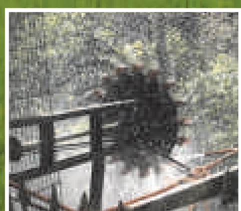
Decentralised Renewable Energy (DRE) Micro-grids in India

A Review of Recent Literature

Prayas Report, November 2012

Prayas Energy Group

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About Prayas

Prayas (Initiatives in Health, Energy, Learning and Parenthood) is a non governmental, non-profit organization based in Pune, India. Members of Prayas are professionals working to protect and promote the public interest in general, and interests of the disadvantaged sections of the society, in particular. The Prayas Energy Group works on theoretical, conceptual regulatory and policy issues in the energy and electricity sectors. Our activities cover research and intervention in policy and regulatory areas, as well as training, awareness, and support to civil society groups. Prayas Energy Group has contributed in the energy sector policy development as part of several official committees constituted by Ministries and Planning Commission. Prayas is registered as SIRO (Scientific and Industrial Research Organization) with Department of Scientific and Industrial Research, Ministry of Science and Technology, Government of India.

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1. Introduction

Access to reliable electricity for all is one of the key drivers of socio-economic development. However, according to the 2011 Census data[a], 45% of rural Indian households (HHs) lack access to electricity supply, though only 6% (~ 35,000) of Indian villages remain unconnected to the electricity distribution infrastructure[b]. Rural electrification, carried out by the Government of India (GoI), primarily involves extending the centralised grid under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), which aims to electrify all villages, lay the distribution infrastructure, and provide free connections to rural households below the poverty line (BPL). While RGGVY has managed to provide a significant number of connections in a short time (electrification of over 1 lakh unelectrified/de-electrified villages, and free connections to over 2 crore rural BPL households)[c] since its inception in 2005, the lack of reliable and sustainable electricity supply remains a persistent problem.

In addition to providing access through the centralised grid, electricity (primarily for lighting service) is also being supplied through small scale decentralised renewable energy generation systems in an off-grid stand-alone mode in certain remote rural areas. Decentralised electricity generation means "an electric power source connected directly to the distribution network or on the customer's side of the meter" [1]. DRE systems use local renewable resources - biomass, water, sunlight and wind - to generate electricity. Such micro-grids can play an important role in bridging the electricity access deficit by providing access to remote villages which cannot be electrified through central grid extension due to techno-economic considerations, those which are unlikely to be electrified in the near future through the central grid, and by supplementing unreliable grid supply in villages already electrified.

Several government and non-government agencies are promoting DRE in India. The Ministry of Power (MoP), through its DDG (Decentralised Distributed Generation) Policy, and the Ministry of New and Renewable Energy (MNRE), through its various schemes such as the Village Energy Security Programme (VESP) and Remote Village Electrification (RVE) Programme, play a central role in remote rural electrification. The MNRE has managed to electrify over 9000 villages with a mixture of biomass gasifiers (16 MW), solar photovoltaic (SPV) systems more than 1 kW (96 MW), and nearly 2000 micro-hydro projects[d]. Despite this progress, the DRE sector in India had yielded mixed results. While such projects have the potential to significantly increase socio-economic development and help in poverty alleviation, the high rate of project/system failures [41, 42] suggests that there are several unresolved technical, socio-economic and institutional factors that play

a Source of Lighting: Houselisting and Housing Census Data Highlights – 2011, Census of India, 2011 http://www.censusindia.gov.in/2011census/hlo/hlo_highlights.html

b Central Electricity Authority (CEA)'s monthly review of the power sector, http://www.cea.nic.in/executive_summary.html

c Physical progress of RGGVY projects under implementation, status as on 30/04/2012, http://rggvy.gov.in/rggvy/rggvyportal/plgsheet_frameplan.jsp

d Cumulative deployment of various renewable energy systems in the country, status as on 31/08/2012,http://www.mnre.gov.in/mission-and-vision-2/achievements/

crucial roles in their long term sustainability. At the same time, one needs to keep in mind the rather difficult conditions under which such projects operate: remote locations, technology under development, and various competing social and commercial considerations.

A number of studies have been published over the last decade focusing on the various technical, social, economic, institutional, policy and regulatory aspects of the DRE sector. This literature is in the form of peer reviewed journal articles looking at techno-economics of DRE, case studies of pilot projects, policy appraisal and advocacy studies, etc. While this has greatly improved our understanding of the sector with regard to specific issues, we felt the need to assimilate and document these diverse learnings to obtain a comprehensive overview of the sector. We believe that such an exercise will help all stakeholders to get a broader perspective and deeper understanding of the challenges facing the DRE sector.

1.1 Objective of the literature review

Through this literature review, the Prayas Energy Group (PEG) attempts to highlight key aspects of the DRE sector in India as documented in different studies. Given the increasing importance of the DRE sector for rural electrification, we believe that this review can place the issues and challenges affecting the DRE space in the public domain, and inform further discussions on various aspects, especially the policy and regulatory framework, and the changes required to increase the effectiveness, long-term viability and sustainability of DRE micro-grids. The review will also help to get a sense of the direction of the sector's progress by identifying opportunities and challenges. Important factors that are crucial to the success of DRE, as well as lessons learned from previous studies, will be useful towards corrective actions by all stakeholders. Hence, the overall goal of the review is to document all issues of concern for the DRE sector, in order to increase the effectiveness and sustainability of DRE micro-grids.

1.2 Scope and methodology of the literature review

Distributed renewable energy is a broad term which includes solar lanterns or lights at the smallest scale, and individual solar home lighting systems (SHLS) and mini/micro-grids based on locally centralised generation at a slightly larger scale. While solar lanterns and SHLS have played a major role in remote electrification, the scope of this review is limited to small-scale DRE based micro-grid applications (with and without centralised grid interface) which provide electricity to rural communities in India. DRE micro-grids can also be classified based on the electricity they produce: extra low voltage DC systems and conventional 50 Hz 230V/400 V AC power systems. A majority of the DRE micro-grid based applications reviewed in this study use the latter (conventional 230V/400 V AC) type of power systems.

In the process of the review, we screened over a 100 documents: peer reviewed journal papers/working papers published largely by academic and research organisations, reports prepared for funding organisations, case studies published by project implementing agencies, etc. However, since we were interested not so much in documenting the history of DRE in India, but in understanding the present day challenges which the sector faces, we have focused on studies (excluding books) published in the last few years. This was also necessary given the stark technological advances and changes in the economic viability of DRE micro-grids, considering equipment prices and grid extension. The final list included in this review has just over 60 documents. In view of Professor Amulya Reddy's pioneering work[e] in the area of rural energy, we have also reviewed two of his important papers on rural energy that were published at the beginning of the last decade. While we have tried our best to be as comprehensive as possible in our selection, some important studies may have been inadvertently left out.

In addition to the published literature, PEG's own field visits to a number of DRE projects have also provided valuable information and insights about the sector. Some of these issues, to our knowledge, have not been adequately highlighted or documented in the published literature, therefore we have included them as well.

This review summarises the key learnings from the DRE micro-grid literature in the public domain. It is important to note that the summary highlights the important issues as reflected in the literature, and are not necessarily PEG's own recommendations/views on the subject. More detailed informal reviews on each of these individual documents (for internal research purposes) are additionally available on PEG's website (http://www.prayaspune.org/peg/publications/item/187).

e http://www.amulya-reddy.org.in/index.htm

2. Key observations from the literature review

DRE power generation in the off-grid mode has a long history in India, and a variety of actors (government/private/social) have been working on its different aspects. Our review brought out several concerns and issues as seen by multiple stakeholders. Such issues need to be carefully considered and deliberated upon so that innovative solutions to address them can be found, if the DRE sector is to effectively grow and scale in the country. Many studies have offered specific suggestions to overcome challenges in this sector. Similarly, the review also found that there were various cases of re-inventing the wheel where mistakes of the past could have been avoided.

As noted earlier, the focus of this review is on the DRE based micro-grids supplying electricity in remote rural India. DRE micro-grids normally have a limited area of distribution with limited number of consumers, who are mainly residential, but could also include commercial and small-scale industrial outfits. A typical micro-grid based on a biomass gasifier which caters to an average household lighting load for 1000 households needs a plant size of approximately 60 kW capacity.

The key issues presented in this summary are organised in the following sections:

Section 2.1 discusses costs of electricity generation and consumer tariffs, including typical DRE electricity costs in Rs/kWh, consumer tariffs and willingness to pay.

Section 2.2 outlines the factors affecting viability of DRE micro-grids, including initial capital costs, Operation & Maintenance (O&M), Capacity Utilization Factors (CUFs) / Plant Load Factors (PLFs), electricity loads, financing and technology aspects of DRE (optimisation/sizing, Demand Side Management (DSM), grid integration and technical standards).

Section 2.3 analyses policy and regulatory issues, including the government's policy approach in promoting DRE, funding and subsidies for DRE projects, planning and regulatory framework (tariff determination, equitable tariffs, etc.).

Section 2.4 discusses the institutional and governance framework, including the role of the government, regulators and local level institutions and their functions, managerial and operational arrangements, Monitoring & Verification (M&V), etc.

Section 2.5 discusses community participation in DRE micro-grid projects, including the importance of community involvement, ownership, and capacity building.

Section 2.6 highlights observations during PEG field visits to DRE micro-grid project sites.

2.1 Costs of electricity generation and consumer tariffs

High specific capital costs for small scale projects, greater O&M expenses in remote rural areas, and low CUFs/PLFs in DRE micro-grids often lead to significantly higher average costs of electricity generation (Rs/kWh) compared to those for conventional centralised coal-based electricity generation. According to a recent study, the cost of generation from different DRE technologies ranges from Rs 4.50 to 18/kWh (micro-hydro: Rs 4.50/kWh, biomass: Rs 5.0/kWh, wind-solar hybrid: Rs 12/kWh and solar PV: Rs 18/kWh) [6]. Another study notes the cost of generation with and without government capital incentives which have been the main instruments of DRE promotion. According to this study, these costs are Rs 6.06-8/kWh for biomass gasifiers, Rs 3.51-5.21/kWh for micro-hydro, Rs 15.25-20.35/kWh for solar PV, and Rs 23.47-35.35/kWh for solar-wind hybrid systems [4]. Estimates for the cost of generation are highly dependent on a variety of assumptions, and the reader should refer to [14, 17, 26, 28, 46, 47, 49, 50, 52] for more details on the costs of generation for DRE micro-grids based on various technologies.

Due to the high cost of electricity generation in DRE projects, the extension of the centralised grid is considered a more cost-effective option in general. However, DRE projects are often situated in remote rural areas which are far away from the electricity grid. In such circumstances, the cost of electricity supply from DRE projects may be lower than supplying centralised grid electricity if the cost of laying transmission infrastructure from the existing grid to the village, its maintenance cost, and electricity losses are factored in. For a load of 100 kW, at a distance of 5 km from the grid to a village, the cost of generation from micro-hydro and biomass systems are lower than the cost of electricity supply (cost of generation + cost of grid extension of a 33 KVA line to the village) from coal-fired grid-based power plants. Solar PV is viable at higher distances [6, 43, 46, 47].

DRE based mini-grids also offer cheaper options in comparison to diesel generators and kerosene, especially when one factors in the subsidies for diesel and kerosene [39]. However, according to another report, the commercial viability of mini-grids is yet to be demonstrated in the absence of subsidies to DRE [38]. In the future, the costs of diesel and coal are expected to increase, while the costs of solar PV components are expected to fall [57]. Additionally, the true costs of electricity generation using conventional technologies would rise substantially when public health and environmental externalities are incorporated into their pricing [6, 57].

High costs of electricity generation in DRE micro-grids also result in high tariffs for consumers, which in turn make it difficult to realise the full potential and scale of DRE micro-grids. Despite the high capital subsidies being availed, DRE micro-grid consumers are often charged much higher tariffs than their grid-connected counterparts [4, 13, 17]. On the question of whether DRE micro-grid consumers are willing to pay, many studies found that users considered the costs to be high, especially given the current expenses on kerosene lighting [4, 6, 13, 14]. Rural households, depending on their socio-economic condition, are willing to pay around Rs 100 - 120 per month (Rs 7-10 /kWh) [47]. Another study specifies that consumers are willing to pay Rs 30-120/HH/month for domestic lighting, and Rs 10-15/kWh for commercial lighting and other productive applications [4]. Electricity consumption has high value for rural households, and where reliable electricity supply exists, willingness to pay is also high. However, it has been observed that the willingness to pay for electricity does not always translate into an ability to pay in the case of rural households [4, 13, 37, 40, 47, 57]. While willingness to pay would be high for initial lighting needs, it declines progressively for each additional kWh [29].

2.2 Factors affecting viability of DRE micro-grids

Let us now consider the various factors which affect the financial viability of DRE micro-grids. Two of the most sensitive factors are the high upfront specific capital costs and the electricity loads and CUFs/PLFs realised in practice [14, 17]. Currently, the average capital cost of a biomass gasifier power plant is ~Rs 50,000/kW, whereas it is twice that for micro-hydro, i.e. ~Rs 1,00,000/kW, and thrice for a solar PV plant, i.e.~Rs 1,50,000/kW [4]. Electricity loads are mainly limited to lighting loads with very limited commercial/industrial loads if at all. Low PLFs/CUFs are a major challenge for the financial viability of DRE micro-grids, as they lead to higher costs of electricity generation. Field experiences have shown actual PLFs to be far lower than those considered in usual economic analyses [17]. Hence, it is important to estimate the demand realistically both for the present and the future [40]. To overcome this challenge, two main approaches are discussed in the literature: i) promotion of productive commercial or small-scale industrial loads through micro-enterprises [10, 18, 28], anchor loads such as mobile phone towers [14], and ii) ensuring grid-compatibility of such DRE micro-grids to enable them to interface with the centralised grid as and when it arrives [10].

Additionally, specific O&M costs are also very high given the small size of the projects. Fuel costs are very important for biomass gasifier projects (typically the fuel-wood costs are 60% of their operating costs [39]), and a sustainable and affordable supply of biomass feedstock is the main concern while operating the plant[13, 22]. The availability and prices of biomass in the local market are influenced significantly by its alternate uses as building material and fuel for thermal applications like brick kilns. As a way forward, monetising biomass supply and encouraging biomass plantations have been suggested [13]. For solar PV, the largest O&M cost is for maintaining and replacing batteries every few years. Only in some projects are consumer tariffs collected into a fund which is used to replace batteries as and when needed. Battery costs and maintenance/replacement remain the most crucial challenges for the long term sustainability of PV based micro-grids.

From an entrepreneur's perspective, raising debt for a DRE project is still a big challenge. Given the various uncertainties and high risks associated with DRE micro-grids, financial institutions do not consider it an economically viable option, as the sector is still developing, and very limited information is available which can aid financial institutions in evaluating the viability of projects [9]. Additionally, the long and uncertain break-even period associated with DRE micro-grids make them uneconomical for banks to evaluate their applications. To ease the burden of high capital investments for setting up DRE projects, MNRE provides capital subsidies through various schemes. Similarly, various funding agencies also provide capital grants for setting up projects. However, given the way capital subsidies for DRE are structured in India, they do not incentivise cost reduction and efficiency improvements. They also do they force developers to provide long-term and sustained O&M for their systems, a shortcoming which can be overcome through performance-based generation incentives [29]. While capital grants are needed to kick start any new initiative, the lack of focus on performance to ensure that interventions have resulted in desired outcomes is a long-standing problem[13, 38]. Long term commercial viability of projects too has taken a back seat in various business models, hence new and innovative sustainable business models are the need of the hour [4, 10, 21, 38, 42].

MNRE has recently suggested setting up a trust fund which could accept donations from a variety of sources to meet the financial requirements for electricity access through DRE micro-grids [10]. Efforts should be concentrated on acquiring multilateral and bilateral direct funding, where the provision of energy access does not offer adequate commercial returns [3, 11].

Technology aspects of DRE micro-grids

The literature describing technology related aspects of DRE has mainly focused on details specific to individual technologies (advantages and limitations), optimisation studies (proper sizing, reduction in distribution losses, use of smart-grid features) and grid-integration prospects (grid connectivity standards and safety issues). There are a variety of technology specific concerns that must be considered while designing any project.

For DRE micro-grid projects, robust resource assessment studies followed by continued reliable availability of such resources are crucial for their financial viability. This is especially true with regard to biomass gasifiers and micro-hydro projects where secure and sufficient supplies of biomass feedstock and water streams respectively, are a challenge for their effective and optimal operation [13, 17, 22, 42, 47, 56]. For biomass gasifier projects, the gas engine technology is also not yet fully standardised for remote village operations [9]. In addition, gasifier projects have a higher scaling up/gestation time, which needs to be factored in while estimating their pay-back periods.

Solar PV based electrification is mainly suitable for small power requirements (lighting, mobile charging and few appliances) since its high cost prevents its use for high wattage applications. Additionally, in solar PV projects, significant attention is needed to ensure that its batteries are charged and discharged properly for longer life. The environmental impacts from production, recycling and disposal of PV components is expected to become a crucial issue in the future [22].

For micro-hydro projects, robust and reliable flow data and the seasonality of flows is a major concern. Further, the absence of standardised equipment parts and designs has also been a barrier for the large uptake of this low cost resource.

Solar-wind-biomass hybrid systems may improve the reliability and performance of the DRE system while simultaneously reducing specific costs and thereby providing improved quality of access to consumers [24]. The suitability of such options based on hybrid technology for micro-grids which can complement each other need to be evaluated further [24].

Besides considering individual technology related issues, proper sizing of the DRE generation unit based on correct demand estimation is also crucial. One study noted that most existing DRE plants studied were oversized, and that there is significant potential to reduce distribution losses [35]. Voltage and current imbalances is another concern. This points to a need for documenting the actual field performance of isolated power systems, and improve the methods for sizing and planning the location and distribution network [35]. However, since DRE plants are located in remote areas, it would not be economical to undertake manual inspection of the energy generated and utilised at regular intervals. In such a scenario, smart-grid features such as remote metering with integrated communication capabilities can be used [45] to enable the local utility/concerned authority to monitor performance.

DRE micro-grids are often limited by the peak demand they can supply, hence effective demand-side management (through use of efficient appliances, use of load limiters, etc.) coupled with smart grid features is critical to their success [2, 35, 60, 62].

Another emerging issue for the viability of DRE micro-grids is the perceived threat from centralised grid expansion which would offer cheaper electricity. Hence, an important technical requirement for the sustainability of DRE micro-grids is the ability to integrate with the centralized grid and feed-in surplus electricity into the grid, import during higher demand, or isolate and supply the micro-grid when the main grid is down [2, 10, 19]. However, considering the poor quality of grid supply in rural areas (blackouts/brownouts, large voltage and frequency fluctuations, etc.), reliably integrating DRE micro-grids with the central grid is a technical challenge [45]. The Central Electricity Authority (CEA) is in the process of finalising regulations which will specify technical standards for interconnection for distributed resources as well as safety requirements. An important safety requirement for workers is related to the 'islanding' effect, where a DRE plant continues to supply electricity in one section of the grid even though the centralised supply from the electric utility is cut off [45].

Other important factors weighing down on the viability of DRE micro-grids are a lack of good quality technical designs and minimum technical standards [60], coupled with poor implementation and construction quality.

2.3 Policy and regulation

In addition to the techno-economics of DRE systems, a robust policy-regulatory framework is also important for the success of DRE micro-grids. There are various enabling legal and policy provisions for using renewable energy sources for rural electrification. The Electricity Act 2003 (EA 2003), in Section 4, mandates the central government to formulate policies for stand-alone systems for rural electrification using renewable energy sources. The National Electricity Policy (NEP), formulated in compliance with Section 3 of the EA 2003, has important provisions regarding the use of renewable energy resources and rural electrification. Subsequently Rural Electrification Policy (REP) has also suggested using off-grid based stand-alone systems for village electrification, where grid connectivity is neither feasible nor cost effective [4, 34]. Despite several such provisions for decentralised power generation and supply, a large number of people in rural parts of the country continue to lack access to clean and reliable energy sources indicating that past policies and programmes have not led to desired outcomes [34, 37].

One of the reasons behind the slow progress in rural electrification is the government's over emphasis on expanding the centralised grid to remote locations [10]. Such an approach involves significant expenditure on infrastructure, high Transmission & Distribution (T&D) losses, and unreliable power supply, especially in the current situation of country-wide shortages. Although the lack of a reliable power from the central grid should potentially drive the development of the market for clean energy in rural areas, the availability of free or inexpensive 'dirty' fuels such as kerosene and subsidised diesel in the market hampers these efforts. Moreover, a significant portion of the subsidised kerosene intended for public distribution is soldin the black market at higher prices, which makes the subsidy considerably less effective [6, 8, 34, 39]. Hence, some studies suggest that the kerosene subsidy could be diverted for rural electrification [10, 39].

Various studies note the importance and advantages of DRE micro-grids, especially their cost advantage in certain areas considering grid expansion costs. Hence, policy should support DRE micro/mini grids [1, 2, 11, 25]. They are especially favourable in areas with a flat terrain and dense population having a high number of HHs [45]. Similarly, policies geared towards promoting the use of DRE for telecom power should also be promoted, especially given that the economics is favourable with rising diesel costs and falling DRE equipment prices [20].

Present Decentralised Distribution Generation (DDG) guidelines as well as those of the Remote Village Electrification (RVE) Programme of the MNRE state that consumer tariffs for DRE electrification projects should be in line with existing tariffs in neighbouring areas (as per DDG) and those electrified through the grid (as per RVE). There is presently no mechanism to ensure adherence to such guidelines, and in many DRE projects, consumer tariffs are high (needed to cover the high cost of generation) compared to grid tariffs. A policy-regulatory mechanism to spread the incremental cost of DRE electrification over all grid-connected consumers could lower the tariffs of DRE consumers. The viability gap for economic sustainability of the projects could be procured by spreading the extra cost of DRE systems across the larger base of grid-connected consumers or through government budgetary allocation [10, 29]. Various studies have noted the need for regulation in the DRE space [1, 4, 17, 25, 29, 65]. A recent study has analysed this question in detail and proposed a new sustainable business model, namely 'Off-grid distributed generation based distribution franchise model (ODGBDF)', in which the project developer shall provide electricity service to consumers and collect revenue or consumer tariffs. Utilities will provide the generation tariff decided by the State Electricity Regulatory Commission (SERC) to the project developer, and receive financial assistance from the GoI if any. This new business model provides more revenue certainty to the developer, and further allows for effective grid integration of off-grid projects [4]. The forum of regulators (FoR) has accepted this report and framing of off-grid guidelines to support DRE programmes, in order to enable effective electricity access to remote rural households, is underway. A similar model has also been proposed by a recent World Bank study [29].

It has also been suggested that off-grid DRE generation should be counted towards Renewable Purchase Obligation (RPO) obligation, or in the Renewable Energy Certificate (REC) mechanism by making appropriate regulatory changes [4, 17, 29].

Another important consideration for policy change is the move from existing capital based subsidies towards more performance-based incentives [3]. Similarly, facilitating grid integration of DRE is an important aspect in terms of policy [3, 55].

Finally, one cannot emphasise enough the role of policy in making finance and credit available to both, DRE generators/developers and more importantly, DRE consumers [11]. Access to credit is very difficult and limited, so new mechanisms tailored to consumer requirements which can play a pivotal role in the long term growth and sustainability of the programme must be evolved [38, 59, 65]. An important policy suggestion in this regard is that the Reserve Bank of India (RBI) should accord priority lending status to DRE projects [3, 10, 39].

2.4 Institutional and governance framework

An effective and implementable institutional and governance framework is a must for the success of any DRE programme. While there exist a number of successfully implemented and operational DRE projects [5, 12, 23], many past projects have failed due to an over-emphasis on technical installation, while ignoring long-term sustainability [42]. Other important reasons for failures and the difficulty in replication at a large scale (in spite of techno-economic viability) are poor supply chains, weak institutional arrangements, and lack of appropriate local organisational leadership [47]. What is essential for good service delivery is a well-defined administrative, management and operational structure, with clarity over roles of various stakeholders [15, 19, 42], a system which aligns economic incentives with institutional structures [47].

A prime example of aligning economic incentives is moving from capital subsidies to performance incentives, a move which would force better long term O&M of DRE projects, and would go a long way in sustaining them. As far as government subsidies are concerned, the effectiveness of the subsidies needs to be assessed[3] while ensuring that they are targeted to reach the poorest. For this purpose, the application process should be streamlined to improve the accessibility of current subsidies and incentives in a time-bound manner for existing and potential DRE service providers [39]. If possible, subsidies should be administered through financial intermediaries with a viable track record [3]. There is also a need for an effective third-party independent M&V process coupled with a grievance redressal mechanism for dissatisfied consumers, if the quality of service does not match the minimum prescribed service standards.

There is also a need for better integration of DRE micro-grids within overall energy planning, and linking DRE to development goals [3, 38]. This would require better coordination between ministries with regard to rural electrification [34].

A review of MNRE's Village Energy Security Programme (VESP) show that out of 67 sanctioned projects, only 51% were operational [13]. The review states that the moderate success of the programme was partly due to the ineffectiveness of the state nodal agencies (SNA) in its implementation. Also, decision making remained centralised, which caused delays in sanctioning projects. To enhance the effectiveness of the programme, the review recommended that the process be more decentralised, and that entrepreneurs should manage the plants instead of VECs. Also, it recommended a focus on performance. This would need a change in monitoring metrics, from outputs to performance (generation). Such data, along with third part independent M&V, could be used towards contractual enforcement of minimum performance standards [13].

To address some of the shortcomings mentioned above, systematic approaches should be developed, benchmarked, and followed for project planning and formulation [42]. These considerations point to the crucial need for strengthening and fostering an institutional arrangement involving all stakeholders: central/state governments, utilities, Panchayati Raj institutions, village committees, civil society groups and developers [16].

2.5 Community participation in DRE micro-grid projects

The design of DRE programmes and projects is a top-down activity in many cases, so that the needs of the local people are not taken into consideration [58]. Also, local people are considered to be mere 'beneficiaries'. Instead, setting up a truly participatory planning process would be able to better assess user needs through their active involvement. Use of local knowledge, social inequities and class-caste structures are often not considered [58]. Such an approach is not focused on poverty reduction, motivation, quality control, maintenance and community mobilisation while designing electrification policies [6]. The technology and project size should be based on the needs and resources available at the project site, rather than on prior guidelines [13]. In that sense, policy should be technology and size neutral.

Time and again, studies have pointed to the central role of community participation in practically all stages of the project, including conception, planning, implementation, and successful long-term operation [30, 55, 60, 62, 63]. Community involvement helps to achieve a better understanding of the local ground realities. The literature highlights that community contribution is indispensable irrespective of whether the project is a private or government project [16, 34, 41, 58].However, according to a recent study, "the reality of capacity constraints among communities, local level conflicts and elite capture subvert the established premise on community participation"[16].

Good planning also demands better communication of the pros and cons of upcoming projects [15, 18]. An important consideration for the community is whether one should continue to operate the plant in an off-grid mode if the central grid arrives, operate it in a grid-integrated manner, or cease operations altogether.

Another feature of DRE micro-grids is the lack of long-term interest on the part of project developers for effective O&M, given the remote locations involved. Thus, capacity building in the community including local operators and maintenance personnel is needed to ensure that crucial O&M tasks are performed in-house for the smooth running of the plant for a longer period [30].

However, there are challenges in involving local communities in DRE micro-grid projects [22]. Caste, class and gender dynamics play an important role in land allocation, electricity allotment and collection of tariffs. Besides, electricity theft is normally a major concern in rural areas [58]. Hence, combining a sociological outlook along with the technical would help to understand the DRE space better [30].

2.6 Observations during Prayas Energy Group (PEG) field visits to DRE micro-grid project sites

The field visits conducted by PEG revealed some aspects of DRE micro-grids which were not highlighted in the literature.

Visits to two identical solar PV micro-grid projects located close to each other, one of which was owned by the government and the other privately owned, revealed a significant tariff difference among them. While consumers of the 10 kW capacity solar PV micro-grid project implemented by the state nodal agency (SNA) were paying about Rs 30/month, consumers of the privately run project were paying as much as Rs 85/month as their monthly tariffs for similar load consumption.

Duplicity in rural electrification efforts was a feature in some villages visited, where one could observe the infrastructure laid under the RGGVY scheme, the DRE micro-grid network, and other state-run electrification schemes at the same location. This highlights the overlap among different schemes for rural electrification in the same area. In contrast to this duplicity in effort, community members from various villages where DRE projects were coming up were apprehensive about whether the DRE micro-grid would deter the utility from extending the central grid to their village.

It was observed that the village Panchayats or the village energy committees (VEC) played a limited role in the rural electrification projects. Community participation in its various forms was much higher in social sector projects run by NGOs, while it was lacking in centralised government run projects. As noted earlier, community participation is crucial for any DRE project, and it is here that local NGOs can play a facilitating role in enhancing participation, leadership, entrepreneurship and capacity building.

An interesting synergy between government schemes was observed in one place, where the local community had contributed labour for the construction of the micro-hydro project, which would potentially be compensated through the Mahatma Gandhi National Rural Employment Guarantee (MGNREGA) scheme.

In some projects, effective village-to-village mentoring was instituted. Through this mechanism, people from villages with commissioned micro-hydro projects would assist and mentor the community where a new project was being commissioned.

Observations from a survey of 12 biomass gasifier installations:

Technical issues: The part of the system that failed most frequently was the engine and generator set. Starter motor and actuator burn out, generator winding problems, oil contamination over time due to lack of maintenance, and wires being eaten by rodents, were some of the main failures observed. Batteries that were used to start the gasifier system would often be completely discharged, due to non-operation or repeated attempts at starting the engine, and would need much effort and money to transport over long distances to the nearest charging station. There were also difficulties in startup due to high moisture content of biomass during the monsoon season, and DC pump failures due to clogging of pipes and foot valves by tar sediments, leading to meltdown of plastic pipes due to inadequate gas cooling. Transmission shorting due to the use of bare wires, and pole breakages due to extreme weather events, were also observed. Lastly, increased loads due to replacement of CFLs with cheaper incandescent bulbs, and an increased need for appliances, would overload the system causing brownouts or blackouts. What was clear from the survey was that maintenance costs for gasifiers are generally much higher than those expected during project appraisal.

Economic and institutional issues: Most systems charged a fixed monthly fee and contribution of biomass from each beneficiary for operating the system. While the capital cost of the system was covered through government/donor subsidies, the operator salaries were covered through the collection of consumer tariffs. However, gasifier non-operation, whether due to the non-contribution of biomass or technical issues, would lead to non-payment of tariffs, which would turn into a vicious cycle of non-payment of salaries, operator negligence, and the gasifier system in turn becoming defunct. Lack of annual maintenance contracts with the manufacturers prevented timely intervention in case of a technical failure. Further, the VECs set up to oversee the functioning of the system were in most cases defunct, either due to lack of capacity or monetary compensation.

The way forward: Many of these issues are not insurmountable and can be addressed by appropriate institutional arrangements that ensure quality O&M, and proper economic incentives. These could include institutionalising annual maintenance contracts, delinking operator salaries from payment of dues, monetising biomass collection, establishing technical standards for gasifier systems, and providing adequate compensation to project developers, while holding them responsible for the continual operation of these systems.

3. Conclusions

DRE micro-grid systems can play an important role in remote rural electrification. If implemented effectively, they can have a high positive impact on local socio-economic development.

While the cost of electricity generation from DRE projects is certainly higher than conventional thermal power generation, it is more cost-competitive in remote areas, especially if one considers the cost of laying down the transmission infrastructure of the centralised grid. As a result of higher costs, DRE tariffs are high, though there is willingness to pay for essential lighting services considering the savings from avoided kerosene costs. However, new policy-regulatory instruments for more equitable tariffs and innovative sustainable business models should be put in place going forward.

Ground experiences have pointed to a high number of project failures in the past. A number of interconnected factors affect the long-term viability of projects. The most important among these are high specific equipment costs, coupled with low loads and low PLFs/CUFs of the plants. Promotion of productive/anchor loads, or integration of systems with the centralised grid, could be a way around this issue. Careful attention must be paid to technical features such as proper demand estimation, project sizing, and DSM measures including the use of efficient appliances, load limiters, etc. which can significantly reduce the size requirement of the generation system, and thus lower capital costs and consumer tariffs. Another crucial aspect for the sustainability of projects is appropriate institutional arrangements with clearly defined roles and responsibilities for each stakeholder. This would ensure quality O&M and proper economic incentives linked to electricity generation will sustain the interest of the developer and increase the effectiveness of subsidies/incentives.

Policy and regulation can play a supportive role in promoting DRE by making finance more easily accessible. One way to go about this is to accord priority lending status to DRE and make credit more easily accessible for both developers and consumers. Regulation should be enforced to ensure that the subsidies/incentives provided by the government are reaching the targeted audiences and being used effectively. A strong institutional and governance arrangement with an effective M&V framework is required to ensure adherence to minimum standards of performance, and to make the programme credible in public perception. Similarly, the importance of community participation in all stages of the project cannot be emphasised enough, and is crucial for the long term sustainability of the project.

In Professor AKN Reddy's words, "Rural energy systems must advance rural economic growth that is economically efficient, need oriented and equitable, self-reliant and empowering and environmentally sound". Keeping in mind this overarching goal of rural energy systems, it is important to bridge the gap between practice and policy change to increase the effectiveness of the DRE sector and leverage its multiple benefits.

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While decentralised renewable energy (DRE) has had a long history in India, there is now renewed interest in remote rural electrification through DRE micro-grids, given the political commitment to provide electricity to all, the continuing electricity shortages, the fall in DRE equipment prices, especially solar PV, and the growing threat of climate change. There is a significant amount of existing literature which captures the technical, social, economic, institutional, and policy aspects of DRE micro-grids in India. This literature review attempts to present the distilled knowledge from these studies to a broader audience.

In a nut shell, while it is clear that DRE micro-grids have significant potential in remote areas, can increase socio-economic development and help in poverty alleviation, the high incidence of project and system failures suggests that there are several unresolved technical, socio-economic and institutional factors that fundamentally impact its long-term sustainability.