Solar Mini-Grid for Improved Energy Access

CSTEP

Project Stakeholders

Kudagaon Island Smart Microgrid Project
Athmallik, Angul, Odisha

Kudagaon Community

CSTEP

SunMoksha

Good Energies

Introduction

In 2016, CSTEP started studying issues associated with electrification of a few villages in Karnataka. A policy brief was prepared in response to MNRE draft mini-grid policy of 2016, wherein CSTEP discussed these scenarios in grid-tied mini-grid model and other key aspects as well. It implied that there was a need to examine the issue of energy access in the context of mini-grids.

This included aspects such as social and technical factors like - overall living conditions, aspirations of the people, energy needs, availability of solar resource, size and location of villages, and the available infrastructure. These would then translate to

- Energy-consumption profile
- Solar PV generation potential
- Storage capacity requirements for the village of interest

The aspiration was to develop a robust model with rigour, based on publicly available information, government-approved norms, and encompassing a pan -India scope.

In view of this, we framed the **objectives as** mentioned below:

- *Understand the ground realities of providing energy access, by supporting a pilot installation in an un-electrified remote location*
- *Build an **open-access web tool,** which could help in techno-economic assessment of many such potential sites for informed policy analysis and decision-making related to improved electricity access*

How we did it…

Site Selection

Survey

System Design

Implementation

Impact Assessment

Site Selection

Criteria:

This project was undertaken to study viable solutions (off-grid and grid-interactive) for electricity distribution in the remote areas of India. The erstwhile village-electrification scheme had yet to provide assured and quality supply of power to remote areas.

Erratic supply of power, and voltage and frequency fluctuations are some of the issues faced by these rural communities.

In this context, the mini-grid model has proven to be a viable solution, to improve the energy access in remote areas.

Selection Criteria	
Electrification Status	Non-electrified village
Population	~ 400 people
# of Households	~100
Land Area (for plant)	Greater than 0.3 acres
Willingness to pay	~INR 100 per month
Solar Resource	>1500 kWh/m^2/annum

Site Selection

Before selecting a site in Odisha, CSTEP team inspected several proposed sites incl. some existing microgrids to understand the various challenges with respect to implementation, monitoring, etc. These sites included:

- **Maharashtra** (Biogas Plant: Pirangut; Solar PV Plant: Darewadi & Vansipada Villages)
- **Jharkhand** (Solar PV Microgrid: Karankunj Village; Hodum & Dandiya Villages, Khunti District; Potential Mini-Grid Site: - Kobi Toli, Gumla District)
- **Bihar** (Banda Village, Budhwa Tala Village, Ranadi Village, L&T Mini-Grid site Rohtas District)
- **Manipur** (Potential Mini-Grid Site - Heirok District - Part 1 and Part 2)

This process was time consuming due to challenges such as: floods in North and North-Eastern India, possibilities of conventional grid arrival at several proposed sites, lack of interest from local authorities to support mini-grid initiatives, socio-political issues in interior areas, site-specific impedances due to – uneven terrains, need to chop down heavy tree covers for project, etc.

Finally, CSTEP reviewed the work of Orissa mini-grids and approached SunMoksha for a discussion. SunMoksha identified a site which was suitable to CSTEP's criteria. The chosen site at Kudagaon was finalised through concerted efforts of local authorities, **CSTEP** and **SunMoksha** (identified partner for development of mini-grid).

About Kudagaon

- Kudagaon is an island village in Mahanadi river, located in Athmallik tehsil, in the Angul district of Odisha.
- It has a population of ~400 people (Census, 2011), with no provision for electricity supply from the conventional grid system.

Accessibility Challenges

Its access to the mainland is a makeshift road on one side of the river-bed, which gets washed away for several months during monsoons and floods.

Life at Kudagaon

Accessing the island village is a challenge. With around ~640 acres of cultivable land, the livelihood of villagers has been based on conventional, rain-fed agriculture. Only 60 acres of land was being cultivated. Post-sunset, life was limited to indoors, with the danger of snakes lurking in the open in the dark.

# of households	85
Energy source	Kerosene, Firewood
Cost per month per household	INR 125
# of handpumps for domestic use	1 handpump (20-30 litres per hour)

Design & Implementation

Survey & Scoping

Survey, Smart NanoGrid™ and System Design

Implementation Activities

Installation Works, Testing and Commissioning Activities.

Post-Implementation Activities

Quality of Life Survey

Survey

Discussions were held with the local community to assess the following:

- Aspirations for electricity
- Willingness to pay for electricity
- Current sources of fuel
- Utilities such as school, hospitals, mode of farming
- Entrepreneurial aspirations such as mobile charging shops, *kirana* shops, food processing, rice and/or flour mill, etc.
- Network availability

Agriculture being the mainstay, details regarding the major crops, irrigation facilities (pump-sets), market facilities, etc. were collated. We learnt that diesel was used for operating irrigation pump-sets, while rice, a rain-fed crop, was being cultivated. The survey revealed that pulses such as *arhar*, *biri*, *moong*, and *kolatha* were being grown. We also realised that goat farming was one of the main livestock activities, and that households used biomass for cooking.

What we did…

Engineering aspects

These included detailed information gathering through ground survey, compilation of door-to-door details, assessment on existing number of houses, and their load requirements. This step was an input to the design calculations and preparation of drawings for the solar-battery system and smart mini-grid components.

In coordination with SunMoksha, various ground-level village-assessment activities were undertaken for the effective implementation of the mini-grid at the Kudagaon site. These included detailed technical and social surveys, village-level mobilisation and trust-building, community engagement, land acquisition, and formation of Village Energy Committee (VEC) to manage day-to-day mini-grid operations. These activities were useful inputs towards the development of the village power plant.

Community mobilisation

Trust-building-exercises were conducted through several group discussions on project scope, prospects, expected roles, and responsibilities of villagers.

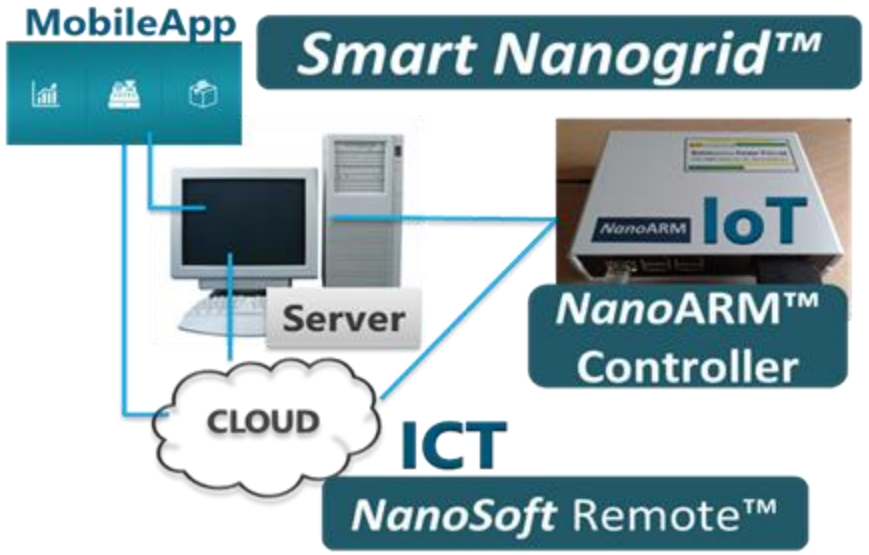
Administrative and legal aspects

These comprised the formation of VEC, registration under Association of People (AoP) for bank transactions, land lease agreement, and exploration of the optimum location for a power plant.

Choice of technology: About Smart NanoGrid™

Smart NanoGrid™ deploys a network of sensors and meters communicating over M2M (machine-to-machine)/ IoT network, to deliver the right amount of energy to the right location, at the right time, at the right price. Consumers have access to not just reliable power but also the advantage of scheduling their power requirement according to their convenience; viewing their electricity consumption and bill in real-time; paying their bills and registering complaints through a simple user-friendly mobile app. The IoT+MobileApp system manages metering, payment, differential tariff, connect/disconnect, scheduling, alerts, etc. The system also manages consumer relations, technical support, training and e-governance.

Choice of technology: About Smart NanoGrid™



Energy: Metering & Control, Connect/Disconnect, Theft-Management, Limits and Control.

Environment: Temp, Humidity, Pollution, Radiation, etc.

Hybrid RE Generation, Process Equipment Sensors, Assets

Smart NanoGrid™ Control Functions

This technology not only ensures operational efficiency, but also the scalability, by remotely monitoring and technically supporting the village projects in a cost-efficient and timely manner. It makes data available to experts in real time for a timely intervention, in case of failures or malfunctions; thus bringing long-term sustainability and scalability. The Cloud data is available to all remote stakeholders such as sponsors, government agencies, implementers, O&M providers, and domain experts to remotely monitor the performance of the project and intervene, if needed, bringing complete transparency

System Design

Based on the survey and other considerations, the design was finalised as below:

- Load consideration for 1 H.H = 114 W
- Eleven streetlights of 15-Watt each considered
- One 3 HP pump considered inside the Power Plant for PV module cleaning.
- 2 Nos. of 3 HP irrigation pumps considered for 5 hours of operations.
- 2 Microenterprises pumps/motors considered for 3 hours of operations
- **Total Microgrid load/day = 16.57 kW**

Equipment per Household (H.H) considered	Wattage	No.	Total (W)
LED Bulbs	4	2	8
Mobile Charger	6	1	6
Fan	60	1	60
TV	40	1	40
Total			114

System Design

PV Array

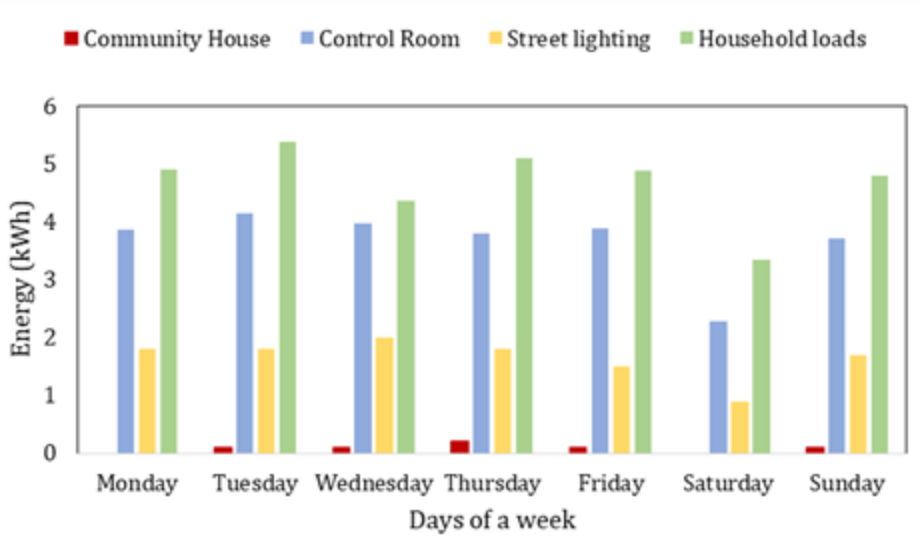
240V, 300 Ah Battery

415, 25 kVA PCU

DC

AC

To Mini-Grid distribution



Energy Demand of Kudagaon Village for a Representative Week

System Design

Specifics of microgrid:

- PV system size: **19.5 kWp**, poly crystalline
- Module: 325 Wp, 6 strings (10 modules each, 72 No. 6” solar cell)
- Inverter: 25 kWe (includes design margins at 10%)
- Battery: 300 Ah (2V), at 240 V DC (floor stacked, flooded type)
- Communicator: SunMoksha Nanoarm™ (IoT & cloud-based, hardware-software, node point energy manager)
- T&D: 500 meters (RCC poles, armored cables, conventional switchgear)

Grid Interconnection:

- Provisions for grid connectivity available

During Construction...

Access to Kudagaon was a challenge. There was a makeshift road on one side of the riverbed, which would get washed away for several months during monsoons and floods. From July 2018 – December 2018, the vehicular movement on this makeshift road was completely stopped due to flooding. There was no transport of heavy materials, such as battery bank, inverters, and solar panels to the village. Only light materials such as wires and cables could be taken to the pilot site in several consignments via boats.

Site Development

Plant Testing & Commissioning

A three-step process under various stages of implementation was adopted to ensure quality.

- Pre-Commissioning:
  Physical Verification of Equipment
- Plant Performance Tests:
  Plant Testing Activity
- Hand Over - Plant Management:
  Finalisation of Maintenance Schedules

Pre-Commissioning	Plant Performance Tests	Hand Over - Plant Management
Overall Project Civil Works	Battery Drain Test	Preventive & Corrective Maintenance
Transmission and Distribution Works	Generation Test	Scheduled Maintenance
Generation Plant	Inverter Capacity Test	Consumer Management
Household Connections	Priority Logic Test	Disaster Management
Safety	AC Smart Mini-Grid Performance Test	Asset Life Cycle Management
Smart Grid Communication Infrastructure	-	Community Management

Plant Testing & Commissioning…

Design v/s Test Results

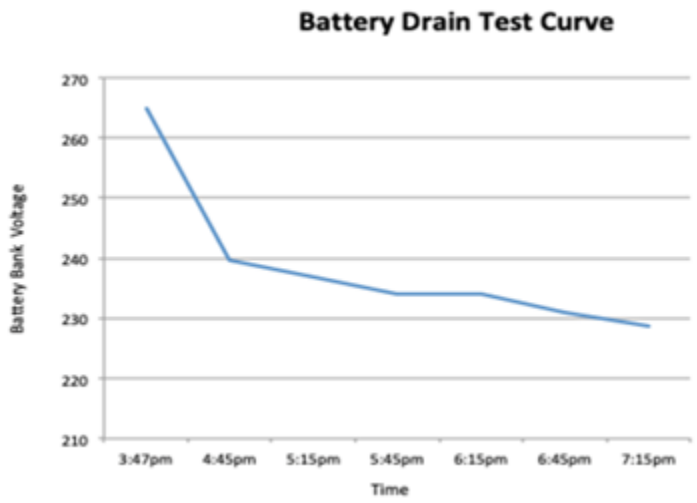
- Max Gen. Req. (design): 86 kWh
- Total PV Gen. (tested): 91 kWh
- Peak System Load (design): 13.44 kW
- Peak System Load (tested): 14.04 kW
- Battery Power Evacuated (test): 35 kWh (50% DOD)
- Battery Power (design): ~34.2 kWh (Max. night load calculated), consistent with the designed output of 72 kWh
- 12.85 kW night load (expected)
- 7.3 kW day load (expected)

AC Microgrid performance test

19.5 kWp Kudagaon Power Plant Voltage Drop Test Sheet

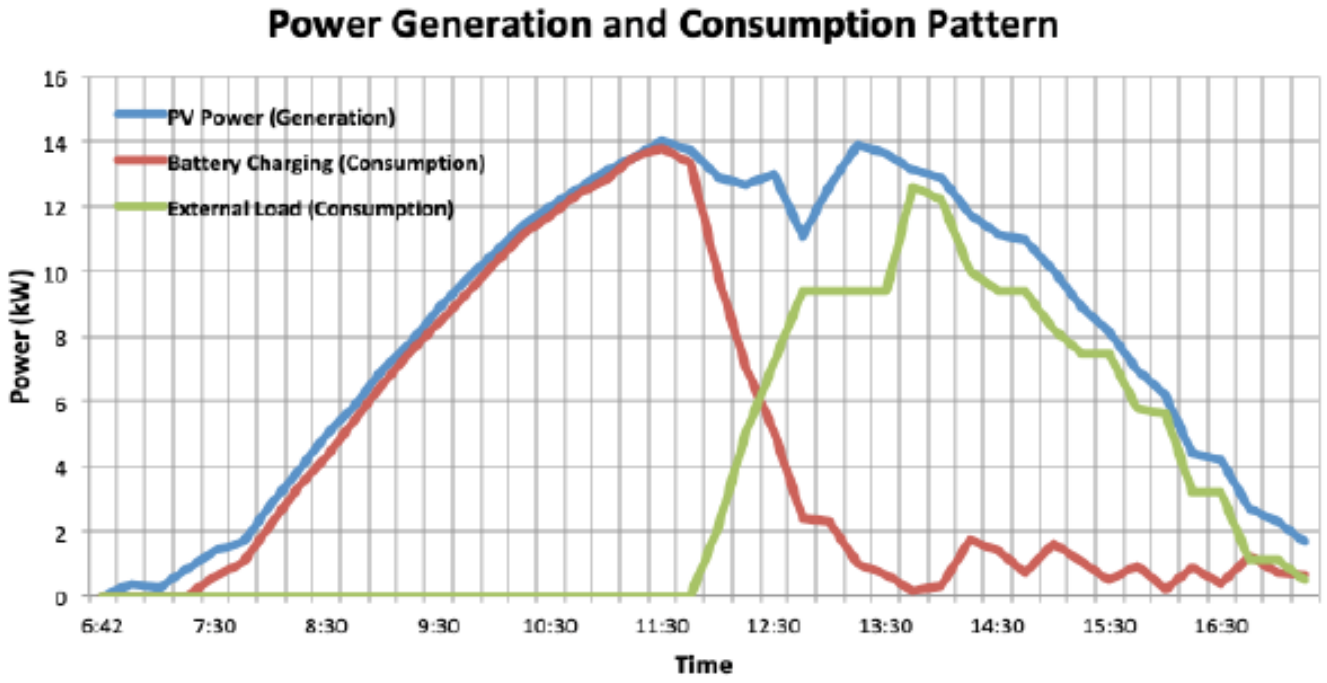
Actual Voltage Drop (Volt) @ No Load								Date- 21December 2018		
S.No	Phase	PCU	ACDB	CB/DB-02	CB/DB-03	CB/DB-04	CB/DB-05	CB/DB-06	CB/DB-07	
1	R-N	240.6	240.6	240.6	240.6	240.5	240.5	240.6	240.6	
2	Y-N	239.6	239.6	238.5	238.6	238.6	238.5	238.5	238.5	
3	B-N	240.6	240.6	240.2	240.2	240.2	240.1	240.2	240.2	
4	R-Y	412	412	411	411	411	411	411	411	
5	Y-B	412	412	411	411	411	411	411	411	
6	R-B	415	415	415	416	415	416	415	415	
Actual Voltage Drop (Volt) @ Load 1.07 kWe (Total Load on Inverter)								Date- 14 February 2019		
S.No	Phase	PCU	ACDB	CB/DB-02	CB/DB-03	CB/DB-04	CB/DB-05	CB/DB-06	CB/DB-07	Comments
1	R-N	240.6	240.6	240.6	240.6	240.5	240.5	240.6	240.6	As there is insufficient house hold load, the voltage drop is too low.
2	Y-N	239.6	239.6	238.5	238.6	238.6	238.5	238.5	238.5	
3	B-N	240.6	240.6	240.2	240.2	240.2	240.1	240.2	240.2	
4	R-Y	412	412	411	411	411	411	411	411	
5	Y-B	412	412	411	411	411	411	411	411	
6	R-B	415	415	415	416	415	416	415	415	
Theoretical Voltage Drop (Volt) @ 13.5 kWe Peak Load										
S.No	Phase	PCU	ACDB	CB/DB-02	CB/DB-03	CB/DB-04	CB/DB-05	CB/DB-06	CB/DB-07	
1	R-N	240	240	236.4	236.9	233.2	231.9	231.5	229.6	
2	Y-N	240	240	236.4	236.9	233.2	231.9	231.5	229.6	
3	B-N	240	240	236.4	236.9	233.2	231.9	231.5	229.6	
4	R-Y	415	415	411.4	408.3	404.6	403.3	402.9	404.6	
5	Y-B	415	415	411.4	408.3	404.6	403.3	402.9	404.6	
6	R-B	415	415	411.4	408.3	404.6	403.3	402.9	404.6	

Table 4: Voltage Drop Per DB



Commissioning

Various **tests** were conducted during the first week of **Feb 2019** before the commissioning of the plant on **14 Feb 2019**. The SPV plant generated a peak power equivalent to 73.8% of the rated peak power on a certain day. Considering the time of the year (February 2019) and the given weather conditions, the projected generation was found to be in line with the designed generation.



Mini-Grid Performance....

Sl#	House Number	Connection ID	Customer Name	Phase Status	Meter Status	Connection Status	Last Reading	Last Reading Time	Today's Consumption	Due	Last Billing Unit
1	Community House	322	Kudagaon Village Energy Committee	On	On	Active	6.2	14/03/2019 09:07 PM	0.1	0	
2	Control Room	279	Kudagaon Village Energy Committee		On	Active	160.4	14/03/2019 09:12 PM	4	0	
3	Inverter Output	319	Kudagaon Village Energy Committee		On	Active			0	0	
4	Street Light -DB02	313	Kudagaon Village Energy Committee	On	On	Active	36.2	14/03/2019 09:12 PM	0.4	0	
5	Street Light -DB03	314	Kudagaon Village Energy Committee	On	On	Active	12.3	14/03/2019 09:07 PM	0.1	0	
6	Street Light -DB04	315	Kudagaon Village Energy Committee	On	On	Active	12.8	14/03/2019 09:07 PM	0.1	0	
7	Street Light -DB05	316	Kudagaon Village Energy Committee	On	On	Active	12.3	14/03/2019 09:04 PM	0.2	0	
8	Street Light -DB06	317	Kudagaon Village Energy Committee	On	On	Active	23	14/03/2019 09:04 PM	0.3	0	
9	Street Light -DB07	318	Kudagaon Village Energy Committee	On	On	Active	33	14/03/2019 09:04 PM	0.3	0	
10	Total Load meter	321	Kudagaon Village Energy Committee		On	Active	201.577	14/03/2019 09:03 PM	5.471	0	
11	Village Load meter	320	Kudagaon Village Energy Committee		On	Active	142.636	14/03/2019 08:53 PM	3.953	0	
12	DB02 / 59	280	Laba Behera	On	On	Active	-1	14/03/2019 09:12 PM	0.1	0	
13	DB02 / 60	271	Gopala Pradhan	On	On	Active	3.9	14/03/2019 09:12 PM	0.4	0	
14	DB03 / 12	275	Jagannatha Pradhan	On	On	Active	3.6	14/03/2019 09:07 PM	0.1	0	

Live consumer data in the microgrid

Impact of Electrification

Key Statistics

- No. of households electrified: 59
- Max. no. of households that can be served : 85
- Minimum load per household: 14 W (2 LED bulbs + mobile charging point)
- Permissible sanctioned load per house is about 114 W
- Monthly cost per household: INR 100 for basic, with INR 10/ unit up to 4 units, and INR 15/ unit above 4 units.
- No. of Streetlights installed: 11 (includes 2 in power plant)

Livelihoods

Improvement

How quality of life improved?

A quality-of-life survey was conducted 5 months after the commissioning of the mini-grid, to gauge the impact of access to electricity on the lives of villagers.

The survey included interviews with individuals and groups across different segments of consumers. Overall, 35 respondents were chosen who were interviewed individually. Apart from **individual** interviews, **Focus Group Discussions** (FGD) were also conducted.

Keeping the local culture in mind, separate FGDs were formed for men and women. This ensured frank discussions and opinion sharing by women.

Survey Metrics

The following parameters were chosen to measure the change brought in by mini-grid installation in the village:

- Education
- Safety
- Indoor quality of life
- Social life
- Agriculture
- Entrepreneurial opportunities
- Migration patterns
- Happiness index

Education

- Study duration of children has increased.
    - Children were happy to study under the bright light from LED bulbs, instead of the kerosene lanterns

- Aspiration of villagers: The survey captured the educational aspirations of many residents:
    - Parents have shown interest to enroll their children in tuition classes. They were willing to pay for private tuition services.
    - Parents were exploring the possibility of **relocating their children back to the village**. Many school-going children stay outside the island to attend the local schools.
    - Some parents have even shown interest in computer training for their children.

Safety

The availability of electricity has influenced the timing and duration of daily activities of the villagers. The villagers are happy to have the freedom and ease to conduct their daily chores even after dark.

The following points illustrate the change:

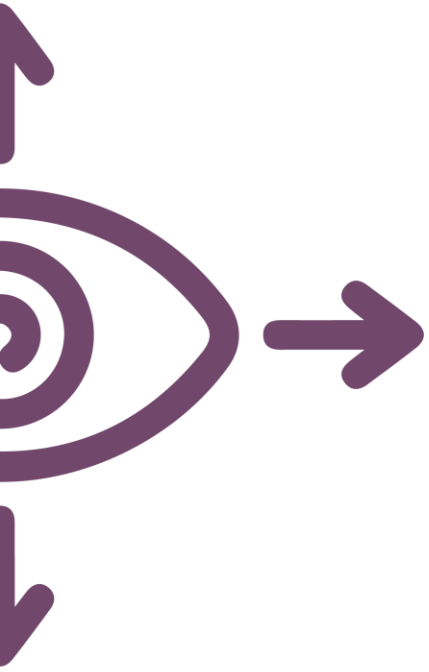
- Snakes were the biggest threat after dark. Since the installation of streetlights and the bulbs, the threat has reduced significantly.
- The use of lantern has reduced, resulting in reduced fire-related incidents.
- With the installation of streetlights, the movement of villagers and visitors after sunset has increased.
- Some farmers have started spending more time on the farm, as they can return home safely.
- The anganwadi teacher spends more time in the village, as it is easy to commute.

Improvements:

Indoor Quality of Life

Perspective:

Before & After



Social Life

Socialising for women and families: With the access to electricity, some of the households have bought television sets, allowing neighbours—especially women and children—to come over to watch movies, news, etc. Also, post-sunset, it is now easier for the women folk to indulge in outdoor socialising and participate in group meetings/events.

Socialising for men: Men are more interested in watching movies, sports such as cricket, and the daily news on TV.

Increased internet usage: Previously, the families used to get their mobile phones charged from Nuakudagaon (village on the mainland) once a day, but now they have the ease and flexibility of charging phones at their convenience.

Village Social events: At the request of the residents, the VEC has made provisions to supply subsidised electricity during two major festivals. This has reduced their expenditure on diesel generator during the carnival. The savings have helped raise the quality of village feast during the festivals.

Agriculture

- Currently, the farmers practice agriculture only during monsoon season, which lasts for a period of 4 months in a year. They grow crops, such as eggplant and ladies finger, with a few growing rice, lentils, and tomato. For the rest of the year, they either depend on rains or kerosene pumps to irrigate their fields.
- Aspirations: With reliable electricity from the mini-grid, the villagers have requested access to water for irrigation to practice agriculture throughout the year.
- A person recalled that a few years ago the fields got enough water under the impact of a natural flood, which increased the agricultural produce, bringing in good revenue.
- They believe that with steady water supply, they can grow cash crops all year round and have a better income. Some of the families own mango orchards and earn up to INR 30,000/- during the season. Useful additions such as food-processing units and food-storage facilities can help boost the economy of the village in future.

Entrepreneurial Opportunities

- Entrepreneurial opportunities are of specific interest to the villagers as they not only provide economic support but also uplift them. Women, especially the youth and middle aged, are keen to explore such possibilities
- Many have specifically shown interest in the commercial opportunities offered by flour mill, rice mill, and cold storage facilities
- Some women are keen to take tuitions and pursue vocational opportunities such as computer courses and stitching
- Many women have also come forward to be a part of VEC, indicating a major social change.

Migration Patterns & Impact on Level of Happiness

- Migration from the village is a cause for concern. People migrate in search of better earning opportunities
- Some of those who used to venture outside the village for daily wages have requested for irrigation facility, so that they can practice agriculture all year round
- Locals believe that if there are enough job opportunities in the village or a scope for long-term agricultural activities, their children might return to settle in the village
- The mini-grid has been instrumental in impacting the lives of the villagers positively. For instance, the mini-grid operator used to earn daily wages in neighbouring villages. Now he has a monthly salary and doesn't need to step outside the village for livelihood. Additionally, he gets enough time to practice agriculture
- Villagers have expressed gratitude for the many opportunities and benefits that the access to electricity has bestowed on them
- Now women can conveniently complete their chores even after sunset. Parents are happy to see their children studying and playing more
- Both men and women are happy to socialise under the streetlights
- The fear of snakes has gone down.

Recommendations

- With many women showing an interest in learning stitching, computers, and in giving tuitions, there is an opportunity for women empowerment
- There is a demand for flour mill, rice mill, and cold storage in the village and refrigerator for home usage. To accommodate this, the size of the plant needs to be increased
- People need to be further educated on energy-efficient electronic appliances to save on monthly electricity bills
- Provide irrigation possibilities to the village that can be powered via the existing power plant.

Device Purchased Post Commissioning	Number of Households Owning the Device
Additional bulb connections requested	16
Fans	27
TV sets	6
Home Theatre with Woofer	3
Coolers	2

Predicted increase in load over the next two years

- Increase in domestic load
- Huge potential for irrigation loads; 7 pumps of 3HP required
- Potential for micro-economic zone as well

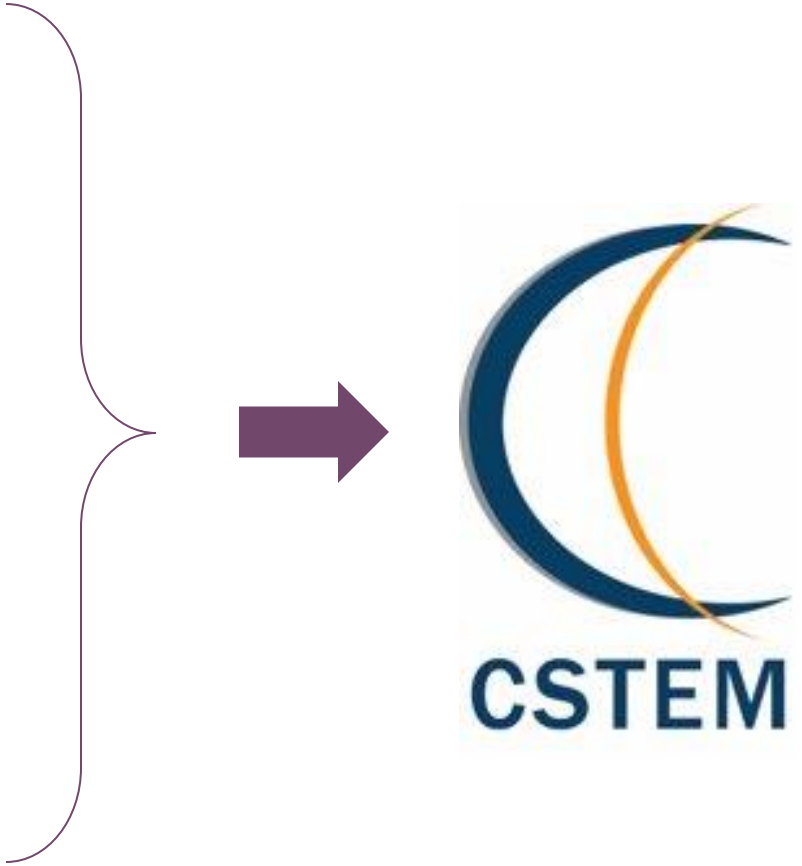
	Immediate Loads	Next Six months	Next two years
Domestic	• 59 households with lights and sockets • 11 streetlights • Community Centre • Panchayat Office	• Increase in domestic consumption due to TV, refrigerators	• Domestic consumption increase due to reverse migration
Commercial	• Two *kirana* shops • Rice huller • Three diesel-operated pumps	• Switch from diesel to electric pumps • Clean drinking water • Flour machine, oil expellers	• Cold storage • Food processing units • Complete Micro-Economic Zone • Eco-tourism

Computational Tool

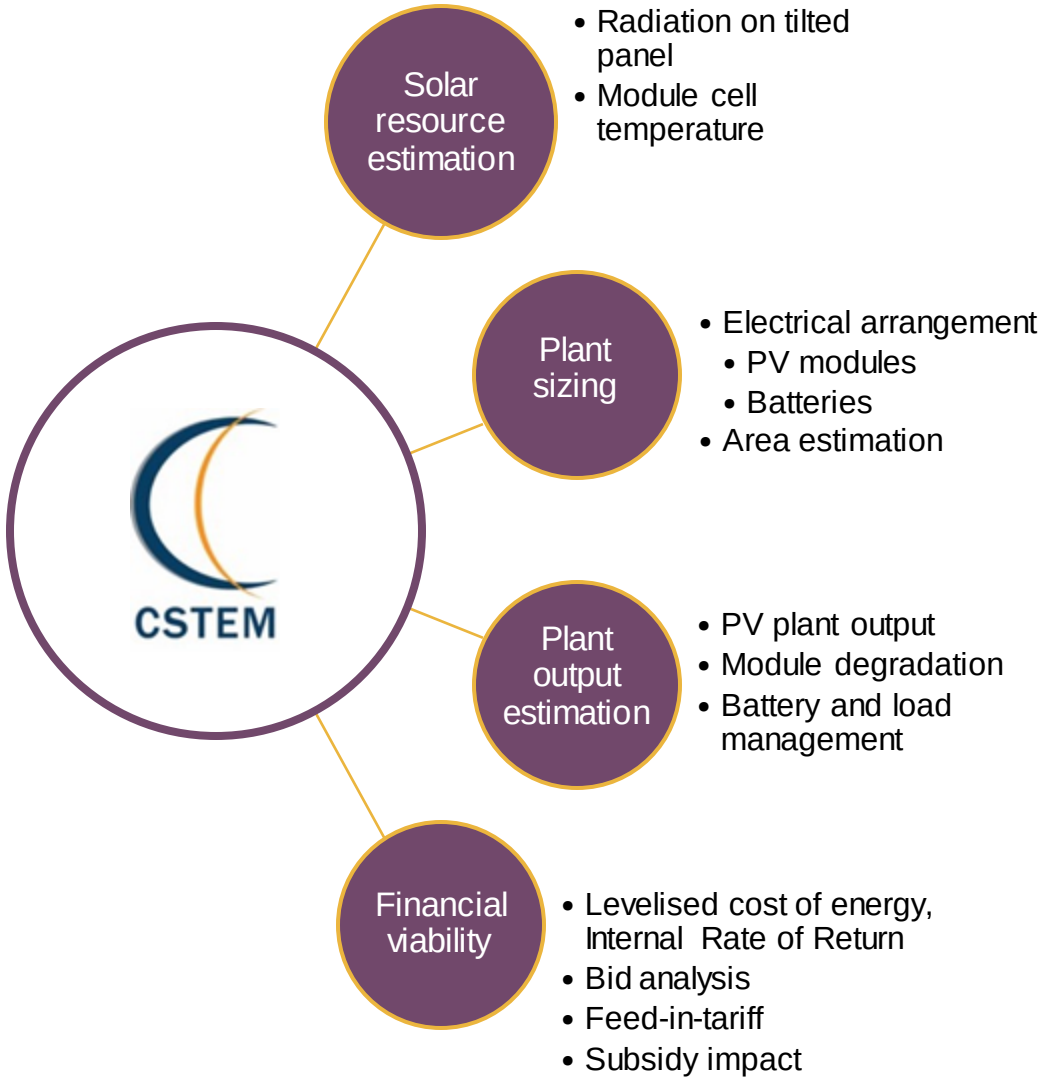
CSTEP's Solar Techno-Economic Model for Photovoltaics (CSTEM PV)

Scope/Features

- Pan-India site identification
- Quick techno-economic pre-feasibility assessment
- Web-based, hence easily accessible
- Compatible with Indian norms and based on Public information



Brief Context of CSTEM PV



An open-access tool called *CSTEP's Solar Techno-Economic Model (CSTEM) for Mini-grid* was developed to facilitate pre-feasibility analysis of PV and battery-based mini-grid system across India.

This tool aims to support policymakers, developers, and researchers in making informed decisions for setting up mini-grids.

https://cstem.cstep.in/cstem/

Input – Output Framework

Choose system type

Design a utility-scale PV plant

Design a mini-grid

- Grid-connected
- Off-grid

Inputs

Choose site for assessment

Enter electricity demand or PV plant size*

Choose technology

Enter costs & financial metrics

Outputs

Design summary

Resource availability

System design details

Financial outcomes

* Input PV capacity for utility plants. For mini-grid systems PV capacity is derived based on electricity demand.

Example Output from the Tool...

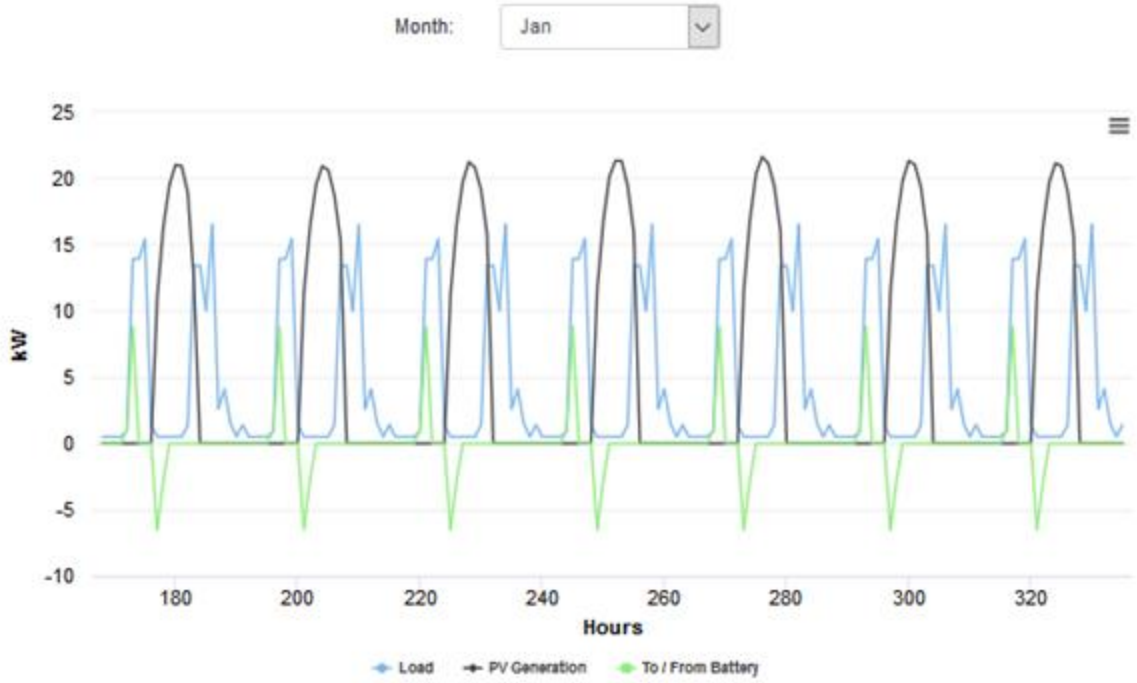
Simulated Plant

Based on the above choice the summary of the plant designed and simulated is as follows

PV Capacity Plant DC capacity at Standard Testing Condition (STC) 32.4 kWp	**Battery Capacity** Estimated Capacity for chosen time window of backup 630 Ah, 30.24 kWh
DC to AC Ratio Scale of DC side system for unit capacity of AC system 1.08	**Battery Life** Estimated average battery life over the PV plant life. 4.83 Years
Time Window Recommended window for shadow free operation of panels 9-15 Hours	**Battery Backup Hours** Number of hours in a day supported by battery power 2 Hours
Plant Area For shadow free operation in recommended time window 0.091 Acres	**Battery Replacement** Number of replacements over the PV plant life. 4

Interaction Between Load and PV - Battery System

The following graph presents the hourly interaction between the load and PV - Battery system for a representative week of every month. Power from battery (discharging) is considered positive and to battery (charging) is considered negative.



Recognition of Work: Smart Grid Award

The Kudagaon Mini-Grid Project by CSTEP and SunMoksha won several prestigious awards. The most prestigious of them is the ISGF Innovation Award

ISGF INNOVATION OF THE YEAR AWARD, 2020

ISGF's Highest, The DIAMOND AWARD 2020 – Kudagaon Mini-Grid

Conclusions and Way Forward

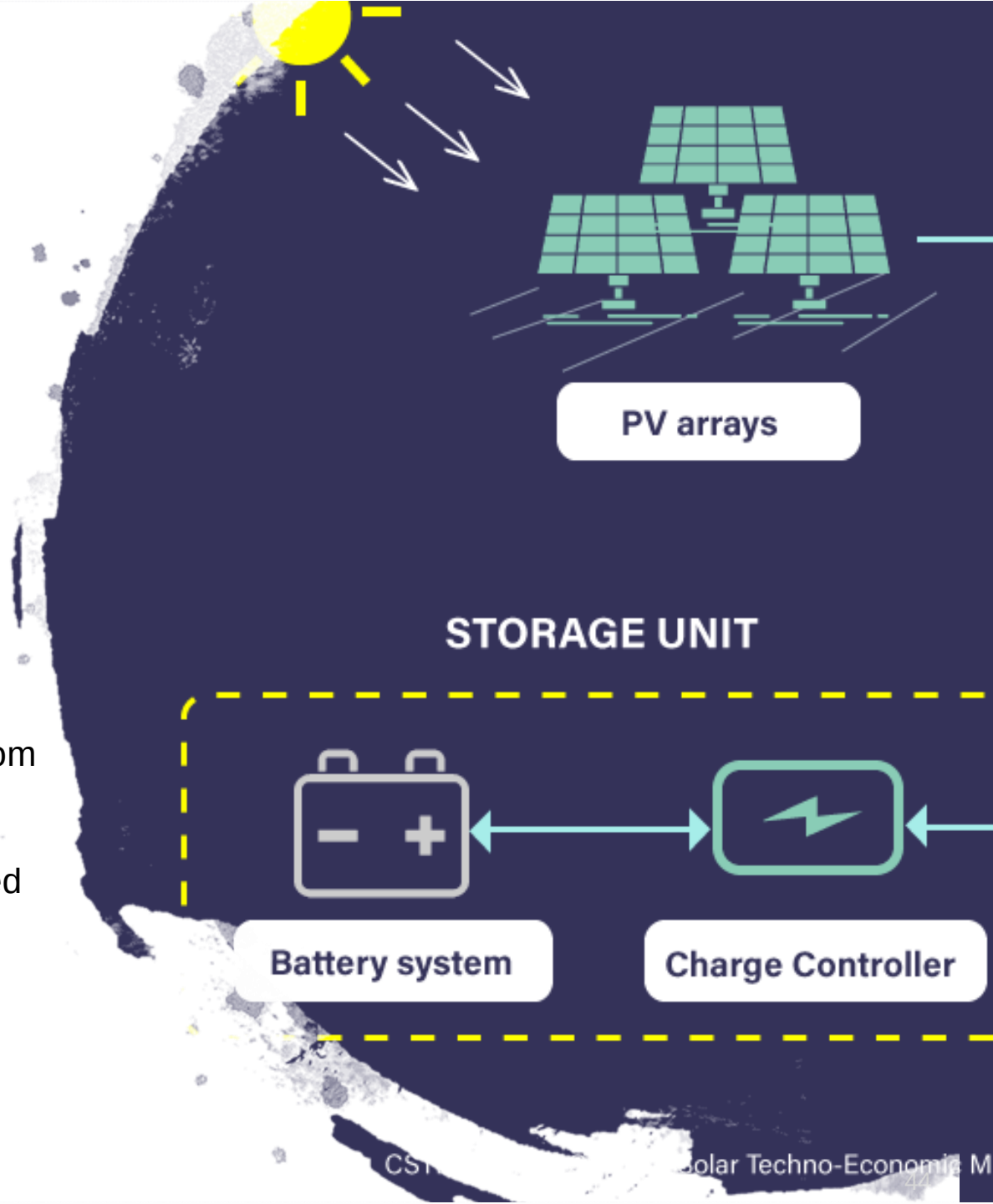
Mini-Grid

- Demand accommodation of the following by increasing the plant size
  - Rice mill, flour mill
  - Post-harvest machines
  - Support irrigation possibilities
- Spread awareness on efficient appliances and electrical appliances and savings that can accrue through them
- Create and Implement opportunities for women empowerment
- Install Sunmoksha’s smart Aquanet to support sustainable agriculture

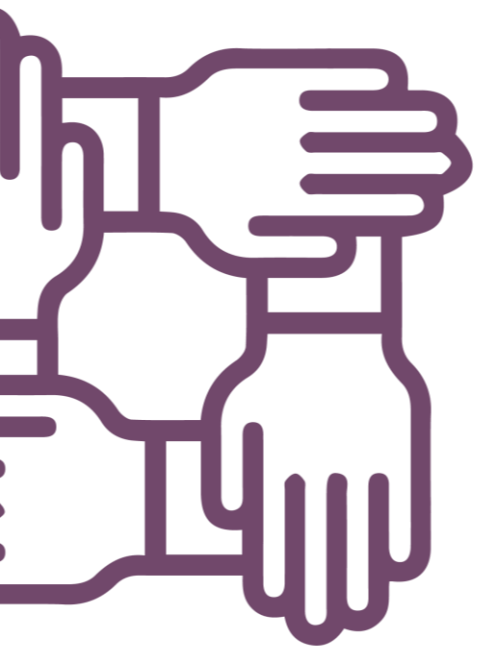
Conclusions and Way Forward

CSTEM PV tool

- Expand depth of models:
  - Demand model
  - Storage technologies
  - Module tracking and shading
- Include other business models
- Provisions for:
  - Uploading technical/financial details from other sources
  - Generating and downloading automated reports



Contributors



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