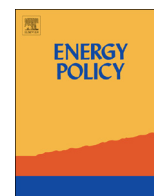




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Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required?

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HIGHLIGHTS

- The academic and action research activities undertaken through OASYS South Asia Project are reported.
- Evidence produced through a multi-dimensional participatory framework supplemented by four demonstration projects.
- Funding and regulatory challenges militate against universal electrification objectives by 2030.
- Innovative business approaches linking local mini-grids and livelihood opportunities exist.
- Enabling policies are suggested to exploit such options.

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ABSTRACT

With 1.2 billion people still lacking electricity access by 2013, electricity access remains a major global challenge. Although mini-grid based electrification has received attention in recent times, their full exploitation requires policy support covering a range of areas. Distilling the experience from a five year research project, OASYS South Asia, this paper presents the summary of research findings and shares the experience from four demonstration activities. It suggests that cost-effective universal electricity service remains a challenge and reaching the universal electrification target by 2030 will remain a challenge for the less developed countries. The financial, organisational and governance weaknesses hinder successful implementation of projects in many countries. The paper then provides 10 policy recommendations to promote mini-grids as a complementary route to grid extension to promote electricity access for successful outcomes.

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1. Introduction

About 1.2 billion people in the world did not have access to electricity in 2013 (International Energy Agency, 2015) and achieving the universal access to sustainable energy even by 2030 remains a significant policy challenge. The visibility of the energy access challenge has improved since the launch of the Sustainable Energy for All (SE4ALL) initiative in 2012, attracting international and national players in a big way. It is now accepted that despite undue preference for grid extension, alternative approaches to electrification have to be pursued as well in order to meet the universal electrification objectives by 2030 due to the compressed timescale to achieve the target (Bazilian, et al., 2012), cost disadvantage of grid extension particularly

in remote areas or for dispersed population (Moner-Girona et al., 2012), technological innovation for electricity generation and end-use technologies (such as LED lamps, efficient storage) and rapid price decline of some technologies (The World Bank and International Energy Agency, 2015).¹

It is estimated that 135 million people have to be provided access to electricity every year in order to achieve the universal access by 2030 (The World Bank and International Energy Agency, 2015) and that grid extension will be feasible for only 40% of the population, and stand-alone and local grid options delivering electricity to 60% of the non-electrified rural areas (International Energy Agency and the World Bank, 2014). While the stand-alone individual solutions have traditionally received greater attention in the literature, mini-grid systems can offer a collective solution

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¹ While both standalone individual systems and mini-grid are considered as off-grid, this paper deals with mini-grids only and did not consider any stand-alone individual systems (such as solar home systems and/or solar lamps).

at a relatively lower cost to facilitate basic needs as well as productive use of electricity thereby promoting local economic development. However, being a more recent development for rural energy delivery, the mini-grid based electricity supply business faces a number of challenges including a risky business environment due to unknown consumer characteristics and unfamiliar business activities, weak institutional arrangements arising from non-supportive regulatory and policy frameworks, limited access to low cost finance and inadequacies in local skills and capacities.

The purpose of this paper is to share insights and lessons from a recently concluded research project on off-grid electrification in South Asia and to present a set of policy recommendations for mainstreaming and up-scaling of local mini-grid based systems in non-electrified areas of the developing world. Funded by Engineering and Physical Sciences Research Council (EPSRC) and Department for International Development (DFID, UK), the project, OASYS South Asia,² has investigated off-grid electrification using mini and micro-grids and undertook action research through demonstration activities. The knowledge gained through this project can contribute towards developing an enabling ecosystem for mini-grid based electricity service in the developing world.

The organisation of the paper is as follows: the second section presents the analytical framework followed in the project; Section 3 provides a summary of lessons from local and national level case studies and other desk-based research while Section 4 presents the insights from the demonstration activity; Section 5 offers ten policy recommendations distilled from the experience gained from implementing the OASYS project in order of preference, while Section 6 contains the concluding remarks.

2. Analytical framework

The basic premise of this research was that if any modern energy has to compete with traditional energies in rural areas, any credible off-grid electrification alternative has to ensure a reliable electricity supply to support income-generating activities for the poor on a regular basis. In other words, decentralised electricity solutions have to cater to productive activities in rural areas, but the existing stand-alone solutions offer limited potential for productive use of electricity. Therefore, this research, through an elimination process, focused essentially on mini-grid -based electrification.

The logical framework adopted in the project involved the following steps:

- 1) An in-depth multi-disciplinary review³ of the existing off-grid electrification efforts in South Asia and elsewhere was undertaken to take stock of the present situation. It revealed that a database of off-grid projects is lacking and there is also a dearth of studies with integrated frameworks of analysis.⁴
- 2) To bridge the data gap, a database of off-grid projects in India⁵ was developed from the documented experiences of a large

² An international consortium of research organisations consisting of De Montfort University, Edinburgh Napier University, Manchester University, the Energy and Resources Institute (TERI) and TERI-University participated in the project activity. Initially, University of Dundee was involved as the lead institute but since September 2012, the project was transferred to De Montfort University when the PI moved there.

³ The review considered the technical options, regional and national experiences, delivery models, electricity-development linkage, regulation and governance, funding as well as alternative approaches used to analyse off-grid problems.

⁴ Most of the studies either are anecdotal, or focus on techno-economic assessments or present policy narratives without adequate attention to the local contexts and key determinants shaping the development trajectory of these projects.

⁵ The dataset is available from here: https://www.academia.edu/15719978/Selected_Data_of_off-grid_projects_in_India.

number of off-grid projects supplemented by field visits to selected project sites. The database covers, among others a range of technologies, geographical locations, capacity of the plants, tariff structures, ownership and management arrangements.

- 3) An integrated framework for the analysis of the business case for off-grid projects in South Asia was developed, which was informed by the data available from the off-grid project database indicated above, supplemented by information obtained from the literature, field visits and stakeholder consultations.
- 4) An action research component was carried out where alternative delivery options were pilot tested on the ground. Four demonstration activities⁶ provided practical insights about managing the entire process.

Fig. 1 presents an iterative process of decision hierarchy for off-grid energy projects consisting of six essential stages (namely, demand mapping, project scenario design, technology mapping, techno-economic analysis, business case analysis and financing mechanism).⁷ At one extreme, the private-led business development will be feasible where users are willing to accept the services on a commercial basis. On the other extreme, where users cannot afford the services on a commercial basis, public and socially-driven funding would be required. In between these extremes, many combinations of contexts are possible, which would require a mixed form of financing.

The framework with adaptations for specific cases has been applied to various case studies undertaken in the project, namely for Bangladesh (Bhattacharyya, 2015), India,⁸ Nepal (Sarangi, et al., 2014) and Sri Lanka (Sarangi, et al., 2015). The same framework has also been followed in the demonstration activities carried out in India: Dhenkanal and Kandhamal districts (Odisha), as Sunderbans (West Bengal) and Sitapur (Uttar Pradesh).

The next section presents the main findings from our case studies and analytical research while Section 4 presents the lessons from our action research activities.

3. Main findings from the research activity

A brief summary of notable findings and lessons is presented below based on a review of various publications and case studies from the project.

3.1. Electrification progressed but affordable universal electrification remains a dream

Our literature review found evidence of a significant progress in electrification around the world but the success has varied depending on the level of government commitment, and institutional and financial support to the process. Better performance was achieved with clear policy frameworks and milestones, enforcement of appropriate technical standards, standardised operational metrics, and support for finance, R&D and stakeholders'

⁶ These are as follows: a community-managed micro-grid based solar PV electrification in a cluster of villages in Dhenkanal district of Odisha, a solar AC mini-grid in partnership with local administration in Kandhamal district, Odisha, a private developer managed solar DC micro-grid in Uttar Pradesh and a social foundation managed solar AC pico-grids for remote island villages in the Sunderban Islands.

⁷ Further details on the analytical framework are available in and are not repeated here.

⁸ A number of studies were done for India, which include among others the following: Borah et al. (2013), Mahajan and Fernandez (2014), Palit (2013), Sarangi et al. (2012), and Palit et al. (2014).

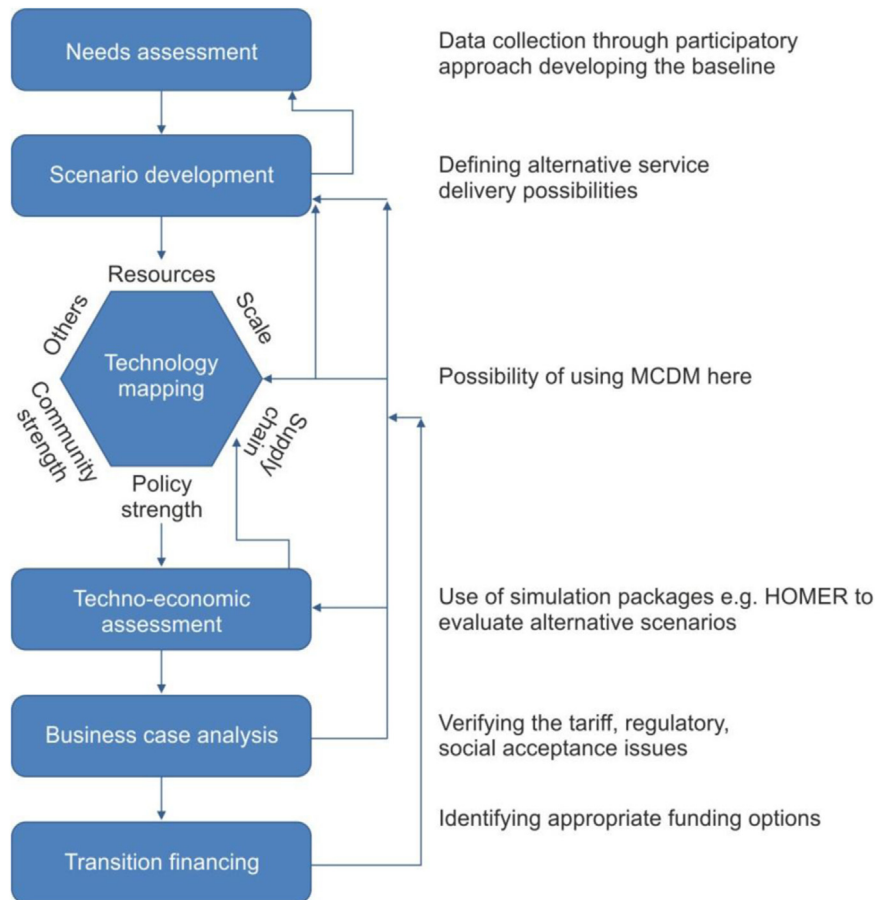


Fig. 1. Theoretical framework.

training (Palit and Chaurey, 2011). The state has generally borne the cost of infrastructure development and network extension but some contribution from the users has also been found in a number of cases (Bhattacharyya, 2013c). A top-down, grid extension driven electrification emerged as the preferred approach.

On the other hand, the motivation for off-grid electricity projects varied: regional governments aimed at increased economic activity, access to modern forms of energy inspired local communities, whereas private entrepreneurs were looking to build for-profit energy businesses. Accordingly, different business models have been experimented with (Krithika and Palit, 2013). However, off-grid options, with limited generation capacity and hours of use, act more often as a pre-electrification option that caters to limited needs of the consumers for lighting and some entertainment through radio/TV connections. Productive use of energy for income generation was hardly promoted and consequently, communities continue to aspire for grid connectivity to meet their aspirational loads. This sense of “inferior” or “temporary” nature of these solutions reduces their acceptability and attractiveness. This also creates a sense of “discrimination” or “isolation” in the minds of the users and can adversely affect the success of such programmes (Bhattacharyya, 2013).

Cook (2011, 2013) found that rural electrification schemes have not so far provided universal access and have been unaffordable for most bottom-of-the-pyramid (BoP) people. He found that connection charges and electricity tariffs were major barriers for the poor to access electricity and that innovative targeted subsidy schemes are required to bring the poor on board. Any successful rural electrification programme also requires complementary

infrastructure development and the existence of an effective implementing agency.

3.2. Universal electrification by 2030 remains a big challenge

Globally, sub-Saharan Africa and South Asia account for most of the unelectrified population and a low rural electrification rate is quite common in many countries. The main challenge facing the universal electrification agenda is how to achieve mass electrification given the existing electricity network infrastructure in different countries, the cost of further grid extension and the possibility of electrification through a portfolio of off-grid solutions. Electrification experience suggests that countries have achieved high rates of grid expansion over a long period of time and countries with a very low penetration of electricity network will find it challenging to expand the system rapidly. Similarly, (Bhattacharyya and Cook, 2013) argue that if off-grid electrification market is believed to follow the S-curve with three distinct stages (namely preparation, take-off and scale-up), most of the countries find themselves in the preparation and market test phases and only a few preparing for take-off in some areas. Finding sufficiently skilled workforce, training them for the job, and retaining them can be a challenge for any given project. The problem aggravates when the human resource has to be multiplied for scale-up and replication programme. Aligning the human resource development programme with the off-grid development programme remains a challenge. Consequently, the universal electrification target appears to be highly ambitious. Our action research, discussed below, confirms that a utility-like approach is required to deliver the ambitious objective.

3.3. Timely mobilisation of sufficient funds for investment holds the key

The enormity of the financing challenge is indicated in a report by (International Energy Agency and the World Bank, 2014) that suggests to achieve the universal electrification objective by the year 2030, an investment of \$890 billion will be required between 2011 and 2030, excluding funding required to ensure proper operation and maintenance of grid and off-grid systems. (Bazilian et al., 2010) suggest even higher investment requirements, highlighting the uncertainty in the estimates. As the required level of investment is four to five times higher than the average annual investment in energy access in recent years, (Bhattacharyya, 2013a) concludes that the least developed countries will find fund mobilisation as the most critical issue. Even investing their entire energy-related capital budget on electricity access will not achieve universal electricity access by 2030. Electricity services to the BoP will need non-government actors including the private sector but an enabling environment to attract different actors is a must. As rural electrification projects face a number of barriers, including “first generation” barriers,⁹ removing them to promote investment and business, and supporting innovative approaches through collaboration, learning from others and experience sharing will be very essential.

It is important to highlight that affordable service delivery to consumers with low paying capacity requires financial support, despite declining capital costs of technologies. High transaction cost of projects in remote areas and limited economies of scale and scope increase costs. On the end-use side, while micro-financing has been widely used to enhance access to small appliances through credits, irrational interest rates for micro-lending to poor households remain rampant. Flexible financial instruments, such as interest rate buy-down, viability gap funding, output based aid, for both the end-users and/or energy entrepreneurs, and appropriate risk mitigation measures for the rural banking sector will be more effective in ensuring not only dissemination of solar products but also their sustainability. There is also a need for creating a mechanism for easy access to credit and financing through simpler processes and better accountability mechanisms (Palit, 2013).

Hence from a policy perspective, devising a strategic and flexible support mechanism is essential for promoting mini-grid based electrification.

3.4. Governance arrangement for off-grid electrification requires priority attention

Our stakeholder interactions revealed that regulatory uncertainty and policy vacuum hinder growth of the off-grid sector. Policies vaguely define the off-grid systems and tend to be ambiguous on technology choice, resulting in inappropriate technology selection in some cases. Sole attention to initial investment and poor recognition of the capital requirement at regular intervals for component replacement make the financial support mechanism less adapted to the needs of the projects. Similarly, multiple ministries with overlapping organisational arrangements for off-grid electrification lead to poorly co-ordinated approaches and strategies, thereby causing confusion and duplication in some cases (Mishra and Sarangi, 2011). The case study on Nepal (Sarangi et al., 2014) shows that political instability, uncertainty and ad-hoc donor funded programmes are major hindrances of the sector.

Moreover, policy uncertainty about grid extension, poor access to credit and absence of formal financial institutions at the local level deter private entrepreneurs to venture into the sector (Sarangi et al., 2014).

Strengthening the regulatory environment is one of the prerequisites for creating an enabling environment for attracting private investment in the off-grid sector. As mini-grid based electrification involves a natural monopoly component (e.g. distribution network), some form of control is required to ensure investor and consumer protection, reporting of information and incidents, and monitoring of service quality (Bhattacharyya, 2013b). Depending on the stage of the market development, local capacity, governance endowment and the stakeholder involvement in the activity, different regulatory arrangements can be considered (such as a generic waiver, or a light-touch simplified arrangement or a formal fully developed arrangement). Any regulatory approach must (1) avoid confusion about the service area; (2) protect the investor against the grid extension threat; (3) ensure quality and reliability of service, (4) promote health and safety and (5) ensure transparency and flow of relevant information; (6) ensure financial sustainability through tariff and support systems (Bhattacharyya, 2013b). The framework also needs to be flexible to support different types of interventions with unique characteristics.

As the threat of grid expansion remains a major uncertainty for the investors, any assurance in this respect can improve the investment prospects. In Sri Lanka off-grid electrification was undertaken in areas where the utility certified that the grid will not reach at least in the next five years (Sarangi et al., 2015). Similarly, the concession system, such as the PERMER programme in Argentina, also provides exclusive rights to the investors to carry out off-grid electrification (Best, 2011).

As in any energy project, tariffs are crucial for any mini-grid project but setting a tariff satisfying the consumers and investors simultaneously remains a challenge. The dilemma arises from a number of factors (Bhattacharyya, 2013b): limited paying capacity of consumers; expectation of a subsidised supply due to subsidy for grid electricity; higher capital costs and high cost of supply due to low consumer base, high incidence of peak demand and limited capacity use due to low demand. In the absence of any regulatory intervention, a mutually agreed tariff is decided but with bargaining power on the supplier's side, to protect its interests. The threat of a credible substitute however provides a check, forcing the suppliers to set the charges competitively against such alternative options (e.g. monthly expenditure on kerosene, payments for supply from a diesel generator). Our case studies clearly highlight this issue: Husk Power and Mera Gao Power have fixed the tariff following the above-mentioned logic (S. Bhattacharyya, 2014; S.C. Bhattacharyya, 2014). However, in such cases consumers in adjacent villages may pay different charges and suppliers may exploit the poor by charging relatively high rates. A regulated tariff on the other hand can be more demanding administratively given the limited regulatory capacity in most developing countries. Moreover, regulators may not be able to discriminate between grid-connected and off-grid supplies in terms of subsidy. Yet, the subsidy provision, record keeping and verification can be demanding, costly and difficult to implement. Our case study on Chhattisgarh finds that the state has provided the same level of subsidy for grid-connected and off-grid systems and that the state agency has effectively used the subsidy to enhance operational viability of its mini-grid interventions (Palit et al., 2014). However, subsidised grid-based power creates a non-level playing field and even 100% capital cost subsidy for mini-grid based supply will not be sufficient to ensure price parity with such subsidised tariff (Bhattacharyya, 2015). As the operating cost subsidy will impose a recurring burden on government's finances, it is unlikely to be

⁹ Such as low returns on investment, high transaction costs, lack of experience with energy access financing, high cost of capital, and unsuitability of existing credit facilities.

sustainable.¹⁰ This makes the energy access challenge significant (Bhattacharyya, 2015).

From a policy perspective, the mini-grid based electrification requires a clear set of rules that recognises the specific features of mini-grid business and a suitable regulatory system that supports such businesses.

3.5. Innovative business opportunities exist

We observe that in the off-grid electrification space, enterprising actors have exploited innovative ideas and opportunities to deliver electricity. In the area of mini-grids, three broad types of business models can be identified, namely lighting only, lighting plus and anchor load models (see Fig. 2).

Lighting only micro-utilities generally use micro/pico systems (few hundred Watts) to electrify households in small villages or hamlets with a concentrated population. Each user typically gets two light points (1–3 W each using LED lamps) and a mobile charging point, thereby keeping the demand less than 10 W per household. This is the basic level of service that displaces harmful kerosene lamps by renewable energy based electricity. Mera Gao Power, Mlinda Foundation, Chhattisgarh Renewable Energy Development Agency (CREDA), IDCOL solar programme have followed this model.

The lighting-plus model extends the service to other household electricity demands as well as to productive and community electricity needs. Consumers with higher paying capacity can use higher loads while commercial and industrial demands are also catered for. The private sector led initiatives such as Husk Power Systems or DESI Power and renewable energy -based or hybrid systems in the Sunderbans, Sri Lanka and Nepal constitute some examples from South Asia. The private sector entities generally operate in niche areas and offer services on a commercial basis. Their rates tend to be higher than grid-based supply and they connect only those households who can afford to pay. However, they tend to use innovative approaches and management skills to ensure effective service delivery. On the other hand, the public sector or community-based services often adopt a socially responsible tariff and do not aim to recover full cost.

The anchor load model is a variation of the lighting plus option where a major user (often a telecommunication tower, or a local industry) provides the base demand and the excess supply is distributed to the local community for meeting their lighting needs. In India, OMC Power has used this model to provide renewable electricity to displace diesel-based power supply to telecommunication towers while enhancing electricity access to neighbouring areas. The private sector has followed this approach as a risk mitigation option.

Businesses have developed smart and innovative approaches to deal with the challenging environment. Smart technologies such as LED lamps, smart meters, low maintenance batteries, and grid compatible inverters are commonly used. Companies are employing various risk mitigation strategies as well. For example, Mera Gao and Mlinda Foundation have used Joint Liability Groups (JLG) to manage the credit and payment risks. The group liability makes a group of users jointly liable and if one fails to pay, the group has to take responsibility to avoid default in payment. This increases the peer pressure and checks the free-riding mentality. Similarly, flexible bill collection (on a daily or weekly basis), either in-person or using recharge coupons, was introduced by some to lower the financial burden on the consumers, although the bill collection cost increases for the supplier.

¹⁰ This approach is used in PERMER, where the government cross-subsidises the off-grid tariff.

3.6. Integrating off-grid electrification with livelihood and other development projects is essential

Our study confirms that project viability and sustainability improves by integrating livelihood generation options and productive energy demand in local electricity supply projects. The plant capacity utilisation suffers in a predominantly residential load system but commercial demand during off-peak hours could address this problem and reduce unit cost of electricity.¹¹ In addition, the circular economy effect of income generation through electricity use enhances the paying capacity of users, reducing the non-payment risk. It also supports demand growth over time, ensuring project's long-term cost recovery. Similarly, by focusing on other development infrastructure and training needs, the project can support education, agriculture, health and clean water supply in rural areas, thereby contributing to human capacity development, and social development.

Being remote, any off-grid project incurs high maintenance costs if they have to rely on services from nearby towns. Instead, developing local capacities for resolving minor technical issues can be a cost effective option. Accordingly, engaging with the local actors¹² forms an essential element of project development. Further, the capacity development should be a continuous initiative and the length of such engagement with local actors may depend on the level of absorptive capacity of a particular community and the local institution (Sharma and Palit, 2014).

However, it is important to realise that it may not be cost-effective to integrate livelihood options in all off-grid electrification projects. Productive load integration may be easier for technologies such as bio-gasification or micro-hydro, which may otherwise waste a significant amount of energy. Livelihood options can be considered separately in other cases considering the private cost and expertise required to develop them. Where an off-grid project just provides electricity to households, it may open up new opportunities through time saving and better communication opportunities.

Hence, livelihood integration and policy coordination are essential for creating an enabling environment.

4. Lessons from action research through demonstration activities

As indicated earlier, the project undertook four demonstration activities of delivering local grid-based off-grid electrification to remote communities of different socio-economic backgrounds through alternative organisational models, funding arrangements and technology choices. This section briefly describes these activities and lessons therefrom.

For all these projects, the regulatory environment is defined by the Electricity Act 2003 and policies deriving therefrom. The Act allows off-grid electrification and has waived the licence requirement for rural electricity generation and supply. The National Electricity Policy and the Rural Electrification Policy allow for local mini-grids in non-electrified villages and allow the tariff to be mutually decided by the supplier and user. Until recently, there was no clarity on the exit policy in the event of grid extension to a hitherto off-grid area but the revised tariff policy in 2016 has

¹¹ This aspect is analysed in detail in . For example, the break-even tariff for a rice husk based power plant supplying only to households can be \$0.4/kWh without any subsidy but if it supplies to a rice mill and the households, the price could come down to \$0.24/kWh.

¹² Examples include local community, energy entrepreneurs selected from within or nearby villages, local government representatives, utility company, NGO and civil society organization representatives.

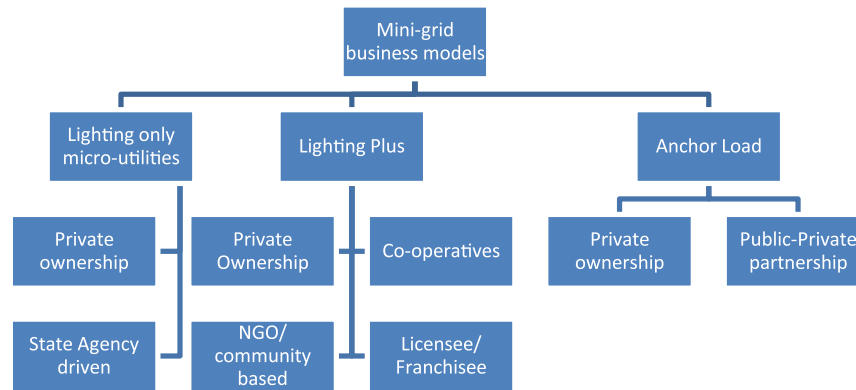


Fig. 2. Business models for mini-grid based rural electrification.
Source: Adapted from Bhattacharyya et al. (2015).

suggested that the mini-grid can be interconnected with the grid system.

4.1. Community-based electrification in a cluster of villages in Dhenkanal district of Odisha

Odisha remains one of the poorly electrified states in India with 34,890 un-electrified villages in 2015 and has low human development indicators. Given the scope for mini-grid based electrification in the state, Odisha was selected for carrying out the demonstration activities.¹³

The initial work for identifying the potential sites for the demonstration project started towards the end of 2011 with the help of a local NGO, IRADA. One cluster of five villages in Dhenkanal district was finally chosen inside a reserve forest that has a very low chance of grid connectivity due to its location (forest area). A household survey was carried out during September 2012 with the help of a structured questionnaire. In addition, twelve focus group discussions including three women-focused group discussions were also administered and each focus group consisted of 8–10 villagers.

The data so generated showed that with an average income of Rs 1000/month/family (~\$15/month), these villagers have very limited paying capacity. Moreover, due to remoteness of the villages and limited prospects of demand growth due to small size of the habitation, the private sector showed no interest in participating in these villages. Accordingly, a community-led intervention was chosen where the research project provided initial capital funding, supported capacity building and offered hand-holding support to the community and the local NGO to ensure successful implementation of the project.

In technology terms, solar PV was chosen for the following reasons: (1) lack of hydroelectricity potential and restriction on bioenergy use in a reserve forest eliminated these options; and (2) solar PV requires limited maintenance and avoids fossil fuel dependence. The project team completed the feasibility study and developed the detailed project report for the sites. A combination of AC and DC power plants was chosen to meet the domestic, livelihood and community load of 140 households (see Table 1 for plant details). The procurement of the power plant and distribution system was initiated through a competitive bidding process in 2013 and the turnkey delivery of the project was completed by end of February 2014.

In parallel, a village level group, called the Village Energy Committee (VEC) was set up and was made responsible for

managing and operating the system, collecting revenues and resolving any disputes/grievances related to the system. Through onsite training sessions as well as through exposure visits to other solar power plants, the VEC capacity was developed in basic record-keeping, banking, and basic plant operation and maintenance. The VEC appointed one villager at each site as the plant operator who collects the monthly fee from the users and undertakes routine cleaning of the panels.

The plant included smart features and practical considerations, including the following:

- 1) Smart PV system design through separation of day and night loads and the night load being fed from batteries.
- 2) Feeder segregation for residential and non-residential loads (see Table 2 for commercial load details) and use of a load interrupter that automatically sheds non-residential load to prevent over-use of the batteries. This helps servicing the essential load (night time load) more reliably (see Table 3).
- 3) Allowance for demand growth is built-in by slightly over-designing the plant. Although each household gets 10 W at present (2 LED bulbs of 3 W and a charger of 3 W),¹⁴ the power plant has been designed to service 30 W demand per household. The distribution network can carry a much higher load as well, so that if grid electricity reaches the village the same distribution network can be used.
- 4) Grid readiness: A grid-tied inverter has been used in the larger village to ensure integration with the central grid in the future, if it arrives.
- 5) Demonstration of both DC and AC distribution systems in the same village cluster was achieved by using DC systems in two smaller villages with 15 households and using AC distribution for larger villages. However, to avoid any social tension, both DC and AC LED lamps provide the same level of illumination. To minimize such user-interference, the battery and the charge controller have been placed inside a secure wooden box, equipped with a lock, with IRADA having the key. Additionally, a timer circuit has been included to automatically switch on and off the system so as to avoid any human interference on the run time of the systems.
- 6) Irrigation pumps have been provided at two larger villages to reduce dependence on rain-fed agriculture, thereby creating income opportunities. Productive loads in the village, being seasonal, will not be used when the pump will be in operation during dry months.
- 7) Solar plant autonomy: it takes 5 days to charge the batteries,

¹³ See for a detailed discussion on this demonstration project.

¹⁴ The household energy availability has been kept low to cater to the basic needs initially but the support for productive load makes this interesting.

Table 1
Technical details of power plants in the Dhenkanal village cluster.
Source: Sharma et al. (2014).

Site	Current type	Plant details	Length of distribution line (km)
Rajanga	AC	6 kWp SPV power plant, 6 kVA inverter (grid tied), 48 V 500 Ah battery bank	2.1
Kanaka	AC	5 kWp SPV power plant, 5 kVA inverter, 48 V 600 Ah battery b	1.4
Chadoi	AC	2.5 kWp SPV power plant, 2 kVA inverter, 48 V 500 Ah battery bank	1.1
Baguli	DC	400 Wp, 24 V 200 Ah battery bank, 15 A charge controller	0.3
Rajanga Hamlet	DC	400 Wp, 24 V 200 Ah battery bank, 15 A charge controller	0.3

Table 2
Productive loads serviced in the demonstration project of Dhenkanal cluster.
Source: Sharma et al. (2014).

Appliance	Capacity	Purpose
Grinder	1 HP at Rajanga	Grinding turmeric and chilli powder
Electronic scale and sealing machine	Scale – 10–20 W; Sealing machine 150 W both at Rajanga	Measuring and packing products
Saal Leaf plate pressing machine	0.5 HP at Rajanga	Stitching of hand-made plates
Water pump	2 HP at Rajanga and Kanaka	Water pumping for irrigation

Table 3
Day and night energy requirements in the Dhenkanal cluster.
Source: Sharma et al. (2014).

Location	Day load (kWh)	Night load (kWh)
Rajanga	11.7	6.1
Kanaka	7.7	6.9
Chadoi	0.3	5.8
Baguli	–	0.6
Rajanga Hamlet	–	0.6

thereby lowering the total PV capacity required.¹⁵ The possibility of having a day with no sunshine at all occurs on average once every 5 days and the plant gets sufficient time to charge the batteries for the extra night of autonomy.

4.2. Other interventions

To showcase a combination of options working under different conditions and using different delivery models, three other initiatives were implemented in partnership with other organisations, namely (1) a project in association with the local government (District Administration of Kandhamal district of Odisha) to provide electricity for lighting to a village comprising of about 250 households and a school attended by around 700 students; (2) a solar DC micro-grid based lighting service to households in Sitapur district in Uttar Pradesh by a private developer (Mera Gao Power); and (3) a project with a for-profit foundation (Mlinda Foundation) in West Bengal to provide electricity for lighting and productive/commercial use in a cluster of villages in the Sunderbans islands. In all these cases, the financial support from the OASYS project was utilised by the partner agencies to meet their balance investments

¹⁵ The panels charge the batteries which then supply night-time electricity to users. The system needs to ensure that the batteries are not drained in the event of no sunshine.

for ensuring financial viability of the projects. Table 4 provides relevant details of these projects.

The district administration keenly participated in the Kandhamal project and constructed the shed for the power plant and provided land for module installation. An 18 kWp plant with supporting battery bank, converter and control systems was installed at this site to meet the needs of the school and that of the surrounding villages, for which a distribution network was created. The partnership provided learning opportunities for the administration and offered a unique opportunity of integrating electricity in the development agenda.

The private sector projects were selected through a formal competitive bidding process for which expressions of interest were invited from over 20 private entities who were asked to submit a proposal requesting for Viability Gap Funding (VGF) from the OASYS project. After an intensive process of evaluation, Mlinda Foundation and Mera Gao Power were selected and supported. The remaining funds for the projects were raised through debt and equity by the partner entities.

Using the support, Mera Gao Power has electrified around 2200 households in Uttar Pradesh and has undertaken to reinvest the profit from this initiative in extending electricity to another 1200 households. The company installs standardised DC micro-grid systems for 20–30 households in a village to provide electricity for lighting and mobile charging (2 1 W lamps and a 2 W charging point) for around 6 h in the evening and 1 h in the early morning. The company takes care of installation and regular maintenance of the system and users pay a connection charge and a fixed usage charge per week on pre-payment basis. On the other hand, Mlinda Foundation uses a pico-system of 150Wp/225Wp to service 8–10 households for their lighting and mobile charging needs (two 2 W light points and a charging point) and larger systems ranging between 500 Wp and 3 kWp for commercial users in the market place. One shop houses the plant and the remaining shops are connected through cables. Each shop uses one or two light points (of 5 or 10 W) and a mobile charging point and receives electricity for 5–6 h per day.

An innovative feature in both the interventions is the reliance on a joint liability group (JLG) system where the users as a group take the responsibility for paying the bills or paying the micro-credit instalments. The National Bank for Agricultural and Rural Development (NABARD) pioneered this joint liability approach in India and has used this since 2004–05 to a large number of cases. In the Sunderban demonstration activity, Mlinda Foundation has arranged debt funding for the local users from NABARD using the JLG model. The technology model was customised to fit with the existing loan schemes of NABARD. This creates a win-win situation as it enhances the bankability of the borrowers and reduces the risk for the lender.

Table 5 provides a comparative picture of four demonstration projects highlighting the strengths, weaknesses and main features.

Table 4

Demonstration project details at other sites.

Features	Kandamal project site	Mera Gao project	Mlinda project
Technology	Solar PV mini-grid, AC system	Solar PV micro-grid, DC system	Solar PV pico-grid, AC System
Capacity	18 KWp with ~2 km mini-grid (3 phase)	120 Wp system with ~90 m DC grid for 20–30 households	150/225 W systems for 8–10 households
Beneficiary	250 households and a school with 700 students	2200 households and an additional 1400 households in 2 years	500 households and 200 shops
Operation and maintenance	Village Energy Committee	Mera Gao Power	Mlinda Foundation
Revenue collection frequency	Monthly	Weekly	Monthly

4.3. Impacts of and lessons from the demonstration projects

The demonstration projects provided an immense opportunity for learning-by-doing and generated impacts at the sites. These are briefly discussed here.

4.3.1. Impacts from the demonstration projects

Two impact assessment studies were carried out to identify and understand the impacts of the demonstration activities – one for the Dhenkanal site (Palit et al., 2015) and the other for Mlinda Foundation interventions (Murali et al., 2015). The studies relied on a sample survey to find out users' perception about the benefits and impacts of the intervention.

In Dhenkanal site, it was found that kerosene consumption has reduced by half – from 7 l per household per month to 3.5 l and their phone charging costs have reduced. Respondents reported that they are saving money after the intervention and have better communication opportunities with outsiders. Evening light has allowed pupils to read at night, helped womenfolk to continue with their handicraft work for some extra income and instilled a better sense of security in the villages. The project has also brought indirect benefits in the form of better attention from the local administration, improved access to the villages due to improved road conditions, and better opportunities for selling local produce thereby enhancing their income (Palit et al., 2015).

In the Sunderban project, the households reported reduction in their kerosene consumption from 3 litres per month to 1.5 litres. The monetary saving is being used to repay the loan taken by the Joint Liability Group. The survey found that 58% of the surveyed households have lights in the kitchen and 80% of those using lights in the kitchen found the experience very positive compared to cooking with a kerosene lamp. Lighting has allowed longer study times for children: they are spending about 2.8 h in the evening to studies compared to about 1.6 h previously with kerosene lamps. Beneficiary shops in the market area reported higher profit which they attribute largely to the electricity facility. However, the bigger shops, offering communication and entertainment services, appear to benefit more. Some shops have completely moved away from kerosene lamps but others are still consuming some kerosene. The shop owners have approached Mlinda Foundation for bigger systems to take care of growing electricity needs (Murali et al., 2015).

Based on the above assessments, an extrapolation of benefits for four demonstration projects suggests a saving of kerosene consumption between 90,000 l and 150,000 l per year.¹⁶ Assuming a lower heating value of 35 MJ/l for kerosene and a carbon intensity of kerosene of 72 g/MJ, the fuel saving from the demonstration projects achieves a carbon saving between 225 t and 375 t of CO₂ per year. Moreover, the fuel saving offsets their electricity service costs and the households save time and money for

charging their mobile phones.¹⁷ The co-benefits in terms of improved road infrastructure, easier communication and information flow, better access to health facilities, improved access to markets and reduced isolation of the villages are also expected from the interventions.

4.3.2. Lessons from the demonstration activities

Four demonstration activities generated rich experience about mini-grid based electricity development in a developing country context. Our experience from the Dhenkanal project shows that the private sector may not be interested in getting involved in all off-grid locations. Despite having a cluster of off-grid villages in that site, the private sector was not interested due to the small size of the business and limited possibility of load growth, low paying capacity of the people and relative remoteness of the site. Electrification through mini-grids in such cases will require either a government agency or a local entity (such as an NGO) but providing such a specialised service requires hand-holding and continued support. Yet, Mera Gao Power and Mlinda Foundation have demonstrated the feasibility of for-profit business activities in the local grid-based supply but both of them follow a utility-like approach, offering a flexible, efficient and locally-grounded service. A packaged delivery approach, benchmarking the tariff against the substitute fuel (i.e. cost of kerosene consumption), flexible revenue collection (e.g. weekly by Mera Gao) following the micro-lending practices, adoption of JLG concept, and regular servicing and maintenance contribute to their success. Innovative and smart businesses therefore can play a role. Accordingly, our action research confirms that “one size does not fit all” and depending on the local conditions and maturity of the business, alternative business models and options are required.

Given that the poor has limited ability to pay and service providers have limited access to funding, financial support is essential. However, instead of capital subsidy, businesses require a flexible support arrangement to manage their uneven cash-flow and recurring investment needs (e.g. in battery replacements). The viability gap support provided to Mera Gao Power and Mlinda Foundation through OASYS project¹⁸ offered the flexibility of using the funds. Mlinda Foundation used this for placing orders for power plants for which mobilisation fund is required which cannot wait for loan approvals from the bank. Mera Gao Power on the other hand has committed to reinvesting the profit in extending the electricity access to an additional 1000–1200 households, thereby allowing scaling-up of access. A flexible funding mechanism thus achieves the electrification objective more effectively using the limited resources efficiently. This also suggests that the financial support scheme needs to be calibrated according to the socio-economic conditions of a site, size and scale of the service, and technology used.

¹⁶ The lower bound is based on a saving of 1.5 l of kerosene per household per month for 5000 households and shops electrified. The upper bound is based on a saving of 2.5 l of kerosene per month.

¹⁷ Assuming that users paid about Rs 5 per week, the saving arising from on-site mobile charging amounts to Rs. 1.3 million per year (or \$20,000).

¹⁸ Both Mera Gao and Mlinda Foundation received around 30% of the project cost as viability gap support from the OASYS South Asia project.

Table 5
Comparative position of four models.

Description	Dhenkanal Community project	Kandamal project with local administration participation	Mera Gao Power – fully private operator	Mlinda Foundation - rent to own by SHG)
Funding	100% grant funded	100% grant funded	30% grant; rest debt and equity	25% grant, rest debt and equity
Tariff	Rs 50/month	Rs 100/ month	Rs 120/month	Rs 180/month
Strengths	1) Inclusion of productive loads 2) Local community managed 3) Strong NGO support 4) Possibility for nexus theme integration	1) Strong local administration support 2) Local community managed 3) Supply to public institution (such as school) 4) Possibility for nexus theme integration	1) Utility style delivery 2) 24/7 customer support 3) Flexible revenue collection 4) Strong local presence 5) Financially viable 6) Replication possible	1) Strong local presence 2) Flexible revenue collection 3) Strong support service 4) Financially viable 5) Replication possible 6) Caters to some productive load as well
Weaknesses	1) Weak financial viability without support 2) Limited local capacity 3) Repair and maintenance always not timely 4) Scaling-up difficult	1) Weak financial viability without support 2) Limited local capacity 3) Repair and maintenance difficult 4) Scaling-up difficult	1) Low power lamps to keep tariff similar to low grid tariff 2) No productive load 3) Organisational expansion can be challenging 4) Funding equity and debt can be challenging	1) Service is relatively costly vis-à-vis rural grid tariff in the state 2) Arranging loans can be difficult and time consuming 3) Managing supply chain in remote areas can be an issue
What worked	1) NGO and local community participation 2) Technology acceptance 3) Payment and collection – Village Energy Committee managed defaulters well.	1) Local administration and community participation 2) Technology acceptance	1) Efficient power utility model worked well. 2) Misuse was effectively handled. 3) 24/7 support enhanced reliability	1) Strong local presence of Mlinda staff ensures effective project implementation, revenue collection and maintenance. 2) Flexible revenue collection from home of users improves collection efficiency. 3) Strict operation scheduling ensures effective system utilisation. 4) Over-achieved targets.
What did not work	1) Teething trouble; 2) Outage of a plant due to lightning 3) Some resentment about payment due to system fault 4) Some tampering of connections noticed	1) Securing technical support not easy 2) Obtaining support from a government agency is time consuming.	1) 24/7 service increases operating costs. 2) Cases of system misuse issue continue 3) Delays in implementation due to issues related to social dynamics 4) Target had to be revised due to delays in implementation.	1) Shops remained locked in to diesel connection due to previous supply arrangements 2) Private Tution Centres continued to rely on kerosene, as such centres were not connected under the JLG model. 3) Some households dissatisfied with the brightness of LED lights.

Clearly, a significant amount of preparatory work is involved in identifying a site, understanding the needs, designing a solution and ensuring its delivery. To identify the Dhenkanal site, the project team had to undertake a number of pre-feasibility studies for different locations. This is a costly and time-consuming exercise. Private companies interested in the business find this information gap as a major hurdle and the government agencies may be in a better position to produce and share such information publicly. This can reduce the entry barrier to some extent.

Given that a mini-grid based service is akin to a utility business, it requires significant technical, financial and organisational capacity, which is not readily available in rural locations. At the Dhenkanal site, the NGO supporting the grass root activities lacked any technical expertise. The village, being in a remote area, did not have basic skills for civil and electrical works (e.g. masons, electricians, etc.) and all skilled personnel had to be brought from outside during the periods when the villages remain accessible (i.e. outside the monsoon season). There was no formal knowledge of running a business. Moreover, local contractors have limited experience with mini-grid systems and require supervision and support. Accordingly, training and capacity building is an essential element for implementing such interventions and forms a significant part of the overall hand-holding process.

While projects in Odisha offered significant research potentials, Mera Gao and Mlinda Foundation projects showed that scaling-up of local grid based electrification requires a systematic, utility-oriented approach where standardised systems can be delivered to a site quickly, and a set of after-sales services can be ensured on a regular basis. This requires adequate organisational capacity to deal with equipment order and inventory management, project implementation under strict timelines and quality standards, and service delivery management. Adequate planning and strategic management is required to ensure that business growth is adequately supported organisationally. This is an area that affects the organic growth of start-ups and small-scale entities.

5. Policy recommendations

Based on the lessons from our academic and action research carried out through the OASYS South Asia project, the following

policy recommendations are offered for off-grid electrification, in order of preference.

- 1) **One size does not fit all:** Varying local contexts in terms of socio-economic conditions, resource potential and institutional arrangements require that local solutions must adapt to the contexts to maximize outcomes. The continuum of options covering the basic needs and going up to modern life styles implies that one template will not be suitable to all conditions. A progressive development path, over a period of time, will ensure the transition from basic to conditions suitable for modern living (see Fig. 3). Our action research strongly supports this recommendation.
- 2) **A robust governance structure is a pre-requisite** – The environment for any off-grid electrification intervention is influenced by global, national and local institutional endowment and institutional arrangements. Our action research as well as stakeholder consultation confirm that for successful promotion and sustainability of off-grid electrification, a cohesive institutional arrangement is essential that appropriately links the different levels. The institutional arrangements and linkages would vary depending on the stage of development of off-grid electrification but appropriate, socio-politically acceptable arrangements must be in place with necessary skills and means. A robust framework can include elements of top-down approach and the participatory approach judiciously to ensure successful delivery of off-grid interventions. Local level issues may be better addressed through a participatory approach while policy, financing and technical issues may be better dealt with through a top-down arrangement. It is also important to develop a support system at the intermediary level, which provides an integrating link between the national and local levels, ensuring that plans and policies match the needs of consumers, owners and suppliers.
- 3) **Clear rules of the game are essential:** Our interaction with stakeholders and our analysis of the regulatory and policy environment suggest that off-grid electrification cannot flourish in a regulatory vacuum or in a weak regulatory environment characterised by ambiguous rules and non-transparent decision-making systems. In order to reduce risks to participants, unambiguous and transparent rules of the game are required.

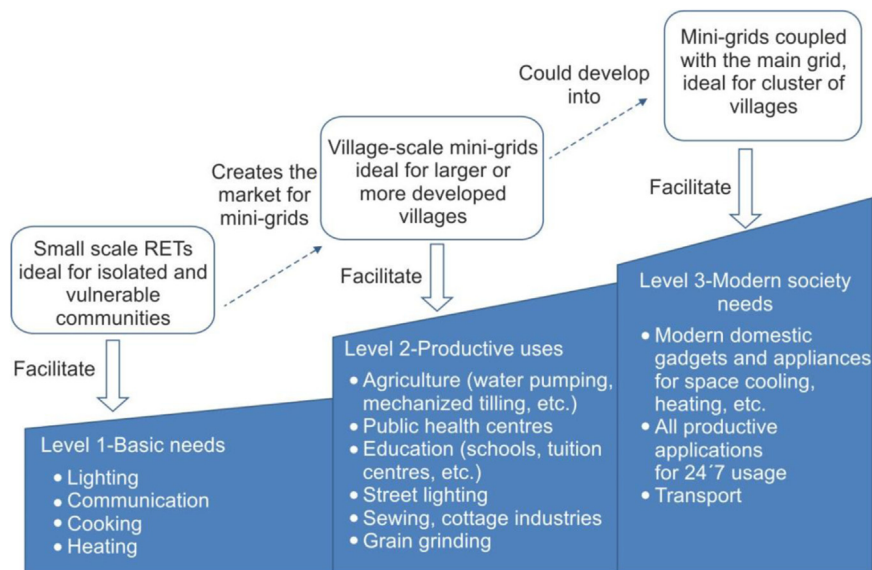


Fig. 3. Gradual development pathway for off-grid electrification (Adapted from Palit (2012)).

Electricity acts and policies should recognise local grid-based decentralised electrification options and provide appropriate regulatory guidance for off-grid business development. The specific characteristics of local grid systems have to be recognised and differentiated from grid services. A light-handed regulatory approach that imposes minimal regulatory supervision but allows for clarity in scope of service and tariffs, puts in place appropriate service standards and supports information collection could be appropriate in this regard. Our action research, case studies and stakeholder consultation provide support to this recommendation.

- 4) **Strategic and locally adapted support to off-grid electrification is key:** Our analysis of mini-grid businesses and our demonstration activities confirm that off-grid electrification options would require support at least in its initial development phase and perhaps even in the subsequent phases before it becomes commercially viable. An innovative support system is required to offer strategic support, ensure better value for money and provide support for long-term benefits. The capital cost subsidies could be replaced by a flexible support system at different levels of the supply chain that caters to demand creation, ensures viability gap funding, links to raising of finance from markets, as well as balances the life-cycle funding mismatches of projects.
- 5) **An enabling policy environment is crucial:** A complex web of policy interactions and inter-relationships influences off-grid electrification outcomes of any country. As indicated in Fig. 4, the policy sphere covers a whole set of issues including financing, pricing, technology use and transfer, labour and land use. A successful off-grid electrification sector requires that all relevant policies are mutually reinforcing and that they support promotion of off-grid interventions by removing policy barriers and challenges. For example, price distorting fossil fuel subsidies and discriminatory subsidy regimes between grid and off-grid connections adversely affect mini-grids. Clear entry and exit policies, flexible and simplified procedures for business set-up, and a single window approval system can facilitate mini-grid business development.

- 6) **Capacity development is urgently required:** Our demonstration activity clearly suggests that availability of appropriately skilled manpower for the entire supply chain is essential for an effective delivery of off-grid electrification projects. The skill set goes beyond technical aspects and includes, among others, regulatory and policy-making capacity at the national level, business development and delivery at the sub-national and local level, finance-related skills at various levels, trained staff and technicians at the project level, and design and implementation capacity at the contractor level. There is an urgent need for capacity building at different levels in the countries to ensure successful outcomes from off-grid electrification.
- 7) **Link carefully with rural development activities:** Our interventions suggest that electrification when embedded within the overall rural development programme is likely to generate opportunities for enhancing the local economy. This synergy can improve money flow to the rural households, enhancing their paying capacity for purchasing the electricity. However, such linkages should be carefully evaluated keeping the costs and institutional arrangements in mind. Inclusion of livelihood opportunities may be appropriate only in certain off-grid electrification systems but for the rest, mere electrification for lighting (thereby extending the working hours for non-mechanised income generation activities) and mobile phone charging may open new possibilities.
- 8) **Eco-system of off-grid electrification solutions:** In order to ensure sustainability of off-grid solutions in the long-term, the entire supply chain has to be developed and properly supported. A local eco-system has to be developed for off-grid electrification activities, including local manufacturing and assembly capacity, an ancillary after-sales service system, a pool of trained technicians, and demand creating services.
- 9) **Clustering and bundling of initiatives help scale up:** Small capacity of off-grid projects implies that any demand aggregation or bundling of projects can increase the market size. Off-grid projects could be identified depending on the availability of local energy resources and clustered, to ensure

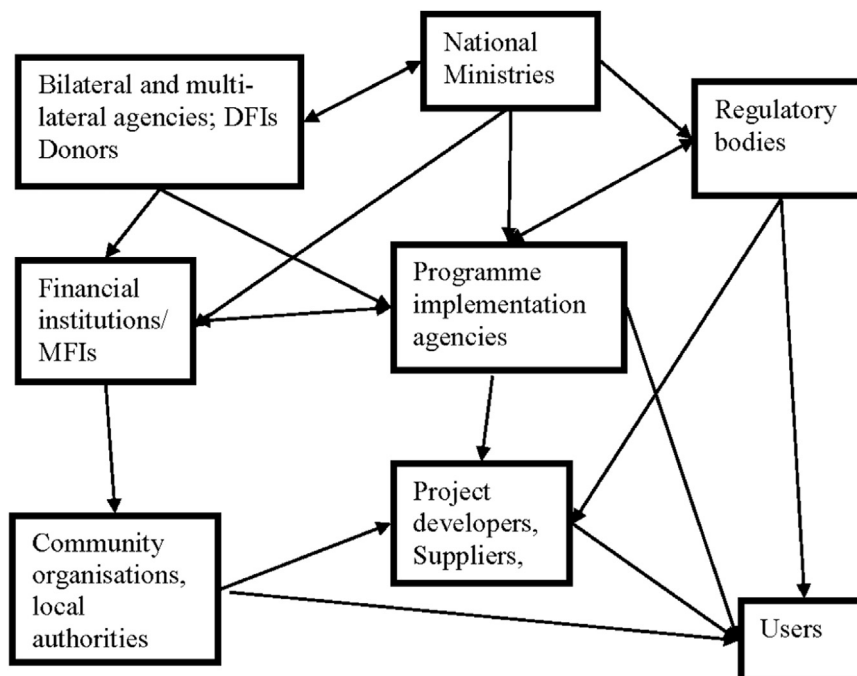


Fig. 4. Web of policy interactions.

economies of scale and scope, and handed over to concessionaires. Private players may get attracted to become concessionaires for multiple areas, where grid connected distribution business could be bundled with off-grid areas, or bundling projects with different off-grid technologies to optimize costs. Financial institutions/banks would also be interested as project implementation and credit risks would be less.

- 10) **Organised delivery for scaling-up and replication:** Mass electrification from pilot projects requires an organized delivery approach through some sort of standardization and utility-like management. This requires attention to organizational absorptive capacity, as well as financial and technical capacity of the organization. Not all entities can take up such responsibilities. Successful mass electrification requires a strong element of top-down influence and the flexibility of a bottom-up delivery. Lessons from good utility management models of grid electricity system can be transferred to the off-grid management model for better delivery. This may require the grid companies to start subsidiaries which can take up off-grid interventions as part of their business [Krithika et al. \(2015\)](#). Currently the two sectors seem to be served by different set of entities and off-grid companies, being small, are unable to negotiate the inherent risks on withdrawal of the promoters' support. A more organised model with proper exit strategy might induce more management level and delivery innovation.

6. Conclusion and policy implications

Based on the research activity carried out through the OASYS South Asia project, this paper has presented a set of lessons and policy recommendations for enhancing off-grid electrification of developing countries. In order to achieve the targets of universal electrification, the reliance on grid extension alone will not be sufficient and off-grid electrification through both, product delivery and local grid-based supply, will have to play an important role. This is also corroborated in a recent review paper by [Palit and Bandopadhyay, 2016](#)). While the state and donor funding has played and may continue to play a significant role, the private sector will also have to be involved. However, this will require a more inclusive partnership of all stakeholders in the form of creating an enabling environment by the government for private sector participation while promoting end-user engagement, project viability and sustainable local development. Further, the electricity provision and development should be synchronized in such a manner that the designed delivery model is attuned to current developmental levels (and affordability to pay) of the community. Simultaneously, the community also needs to be prepared for a bigger and more complex next level delivery model. We also suggest that the main thrust has to shift towards mass electrification efforts from pilot and demonstration projects. Regulatory certainty, strong institutions at the meso and local level with appropriate institutional arrangements, access to soft funding, bundling of projects and standard process and metrics for delivery of electricity will create a win-win situation for all key stakeholders to take the universal energy access agenda forward. The opportunities have to be seen not only from the rural electrification but also in the larger context of enhancing energy security and sustainable development.

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