ cost}$	$years$

Where N represents the duration of the economic analysis, t is the year variable, d is the discount rate.

B. Analysis and Results

This study's financial analysis considers two PV system configurations: 1) a PV system with batteries and 2) an On-grid PV system. Similarly, two financing scenarios are considered: 1) Self-funded, which means a 0% discount rate, and 2) Loan-funded, which means a 16.7% discount rate [36]. Finally, we depended on the PV panel lifetime, 25 years [35], as the duration of the economic analysis. Again, **Table 5** and **Table 6** deliver the results obtained, while Fig . **9**, Fig **.10**, Fig **.11**, and Fig **.12** demonstrate the cash flow diagrams for both PV arrangements at different electricity rates.

Table 5. Summary of the analyzed economic criteria based on the national tariff for Feb 2022.

Economic Measure	**On-grid PV system**		**PV system with storage units**	
	Self-funded	Loan-funded	Self-funded	Loan-funded
PV price ($\$/kW_p$)	1154		1580	
LCOE (\$)	0.0303	0.0975	0.2656	0.3325
SPB (years)	25.9	25.9	Will not payback	Will not payback
Annualized MBS (\$/month)	0.9	-3.93[1]	-57.95	-18.45

Table 6. Summary of the analyzed economic criteria based on the tariff for low-income countries

Economic Measure	**On-grid PV system**		**PV system with storage units**	
	Self-funded	Loan-funded	Self-funded	Loan-funded
PV price ($\$/kW_p$)	1154		1580	
LCOE (\$)	0.0303	0.0975	0.2656	0.3325
SPB (years)	4.89	4.89	Will not payback	Will not payback
Annualized MBS (\$/month)	29.93	3.24	-28.93	-11.28

5. Conclusion and Recommendations

From the above-reached results, it is pretty clear that for a transition to such type of energy generation and to motivate the public to invest in this field, the government has to offer incentives; otherwise, it might not look attractive enough to fix a PV system with a battery bank in a residential area, with a PV price of 1.6 $\$/W_p$. However, when installing a system with storage units, the customer who receives bank funds will spend lesser monthly amounts for a much more stable power supply over the lifespan of the modules.

[1] The negative sign indicates monthly sinking funds rather than savings

The positive annualized MBS values obtained in the case of an on-grid PV system that received personal funds indicate a profitable investment that efficiently contributes to solving power outages during sunlight hours if this option is made possible by the national power grid operator. Still, the long payback period attributed to the low Sudanese electricity tariff for Feb 2022 does not encourage the stakeholders. It should also be noted that the analysis presented regarding the bank loan option is intended only to help the citizen investor in the residential sector, who usually prefers to rely on his income to finance such projects, to visualize the size of the venture and its economics when comparing the possible financing opportunities for such micro-project.

To sum up, policies reforms are needed to promote DSPV, which plays a significant role in improving access to modern energy and consequently reducing poverty and Green House Gases (GHGs), in line with the national obligation according to the published INDCs of Sudan as a result of the *Paris Agreement of UNFCCC*. These upgraded policies should meet national conditions, strengthen firm-level competencies, develop the domestic industry, promote education and research, and facilitate investment and technology transfer. In the end, we list some recommendations based on the authors' expertise, tailored for the case of Sudan, and hover around the policy reforms context, categorized as follows:

A. Technical

1. Build capacities in legal issues, financial analysis, cost-benefit analysis, and the technological aspects of solar energy applications by holding regular workshops and training to ensure adequate levels of education are being achieved and by introducing renewable energy science with an emphasis on solar energy into the institutional systems.
2. Promote the SHSs and off-grid PV systems as more well-suited and efficient for rural areas' dispersed populations than on-grid PV plants.
3. Equip the national network with the necessary hardware to take in the grid-connected inverters and the Net-metering systems.
4. Encourage the use of grid-connected rooftop solar panels in industrial areas.
5. In regions where the national grid is not expected to reach in the next 20 years, promote the mini-grids as an alternative for clusters of villages.

B. Financial

1. Educating possible customers on the value of PV investment is vital using several economic metrics, including the ones mentioned here.
2. Adopt investment promotion measures to attract domestic and foreign investors to support solar PV diffusion.
3. Raise awareness of local banks about grid-connected and off-grid DSPV markets to gain the Know-How on the relevant investment.
4. Form partnerships with the private sector based on cost and risk-sharing to attract them to finance PV projects. This partnership model should introduce dedicated policies and regulatory frameworks that incentivize the private sector, foster innovation in business and financing models, and create conditions that facilitate scale-up and replication.
5. Encourage the industrial sector and local communities alike to rely on DSPV mini-grids (around 100 KW_p) for productive uses, like the value-added chain and agro-pastoral uses.
6. Support local banks and MIFIs to create funding for solar PV.
7. Provide all-inclusive guarantees to the local banks and MIFIs by the Ministry of Finance and Economic Planning and the Bank of Sudan for funding DSPVs across the country.
8. Cancel all PV modules and BoS fees, including the high taxes.
9. Systematically examine the economics of relying on SHSs, which typically use battery banks, and compare it to expanding the power grid coupled with adding utility-scale solar PV plants, all to determine the most financially feasible option.

C. Social

1. Raise the awareness of rural communities concerning the applicability of DSPV mini-grids.
2. Create jobs for rural youth by building their capacity in PV systems installation and O&M, and link them with the private sector, especially the widespread companies working in the mining industry.
3. Conduct multidisciplinary studies on the environmental and social impacts of DSPV and solar-powered mini-grids in the countryside.
4. Promote gender mainstreaming in rural areas regarding energy-related activities in general and DSPV in particular.
5. Leverage public and private investment-sharing networks to adopt and disseminate the technology.

D. Policy

1. Several new incentives have been introduced to stimulate renewable energy utilization [40]. Hence, governmental incentive policy endorsement is required.
2. Initiate extensive energy policy research that investigates the multiple and complex factors hindering the development and implementation of successful RE policies. Such research shall conclude with recommendations dedicated to institutional reforms in the public sector, mapping existing connections, overlaps, and dispersions between standing institutions and identifying alternative governance structures. A significant research perspective recommended here is the *Policy Mixes* approach, which analyses and defines policy problems holistically. Using such an approach will enable addressing the multi-sectoral and complex nature of energy policy challenges in Sudan.
3. Formulate conducive policies and regulations, and incentives to encourage the private sector.
4. Revise Energy policies to encourage investment in the electricity production sector.
5. Adopt a flexible feed-in tariff policy for electricity generated by renewable energy technologies, particularly the DSPV systems.

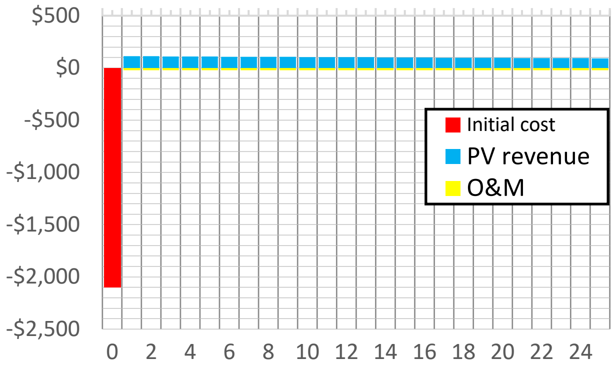


Fig . 9. Cash flow diagram for on-grid PV system (Sudan Feb 2022 tariff)

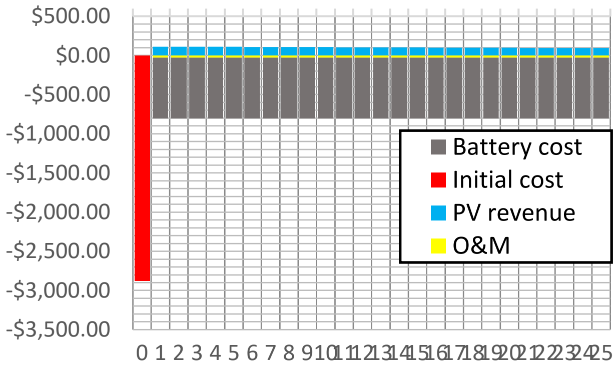


Fig .10. Cash flow diagram for PV system with battery bank (Sudan Feb 2022 tariff)

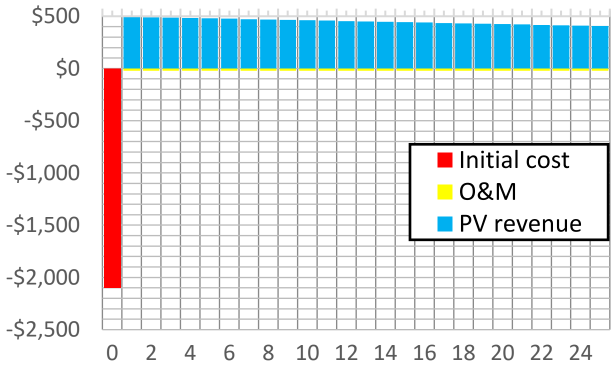


Fig .11. Cash flow diagram for on-grid PV system (Low-income countries tariff)

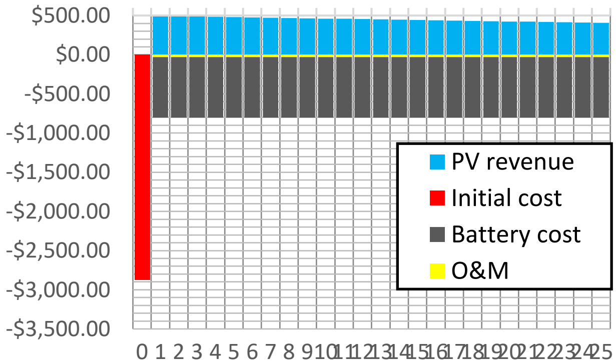


Fig .12. Cash flow diagram for PV system with battery bank (Low-income countries tariff)

Acknowledgment

The authors extend their sincere thanks to the engineers *Abeer Aladdin* and *Mosab Hamed* for providing the technical information to construct and write this article.

REFERENCES

[1] World Bank Group. From Subsidy to Sustainability: Diagnostic Review of Sudan's Electricity Sector. 2019. https://doi.org/10.1596/33702.

[2] IRENA. Energy Profile. 2021. https://doi.org/10.1351/goldbook.e02112.

[3] Ismail EAl, Hashim SM. An Economic Evaluation of Grid Connected Photovoltaic System for a Residential House in Khartoum. Int. Conf. Comput. Control. Electr. Electron. Eng. ICCCEEE, IEEE; 2018, p. 1–6. https://doi.org/10.1109/ICCCEEE.2018.8515807.

[4] Amogpai A. Possibilities of New Light Sources and Sustainable Energy Possibilities of New Light Sources and Sustainable. Ing Iluminatului 2011;13:5–14.

[5] Mentis D, Hermann S, Howells M, Welsch M, Siyal SH. Assessing the technical wind energy potential in africa a GIS-based approach. Renew Energy 2015;83:110–25. https://doi.org/10.1016/j.renene.2015.03.072.

[6] Ontario Tech University. Khartoum, Sudan | Sustainability Today n.d. https://sites.ontariotechu.ca/sustainabilitytoday/urban-and-energy-systems/Worlds-largest-cities/energy-projections/khartoum.php (accessed February 22, 2022).

[7] IRENA. Solar PV in Africa: Costs and Markets. 2016.

[8] World Bank Group. Access to electricity (% of population) - Sudan | Data 2020. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?end=2020&locations=SD&start=2020 (accessed May 23, 2022).

[9] Abdelhafez S. Techno-economic analysis for stand alone solar water pumping system for farm irrigation; A case study in Sudan. PAN AFRICAN UNIVERSITY, 2020.

[10] Wolsink M. Distributed energy systems as common goods: Socio-political acceptance of renewables in intelligent microgrids. Renew Sustain Energy Rev 2020;127:109841. https://doi.org/10.1016/j.rser.2020.109841.

[11] Wen Q, Liu G, Rao Z, Liao S. Applications, evaluations and supportive strategies of distributed energy systems: A review. Energy Build 2020;225:110314. https://doi.org/10.1016/j.enbuild.2020.110314.

[12] Perera P. Constraints and Barriers to Deployment of Distributed Energy Systems and Micro Grids in Southern China. Energy Procedia 2016;103:201–6. https://doi.org/10.1016/j.egypro.2016.11.273.

[13] UNDESA. Accelerating SDG 7 Achievement:

SDG 7 Policy Briefs in Support of the High-Level Political Forum 2019. 2019.

[14] Seidl R, von Wirth T, Krütli P. Social acceptance of distributed energy systems in Swiss, German, and Austrian energy transitions. Energy Res Soc Sci 2019;54:117–28. https://doi.org/10.1016/j.erss.2019.04.006.

[15] Karmellos M, Mavrotas G. Multi-objective optimization and comparison framework for the design of Distributed Energy Systems. Energy Convers Manag 2019;180:473–95. https://doi.org/10.1016/j.enconman.2018.10.083.

[16] Avila N, Carvallo J, Shaw B, Kammen DM. The energy challenge in sub-Saharan Africa: guide for advocates and policy makers: Part 1: Generating energy for sustainable and equitable development. Oxfam Res Backgrounder Ser 2017:100.

[17] von Wirth T, Gislason L, Seidl R. Distributed energy systems on a neighborhood scale: Reviewing drivers of and barriers to social acceptance. Renew Sustain Energy Rev 2018;82:2618–28. https://doi.org/10.1016/j.rser.2017.09.086.

[18] Energy Research Institute. Internal Documents. Khartoum: 1998.

[19] Lahmeyer International GmbH, Sudan Ministry of Electricity and Dams. Solar Mapping Report. 2011.

[20] IEA. Sudan - Countries & Regions 2022. https://www.iea.org/countries/sudan (accessed June 21, 2022).

[21] IEA. Solar PV – Analysis 2021. https://www.iea.org/reports/solar-pv (accessed June 10, 2022).

[22] AFSIA. Annual Solar Outlook. 2022.

[23] Muchunku C, Ulsrud K, Palit D, Jonker-Klunne W. Diffusion of solar PV in East Africa: What can be learned from private sector delivery models? Wiley Interdiscip Rev Energy Environ 2018;7:1–15. https://doi.org/10.1002/wene.282.

[24] Zhang S. Analysis of DSPV (distributed solar PV) power policy in China. Energy 2016;98:92–100. https://doi.org/10.1016/j.energy.2016.01.026.

[25] Internation Energy Agency. Renewables 2019-Analysis and forecast to 2024. 2019.

[26] Yang Y, Elia P, Yan J. Potential of unsubsidized distributed solar PV to replace coal-fired power plants , and profits classification in Chinese cities. Renew Sustain Energy Rev 2020;131:109967. https://doi.org/10.1016/j.rser.2020.109967.

[27] Horváth D, Szabó RZ. Evolution of photovoltaic business models: Overcoming the main barriers of distributed energy deployment. Renew Sustain Energy Rev 2018;90:623–35. https://doi.org/10.1016/j.rser.2018.03.101.

[28] Ouedraogo NS. Opportunities, Barriers and Issues with Renewable Energy Development in Africa: a Comprehensible Review. Curr Sustain Energy Reports 2019;6:52–60. https://doi.org/10.1007/s40518-019-00130-7.

[29] Republic of Sudan. Intended Nationally Determined Contribution. 2015.

[30] DaftLogic. Power Consumption of Typical Household Appliances n.d. https://www.daftlogic.com/information-appliance-power-consumption.htm (accessed March 23, 2022).

[31] Dutton J. Energy Use of Home Appliances, Page 3 | EGEE 102: Energy Conservation and Environmental Protection n.d. https://www.e-education.psu.edu/egee102/node/1915 (accessed March 23, 2022).

[32] Nguyen TB, Van PH. Design, Simulation and Economic Analysis of A Rooftop Solar PV System in Vietnam. EAI Endorsed Trans Energy Web 2021;8:1–12. https://doi.org/10.4108/eai.27-1-2021.168504.

[33] Anadolu Agency. Sudan.. Reducing electricity tariffs for the agricultural sector by 57 percent 2021. https://www.aa.com.tr/ar/اقتصاد/السودان-تخفيض-تعرفة-الكهرباء-للقطاع-الزراعي-57-بالمئة/2484463 (accessed March 23, 2022).

[34] Lindig S, Ascencio-Vasquez J, Leloux J, Moser D, Reinders A. Performance Analysis and Degradation of a Large Fleet of PV Systems. IEEE J Photovoltaics 2021;11:1312–8. https://doi.org/10.1109/JPHOTOV.2021.3093049 .

[35] Sangwongwanich A, Yang Y, Sera D, Blaabjerg F. Lifetime Evaluation of Grid-Connected PV Inverters Considering Panel Degradation Rates and Installation Sites. IEEE Trans Power Electron 2018;33:1125–236. https://doi.org/10.1109/TPEL.2017.2678169.

[36] Union of Arab Banks. Global interest rates .. "zero" in 21 countries and negative in 3 2020. https://uabonline.org/ar/أسعار-الفائدة-عالميا-صفرية-في-21-دولة-2/ (accessed March 23, 2022).

[37] Pueyo A, Bawakyillenuo S, Osiolo H. Cost and Returns on Renewable Energy in Sub-Saharan Africa: A comparison of Kenya and Ghana. 2016.

[38] Osiolo HH. Impact of cost, returns and investments: Towards renewable energy generation in Sub-Saharan Africa. Renew Energy 2021;180:756–72. https://doi.org/10.1016/j.renene.2021.08.082.

[39] The World Bank. Solar resource maps and GIS data for 200+ countries 2020. https://solargis.com/maps-and-gis-data/download/sudan (accessed March 23, 2022).

[40] Drury E, Denholm P, Margolis R. The Impact of Different Economic Performance Metrics on the Perceived Value of Solar Photovoltaics. 2011.

[41] Foster V, Witte S. Falling Short: A Global Survey of Electricity Tariff Design. 2020. https://doi.org/10.1596/1813-9450-9174.