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Sustainability of productive use of off-grid renewable energy: A case of a women's collective from rural India

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ABSTRACT

Renewable energy has emerged as a climate-friendly development alternative to provide clean and reliable energy access. However, the long-term sustainability of off-grid-based applications for productive and income-generating activities remains in suspect as it is an emerging area of development and has yet to be extensively studied for sustainability. With this background, this paper proposes a new framework for the assessment of the sustainability of productive use of off-grid energy based on technical, economic, social, institutional, and environmental dimensions. To ensure it is deeply rooted in practice, a survey-based study of a women-collective from rural India was conducted using the proposed framework. The results indicated that capacity development, participatory approaches, need assessment, and regular cash flows were a few of the important indicators for sustainability of operations. Further, it was also observed that sustainability and socio-economic benefits were intertwined and complementary. The Indian Government envisions a substantial role for renewable energy-enabled productive use to address infrastructure bottlenecks, development issues, and climate change related goals. In this context, the proposed framework would be useful for assessing the sustainability of such interventions for their longevity while accruing socio-economic benefits to the users.

Contribution/Originality: This study proposes a new framework for assessing the sustainability of off-grid, renewable energy-based productive activities. Previous studies have focused on assessing the sustainability of renewable energy-based domestic energy access, as there was no framework for productive activities. In this context, this study endeavors to address this gap.

1. INTRODUCTION

Climate change is an extensively debated topic within the realm of development discourse because of its far-reaching consequences for crucial aspects such as food security, water availability, public health, and the overall environment. These areas hold significant relevance for both humans and the earth as a whole (Yohe et al., 2007). Climate change effects are global in scale and need long-term strategies to avoid catastrophic consequences in future (Klarin, 2018; WCED, 1987). Therefore, in order to mitigate these effects, address depleting natural resources, and meet the development needs of the people, the development strategy is expected to be grounded on the three pillars of sustainable development—social, economic, and environmental sustainability (WCED, 1987). However, in spite of societal, political, and academic debates and discussions, the sustainable development paradigm has not gained prominence in its application on the ground on account of divergent priorities of nations, costs involved, technology transfer impediments, and politics, among other things, which have therefore increased the intensity of climate change effects, affecting the flora and fauna of the planet.

Energy access, which is critical for poverty alleviation and development, has implications for climate change (Rao, 2010). It is particularly relevant to electrical energy—substantially produced using fossil resources—which could be used conveniently for multiple applications, including productive and income-generation activities (Kellow, 1996). Notwithstanding the global efforts, a large quantum of global population still does not have access to reliable electrical energy. Apropos of this need, the United Nations (UN) launched a development initiative, Sustainable Energy for All (SE for All), in 2011 and included it as Sustainable Development Goal (SDG) 7 to provide ecologically sound and equitable universal energy access. Reliable energy access is a prominent development issue in sub-Saharan Africa and South Asia. In fact, because of their underdevelopment and lack of economic activities, this problem is most prevalent in rural and isolated locations in these regions, posing a threat to livelihood opportunities and income for local communities. (Bhandari, Saptalena, & Kusch, 2018; Bhattacharyya, 2012). In the Indian context, fossil resources contribute substantially—about 57 percent—to electricity generation capacity. Although India has achieved 100 percent electrification of its villages, poor reliability and quality of energy have compelled a significant number of households to use fossil fuels. Rural micro-enterprises have also largely remained unconnected to the grid, especially in states like Uttar Pradesh and Bihar, undermining the enterprising spirit of rural communities (Katre & Tozzi, 2018). In this context, renewable energy, which is a climate-friendly energy option, has emerged as a development alternative, especially for isolated and rural locations. Off-grid energy interventions provide end users with a pollution-free indoor environment, opportunities to undertake productive activities, and farm irrigation, among other benefits.

Several corporations, state actors, and not-for-profit organisations have offered off-grid energy solutions to address the issue of reliable and sustainable energy access for domestic use and productive activities in remote locations—a critical gap in infrastructure provisioning. During the year 2022, the Government of India has promulgated an overarching policy framework to augment efforts to address these gaps and harness clean energy resources for productive activities—renewable energy as a factor of production to ensure income generation and livelihood for women and youth in rural areas. The socio-economic benefits of renewable energy interventions and their long-term sustainability have implications for climate change redressal mechanisms and sustainable development. However, off-grid energy projects have yielded mixed results thus far, as a few interventions have discontinued their operations due to various reasons (Bhandari et al., 2018; Dauenhauer et al., 2020). For energy access interventions to achieve a desired socio-economic impact, project design, implementation, operations, and replication need to take cognisance of sustainability (Bhattacharyya, 2012). Therefore, the long-term sustainability of off-grid energy interventions for productive activities merits an analysis as these systems operate in remote locations with constrained resources. Moreover, the sustainability assessment aspect is yet to be studied for such interventions as off-grid renewable energy for productive use, which is an emerging sector in India, and the current focus is on implementation, operationalisation and strengthening of the value chain through policy measures, access to finance, technology development, capacity building, etc. Thus, this research gap necessitated the study of the sustainability of off-grid energy-based productive activities. A few studies, which are conducted for sustainability assessment of domestic energy access—domestic energy access for household purposes and energy access for productive or income-generating activities are two separate domains, with the former usually receiving more attention and focus—underline the importance of community participation, capacity development, and regular cash flows for the longevity of the interventions. Further, these studies also recommend a detailed sustainability analysis of renewable energy applications used for productive activities.

With this background, this paper proposes a new sustainability assessment framework for off-grid interventions used for productive activities, attempts its field applicability by testing the sustainability of a collective-based, off-grid energy-enabled productive activity in rural Maharashtra (India), and in the process finalizes the framework on the basis of feedback received from a field survey and consultations with the subject experts. The paper also endeavors to explain how sustainability and socio-economic benefits are interdependent based on the survey findings. The study is expected to be useful for development sector researchers, academicians, policymakers, financial institutions, and practitioners to understand the importance of sustainability assessment to ensure continuity of renewable energy interventions for productive activities and the accrual of socio-economic benefits to the end users. The research intervention is located in rural areas of Amravati district, Maharashtra. The collective is promoted by a local government, is managed by marginalized women, and is in the business of processing raw cotton into finished garments in an environment-friendly manner—with minimum negative externalities—as it endeavors socio-economic development of beneficiaries. This paper is divided into seven sections, including an introduction. Section two briefly discusses the status of electricity access in India, which underlines the importance of off-grid energy for productive activities. Section three enumerates relevant reviews of literature about sustainability and the conceptual framework for the study. Section four discusses the collective enterprise in terms of its local socio-economic context, its formation process, and its status. The fifth section details the proposed sustainability framework, the methodology for the study, and the finalized version of the framework for future use. The results of the research intervention using the framework and the interplay between sustainability and socio-economic benefits using hypotheses are discussed in the sixth section. The seventh and final section concludes the study.

2. ELECTRICITY ACCESS IN INDIA

Electricity is considered the most convenient and versatile form of energy. Due to its adaptable nature, electrical energy could be used for numerous applications, including productive activities. However, it is also a secondary source of energy and is generated by transforming primary sources—coal, natural gas, nuclear energy, solar, wind energy, etc. In the Indian context, consumption of electrical energy broadly comprises the residential sector at 23 percent, agriculture at 18 percent, commercial at 8 percent, and industrial at 44 percent. Electricity demand for the last 15 years has grown at 6.9 percent and is expected to grow in a similar range till 2030 (Brookings India, 2018a). According to the Central Electricity Authority (CEA), India is projected to achieve a state of power surplus in the foreseeable future. However, this surplus may be attributed to suppressed demand, which arises from the hesitancy of utilities to procure and distribute power. This hesitancy can be attributed to factors such as under-recovery or non-availability of funds, as well as insufficient transmission and distribution infrastructure, particularly in remote and hilly regions. India had about 416 gigawatts (GW) of installed capacity as of March 2023, of which about 58 percent came from fossil-based resources, increasing its carbon footprint. The recorded peak demand was about 216 GW in March 2023 (GOI, 2023). However, India's estimated electricity demand was higher—about 440 GW--rendering a significant part of its population energy-starved. India's per capita electricity consumption also remained low at about 1,180 kilowatt-hours (kWh) against the global average of 3260 kWh (Money Control, 2021), depicting overall energy poverty and creating impediments to achieving human development goals. Therefore, India needs to increase its per capita energy consumption to improve the development indices, which also delineate the need for a reliable energy supply from sustainable resources, especially for rural and isolated locations.

India's abundance of renewable energy resources—solar, wind, and biomass--can provide sustainable and equitable energy access to its population, as these resources are largely untapped and well-distributed throughout the country. Further, India's solar potential is estimated at about 750 GW and its wind potential at 300 GW. Thus, off-grid renewable energy has the potential to become an instrument of sustainable development for poverty alleviation and social welfare, especially in remote and rural areas (Brookings India, 2018b; Deshmukh, Gambhir, & Sant, 2010; Deshmukh, Gambhir, & Sant, 2011; REEEP, 2017). The main grid's connectivity to isolated locations has shortcomings in terms of inefficiencies in transmission and distribution, revenue realization, and reliability. The issue of quality and reliability of energy also hampers the enterprising spirit of the rural population, which is critical for livelihood opportunities, improving farm productivity, and minimizing farm losses. Thus, an alternative development option could play an important role in supplementing grid energy, as access to energy is not just a function of infrastructure provisioning but also about quality of service and managing the aspirations of the people. Further, decreasing prices of renewable energy technologies have made off-grid an attractive and economical energy option (Bhattacharyya & Palit, 2014; REEEP, 2017). The Indian Government foresees clean electricity as the backbone of Indian economy as it envisages the use of renewable energy for applications ranging from transport to cooking in the near future (PTI, 2020). Recently, India has committed to several climate-related goals during the Conference of the Parties (COP) 26 (2021), such as the installation of 500 GW of non-fossil energy capacity, 50 percent of energy from renewable energy sources, a reduction in emission intensity by 45 percent, a reduction in emissions of one billion tons (all by 2030), and becoming a net zero emitter by 2070. In continuation of this philosophical framework, the Ministry of New and Renewable Energy (MNRE) has promulgated a Policy Framework in 2022 to develop and promote Decentralized Renewable Energy (DRE)-based Livelihood Applications targeting rural women and youth to promote productive activities such as solar dryers for food processing, solar powered cold storages, solar charkha for cotton yarn production, solar-powered rice hullers, etc. The Framework is expected to attract the private sector to develop and deploy efficient applications, provide easy access to end use finance, and impart capacity development & training, among other things, thus enabling a way to create a conducive eco-system for sustainable development in areas that have unmet demands, especially for post-harvest, agro-processing-related infrastructure in rural areas.

3. REVIEW OF LITERATURE

Numerous options could be used to provide energy access; however, a few options are more sustainable than others. Some energy resources, which are cheaper, might not necessarily be friendly to ecology and may get exhausted in the long term. Similarly, a few energy access technology options could have low capital costs initially, but they may incur higher operational and maintenance expenses perpetually. Some energy access options could be more difficult to operate, manage, and maintain locally by communities than others. Therefore, to ensure a financially viable, environment-friendly, locally manageable, and socially acceptable technology option, a sustainability assessment needs to be carried out. In view of this, the sustainability of solar based off-grid interventions is an important issue for the longevity and continuity of their operations. In the context of the study, the concept of sustainability for the intervention can be defined as the ability of the solar off-grid energy project to maintain its operation for electricity supply while complying with technical, economic, social, environmental, and institutional requirements, which are also known as sustainability dimensions (Bhandari et al., 2018). Measurement of sustainability is indispensable as it enables progress to be achieved towards the desired development goals and helps decision-makers make amendments to operational frameworks to reflect changing ground realities (Hardi, Barg, Hodge, & Pinter, 1997). Therefore, a starting point for evaluating project sustainability is the definition of dimensions and corresponding indicators and measures (performance assessment tools). Indeed, the indicators could be qualitative, quantitative, or both for a given dimension. An aggregate high score on these dimensions could be perceived as a sustainable project.

A review of the literature indicates that no specific study has been carried out to assess the sustainability of renewable energy-based off-grid interventions used for productive activities—where renewable energy is used as an input for the production process—as most of the studies are dedicated to the assessment of sustainability for domestic energy access and, in a few cases, the sustainability of various technologies—wind, solar, biomass, etc.—instead of projects. Most sustainability approaches comprise defining dimensions of sustainability and indicators and generally consider five dimensions—technical, economic, social, environmental, and organizational or institutional. Therefore, in this review, studies that are closely relevant to the research topic and have currency are mentioned. The Ilskog framework, developed in 2008, was developed to rate the sustainability of energy options based on a comparison of scores across dimensions. The framework had five dimensions—technical, economic, social, environmental, and institutional--with 39 indicators of equal importance to all dimensions. Bhattacharyya (2012) used this framework to assess the sustainability of energy access programmes (mini grids, solar home systems, grids, petro-fuels, biogas, and clean cook stoves) based on brainstorming among the experts instead of a survey, which was also a shortcoming of the study. In the findings, grid and biogas emerged as the preferred options for lighting and cooking purposes, respectively. However, within lighting, the grid did not show all-around performance on various dimensions, indicating scope for further improvement. Importantly, the study highlighted the need for linking energy access with economic development, as most studies generally focus on providing energy access for domestic use without considering its utility for productive use or long-term sustainability.

Mainali, Pachauri, Rao, and Silveria (2014) conducted a study based on 13 indicators to measure the sustainability of rural energy access (electricity access and cooking fuel) by using the energy sustainability index (ESI) of 6 Afro-Asian countries—China, India, Bangladesh, South Africa, Sri Lanka, and Ghana. The study used four dimensions (leaving institutional aside) and secondary data to rank these countries on ESI. However, as the ESI was used to rank the countries, the findings could not be used to verify the sustainability of the individual clean electricity access projects. A more relevant sustainability study was conducted by Bhandari et al. (2018) for a small-community operated hydropower-based domestic energy access project in Nepal with 54 indicators; the study had four dimensions, i.e., social, economic, environmental, and technical, which were further divided into themes and themes into indicators, with each indictor rated on a scale of 1 to 5. The indicators within a theme and themes within a dimension were assigned different weights. Although the project received a score of 3.7, the researchers suggested not assigning an aggregated score for the project as it might mask the scores received by individual dimensions, which are critical to understanding different aspects of sustainability. Further, the study also mentioned the socio-economic benefits of the project. The study reiterated that, for the sustainability of the project, capacity building of the people and revenue generation through economic activities were important.

A new sustainability framework by Katre and Tozzi (2018) attempted an improvement over the existing frameworks by providing an analysis of indicators and measures for five dimensions of community-managed mini-grid systems for domestic energy access, which is also relevant to this study, although it proposes to assess the sustainability of community-managed interventions for productive and income-generating activities. Using this framework of 2018, a study by Katre, Tozzi, and Bhattacharyya (2019) on the sustainability of mini-grids for domestic energy access in three states of India--Maharashtra, Karnataka, and Jharkhand--argued that community involvement and demarcation of responsibilities during installation and commissioning of the project—a bottom-up/participatory approach—were critical for long-term sustainability, which was also recommended by Gambhir, Toro, and Ganapathy (2012). This is an important finding given the fact that Indian society is structured on the basis of class, caste, economic status, etc., and the technology is in an early stage of adoption, which therefore necessitates community participation for sustainability to overcome these issues. The study further indicated that strong local capacity and its development in terms of institutional, financial, and technical management of the systems and regular payments determine sustainability in the long term. As with the earlier studies, the research mentioned the positive impact of off-grid energy on health, education, safety, and interface with the outside world. Although energy access improved the well-being of women, the study suggested that women's independence due to energy access needed to be probed further. The study also recommended investigation into the sustainability of community-led productive activities due to the limited scope of productive activities in the study area.

Another sustainability-related study was conducted by Dauenhauer et al. (2020) for community-based solar mini-grids for energy access to schools, clinics, and households in Malawi—which has one of the lowest electricity access rates of about 12 percent in the world—through a structured questionnaire for 65 individual projects using four dimensions excluding environment. The results indicated that insignificant community involvement (lower contributions and fewer meetings), absence of project management capacity, unmet training requirements, fewer cash accruals, and undersized systems affected long-term sustainability; the projects had an overall sustainability score of 0.318 (normalized on a scale of 0 to 1). Economic sustainability had the lowest score, although the projects were grant-funded (32 projects had no income at all); the cash reserves were not sufficient to meet the operating and capital expenditures, underscoring the importance of the economic dimension in overall sustainability. Although the reviewed cases do not represent an exhaustive coverage of varied projects, they reflect recent experiences and a wide geographical coverage in the off-grid domestic energy access domain. Further, these studies do not represent interventions related to productive activities due to their non-availability, which provides a scope to design a new sustainability assessment framework for renewable energy-based income generation and productive activities, assess the sustainability of such activities using the framework, and finalize the framework for future use.

3.1. Conceptual Framework

Productive activities have the potential to improve income, secure modern lifestyle conveniences, and achieve development goals for people (Ray, 1998). Studies depict that access to electrical energy could lead to productive activities for income generation and improvement in socio-economic indicators (Aklin, Bayer, Harish, & Urpelainen, 2017; Bhattacharyya, 2012; Kellow, 1996; Mainali et al., 2014; Rao, 2010). In the context of the study, SDG 7 (access to clean energy) can have a socio-economic impact on beneficiaries by way of income generation activities and the associated multiplier effect on food access, health, education, women's empowerment, employment, etc., thus improving their standard of living. Further, sustainability of such interventions is intertwined with the accrual of socio-economic benefits to the members, as the benefits derived have an intrinsic value to them, which enables them to continue to provide their patronage to the intervention, which—longevity of operations—in turn ensures the continuation of the accrual of benefits to the beneficiaries (Parris & Kates, 2003).

In view of the above, assessment of sustainability becomes imperative to indicate whether the interventions can sustain their operations and continue accruing benefits. Thus, for assessing the sustainability of interventions (renewable energy access for productive activities), a new sustainability framework is proposed (see Figure 1), as currently we do not have frameworks for off-grid renewable energy-based productive or income-generation activities. The framework complements the earlier work by Katre and Tozzi (2018) (sustainability assessment of solar mini grids for domestic energy access in India) and Dauenhauer et al. (2020) (sustainability assessment of solar mini grids for schools and health centers in Malawi, Africa). As with the earlier assessment tools, the proposed framework has five dimensions—technical, economic, social, environmental, and institutional--and associated indicators and measures. A high score on these five individual dimensions depicts a higher likelihood of the sustainability of the project and the continuance of the accrual of benefits to the people. The five dimensions of the proposed framework have the following meanings:

1. Social: It indicates assessment of need, community contribution, sense of ownership, unity, connectedness among the beneficiaries, benefits, etc. In general, this dimension is related to the social acceptability of energy access options, well-being, ownership, empowerment, etc.
2. Institutional: It shows capacity to manage and maintain the system, meeting frequencies, participation in meetings, satisfaction with the intervention and governance, etc. The institutional dimension pertains to the survival of the implementing organization, and its ability to facilitate the effective performance of the intervention.
3. Economic: It depicts the financial wellbeing of the project in terms of repayments, cost recovery, cash reserves, bank accounts, etc. The economic dimension defines the carrying capacity of the project in the long term after taking various costs into account.

4. Environmental: The environmental dimension deals with reducing the negative externalities of a technology or energy access option on users, society, and the environment, including its contribution to pollution, health damage, and other environmental degradation.
5. Technical: The technical dimension of sustainability is concerned with maintaining the stipulated technical or energy output during the economic life of a technology and meeting current and future needs, if any. It provides details about technical performance, quality of installations, safety, reliability of operations, etc.

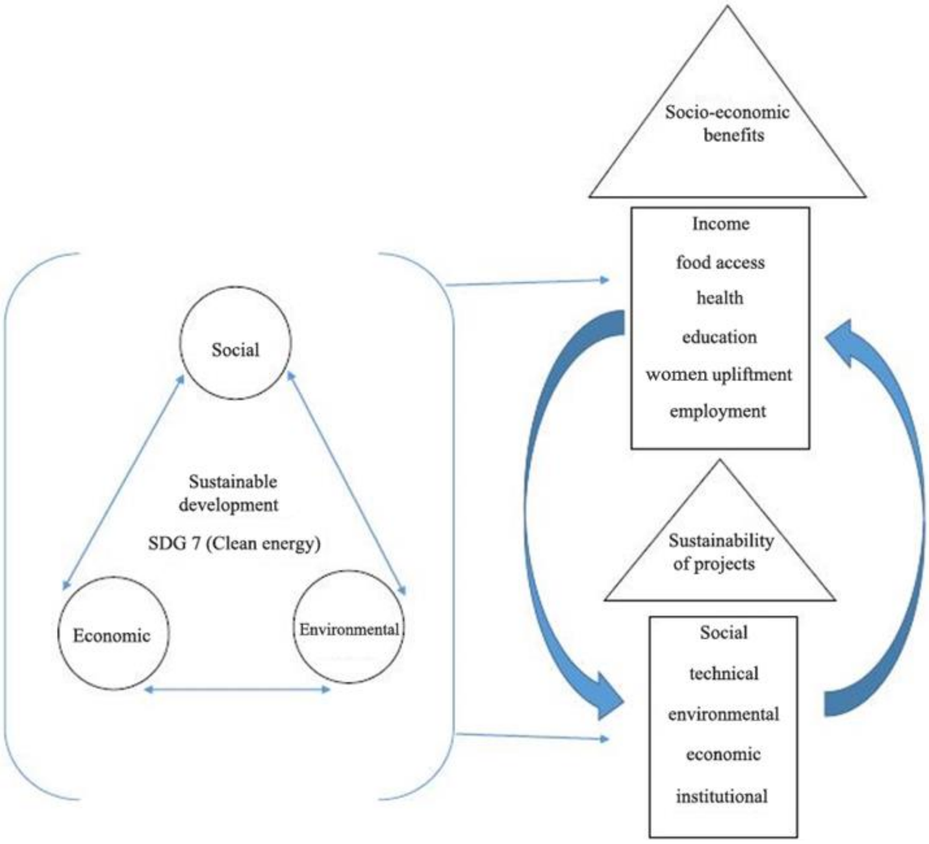

Figure 1. Conceptual framework.

4. THE SETTING

4.1. Kasturba Solar Khadi Mahila Samiti

The eastern region of Maharashtra (India), also known as Vidarbha, is one of the under-developed regions and primarily has an agrarian economy. Amaravati district, which lies in Vidarbha (where the intervention is located and discussed later), has an area of 12,235 square kilometers. As per the 2011 census, the district had a population of 2,887,445 with a literacy rate of 87 percent. About 64 percent of the population resides in rural areas, with 70 percent of the rural workforce engaged in agriculture, which is rain-fed. The district has one of the highest proportions of scheduled castes (SCs) and scheduled tribes (STs) communities, as they are one of the most disadvantaged socio-economic groups in India (Govt of Maharashtra, 2019).

Maharashtra State Khadi and Village Industries Board (MSKVIB), a government of Maharashtra department, has been working in the domain of micro level industrial development and employment generation at the grassroots level in the state. During the year 2014-2015, MSKVIB commenced an initiative to establish a decentralised solar charkha cluster in Amravati district with the objective of providing off-farm livelihood opportunities for women from marginalised SC and ST communities. It had also set up a charitable trust in 2016 also known as Kasturba Solar Khadi Mahila Samiti (KSKMS) for managing the operations of the cluster, with a central office located in Amravati. It is a unique, solar energy-based, and women-managed development project in India. Solar charkha, a spinning wheel machine powered by solar energy, produces cotton yarn from raw cotton (see Figure 2 for spinners working on solar charkha units), which is processed further to produce garments. The project was implemented in 20 villages (see Table 1) where agriculture was a primary livelihood option for the villagers, mainly during the monsoon season. MSKVIB, through a participatory approach, conducted livelihood needs assessments of women in each village, which is an important component of social dimension of sustainable development paradigm. Women members with satisfactory credit histories and an interest in the initiative were selected for capacity development and training purposes. Further, charkha units were financed through loans and subsidies for SC community members, whereas for ST women members, the units were entirely funded through grants to ensure social equity due to their lower socio-economic status.

Figure 2. Spinners working on Solar Charkha units.

Source: Kasturba Solar Khadi Mahila Samiti.

Currently, the cluster has 20 rural centers and one urban center with a total membership of 234 members, with an equal number of members participating from each community. The urban center located in Amravati is used for capacity building and training purposes. At each rural center, the members are provided with raw cotton on a weekly basis to produce cotton yarn using the solar charkha unit. The members are compensated on the basis of the yarn produced.

The cotton yarn is then processed for weaving, bleaching, dying, and printing; later, it is stitched into garments and marketed by the common facility center (CFC) located at Amravati. The CFC, known as Greenfab Khadi Processing Cluster (Greenfab), a not-for-profit company, was established in 2017. The members of KSKMS are also members of Greenfab. The CFC was funded by the local government through grants and was commissioned in

2020, as earlier the value addition process was outsourced, which had a significant impact on the profitability of the initiative. The CFC is also powered by solar energy on a net metering basis along with grid power; it also uses organic dyes and an effluent treatment unit, thus improving green footprints in the value chain. The intervention currently provides livelihoods to more than 300 women, including spinners, weavers, packers, trainers, and administrative staff. Further, to promote climate-friendly measures in its backward linkages, KSKMS has encouraged local farmers to grow organic cotton, thus reducing soil and air pollution and improving farmers' health. For forward linkage and marketing, the organisation has opened a few outlets branded Kutir in the district center and nearby major urban centers. In addition to this, it also actively markets its products under the brand names Kasturba and Green Fab to institutional buyers such as government departments, corporations, schools, and colleges. Overall, the initiative attempts to address the social, economic, and environmental dimensions of sustainable development by empowering socially marginalised communities, generating income through productive activities using solar energy, and increasing green footprints in the value chain.

Table 1. Socio-economic characteristics of members.

Village (Community)	Year of commencement	No of members	Average age (Years)	Average family size (No of persons)	Average landholding (Acres)
Surali (SC)	2015	10	35	4.2	0.7
Nimbha (SC)	2015	11	33	5.7	1.3
Dighi Kolhe (SC)	2015	9	36	3.9	3.3
Kholapur (SC)	2015	9	35	4.6	Nil
Ramtirth (SC)	2016	8	45	4	Nil
Dabha (SC)	2016	10	43	4.1	0.2
Belora (SC)	2016	10	33	3.9	1.2
Shiwangaon (SC)	2016	10	36	3.8	1.4
Belora Hirapur (SC)	2016	10	39	4.4	Nil
Vani Belkheda (SC)	2016	10	37	4.0	Nil
Ghodasgaon (SC)	2017	10	48	4.1	0.6
Nimkhed Bazar (SC)	2017	10	36	4.0	0.9
Koltek (ST)	2018	10	43	4.3	1.9
Toli (ST)	2018	11	26	4.4	1.4
Aki (ST)	2018	11	20	6.2	1.8
Dharakot (ST)	2018	19	25	4.7	1.5
Titamba (ST)	2018	15	27	4.5	2.4
Ghuti (ST)	2018	26	31	5.2	1.6
Mandu (ST)	2018	18	27	5.2	0.9
Bihali (ST)	2020	7	22	5.4	0.4
		Total members 234	Average age of members 33 years	Average family size of members 4.6 persons	Average landholding of members 1.2 acres

5. METHODS

5.1. Framework

After reviewing the relevant literature on sustainability of renewable energy interventions, the research focused on identifying suitable indicators and measures for the new sustainability framework proposed to be used for the assessment of sustainability of the rural-based solar charkha centers and interventions. In the past six years, the author has visited the KSKMS and the intervention several times to understand their operations, which also assisted in preparation of indicators. The framework was divided into five dimensions, 35 indicators, and their measures (see Table 2). The measures were assigned scores on the basis of benchmarks. The scores had discrete values ranging from 0 to 1, 2, or 4 (worst to best), depending upon the type of indicator. For the survey, the indicators and measures were used to prepare a questionnaire. The field survey was conducted in the month of

November 2021 with the assistance of a local associate (during the pandemic in India). The scores obtained for indicators through the interviews of the members of rural charkha centers were validated with the help of local facilitators, community members, records, and documents to avoid the researcher's bias. For calculation purposes, the scores were rearranged on the scale of 0 to 1. For instance, an indicator that had a score of 3 on the scale of 0 to 4 was re-assigned a value of 0.75. Further, the individual dimensions of sustainability were assigned weights after discussions with beneficiaries, the local community, and facilitators to reflect their importance in the sustainability framework. It may also be noted that the weights could be changed or customized depending on the type of productive activity and the local socio-economic context following discussions with the various stakeholders. The overall score obtained by a particular dimension (after adding the rescaled scores of various indictors under that dimension) and multiplying them with the weights assigned indicated the final score and its importance in determining the overall sustainability. After field data collection, feedback received from various stakeholders, and suggestions from experts, the earlier version of sustainability framework (see Table 2) was revised and finalized to the current form as mentioned in Table 3. The updated version has 48 indicators and corresponding measures.

Table 2. Sustainability dimensions, indicators, and measures (During survey).

SN	Dimension	Code	Indicator	Measure	Benchmarks and score range
1	Technical	T1	Quality of components	Component sourcing from reputed manufacturers	2, 0-1
2		T2	Optimal design	Design to meet load requirements	2, 0-1
3		T3	System adaptability	Flexibility and adaptability to accommodate changes in load profile	2, 0-1
4		T4	Actual output	Actual output (voltage & current) to meet the current load	2, 0-1
5		T5	Quality of supply	Voltage & current issues in supply	3, 0-2
6		T6	Safety	Safe installation and connections	3, 0-2
7		T7	Reliability	Frequency of downtime in a month	5, 0-4
8		T8	Maintenance quality	Quality of maintenance being carried out by the contractor	3, 0-2
9	Economic	EC1	Bank account	Savings bank account for members	5, 0-4
10		EC2	Solar charkha funding	Debt or grant for funding the solar charkha unit	2, 0-1
11		EC3	Loan repayment	Loan repayment regularity	5, 0-4
12		EC4	Payback period	Planned payback period achievement	5, 0-4
13		EC5	Raw material supply	Regularity in raw material supply to members	5, 0-4
14		EC6	Compensation	Regularity in compensation to members	5, 0-4
15		EC7	Cash reserves	Sufficiency of cash reserves for repair, maintenance, & battery replacement	5, 0-4
16		EC8	Insurance	Solar Charkha unit insurance	2, 0-1
17	Institutional	I1	Capacity building	Group capacity development in technical, financial, and administrative domains	2,0-1
18		I2	Capacity to manage	Group capacity in managing technical, financial, and administrative issues	3, 0-2
19		I3	Role allocation	Allocation of responsibilities within group for managing technical, financial, & administrative issues	2, 0-1
20		I4	Maintenance	Maintenance arrangement with an external agency	2, 0-1
21		I5	Frequency of meetings	Regularity of group meetings	3, 0-2
22		I6	Level of attendance	Attendance of members in meetings	5, 0-4
23		I7	Level of participation	Participation of members in meetings	5, 0-4
24		I8	Satisfaction with solar charkha unit	Satisfaction of members with solar charkha unit	5, 0-4
25		I9	Satisfaction with governance	Satisfaction of members with governance of the intervention	5, 0-4

SN	Dimension	Code	Indicator	Measure	Benchmarks and score range
26	Social	S1	Need assessment	Need assessment for the intervention by interacting with community	5, 0-4
27		S2	Unity	Feeling of connectedness within the group	5, 0-4
28		S3	Sense of ownership	Feeling of ownership about the intervention within the group	5, 0-4
29		S4	Well-being	Feelings of members about contribution of intervention to improving their standard of living	5, 0-4
30		S5	Financial independence	Financial independence in managing income by members	5, 0-4
31		S6	Social acceptability	Acceptance of the intervention by society or family	3, 0-2
32	Environmental	EN1	CO_2 emissions avoidance	CO_2 emissions avoided in a month vis-à-vis grid power	5, 0-4
33		EN2	Impact on users	Negative impact on the health of members	3, 0-2
34		EN3	Impact on neighborhood	Negative impact of the intervention on neighborhood	3, 0-2
35		EN4	Impact on environment	Negative impact of the intervention on local environment	3, 0-2

Table 3. Sustainability dimensions, indicators, and measures (Post survey).

SN	Dimension	Code	Indicator	Measure	Benchmarks and score range
1	Technical	T1	Quality of components	Component sourcing from established manufacturers	2, 0-1
2		T2	Optimal design	Design to meet load requirements	2, 0-1
3		T3	System adaptability	Flexibility and adaptability to accommodate changes in load profile	2, 0-1
4		T4	Actual output	Actual output (voltage, current, and power) to meet the current load	2, 0-1
5		T5	Quality of supply	Voltage & power issues in supply	3, 0-2
6		T6	Safety	Safe installation and connections	3, 0-2
7		T7	Reliability	Frequency of downtime in a month	5, 0-4
8		T8	Maintenance quality	Quality of maintenance being carried out by the contractor	3, 0-2
9	Economic	EC1	Bank account	Savings bank account for members	5, 0-4
10		EC2	Solar charkha funding	Debt or grant for funding the solar charkha unit	2, 0-1
11		EC3	Conduct of loan account	Loan repayment regularity	5, 0-4
12		EC4	Loan closure	Planned loan closure achievement	5, 0-4
13		EC5	Means for loan closure	Proceeds from solar charkha usage for loan closure	5, 0-4
14		EC6	Raw material supply	Regularity in raw material supply to members	5, 0-4
15		EC7	Quantity of raw material	Adequacy of raw material to use full solar charkha capacity	5, 0-4
16		EC8	Capacity utilization	Solar Charkha capacity use in a month	5, 0-4
17		EC9	Compensation timelines	Regularity in compensation to members	5, 0-4
18		EC10	Adequacy of compensation rate	Satisfaction of members with cotton yarn rates in Rupees per kg	5, 0-4
19		EC11	Surety of operations	Surety of operations perceived by members	5, 0-4
20		EC12	Cash reserves	Adequacy of cash reserves for repair/maintenance, & battery replacement	5, 0-4
21		EC13	Insurance	Solar Charkha unit insurance	2, 0-1
22	Institutional	I1	Solar charkha training	Training to operate a Charkha unit	2, 0-1
23		I2	Capacity building	Group capacity development in technical, financial, and administrative domain	2,0-1
24		I3	Capacity to use full capacity	Ability of members to operate Charkha unit at its full capacity	5, 0-4

SN	Dimension	Code	Indicator	Measure	Benchmarks and score range
25		I4	Capacity to manage	Group capacity in managing technical, financial, and administrative issues	3, 0-2
26		I5	Role allocation	Allocation of responsibilities within group for managing technical, financial, & administrative issues	2, 0-1
27		I6	Maintenance	Maintenance arrangement with external agency	2, 0-1
28		I7	Responsiveness of maintenance arrangement	Responsiveness and effectiveness of maintenance arrangements	2,0-1
29		I8	Frequency of meetings	Regularity of group meetings	3, 0-2
30		I9	Level of attendance	Attendance of members in meetings	5, 0-4
31		I10	Level of participation in meetings	Participation of members in meetings	5, 0-4
32		I11	Level of participation in production	Participation of members in yarn production	5, 0-4
33		I12	Satisfaction with solar charkha unit	Satisfaction of members with solar charkha unit	5, 0-4
34		I13	Satisfaction with governance	Satisfaction of members with governance and management of the intervention	5, 0-4
35		I14	Standard operating procedures (SOPs)	SOPs for operation of the solar charkha unit	3, 0-2
36		I15	Documentation	Maintenance of documents and records for operations of the solar charkha unit	3, 0-2
37	Social	S1	Need assessment	Need assessment for the intervention by interacting with community or members	5, 0-4
38		S2	Unity	Feeling of connectedness within the group	5, 0-4
39		S3	Sense of ownership	Feeling of ownership about the intervention within the group	5, 0-4
40		S4	Well-being	Feelings of members about contribution of intervention to improving of their standard of living	5, 0-4
41		S5	Financial independence	Financial independence in managing income by members	5, 0-4
42		S6	Social acceptability	Acceptance of the intervention by society or family	3, 0-2
43		S7	Project recommendation	Recommendation of solar charkha unit to family or friends	5, 0-4
44		S8	Evincing of interest	Interest shown by villagers to become members	3, 0-2
45	Environmental	EN1	CO_2 emissions avoidance	CO_2 emissions avoided in a month vis-à-vis hypothetical grid-powered charkha unit	5, 0-4
46		EN2	Impact on users	Negative impact on the health of members	5, 0-4
47		EN3	Impact on neighborhood	Negative impact of the intervention on neighborhood	3, 0-2
48		EN4	Impact on environment	Negative impact of the intervention on local environment	3, 0-2

5.2. Hypotheses

In order to establish how sustainability and socio-economic benefits are interwoven and interdependent, two hypotheses were proposed and tested using field data. Since income is one of the major enablers and has a multiplier effect on improving the standard of living (Ray, 1998), we proposed a hypothesis that beneficiaries and non-beneficiaries had a significant difference in their income—in Indian Rupees (INR)—as a rise in income enabled members to derive incremental socio-economic benefits vis-à-vis non-members. These incremental benefits were expected to continue the patronage of the members for the project.

Hypothesis 1:

Ho: There is no significant difference in the income of members and non-members.

Ha: The income of members is higher than the income of non-members.

In order to make it more conclusive that the initiative had indeed a significant impact on the aggregate income of the members and thereby on the incremental benefits, another hypothesis was proposed, where the total income of the members (without including the income from solar charkha unit) was compared with the total income of the non-members.

Hypothesis 2:

Ho: There is no significant difference in the income of members and non-members.

Ha: There is a significant difference in the income of members and non-members.

5.3. Data Collection

For the study, it was proposed to use an observational cross-sectional study framework, where the unit of study was a charkha center/project. Cross sectional studies are generally used to infer prevalence of a disease or find an average value of a quantitative variable in the population at one point in time (Charan & Biswas, 2013; Kumar, Khan, & Chatterjee, 2014; Mann, 2003; Wang & Kattan, 2020). For the survey, it was envisaged to collect the data at project level for one of the 19 solar charkha rural centers/projects, which had a vintage of more than one year, to ensure the project had a meaningful impact on the beneficiaries and association with them. Further, only one center was selected to minimise social contacts and to follow COVID-19 appropriate behaviour due to the pandemic. It is important to note that the sustainability status of the center is not known beforehand (whether it is sustainable or not); therefore, it qualifies for a cross-sectional observational study. As mentioned, the study was conducted through a questionnaire-based survey, which comprised open-ended and closed-ended questions related to indicators such as quality of supply, meetings, participation of members, cash reserves, etc. related to the dimensions of sustainability. For assessment of sustainability, Nimbha Center was randomly selected. For testing the hypotheses, we randomly selected 10 non-members from the same village (Nimbha), community (SC), and similar economic background to minimise confounding bias and compared their income with that of 10 members of Nimbha Center.

6. RESULTS AND DISCUSSION

6.1. Framework

The following Table 4 provides the scores obtained (scaled in the range of 0 to 1 and post weightage multiplication) on five dimensions of sustainability. As shown in the Table, Economic dimension indicates a score of 0.30, followed by Institutional and Social (0.19 each), Technical (0.13), and Environmental (0.04), with an overall score of 0.85.

Table 4. Score of sustainability dimensions.

SN	Sustainability dimension	Score obtained	Weightage	Final score
1	Technical	0.88	15%	0.13
2	Economic	0.75	40%	0.30
3	Institutional	0.94	20%	0.19
4	Social	0.95	20%	0.19
5	Environmental	0.88	5%	0.04
	Total			0.85

The aggregate score (0.85) for sustainability is on the higher side, which suggests that the project has a higher probability of sustaining its operations in future with consequent accrual of socio-economic benefits to the members.

The Center performed satisfactorily on social and institutional dimensions on the basis of absolute scores; however, it had relatively lower scores on technical, economic, and environmental dimensions.

The technical dimension is important as it indicates how effectively the system is meeting the technical output requirements over the productive life of the project. In the case of the Nimbha Center, minimization of downtime (existing 2-5 days in a month) and improvement in service quality by a third party could improve the overall score on technical dimension. Our interactions with the members also indicated that they were trained to conduct minor repair and maintenance work in the absence of external assistance. The experience gained over the years has also augmented their technical knowledge base and resulted in seamless operations of the unit, save for a major maintenance issue that required third-party intervention. The charkha units had standard parts sourced from local companies, optimal solar energy output to drive the unit, modular flexibility to effect change in load profile, rated output, and safe installations, thus improving the overall score on technical dimension. Further, the members had actively participated in installation and commissioning of the units, which reinforces the importance of capacity building and active participation of members in the interventions, as corroborated by studies such as Gambhir et al. (2012), Bhandari et al. (2018), and Katre et al. (2019).

The Economic dimension shows the overall financial well-being of the project. For the members, solar charkha units were procured through loans and grant subsidies (4:1 debt-to-subsidy ratio). The majority of the members had savings accounts with a local bank and ensured satisfactory conduct of the loan account by way of regular repayments. Indeed, most of them had achieved the loan closure in the planned period from the proceeds of the solar charkha unit alone, demonstrating its economic sustainability. However, the Center has a potential to achieve a higher score provided the input raw material (raw cotton) is provided regularly in a quantity sufficient to harness the full capacity of the unit. Raw material supply and regular compensation by central office are dependent upon the sale of finished products, therefore, sustained marketing efforts are required to ensure offtake of the finished products. Members need to maintain a healthy cash reserve to address the issues of major repair and maintenance and battery replacement in future to continue the operations, as cash reserves are critical to sustain activities as depicted by Dauenhauer et al. (2020) in Malawi. This may be achieved through further capacity building on the importance of savings by ploughing back a part of revenues for maintenance purposes, as members in general use revenues for immediate socio-economic benefits of the family. Through the discussions with the members and other stakeholders, it was realized that Economic dimension was the most important dimension to sustain the operations as the patronage of the members to the initiative was contingent upon the economic benefits accrued to them; accordingly, it was assigned the highest weightage.

Institutional capability depicts how well the project is managed and the system is maintained to sustain operations. The Center had capacity-building training programmes in the technical, financial, and administrative realms, which enabled them to manage the initiative locally. The group had a delineation of responsibilities among them, including minor repair work; for major technical issues, they had an arrangement with an external agency. Regular meetings and the participation of members ensured the resolution of issues and the devising of new plans for production; importantly, the meetings provided a platform for members to express themselves, which also resulted in an overall satisfaction with the governance and maintenance of the project.

The social dimension is an important aspect as it depicts a sense of unity and ownership among the members. The Center depicted a high degree of unity and a sense of ownership. Importantly, a need assessment, which ensures a participatory approach, was carried out to address the development needs of the members. This approach ensured continuous patronage as members had substantially contributed both in cash and kind towards the project. The initiative was well supported by the family members and the village and had a significant socio-economic impact on the families as the income accrued was also utilized towards food, health access, education, agriculture input supply, etc. to create an income multiplier effect. Women members also enjoyed financial independence to manage their own funds, as financial empowerment is one of the major impediments to achieving women's empowerment. This had further enabled women members to resolve community issues and celebrate events like Women's Day, which were unheard of in rural settings, thus providing impetus to women's empowerment, as the empowerment aspect is scarcely studied in such types of interventions, as suggested by Katre et al. (2019).

The last dimension of Environment deals with the project's externalities on beneficiaries, society, and the environment. The project had an insignificant negative impact on the health of the members, society, and the external environment in terms of air, water, or noise pollution. Further, as the charkha unit uses solar energy, it also avoids emissions compared to grid energy, as the Indian grid significantly utilizes fossil resources (about 58 percent) for electricity production. Despite the fact that the project was climate-friendly, it became clear throughout the conversations with the beneficiaries that members were unaware of topics like global warming and climate change. As a result, we gave the Environmental component the least amount of weight.

6.2. Hypotheses

We argued that a sustainable development initiative could ensure accruals of benefits to the members and consequent patronage of members to the project. Results for hypothesis 1 in Table 5 indicate that we need to consider statistics corresponding to *Equal variances not assumed* as the significance value associated with Levene's Test is low. The *t*-test result (with Equal variances not assumed) depicts a two-tailed *p*-value of 0.022 for *Equality of Means*. The one-tailed significance value, or *p*-value, can be obtained by dividing the two-tailed value by two (as it is a one-tailed hypothesis). Accordingly, the one-tailed *p*-value in this case is 0.011, which is less than 0.05. Therefore, we reject the null hypothesis at the 5 percent significance level and conclude that the income of members is indeed significantly greater than the income of non-members. In the context of the study, the income from solar charkha had a multiplier effect as members with land ownership procured better agricultural inputs (seeds and fertilizers) using solar charkha income to increase agricultural production and income and improve food security. Proceeds from solar charkha units were also used towards medical expenses and payment of school fees. The project offered safe working conditions and a less drudgery-driven livelihood option to the women's members. It had also positively impacted the women's members in social, familial, political, and economic realms.

For Hypothesis 2, results in Table 6 show that we need to consider statistics corresponding to *Equal variances not assumed* as Levene's Test significance value is low.

Table 5. Results for hypothesis 1.

T-Test					
Group statistics					
	Exposure to intervention	**N**	**Mean**	**Std. deviation**	**Std. error mean**
Income in INR	1	10	51400.00	20977.236	6633.585
	0	10	32900.00	4383.048	1386.042

Independent samples test					
		Levene's test for equality of variances		t-test for equality of means	
		F	Sig.	T	Df
Income in INR	Equal variances assumed	11.666	0.003	2.730	18
	Equal variances not assumed			2.730	9.784

Independent samples test				
		T-test for equality of means		
		Sig. (2-Tailed)	Mean difference	Std. error difference
Income in INR	Equal variances assumed	0.014	18500.000	6776.840
	Equal variances not assumed	0.022	18500.000	6776.840

Accordingly, we get a two-tailed *p* value of 0.356 (this is a two-tailed test), which is greater than 0.05; therefore, we do not reject the null hypothesis at the 5 percent significance level. In other words, this means there is no significant difference between the income of members and non-members if we do not consider income from the solar charkha unit, indicating that without solar charkha unit income, the members would not have derived additional socio-economic benefits vis-à-vis the non-members. Therefore, the members have an incentive to provide patronage to the solar charkha initiative to continue its operation, thus ensuring its sustainability, which is also reflected by final sustainability score of 0.85 as mentioned in Table 4. Thus, substantiating that sustainability of an intervention and socio-economic benefits derived from that intervention are intertwined and interdependent.

Table 6. Results for hypothesis 2.

T-Test					
Group statistics					
	Exposure to intervention	**N**	**Mean**	**Std. deviation**	**Std. error mean**
Income in INR	1	10	39500.00	21098.973	6672.081
	0	10	32900.00	4383.048	1386.042

Independent samples test					
		Levene's test for equality of variances		T-test for equality of means	
		F	Sig.	T	Df
Income in INR	Equal variances assumed	13.009	0.002	0.969	18
	Equal variances not assumed			0.969	9.775

Independent samples test				
		t-test for equality of means		
		Sig. (2-Tailed)	Mean difference	Std. error difference
Income in INR	Equal variances assumed	0.346	6600.000	6814.527
	Equal variances not assumed	0.356	6600.000	6814.527

7. CONCLUSION

Renewable energy-based development measures have the potential to address socio-economic issues, especially in isolated and rural locations, while being climate-friendly. Further, to ensure the continuous accrual of benefits from these measures to the people and to bring about change in operational strategies in sync with field-based realities, the sustainability of these interventions needs to be estimated. Although interventions related to domestic energy access have well-defined assessment frameworks available in the literature, assessment frameworks for renewable energy used for productive interventions and income generation activities are not yet available or are yet to be devised. Therefore, an attempt has been made to prepare one such framework for assessing the sustainability of renewable energy-based productive activity, test it on the field, and finalize it after field-based feedback and expert opinions. The surveyed renewable energy-based development intervention in rural Maharashtra depicted that participatory approaches, capacity development, social equity, sound technical design, good governance, and accrual of revenues are important indicators of sustainability. Sustainability also augments patronage for the initiative, as sustainability and socio-economic benefits are intertwined and interdependent. Although the study was conducted on a small sample size due to the pandemic restrictions, which is also a limitation of the study, nevertheless, it was useful to test the proposed framework on the ground for its efficacy and finalize it for future use. While assessing sustainability, an aggregate higher score is desirable; however, precautions should be taken to ensure individual scores of sustainability dimensions are used for comparing projects, as aggregate scores can mask the importance of individual dimensions, which can vary from one project to another. The finalized framework is expected to be useful as a base model for sustainability assessment of renewable energy-based productive activities and shall be customized after taking into consideration the type of activity and local socio-economic context following discussions with the local stakeholders. As the Government of India envisages DRE-based productive activities to address rural infrastructure gaps, provide livelihood opportunities, and upgrade the standard of living of the people, the proposed framework could therefore be useful for sustainability assessment of such activities and decision-making to improve the longevity of the projects and the continuance of accruals of socio-economic benefits to the people.

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