PV technologies applications to improve electricity access, a focus on microgrids

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- ICEPT - centre for research and policy advice at the interface between energy policy and technology
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Acknoledgments

EPSRC funded Joint UK-India Clean Energy Centre (JUICE):

- Delivering integration of photovoltaics and storage technologies into power networks for improving living standards
- Research:
  - ✓ Clean Energy Potential (WP2)
  - ✓ Clean Energy Provision (WP3)
  - ✓ Economic value (WP4)
- 10 UK universities
- 2 Indian Research Consortia: IUCERCE, UKICERI

Joint UK-India Clean Energy Centre

- Energy Access research within Mitigation team at *Grantham Institute Climate Change and Environment*

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Professor of Physics

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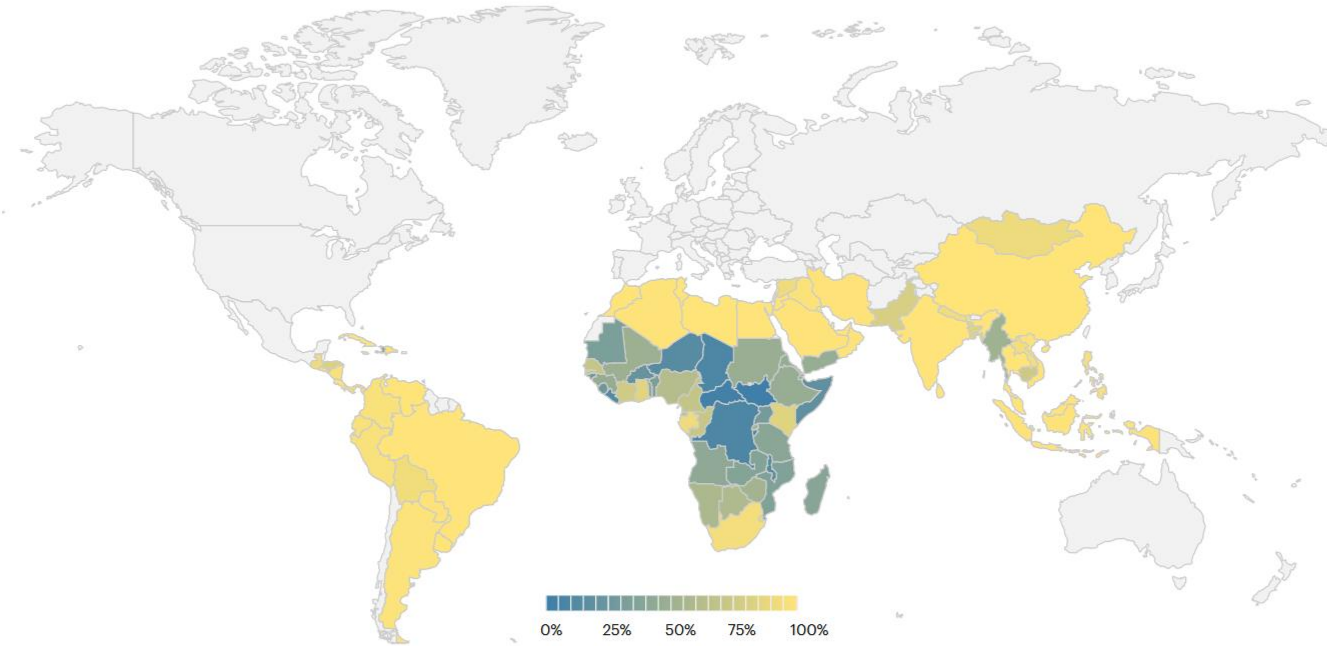
https://www.imperial.ac.uk/grantham/research/energy-and-low-carbon-futures/energy-access/

Electricity access in 2019 (% of population)



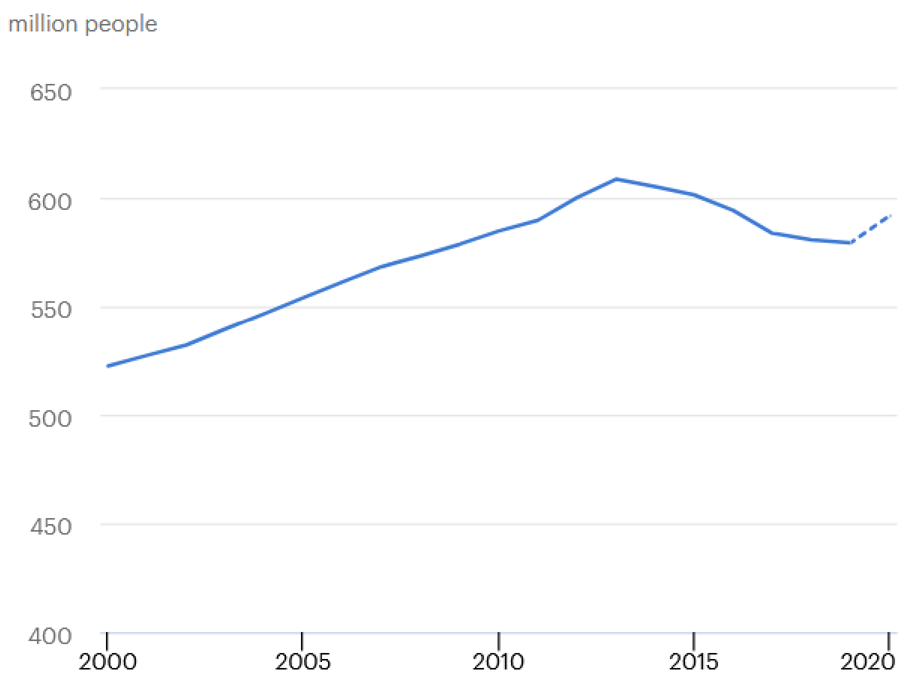
Source: IEA, 2019

- Electricity access has been improving, approaching ~90% in 2019
- Number of people without access to electricity dropped from 860 million in 2018 to 770 million in 2019.

- Indian government announced full electricity access in 2019
- Sub Saharan Africa in particular is more far from achieving goal of universal access to electricity by 2030

Impact of COVID 19

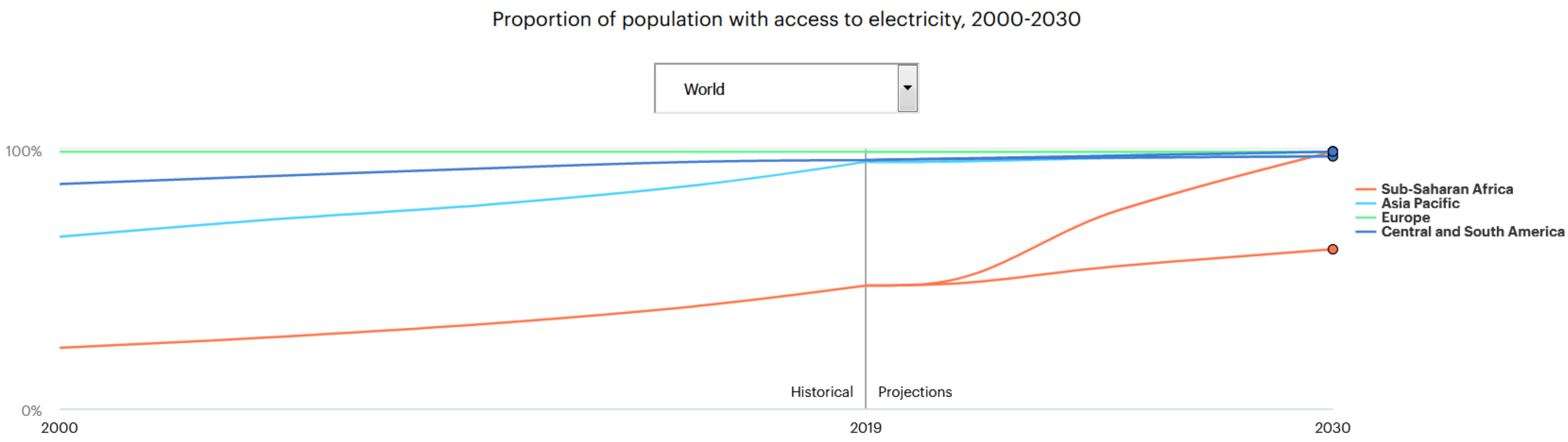
Population without access to electricity in Africa, 2000-2020



Source: IEA, October 2020

- The Covid-19 crisis is reversing progress on energy access
- Number of people without access to electricity in sub-Saharan Africa to rise in 2020

IEA projections 2020-2030

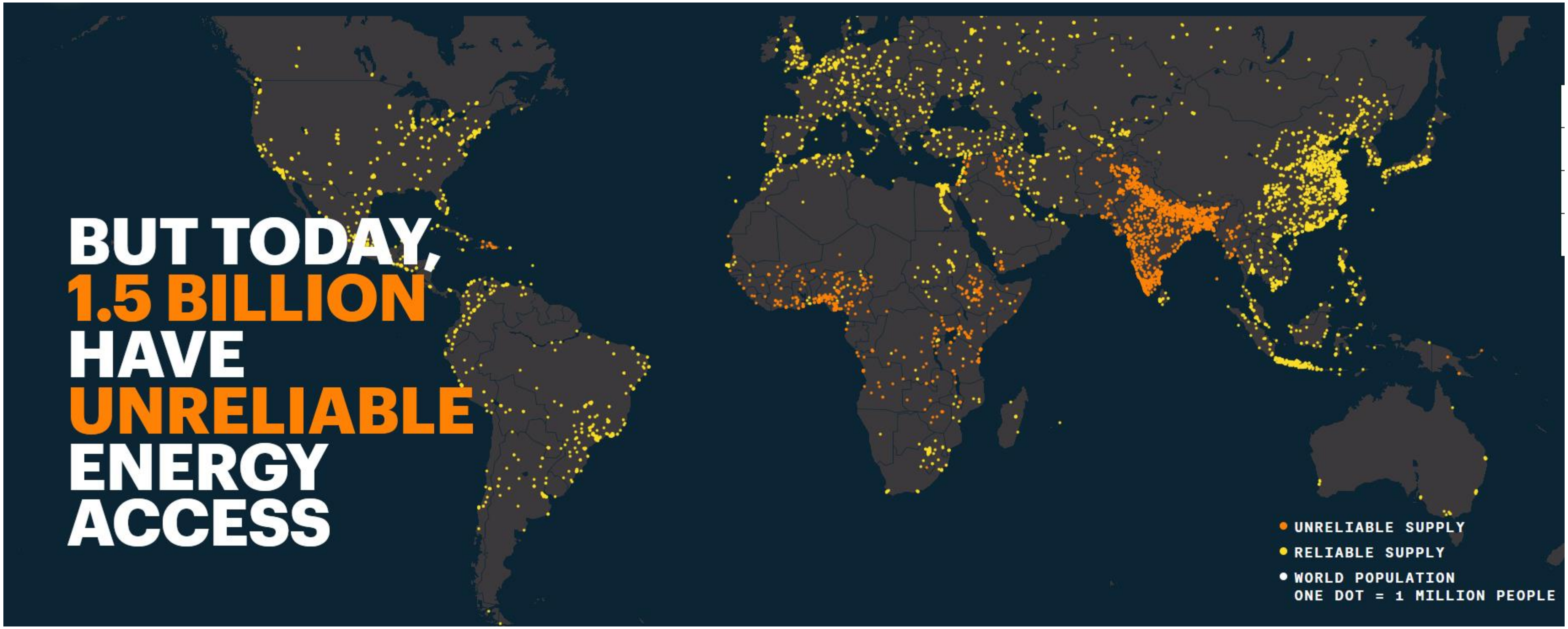


Source: IEA, 2021

- Access to electricity could improve, as a result of a sustainable recovery plan to overcome the Covid-19 crisis

- Sub Saharan Africa expected to reach by 2030:
  - 62% of population under Stated Policies Scenario
  - 100% of population under Sustainable Development Scenario (strong policy support and international cooperation)

Need access to reliable electricity supply



“The Electrifying Economies project” by Sustainable Energy for All (SEforALL) and Rockefeller Foundation, December 2020
https://www.electrifyingeconomies.org/

United Nation - Sustainable Development Goal 7

7 AFFORDABLE AND CLEAN ENERGY

ENSURE ACCESS TO AFFORDABLE, RELIABLE, SUSTAINABLE AND MODERN ENERGY FOR ALL

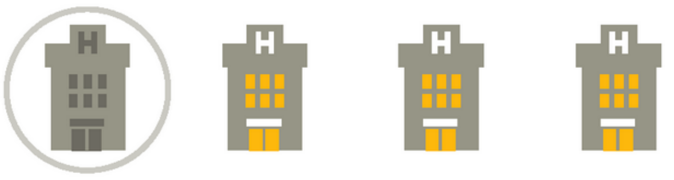
BEFORE COVID-19

EFFORTS NEED SCALING UP ON SUSTAINABLE ENERGY

STEPPED-UP EFFORTS IN RENEWABLE ENERGY ARE NEEDED

COVID-19 IMPLICATIONS

AFFORDABLE AND RELIABLE ENERGY IS CRITICAL FOR HEALTH FACILITIES



1 IN 4 NOT ELECTRIFIED

IN SOME DEVELOPING COUNTRIES (2018)

SDG 7 & SDG 3 - Good Health and Well-Being

- 59% of health care facilities in low- and middle-income country do not have reliable electricity

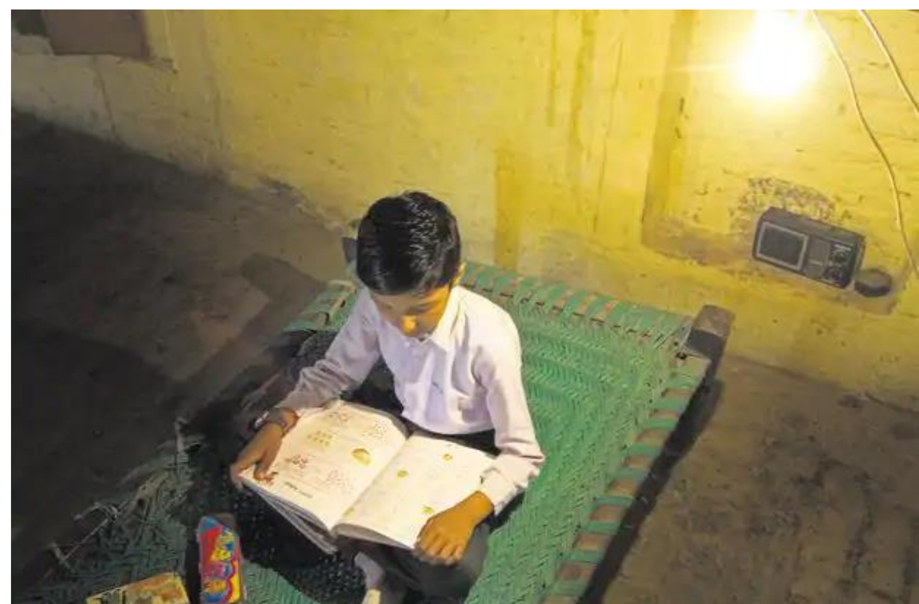
- Access to electricity to health facilities is needed:

  - provide basic amenities: including lighting, ventilation, ICT, and life-saving medical devices;
  - expand operating hours (e.g. increased night-time health provision)
  - safely preserve and store vaccines, blood, and other medicines requiring refrigeration
  - provide adequate and continuous lighting along with medical equipment during pregnancy and childbirth
  - support ICT for wider “telemedicine” strategies, such as remote health worker consultations and ongoing training and education.

Source: United Nations Foundation, 2019

Rural electrification

- About 80% of people without access to electricity live in rural areas
- Most of the electrification effort is targeted toward rural electrification
- Electricity access improves livelihoods and resilience of rural communities, supporting:
    - ✓ Productive uses (agriculture and commercial activities)
    - ✓ Community services (e.g. health care, education)
    - ✓ Wider socio-economic benefits (including improving food security, gender issues)



Rural electrification – productive uses

- Foster agricultural development, by:
  - ✓ increasing productivity (for example by providing access to water pumping and irrigation)
  - ✓ efficiency of conversion
  - ✓ storage of crops and agrifood products.
- Increase productivity of commercial services and Small & Medium Enterprises (SMEs) through
  - ✓ e.g. extended operation hours, mechanization, and
  - ✓ preservation of products
  - ✓ enhanced communication
- Enable growth of new income generating activities (e.g. selling crops to markets, scaling up commercial activities)

Energy services	Income-generating value
Irrigation	Better crop yields, higher value crops, greater reliability of irrigation systems, enabeling of crop growth during periods when market prices are higher
Illumination	Reading, extending operating hours
Grinding, milling, husking	Creation of value-added products from raw agricultural commodities
Drying, smoking (preserving with process heat)	Creation of value-added products, preservation of products that enables sale in higher-value markets
Expelling	Production of refined oil from seeds
Transport	Reaching new markets
TV, radio, computer, internet, telephone	Support of entertainment businesses, education, access to market news, co-ordination with suppliers and distributors
Battery charging	Wide range of services for end-users (e.g., phone charging business)
Refrigeration	Selling cooled products, increasing the dura-bility of products

Community services - Education

TABLE 1. ACCESS TO ELECTRICITY IN PRIMARY AND SECONDARY SCHOOLS[14]							
School Type	Region	2012	2013	2014	2015	2016	2017
Primary	Sub-Saharan Africa	--	--	--	34.%	34.5%	35.1%
	Southern Asia	49.0%	49.5%	50.0%	50.4%	50.6%	50.7%
	World	66.4%	67.1%	67.7%	68.4%	69.0%	69.1%
Lower Secondary	Sub-Saharan Africa	--	--	--	49.1%	49.3%	--
	Southern Asia	63.9%	64.2%	64.6%	65.1%	65.6%	65.8%
	World	77.3%	77.8%	78.3%	78.9%	79.7%	79.5%
Upper Secondary	Sub-Saharan Africa	--	--	55.1%	56.0%	57.1%	--
	Southern Asia	83.8%	85.0%	86.1%	87.1%	88.1%	88.2%
	World	87.7%	88.1%	88.4%	88.8%	89.4%	89.5%

- Only 35.1% of sub-Saharan African primary schools and 50.7% in Southern Asia have access to electricity (UNESCO 2017)

- Access to electricity support education by:
  - ✓ Providing lighting for extended hour studying
  - ✓ Improving access to ICT services
  - ✓ Improve school quality (proving access to clean water, sanitation, lighting, and cooling)
  - ✓ and retention of teachers

Source: United Nations Foundation, 2019

Wider socio-economic benefits of electrification

- Support productivity increases and income generation, thus helps in poverty reduction

- Improve food security*:
  - ✓ *direct impact on agricultural production*
  - ✓ *indirect impact though income generation*

- Gender issues:
  - ✓ improve safety conditions (lighting reduce risks as sexual and gender-based violence at night) and health levels (reduction of kerosene lamps indoor)
  - ✓ reduce the time spend on typical women tasks (fetching water)
  - ✓ opportunities to save time (e.g. water pumping) and generate income (women empowerment)

* Candelise, C. Vallino, E. Saccone, D. (2021) “An empirical assessment of direct and indirect effects of electricity access on food security ”, World Development, 141: 105390.

Electrification options

- Common electrification options:
  - ✓ grid extension of existing centralized system
  - ✓ Solar-Home Systems (SHS)
  - ✓ decentralized mini-grids (based on diesel generators and/or renewable energy and storage)

- Grid extension: traditional approach to electrification

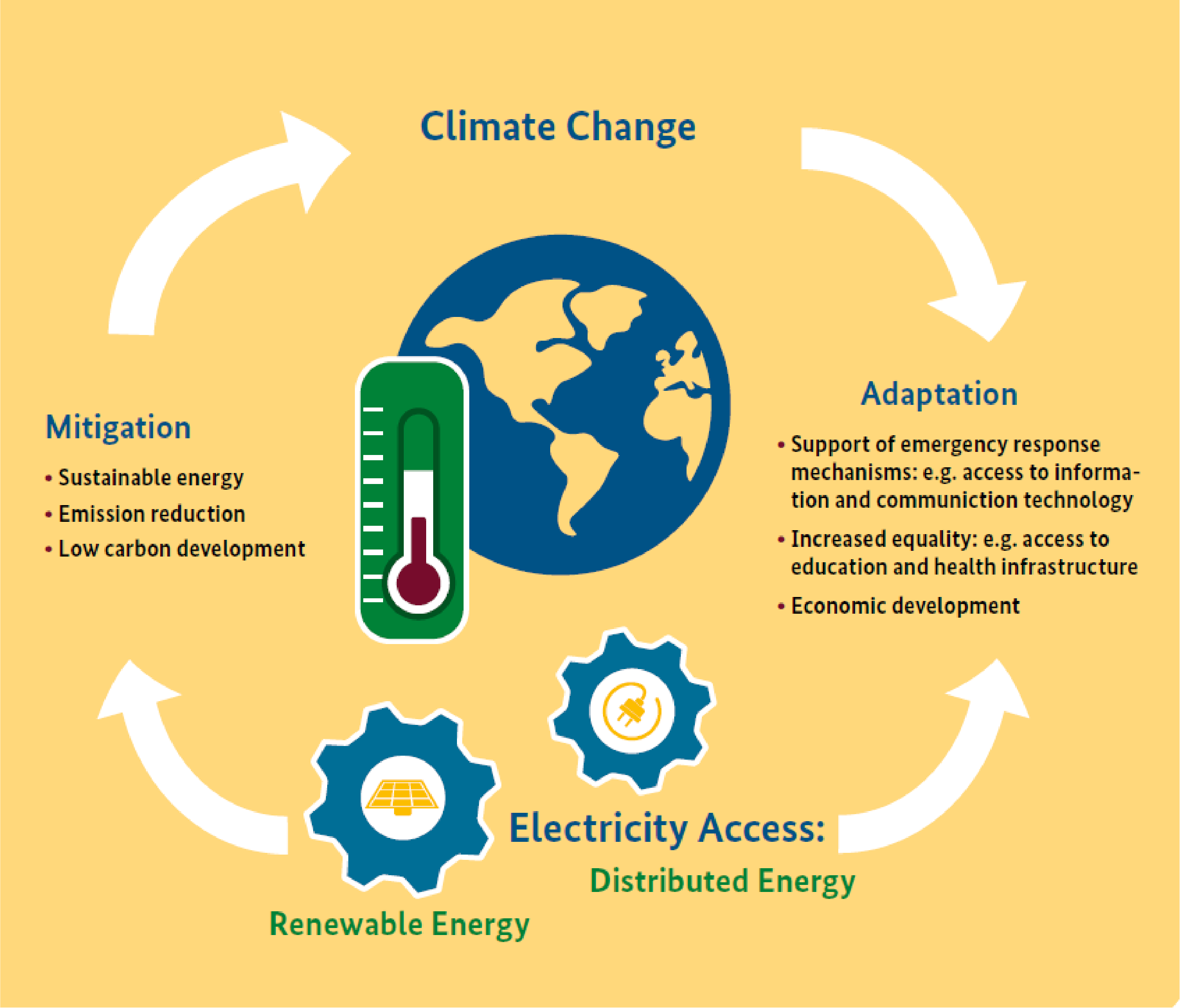
- Challenges with grid extension:

  - ✓ long distances to remote and low densely populated areas
  - ✓ weak quality of supply of on-grid sector (frequent power outages)
  - ✓ low end-consumer tariffs which challenge utilities' business models.

- Off-grid options have become more competitive and attractive for rural electrification

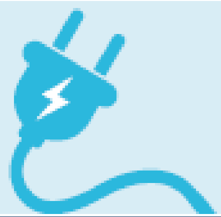
  - ✓ SHS for individual households
  - ✓ Mini-grids to supply larger villages and productive loads

SDG 7 – energy access & SDG 13 - Climate change



Productive uses – crop milling in Ethiopia

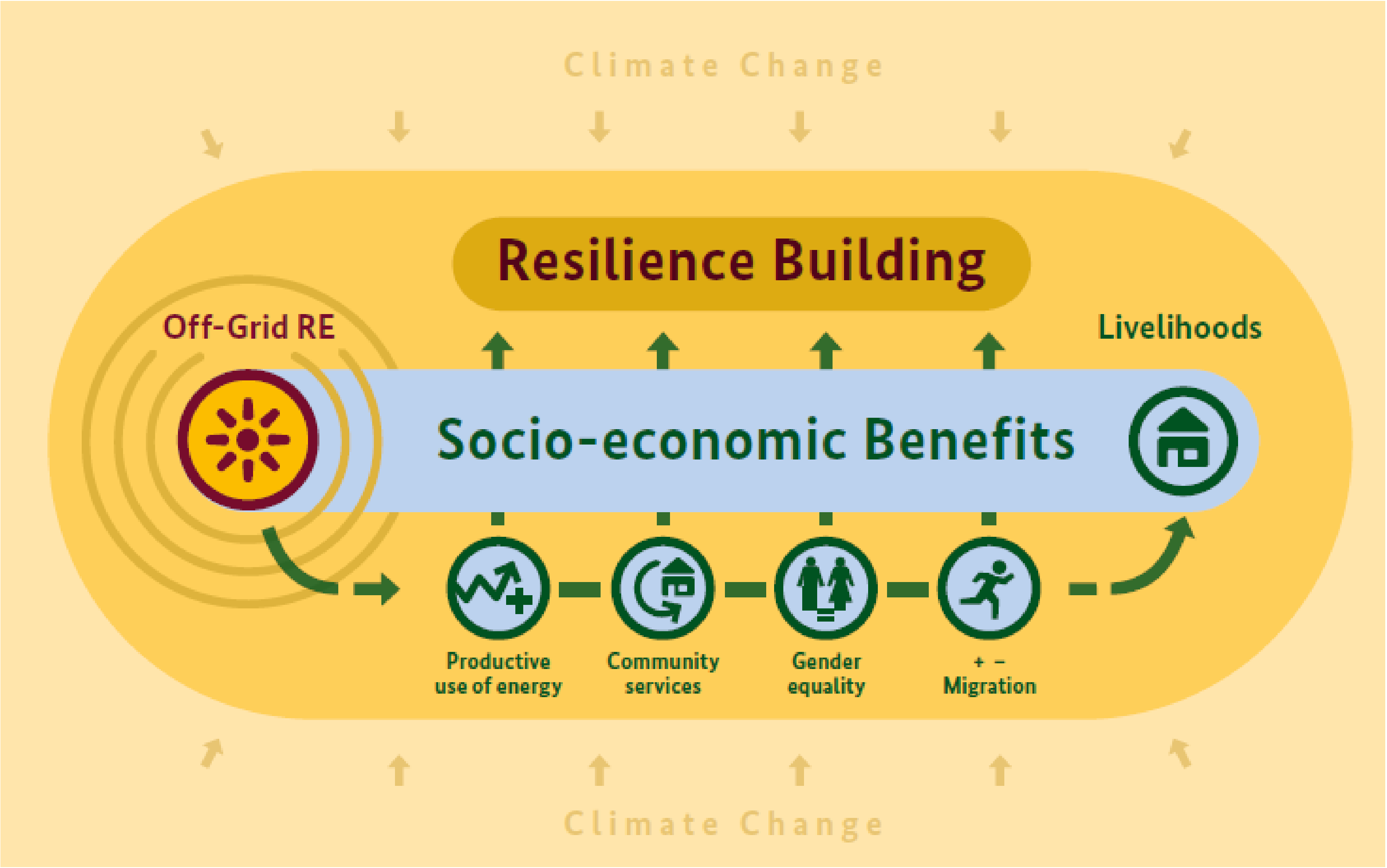
- Majority of grain are milled into flour (for further food processing)
- In Ethiopia the majority of mills run on diesel
- Electric mills is
  - ✓ more efficient than diesel (higher throughput)
  - ✓ cheaper than diesel (lower cost per ton milled)



	Electric **Kalmeks Electric Mill**	**Diesel** **Changfa 1125 Diesel Mill**
Power Rating	18 kW	20 kW
Throughput	1,000 kg/hr	288 kg/hr
Assumed Lifetime	5 years	5 years
Fuel Consumption ***Might vary by crop type milled**	0.02 kWh/kg milled	0.02 L diesel/kg milled
Energy Cost ***2019**	US$1.06/ton milled	US$10.76/ton milled

Source: Borgstein et al, 2020 "*Capturing the Productive Use Dividend Valuing the Synergies between Rural Electrification and Smallholder Agriculture in Ethiopia*" Rocky Mountain Institute Report

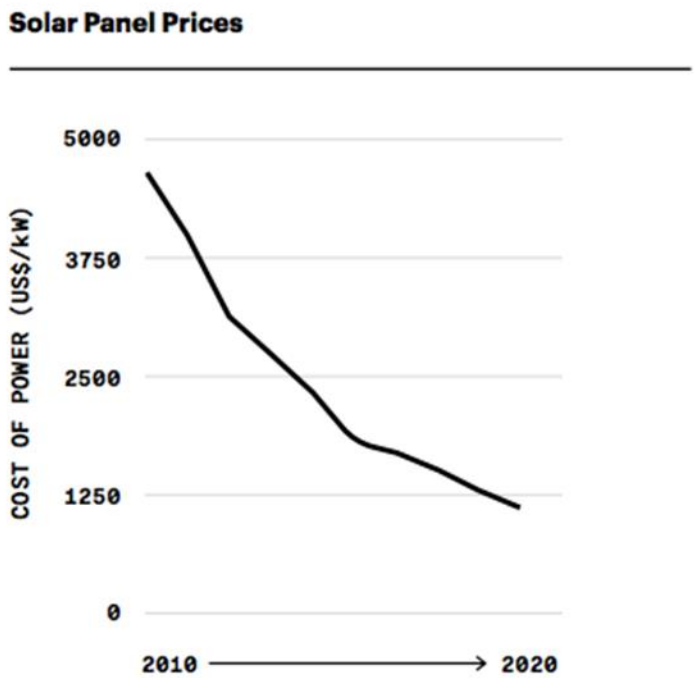
Renewable off grid solutions to support SDG7, SDG13 and community development

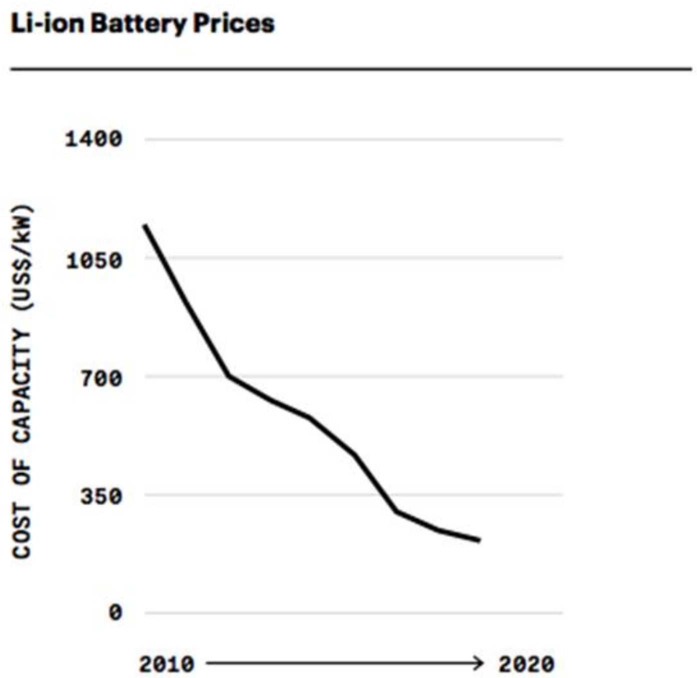


Off grid renewable solutions – decreasing costs

- *"Decentralised solutions are the least-cost way to provide power to more than half of the population gaining access by 2030"*, IEA 2021

- Costs of PV and storage technologies have been decreasing over time





Source: RMI, 2021

Why Minigrids

- Provide reliable electricity to **unelectrified** or **partially electrified communities**
- Can be deployed more quickly and often cheaply than grid extension, in particular when serving rural communities (last mile challenge)

- Provide **community scale access to power -** beyond household scale - to support community end uses and wider community development:

  - ✓ Agriculture productivity
  - ✓ Small business development
  - ✓ Health facilities deployment
  - ✓ Community enhancement through education and skills development

Minigrids system design

- Minigrids system design should take into account:

  - ✓ *Energy needs of the community is serving -> electricity demand*
  - ✓ *Investigate the available technologies, assess their operation and performance during implementation*

- Optimal sizing
  - ✓ *Too small – not reliable*
  - ✓ *Too big – not cost effective*

- Aim is to provide a system which is:

  - ✓ *Affordable - minimizing cost of electricity provided (LCOE)*

  - ✓ *Reliable – able to provide reliable supply of electricity to the served community*

  - ✓ *Sustainable – minimize GHG emissions*

Modelling minigrids

- HOMER
  - ✓ World leader commercial model
  - ✓ Techno-economic optimization of minigrid design

HOMER Energy by UL

- CLOVER (Continuous Lifetime Optimisation of Variable Electricity Resources)
  - ✓ Open source model and customizable
  - ✓ simulate minigrid systems to assess economic and environmental performance
  - ✓ Optimize components sizes (for a selection of criteria)

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Developed by P. Sandwell - Prof. J. Nelson, Energy Access research group

- JRC PV GIS (https://ec.europa.eu/jrc/en/pvgis)
  - ✓ PV performance estimation for user specified system design in Europe and some other geographical areas
  - ✓ Provides monthly average values of PV system energy output

CLOVER – how it works

1. Select a any combination of generation sources,
   - ✓ *e.g. PV and battery*
2. Choose if grid connected & level of reliability of the electricity provided
3. Select combination of electricity uses, both domestic and income-generating

***Then either*:**

3. <u>Simulate</u> economic and environmental performance for any given system size (over several years & at an hourly resolution), e.g. outputs:
   - ✓ *Electricity production by each source*
   - ✓ *Cost of electricity*
   - ✓ *CO2 emission reduction*
   - ✓ *System reliability (periods of downtime)*
   - ✓ *Unmet demand*
4. <u>Optimise</u> system size against set criteria, e.g.:
   - ✓ *Minimum cost*
   - ✓ *Maximise reliability*
   - ✓ *Minimise environmental impacts*

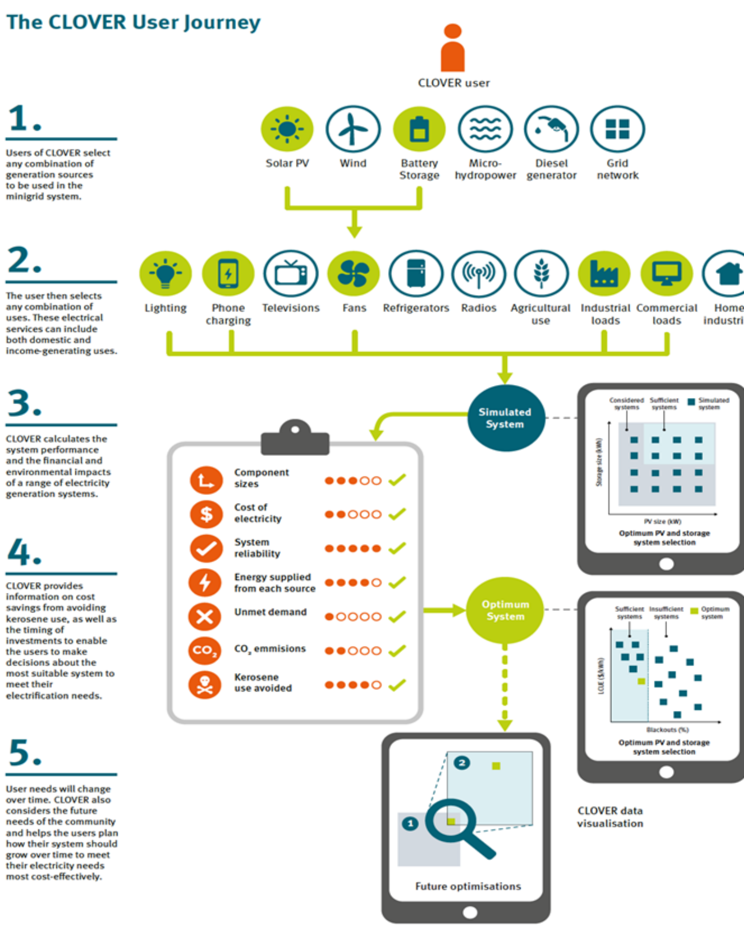


Figure 1: Clover User Journey

CLOVER – how it works (2)

- Demand modelling:
  - ✓ Can be calibrated to measured demand data
  - ✓ Or can be modelled by predicting peak and electricity demand from a population of devices
  - ✓ Based on survey data on probability of given device to be on or off at any given time (and power ratings of devices)
  - ✓ Accounts for seasonality
  - ✓ Accounts for device diffusion rates in a community

- It can optimise system size to meet future electricity demand growth and community needs

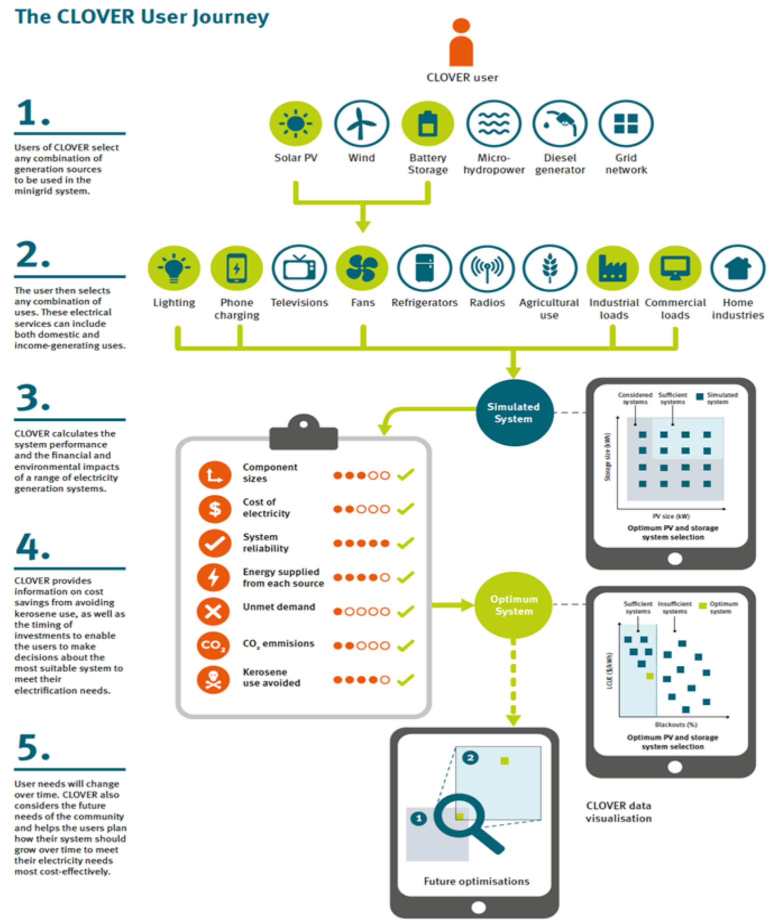


Figure 1: Clover User Journey

- Sandwell, P., Wheeler, S., Nelson, J., “CLOVER: Modelling Minigrids for Rural Electrication”, Grantham Briefing Note, 2017;
- Sandwell, P., Ekins-Daukes, N. & Nelson, J., Energy Procedia 130, 139–146 (2017).

Performance assessment of a minigrid

- <u>Technical performance</u>
  - Optimal balancing of demand and supply
  - Reliability
    - ✓ time during which electricity service is available
    - ✓ % of demand met (if load varies significantly this measure tells us how "usable" is the supply, e.g. one hour loss of service during peak demand is more impactful)

- <u>Economic performance</u>
  - ✓ Levelised Cost of Electricity (LCOE) common metric to assess economic performance over lifetime
  - ✓ Equal the minimum tariff to be charged to break even

- <u>Environmental performance</u>
  - ✓ Total embedded emission of a system, measure overall climate impact (tCO_2eq)
  - ✓ Emission intensity: total embedded emission divided by energy produced over lifetime (gCO_2/kWh)

Key inputs - PV resource availability, technologies, costs, emissions

- Solar resource availability
  - ✓ Location
  - ✓ Climate
  - ✓ Time of the year (seasonality)
  - ✓ Time of the day

- Key technologies
  - ✓ PV technology (efficiency, climate performance)
  - ✓ Storage technology (generally lead acid or litium-ion)
  - ✓ Diesel generators/biomass gasifier in hybrid systems

- Costs
  - ✓ Initial equipment cost (€/kWp) - CAPEX
  - ✓ O&M costs (no fuel) - OPEX
  - ✓ Fuel costs

- Lifecycle emissions of technologies (kg CO2e/kWp)

Minigrids system design – modelling electricity demand

- Strongly dependent on characteristics and load profile of the end uses served
  - ✓ E.g. consumption and load profiles of households differ from productive uses

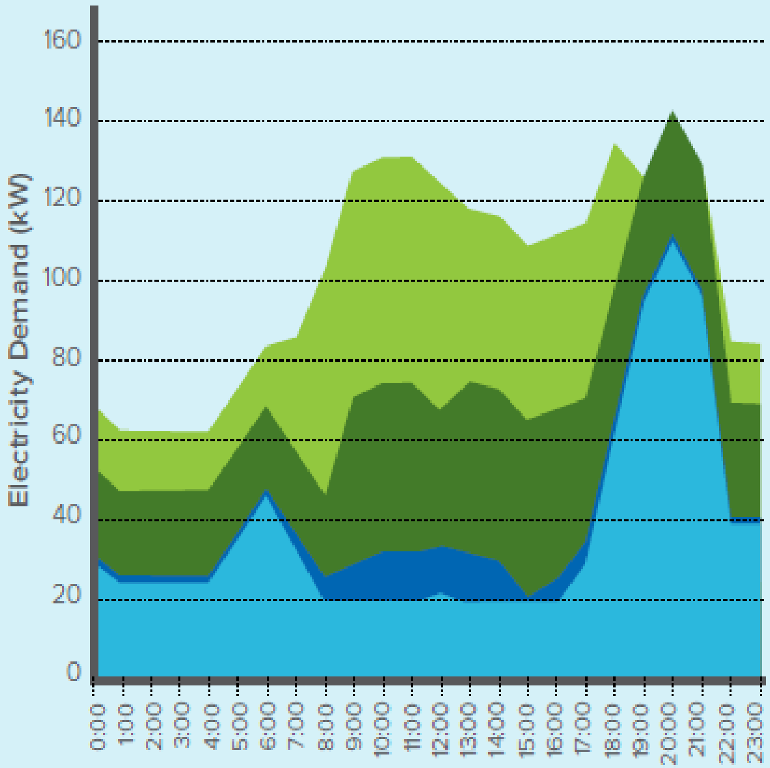
- Variability of load (diurnal, weekly and seasonal patterns)
  - ✓ E.g. household demand for cooling respond to daily and seasonal cycle
  - ✓ or agricultural demand respond to crop cycle or rainfall seasonality

- Depended on contexts
  - E.g. in rural vs urban, different level of economic development, different end uses and appliances

Characterizing electricity demand

EXHIBIT 8

Load Curve of a Medium-Sized Community with the Electrification of Potential Productive Uses



Modeled Energy Consumption Profiles	
Households	500 grid-connected households, of which 350 are small, 100 medium, and 50 large
Small Businesses	50 shops, 5 restaurants, 2 hotels, 1 telecom tower, 2 sawmills, 2 welders, 6 hair salons
Institutional Loads	1 health center, 4 schools, 15 domestic water pumps
Additional Productive Uses	50 irrigation pumps, 12 grain mills, 15 injera mitads, 10 bread ovens

Aggregated site survey data collected from 2018–2020 in unelectrified sites throughout Ethiopia, complemented with regional consumption benchmarks and typical appliance specifications

Source: Borgstein et al, 2020 "*Capturing the Productive Use Dividend Valuing the Synergies between Rural Electrification and Smallholder Agriculture in Ethiopia*" Rocky Mountain Institute Report

Minigrids system design – modelling electricity demand

- Strongly dependent on characteristics and load profile of the end uses served
  - ✓ E.g. load profiles of households differ from productive uses
- Variability of load (diurnal, weekly and seasonal patterns)
- Depended on contexts
  - E.g. in rural vs urban, different level of economic development, different appliances used
- Electricity demand grows over time
  - ✓ Minigrid lifetime is over 15 years
  - ✓ Demand growth interlinked with socio-economic development

Electricity consumption and socio-economic development

- In 2015 the Energy Sector Management Assistance Program (ESMAP) by World Bank provides conceptual framework to redefine energy access: "Beyond connections, energy access redefined"
- Key concepts:

✓ *<u>Socioeconomic development is the primary objective</u> of expanding energy access.*

✓ *Access to energy is needed at multiple locales. Socioeconomic development requires increased use of energy services across households, productive engagements, and community facilities.*

✓ *<u>Access pertains to **usability** of supply rather than actual use of energy</u>. The usability of energy is the potential to use the available energy supply when required for the applications that a user needs or wants.*

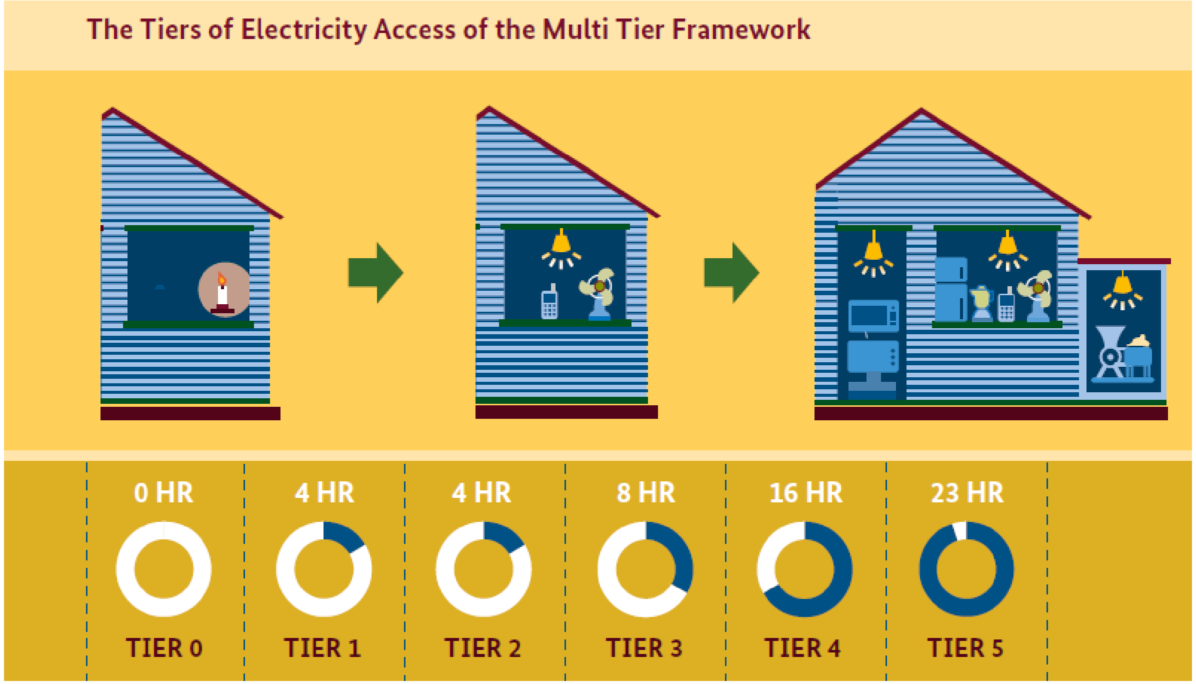
✓ *<u>Attributes of the energy supply affect the usability</u> of energy for desired services. The attributes of energy include capacity (adequacy), availability, <u>reliability</u>, <u>affordability</u>, quality, legality, health impact, safety, and convenience, among others.*

Source: ESMAP 2015 «Beyond connections, energy access redefined» https://www.esmap.org/node/55526

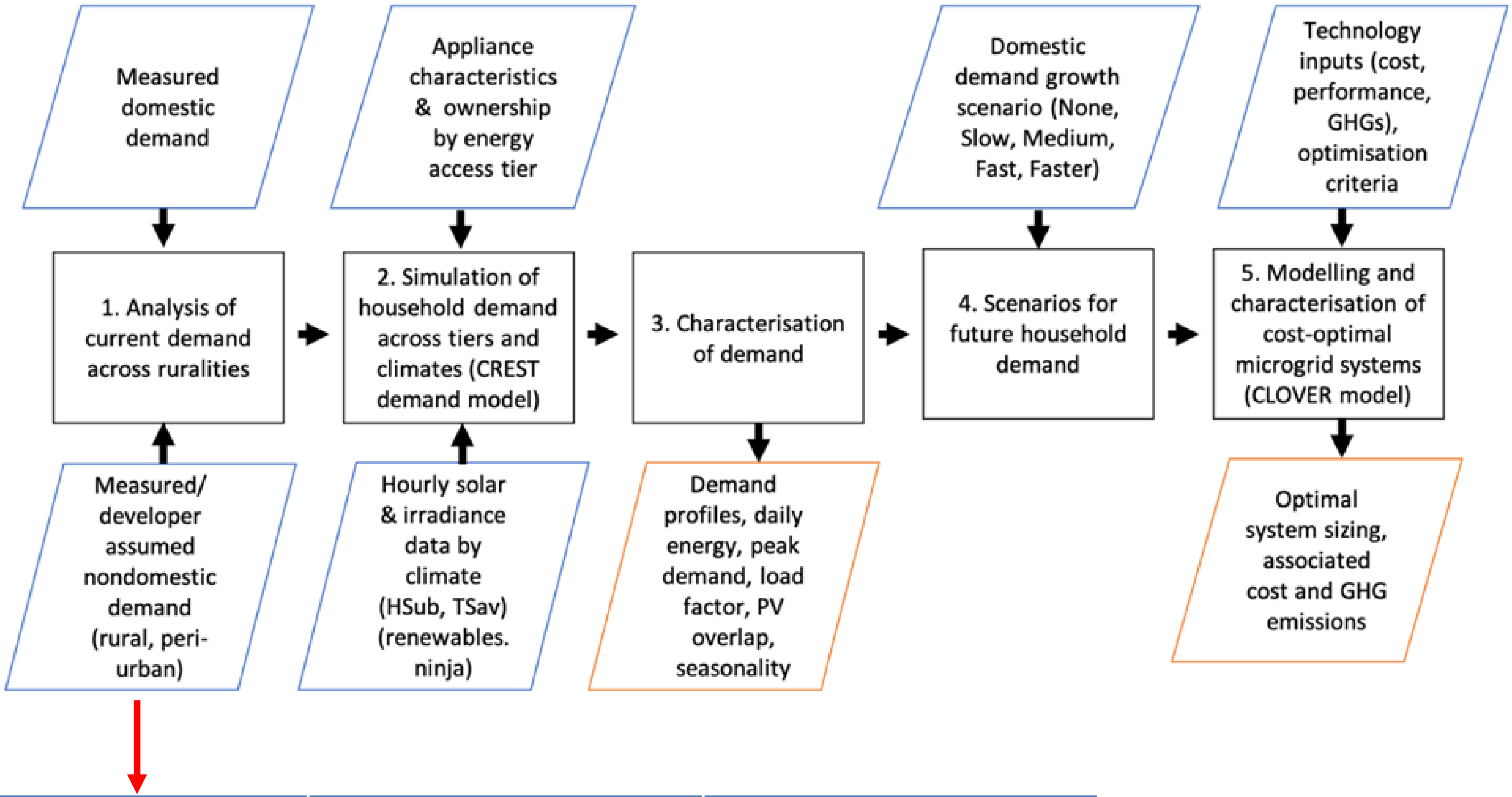
Electricity demand - World Bank's Multi-Tier Framework

- Classifies electricity access across five tiers, based upon increasing availability of energy, power, associated energy services, and reliability (minimum level of availability, minimum power)

- Each tiers also associated with use of power devices of increasing levels of power and energy consumption, ranging from "very low power" (Tier 1) to "very high power" (Tier 5)



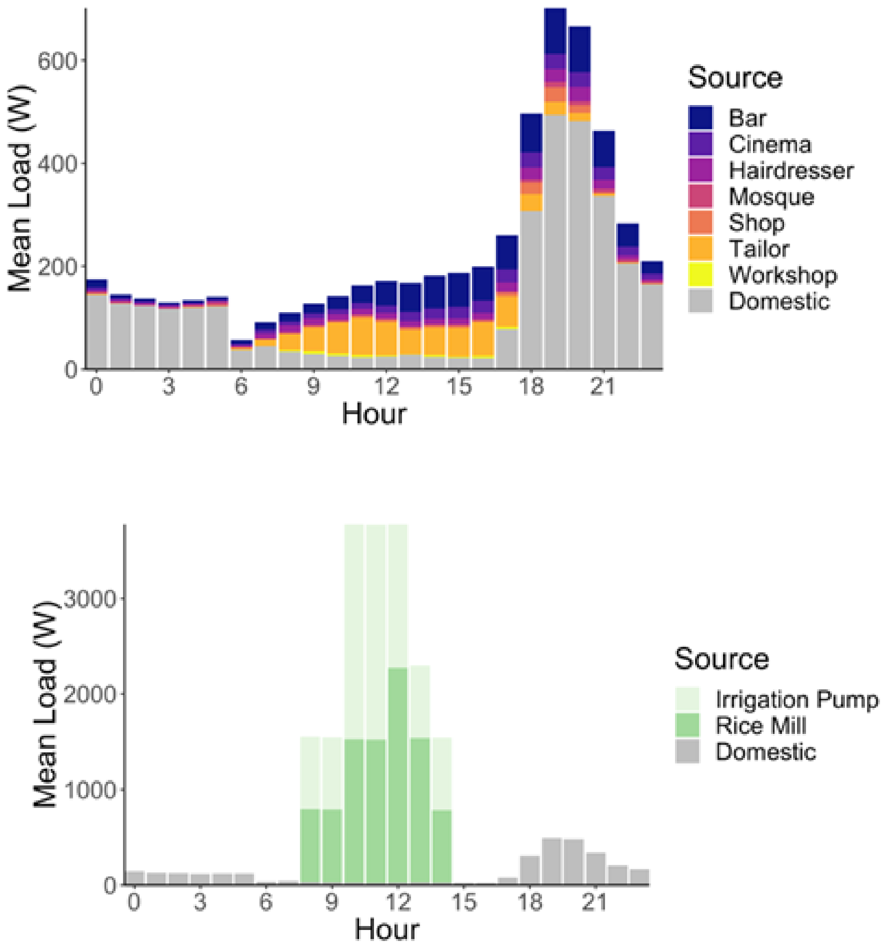
Modelling Electricity demand for microgrid optimization



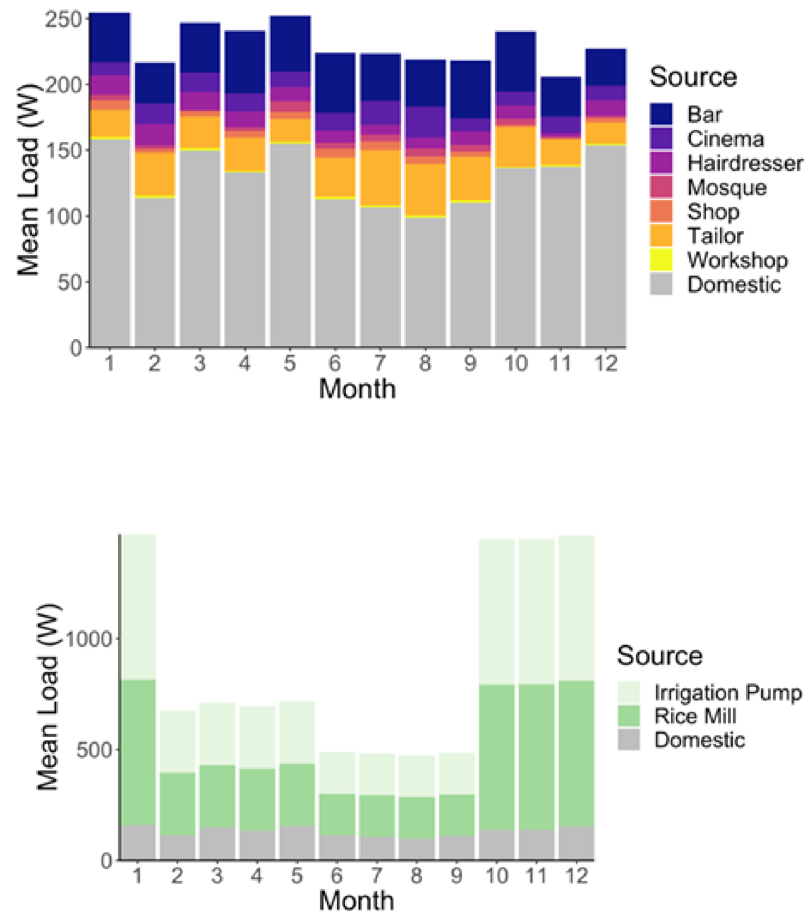
Community Details	Peri-urban	Rural
Number of households	100	100
Household appliances	Lights, USB charging	Lights, USB charging
Nondomestic electricity users	4 bars, 1 cinema, 2 hairdressers/barbers, 1 shop, 2 tailors, 1 welder/workshop, 1 mosque	1 rice polisher, 1 irrigation pump

Source: Few et al, 2021 "*Electricity demand in populations gaining access: impact of rurality and climatic conditions, and implications for microgrid design*" Forthcoming

Characterizing electricity demand – daily profile and seasonality (peri-urban vs rural loads)



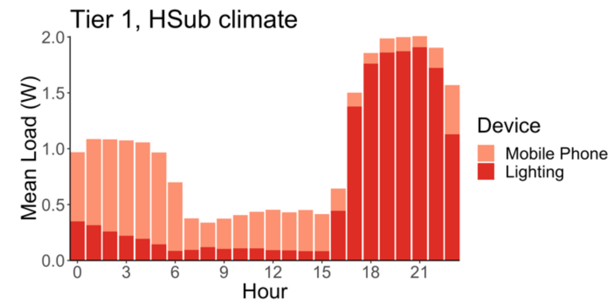
Mean daily demand by source for a microgrid in (a) a peri-urban and (b) a rural location

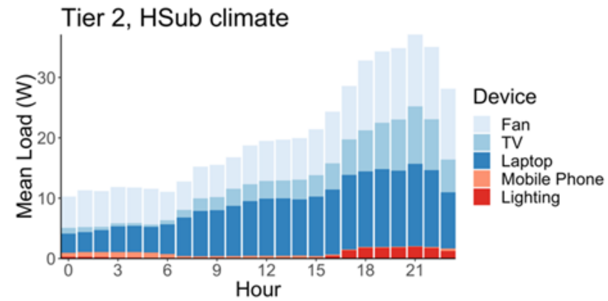


Mean monthly demand by source for a microgrid in (a) a peri-urban and (b) a rural location

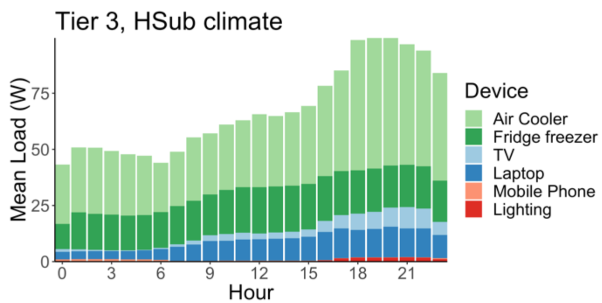
Source: Few et al, 2021 "*Electricity demand in populations gaining access: impact of rurality and climatic conditions, and implications for microgrid design*" Forthcoming

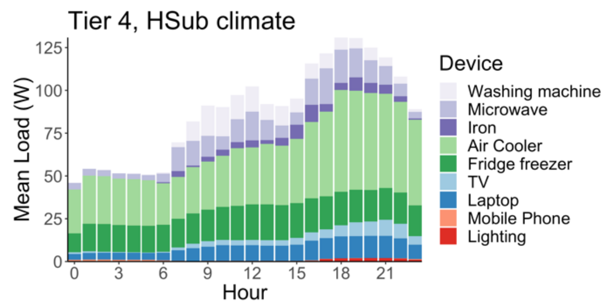
Mean daily demand by device for a simulated household in energy access tiers 1-5

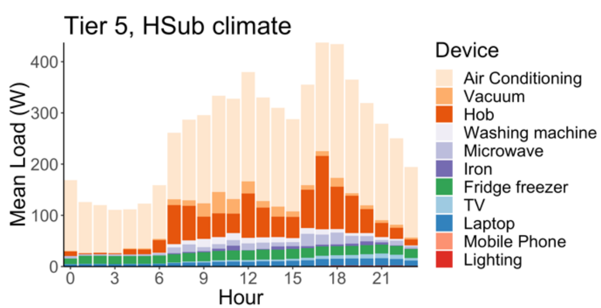


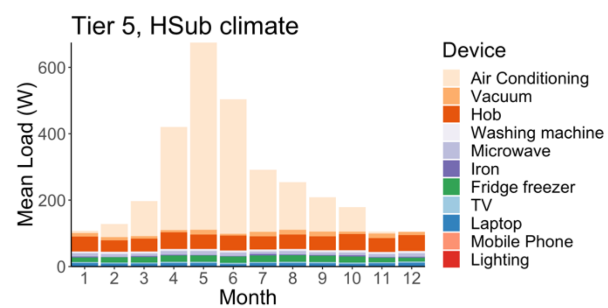


- Humid subtropical (HSub): hot climate



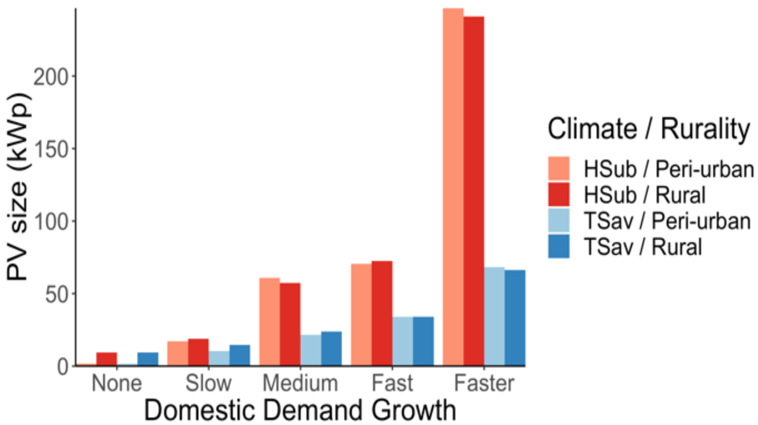


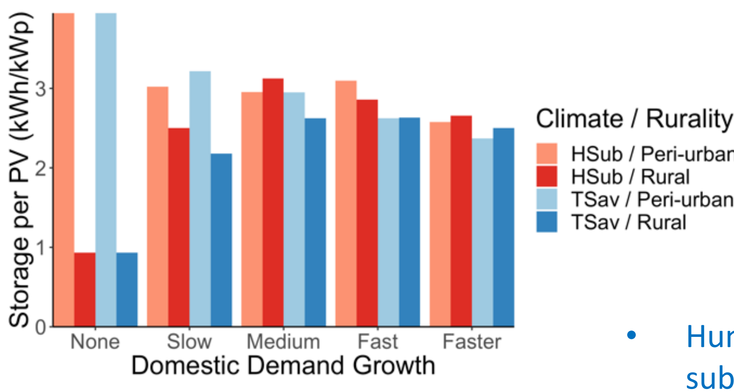




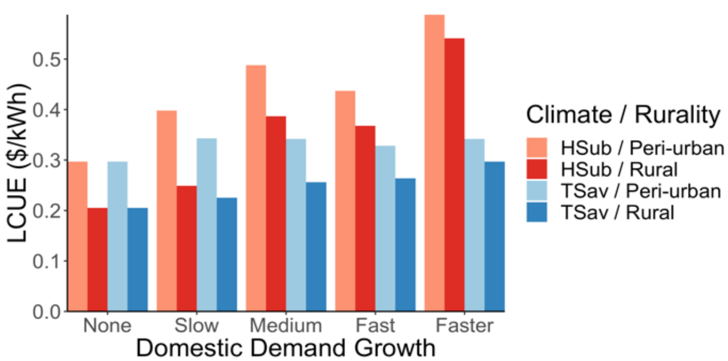
- Growth in magnitude of demand
- Shift from maximum demand in the evening to higher daytime demand (associated with WM, tier 4, and air cooling devises tier 3,5)

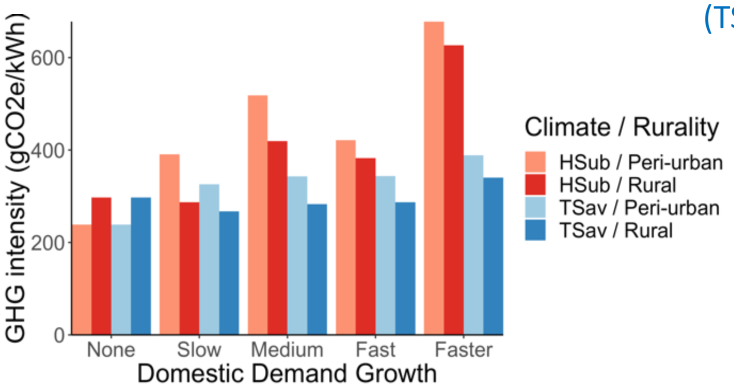
Optimal minigrid system design (using CLOVER model)





- Humid subtropical (HSub)
- Tropical savanna (TSav)



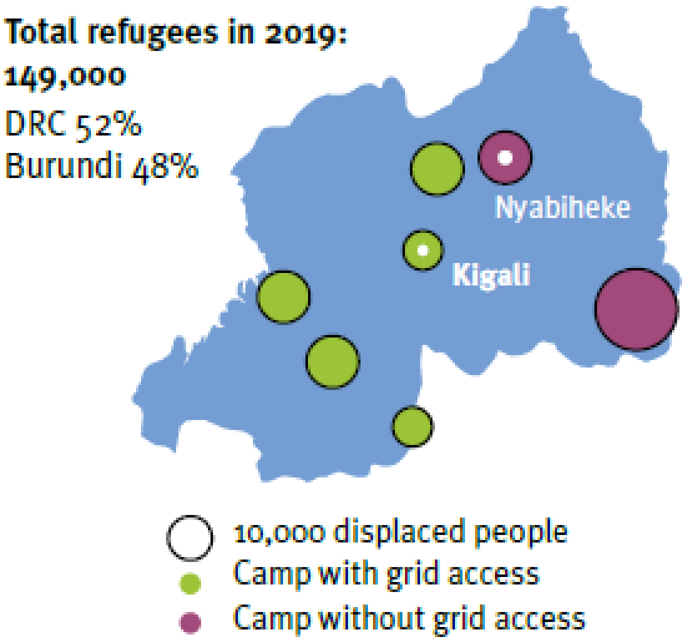


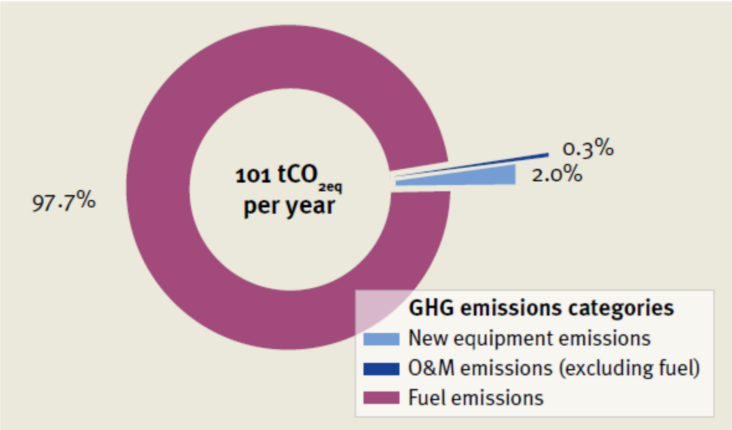
- **Hsub**: Higher demand (Tier 3-5) – > larger PV system -> higher costs -> higher GHG intensity
- **Periurban**: mismatch demand/supply -> more storage needed -> higher costs -> higher GHG intensity

Minigrid to supply refugee camp in Rwanda

- Nyabiheke Refugee Camp, 13,000 refugees since its creation in 2005
- No grid access

- Minimum of 13 kW of diesel generation capacity
- Cost of diesel $30,000 per year
- Greenhouse gases emissions equivalent to 101 tonnes of CO2 (tCO2eq) annually, mostly due to the fuel use





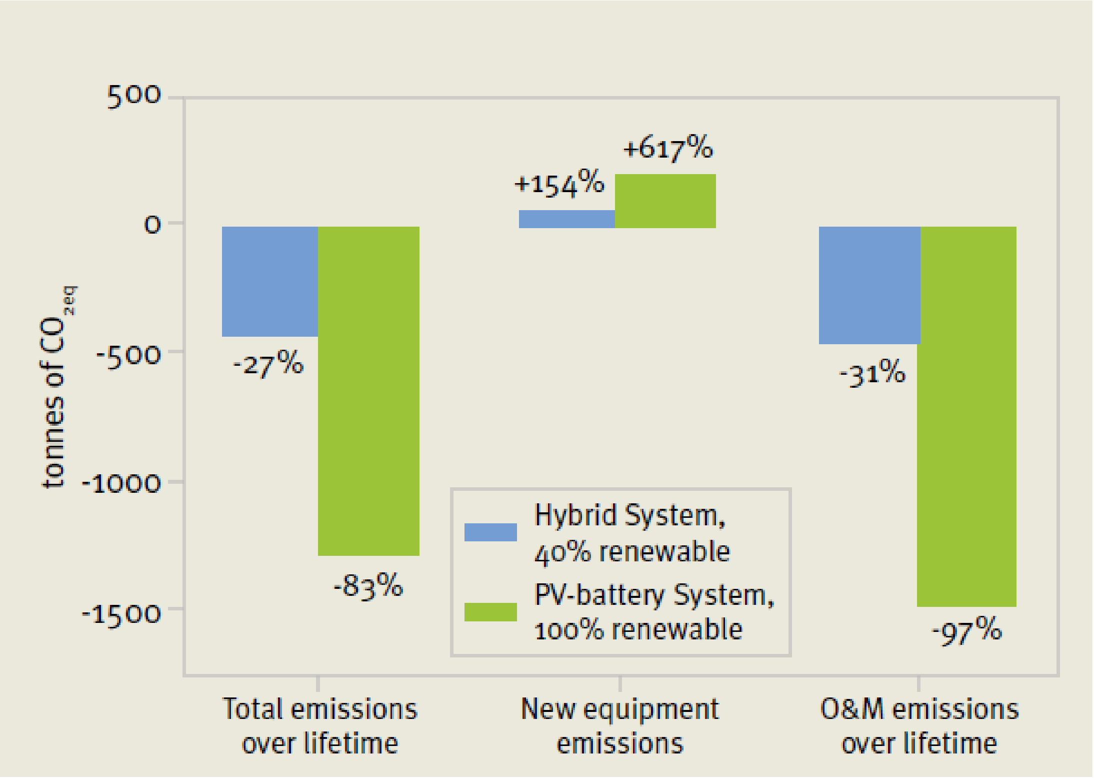
Source: Baranda, A.J. Sandwell, P. «Sustainable minigrid systems in refugee camps: a case study of Rwanda» Grantham Institute Briefing Note N.12. March 2020

Minigrid to supply refugee camp in Rwanda (2)

- Studied introduction of minigrid, based on PV and storage, as alternatives to diesel
- Two options: fully renewable (100%) or hybrid (40% renewable)

- Minigrids require new equipment (which imply embedded CO2 emissions)

- But lifetime GHG emission reduction is 27% for hybrid system and 83% for full renewable compared to diesel



Minigrid to supply refugee camp in Rwanda (3)

- Lifetime costs are also reduced by 22% for hybrid and 32% by full renewable systems
- Cheaper electricity, but higher upfront cost
- High up front cost is a barrier to deployment, also due to long payback period over the investment

Metric	Diesel	Hybrid	Fully Renewable
Long-term cost (LCOE)	$ $ $	$ $	$
Upfront cost	$	$ $	$ $ $
Operational cost	$ $ $	$ $	$
Payback period	-	🕒	🕒 🕒
GHG emissions reduction	-	✓ ✓	✓ ✓ ✓
Marginal Abatement Cost (MAC)	-	✓ ✓ ✓	✓ ✓
Asset management requirements	✓ ✓ ✓	✓ ✓	✓

Community involvement

- Upfront community involvement during minigrid system design and installation is deemed to empower local actors
- Minigrid designed to respond to real community needs

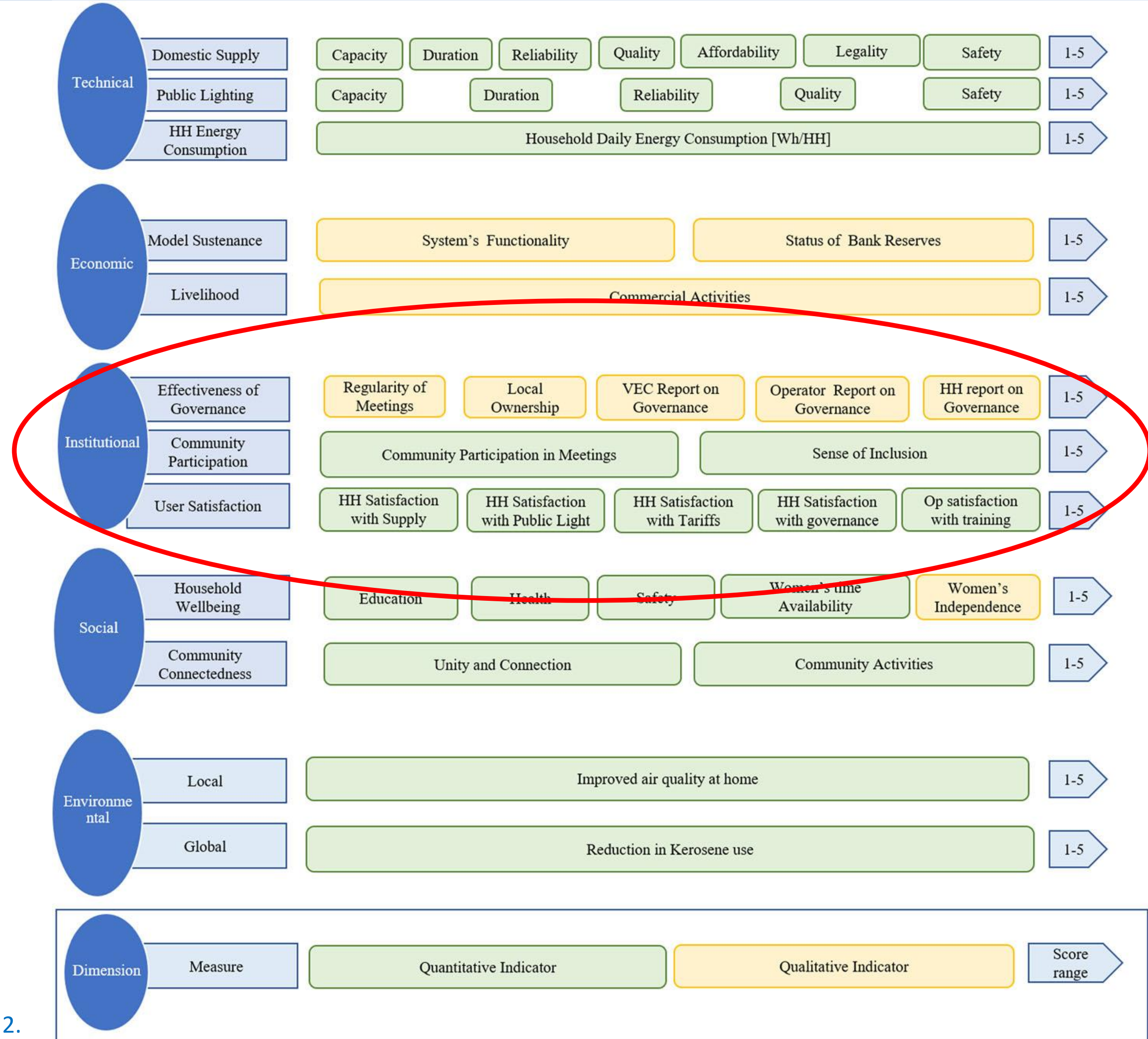
- Beneficiaries of minigrid active stakeholders in the project
- Responsible of plant's ongoing technical and financial management and sustainability
- Creates a sense of ownership
- Increases user satisfaction

Community owned minigrid – an assessment from India

- 24 minigrids installed by Graam Oorja, a social enterprise in India
- 3 different Indian states
- Operating from few months to over 5 years
- Uses supplied:
  - ✓ Domestic uses
  - ✓ Household level commercial activities
  - ✓ Public spaces
  - ✓ Water pumping
- Governance:
  - ✓ Installation are community owned
  - ✓ Locally elected Village Energy Committee –VEC - (responsible for daily technical and financial operations)
  - ✓ Ownership of the asset retained by the funder, ability to withdraw the asset if not operational due to the community
- Hybrid financial model:
  - ✓ CAPEX provided upfront
  - ✓ O&M costs covered by billing metered household consumption
  - ✓ Payment collected by a local plant operator and deposited on bank account managed by VEC

Community owned minigrid – scoring methodology

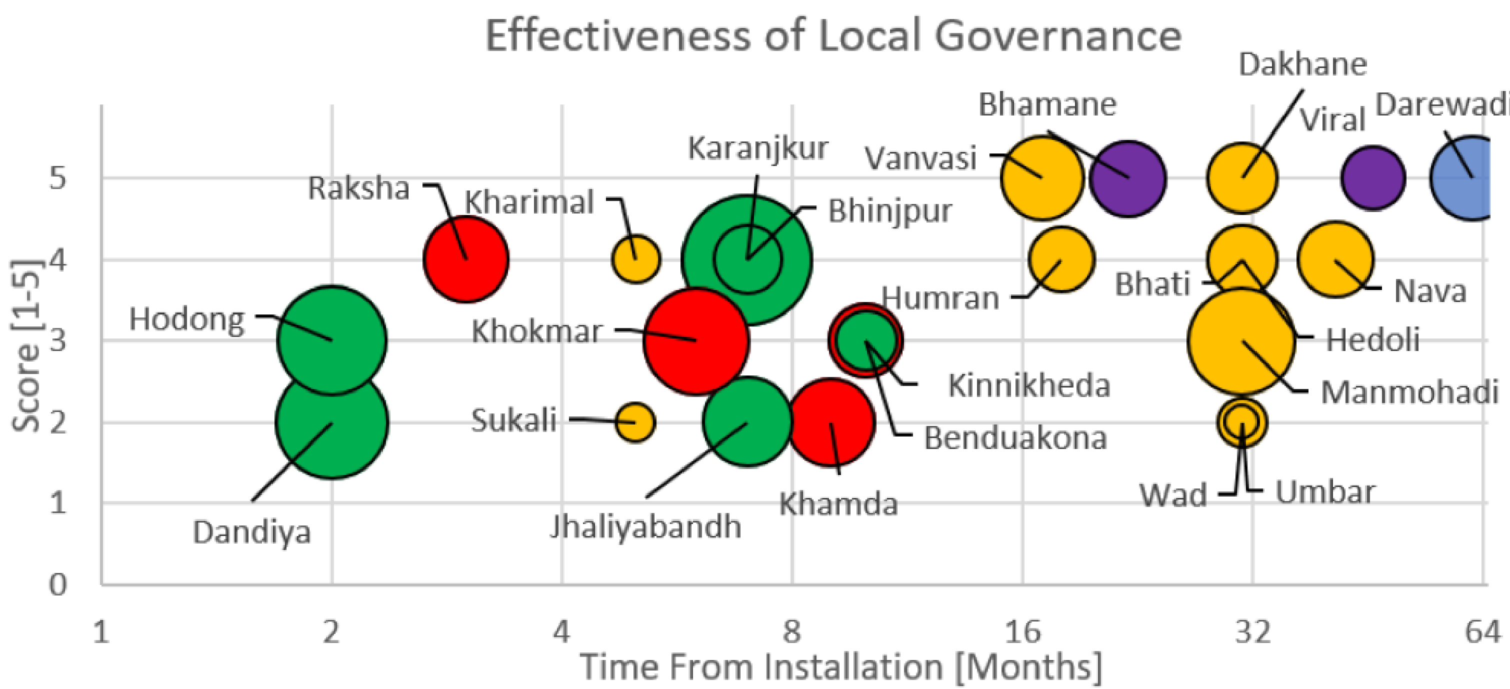
- Scoring methodology to assess performance of minigrids along five dimensions
- Data collected using semi structured interviews with VEC members, surveys with households and local operators, recording data from meters and bank passbooks



Katre, A., et al. (2019). "Sustainability of community-owned mini-grids: evidence from India." Energy, Sustainability and Society 9(1): 2.

Effectiveness of local governance

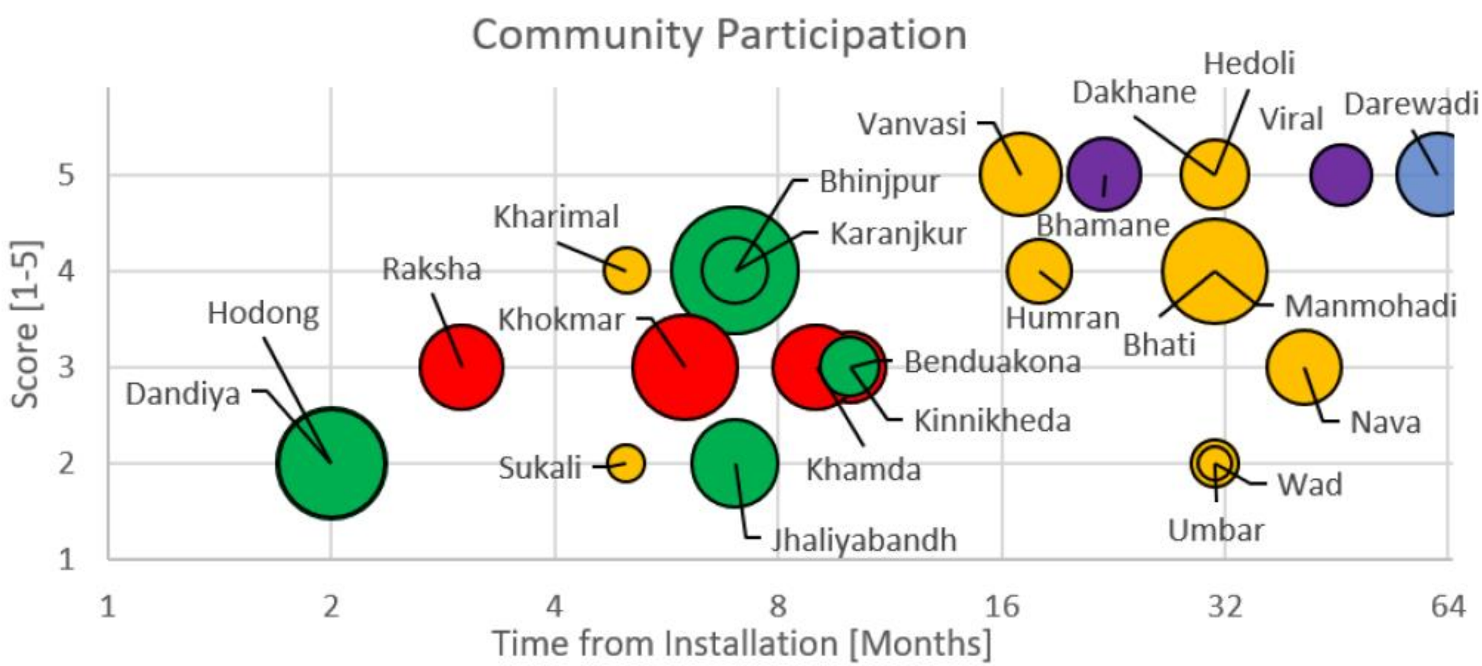
- Measures of Effectiveness of Local Governance show high scores across all sites and a growing trend with time of installation (yellow and purple are older minigrid sites)
- Sites where woman have more prominent voices as members of the Committees seem to be able to establish more effective governance structures(Bhinjpur, Kharanjkur, Vanvasi Pada)



(diameter of the circles proportional to the number of households served by the installation in each village)

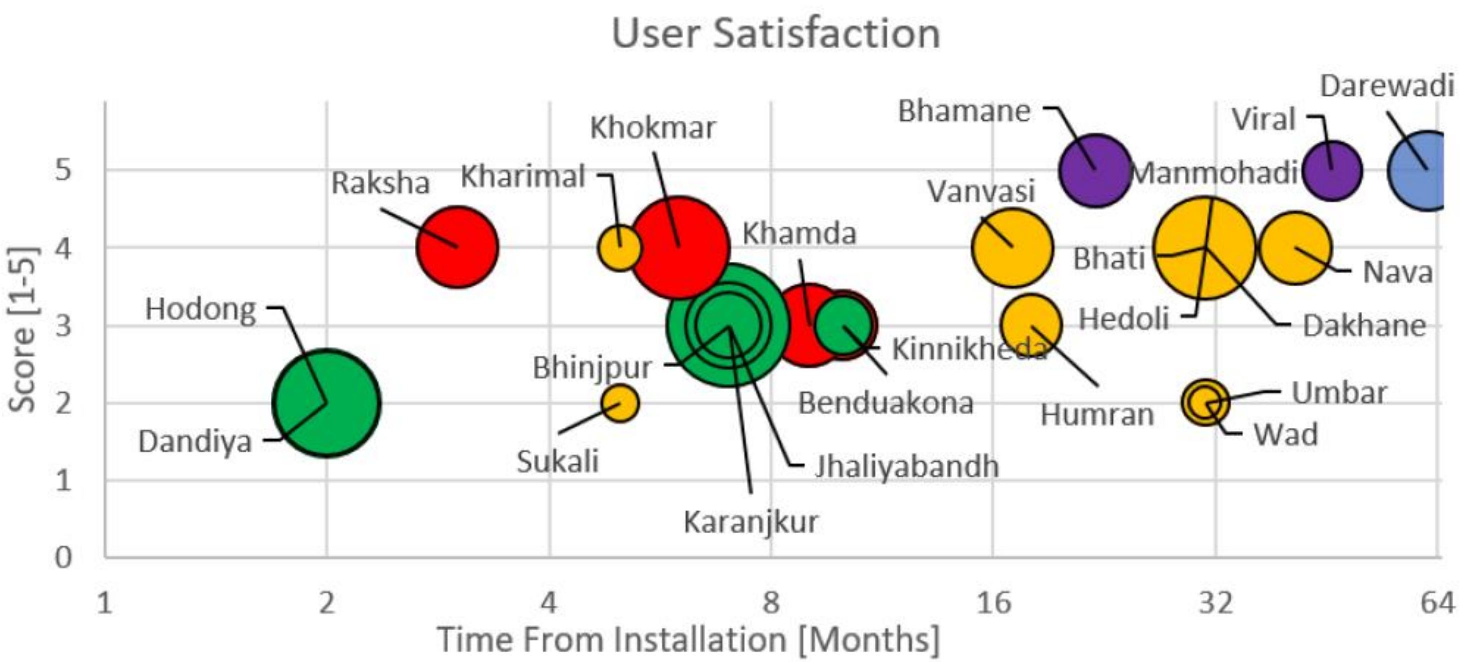
Community partecipation

- Similar high score and growing trend over time for Community participation
- 74% of respondents mentioned a feeling of the community being able to take care of the solar grid.
- *"The localized dimension of the institutional set-up and the knowledge of those accountable and responsible for the operation of the plant, was a key driver for community engagement and participation"*



Community satisfaction

- Communities also reported high levels of satisfaction with the system, generally scoring 3 or above
- Older installations reported higher levels of User Satisfaction
- Results suggest strong link between the three Institutional measures



Concluding

- Universal electricity access is still a challenge to be overcome, in particular for Sub-Saharan Africa countries
- Electricity access is not just connection, but aims at providing reliable, sustainable access in order to foster wider socio economic development
- Off grid renewable based solutions (SHS, minigrids) are increasingly becoming more attractive and competitive than grid extension, in particular to serve rural and remote communities
- Minigrid implementation should take into account the energy needs of the community it serves…
- .. and optimize design in order to minimise costs and embedded emission, while guaranteeing reliable electricity supply

Questions, comments?

THANK YOU

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