Solar energy for unreliable urban grids

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Abstract

Africa is plentiful in renewable energy resources, especially solar. These resources are well spread across the continent and could contribute to secure and affordable supplies of energy where they are in high demand such as urban areas. A long-term vision to support effective investment in renewable energy is paramount to safeguard the effective use of available regional resources by both countries as well as regional groups. A hybrid energy system such as LPG and solar can be applied successfully in urban areas where grid connections are unreliable, not available or considered uneconomical. This research article aims to conduct cost-benefit analysis of interventions targeting low urban electrification rates in Africa through regional energy parks with the hybrid system. The intervention focuses on improving energy access in urban areas. Nairobi and Accra are used as a case study. The city of Nairobi, Kenya, and City of Accra, Ghana were chosen due to their geographic and climate characteristics which create optimal conditions for the development of PV and LPG gas reticulation, and therefore of a system that allow for the full integration of RES hybrid via Feed-in Tariff or net metering in the distribution grid. The shared energy park project's innovation components may be summarised as follows: 1 MW Solar plant smart monitoring & metering system, solar water Pumping, treatment and smart refilling, Shared Solar Cooling & Refrigeration at the park, 10 Ton LPG ATM integration and smart gas distribution cylinders, storage based on Li-Ion battery technology, EV charging infrastructure, and home energy consumption monitoring equipment. The analysis of the system indicates that regional energy park will have a net benefit of US$6,662,608 at a 5% discounted rate with a benefit-cost ratio of 3.256 an indication that the proposed intervention is economically feasible.

The problem

Africa is facing energy poverty, it poses great threats to the economies, environment and regional security despite being home to roughly 13% of the global population. Africa's energy sector is crucial to its future development [1]. Approximately 625 million sub-Saharan Africans lack electricity access and the average on-grid energy generation capacity of Africa is approximately 90 Gigawatts (GW) in 2012, with roughly half being in South Africa (SA), 45% of the generated capacity is coal (highest percentage from SA), 14% gas (mostly Nigeria), 17% oil and 22% hydro (more evenly spread)[68-69]. The inaccessible, unreliable and insufficient power supply has led to large scale individual ownership of expensive oil-fuelled generators across Africa and more focus shifted on developing off-grid mini power generation systems. The demand for energy is only set to increase with increasing population, economic productivity as well as urbanization[70]. For those without access to electricity in SSA, mean residential electricity consumption/capita is 317 kWh/year (225 kWh excluding SA). Consumption per capita is undoubtedly lower in rural and urban areas in Africa, normally in the range of 50-100 kWh/year for rural areas.

Green energy is usually preferred due to its win-win nature for SSA. Green energy has a major role to perform in energy sector decarbonisation and mitigation of the climate

[68] Adwek, G., et al., The solar energy access in Kenya: a review focusing on Pay-As-You-Go solar home system. 2019: p. 1-42.

[69] Nganga, M.W. Understanding Africa's Energy Needs. in World Economic Forum. Available from: https://www. weforum. org/agenda/2016/11/understanding-africas-energy-needs. 2016.

[70] Nacer, T., A. Hamidat, and O.J.J.o.C.P. Nadjemi, A comprehensive method to assess the feasibility of renewable energy on Algerian dairy farms. 2016. **112**: p. 3631-3642

change effects. Solar, which is currently not fully utilized for electrification could jointly address the severe deficit of electricity access in the region, tackle energy security and also mitigates climate change[71]. Green energy capacity is increasing rapidly though from a very low base (except hydropower). The huge amount of green energy remains untapped; especially the attractive solar energy across Africa, hydro (Congo and other countries), wind (countries along the coast) and geothermal (East Africa (EA) rift valley). Countries having low electrification rates commonly have lower GDP/capita and less developed. For that reason, there is a dire need to improve electricity access to the urban populace. The intervention aims at widest possible applicability. The basic logic is that most urban areas are densely populated and the increasing energy access leads to greater benefits including, healthcare, security, education, environment, economic and life expectancy improvements

The intervention: Regional energy parks in Africa.

The energy parks form the backbone of the green energy supply chain just like the petrol stations are to the fossil fuel (oil & gas) industry improving market access, saving cost and uplifting millions out of environmental and energy poverty while taking back ownership to the end-users which includes both residential and small-commercial enterprises within the estate or energy catchment zone. The Shared Energy Park infrastructure of renewable distributed energy generation integrated with smart communication and intelligent protection systems for maintaining high quality standards of managing generation, loads and faults in an efficient, targeted and timely manner. This intervention will provide end-users with more electricity when it is fed to the main grid but can also be used as a stand-alone hence providing energy when the national grid is offline.

The Shared Energy Park will enable a new approach to distributed generation, by monitoring it through the active involvement of distributors and clients. For the first time, customers will be involved in an experimental programme on consumer awareness. Participants in this programme will receive the Smart Monitoring Kits providing energy consumption data in real time. The customers will receive phone alerts and advice every time energy employment exceeded predefined levels, so to foster more rational energy employment patterns. The above innovative distributed renewable energy grid solution can be implemented as a Green Energy Station or Shared Community Parks within estates. The system can function as a stand-alone energy park given that the energy storage component is included in the design.

In estates energy communes, these can operate as coops by the residents thus ensuring a win-win in ownership governance as well as plough back revenues in the hands of the users/market in form of dividends for every energy share held, with regards to the potential sustainability of the investment if a collection of investors is needed to scale-up, then Pay-As-You-Use by the end users will be more applicable. The region, community or estate residents agree to collectively lease to the coop/agency their rooftops to be used to generate PV energy, or have a common central location (for all the renewable energy sources identified) for the whole region or community this reduces issues of right of way and reduces the cost/capex associated with individual implementation of the same.

Costs and benefits

For discounted cost calculations, the project has considered capital cost and operation, maintenance (O&M) cost, environmental cost et. cetera. The auxiliary facilities will exist within the park and end-user's premises, they include smart meters, charging ports, batteries for energy storage, water dispensing facilities, productive elements within the energy parks,

[71] Pueyo, A., S. Bawakyillenuo, and H. Osiolo, Cost and returns of renewable energy in Sub-Saharan Africa: A comparison of Kenya and Ghana. 2016, IDS.

customers support centers, charging points, solar coolers, solar pumps, etc. Capital cost for the system in this analysis comes to a total cost of US$ $2,953,550. All values are discounted at 5%. The benefits are involving both direct and indirect benefits, the direct benefits include the energy and carbon emission savings. Indirect benefits entail long term employment generation. The direct benefits will result to reduced power outages in days, improved security (street lighting), mitigation of climate change, reduced oil and charcoal consumption, minimized emissions with improved health benefits.

TABLE 1. COSTS

Parameter	Value (US$)
Initial Investment Cost (Feasibility, Design & EPC)	2,042,500
O&M (Administrative Operations & Variable for Grid-Connected Mode)	265,525
Auxiliary Facilities	612,750
Fuel (Grid-Connected Mode)	28,500
Emission Control	1,900
Emissions Allowances	1,425
Emissions Damages (Grid-Connected Mode)	950
Total	2,953,550

TABLE 2. BENEFITS

Benefits	Value (US$)
Economic benefits	8,690,929
Security benefits	748,718
Environmental benefits	176,511
Total	**9,616,929**
Total Benefits	**9,616,929**
Net Benefits	**6,662,608**
BCR	**3.3**

Source: Author's Calculation; Notes: Assuming a 5% discount rate.

Implications of scaling-up shared energy parks in Africa

The various foreseeable impediments and barriers in Africa energy space include insufficient policies and not providing the needed support, lack of information and awareness, high cost of production unless scaled-up, and limited institutional capacity to promote green energy up-take[72]. In the scaling-up effort of shared energy parks, this will require financing from either donors, governments et. cetera which may result in additional costs. According to Hellen[73] there is positive willingness to pay for improved energy sources in Kenya. Analysis conducted by Daniel[74] indicated that, households in Ghana are prepared to pay on the average about ₵0.2734 for a kilowatt-hour which is about one and a half times more than what they were paying. The Kenyan and Ghanaian regulatory frameworks used as case study in this analysis are all friendly to Shared Energy Parks. The energy Kenyan regulatory frameworks are provided in appendix 5. In the case of Ghana, there is no specific mention of mini grids in the 2010 policy statement, but there is scope to consider mini grids as one of the options for achieving universal access by 2020[75]. The purchasing and installation costs in this article are specific to the two countries considered although other countries and solar companies costing may slightly vary. This intervention can be replicated in All Africa countries.

Conclusions

The shared regional energy parks in Africa are a feasible solution to the low electrification rates in Urban areas in African cities. With a BCR of 3.3, this system will be viable for 39% of the population in SSA that live in urban areas and already have an existing but unreliable grid connection. It can also be adaptable for off-grid use since the storage component is catered for in the auxiliary facilities. Meaning, it can function as a stand-alone system, in both cases, BCR will still remain higher than 1. The system is also very much ideal for rural setup since it can function as standalone given that land and way-leave is not an issue, especially in rural

[72] George, A., et al., Review of solar energy development in Kenya: Opportunities and challenges. 2019. **29**: p. 123-140

[73] Helen Hoka Osiolo, Willingness to pay for improved energy: Evidence from Kenya, 2017. 112: P. 104-112

[74] Daniel Kwabena Twerefou, Willingness to Pay for Improved Electricity Supply in Ghana, 2014. **5**, P. 489-498

[75] The World Bank, MINI GRIDS FOR TIMELY AND LOW-COST ELECTRIFICATION IN GHANA, 2017. Technical Report.

market centers. It can be applied to all African countries. Further research should therefore be undertaken for system implementation with increased number of DER in rural areas in Africa.

References supporting the benefit-to-cost ratio

APPENDIX 1. FINANCIAL AND ECONOMIC ASSUMPTIONS FOR NAIROBI, KENYA

Parameters	Unit	Reference value	Ref.
Time horizon	Years	20	Author's value
No. of people served		8,000	Author's calculation
Solar insolation hours	hours	6	[5]
Unit investment cost	US$/Kw	2150	[4]
O &M costs	US$/kW	21.5	[4]
Average electricity energy tariff-off grid	US$/kWh	0.52	[76]
Average electricity energy tariff-on grid	US$/kWh	0.158	[77]
Economic avoided costs	US$/W	5.1	[78]
Inflation rate	%	4.4	[79]
Fuel/Oil price	US$/litres	1.0281	[80]
Average CO_2 price	US$/t$CO_2$	13.3	[81]
Reduced pollutants			
NO_x	US$/kg	3.15	[11]
SO_x	US$/kg	0.7	[11]
PM_{10}	US$/kg	0.2	[11]
LPG cost	US$/kg	1.6	[82]

Exchange rate 1 US$=102.192 Kenya Shillings (https://www.centralbank.go.ke)

[76] Safdar, T.J.S.V., Business models for mini-grids. 2017
[77] KPLC, Approval of the schedule of tariffs set by the energy regulation commission for supply of electrical energy by Kenya Power & Lighting Company Limited, pursuant to Section 45 of the Energy Act, 2006. 2018
[78] Rose, A., R. Stoner, and I.J.A.E. Pérez-Arriaga, Prospects for grid-connected solar PV in Kenya: A systems approach. 2016. **161**: p. 583-590
[79] IMF. Inflation rate, average consumer prices. 2019 [cited 2019 June 26]; Available from: https://www.imf.org/external/datamapper/PCPIPCH@WEO/GHA.
[80] ERC, Petroleum prices. 2019.
[81] Kempener, R., P. Komor, and A.J.I.R.E.A. Hoke, Smart grids and renewable–a cost-benefit analysis guide for developing countries. 2015
[82] KNBS. Economic survey 2019, Kenya 2019

Appendix 2. Financial and economic assumptions for Accra, Ghana

Parameters	Unit	Reference value	Source
Time horizon	Years	20	[83]
No. of people served		8,000	Author's calculation
Solar insolation hours	hours	5	[84]
Unit investment cost	US$/Kw	2014.52	[4]
O &M costs	US$/kW	20.83	[4]
Average electricity energy tariff-off grid	US$/kWh	0.22	[85]
Average electricity energy tariff-on grid	US$/kWh	0.164	[86]
Economic avoided costs	US$/W	5.1	[8]
Inflation rate	%	9.1	[9]
Fuel/Oil price	US$/litres	0.99	[87]
Average CO_2 price	US$/t$CO_2$	50	[11]
Reduced pollutants			
NO_x	US$/kg	3.15	[11]
SO_x	US$/kg	0.7	[11]
PM_{10}	US$/kg	0.2	[11]
LPG cost	US$/kg	0.86	[88]

Exchange rate 1 US$=5.46 Ghana Cedi (https://www.bog.gov.gh/markets/us-dollar-daily-forex-interbank-rates)

Appendix 3. Financial and economic assumptions for both Nairobi, Kenya and Accra, Ghana

Parameters	Unit	Reference value
Time horizon	Years	20
No. of people served		8,000
Solar insolation hours	hours	5.5
Unit investment cost	US$/Kw	2082.26
O &M costs	US$/kW	20.15
Average electricity energy tariff-off grid	US$/kWh	0.33
Average electricity energy tariff-on grid	US$/kWh	0.134
Economic avoided costs	US$/W	5.1
Inflation rate	%	6.75
Fuel/Oil price	US$/litres	1.01
Average CO_2 price	US$/t$CO_2$	31.65
Reduced pollutants		
NO_x	US$/kg	3.15
SO_x	US$/kg	0.7
PM_{10}	US$/kg	0.2
LPG cost	US$/kg	1.23

[83] Adaramola, M.S., et al., Multipurpose renewable energy resources based hybrid energy system for remote community in northern Ghana. 2017. **22**: p. 161-170
[84] Asumadu-Sarkodie, S. and P.A.J.A.E. Owusu, A review of Ghana's solar energy potential. 2016. **4**(5): p. 675-696.
[85] Nyarko, E.J.W., DC: Center for Global Development, The Electricity Situation in Ghana: Challenges and Opportunities, CGD Policy Paper. 2017
[86] http://purc.com.gh/purc/node/7771
[87] Prices, G.P. *Ghana Gasoline prices, liter*. 2019; Available from:www.globalpetrolprices.com/Ghana/gasoline_prices/.
[88] Asante, K.P., et al., Ghana's rural liquefied petroleum gas program scale up: A case study. 2018. **46**: p. 94-102

APPENDIX 4. STAKEHOLDERS BENEFITS AND COSTS IN SCALING UP EFFORT.

Stakeholders	Benefits	Costs
Donors	Climate change associated Sustainable funding's Social impact	Feasibility cost Capacity building cost Financing/Corporate Service Investment cost
National government	Security enhancement Social impact Economic growth	Tax benefits/ tax incentives
Local government	Security enhancement Social impact Economic growth	Tax benefits/ tax incentives Land and way-leave
Commercial enterprises	Reliable energy Improved security Affordable energy Reliable utilities e.g. water	Forgone costs of existing back up system e.g. generators
Private investors	Economic benefits	Financing costs
Utilities	Reduced expansion costs More reliable More grid stability	Reduced customer base Loss of revenue Maintenance costs
Energy providers	Improved customer engagement Increased customer base Reliable energy data	Operation and management costs CAPEX costs

APPENDIX 5. REQUIRED AUTHORIZATION FOR MINI GRIDS IN KENYA

	Undertaking or activity	Required authorization	Applicable regulation
1	Generation of electricity not exceeding 1MW for own use	None	-
2.	Generation and supply of electrical energy not exceeding 3MW	Permit	Energy (Electricity Licensing) Regulations 2012
3.	Generation, transmission, distribution, and supply of electrical energy exceeding 3MW	License	
4.	Electrical installation work at the premises of a customer	Electrician's license and Certificate of Registration as an electrical contractor	Electrical Power (Electrical Installation Work) Rules 2006

Source: http://www.erc.go.ke