REPORT
MARCH 2025

IT TAKES A **VILLAGE**

ASSESSING IMPACT OF CLIMATE FRIENDLY SOLUTIONS IN RURAL INDIA

NRDC SEWA AREAS

Women in Rasnol village in Gujarat

Credit: NRDC

ABOUT THE REPORT

The report "It Takes a Village: Assessing Impact of Climate-Friendly Solutions in Rural India" aims to analyze the impact of the work done under the Hariyali Gram (Green Villages) initiative over the last five years across select households in the two villages namely of Nagano Math in Gujarat and Beraniya in Rajasthan. The report includes detailed assessment of a suite of climate friendly solutions adopted by these households and measures impact indicators around: (a) household incomes and savings, (b) appliance ownership and cooling strategies, (c) fuel usage pattern, and (d) detailed analysis of specific climate friendly technologies. In addition, the report covers expected long-term health benefits and emission reduction potential of the overall initiative. The report captures success stories of three beneficiaries and highlights key learnings and suggestive recommendations to further scale up the initiative to accelerate rural energy transition in India.

About AREAS

Association of Renewable Energy Agencies of States (AREAS) has been formed and registered as a society on 27 August 2014 under Society Registration Act 1860. The Ministry of New & Renewable Energy (MNRE) is the nodal agency at the central level for promotion of grid-connected and off-grid renewable energy in the country. Ministry's programmes are implemented in close coordination with State Nodal Agencies (SNAs) for renewable energy (RE). Over the period the SNAs have developed considerable knowledge and experience in planning and implementation of RE programmes. With this background, it is important that SNAs interact and learn from each other's experiences and share their best practices and knowledge regarding technologies and schemes/programmes. All SNAs are members of the Association.

www.areas.org.in

About NRDC

With over 50 years of experience, the Natural Resources Defense Council (NRDC) combines the power of more than three million members and online supporters with the expertise of over 700 scientists, lawyers, and policy experts to drive climate and clean energy action, protect nature, and promote healthy people and thriving communities. NRDC works in the United States, China, India, and key geographies to advance environmental solutions. In India, NRDC partners with leading organizations on clean energy access, climate resilience, and clean air and healthy cities. For over 10 years, NRDC has also worked with government officials at the national, state, and city level partnering with local groups and businesses to combine scientific research and policy acumen to implement impactful climate solutions.

www.nrdc.org; Twitter @NRDC

About SEWA

Self Employed Women's Association (SEWA) is a member-based organization of poor, self-employed women workers in India. SEWA has a membership reach of 3.2 million spread across 18 states of India in urban and rural areas with deep penetration at grassroots level. SEWA also works in Afghanistan, Nepal, Sri Lanka, and Myanmar. SEWA's twin goals are "Full Employment" and "Self-Reliance." "Full employment" includes work security, income security, food security and social security (at least healthcare, childcare, nutrition, shelter) whereas "self-reliance" means making members autonomous economically and in decision-making. SEWA facilitates the women to build and manage various forms of members own collective / organization that includes self-help groups, producers groups, cooperatives etc. based on their respective trades and channelizes information, awareness, health interventions, trainings for skill development, financial support (e.g. savings, insurance, credit, and pension), market information / linkages to enable members to improve / increase their livelihoods and become self-sustainable in their trades.

www.sewa.org; Twitter @SewaComm

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ABBREVIATIONS

Acronym	Full Form
AC	Air Conditioners
AREAS	Association of Renewable Energy Agencies of States
COPD	Chronic Obstructive Pulmonary Disease
DAY - NRLM	Deendayal Antyodaya Yojana - National Rural Livelihood Mission
DDUGJY	Deendayal Upadhyaya Gram Jyoti Yojana
DDU-GKY	Deen Dayal Upadhyaya – Grameen Kaushalya Yojana
DRE	Decentralized Renewable Energy
FGD	Focused Group Discussion
GHG	Greenhouse Gas
GSDP	Green Skill Development Programme
GW	GigaWatt
HP	Horsepower
IAP	Indoor Air Pollution
INR	Indian Rupee
IPCC	Intergovernmental Panel on Climate Change
L	Litres
LED	Light Emitting Diode
LPG	Liquified Petroleum Gas
MGNREGA	The Mahatma Gandhi National Rural Employment Guarantee Act
MNRE	Ministry of New and Renewable Energy
MoRD	Ministry of Rural Development

MSDE	Ministry of Skill Development and Entrepreneurship
MSK	Mahila Shakti Kendra
MoMSME	Ministry of Micro, Small and Medium Enterprises
MWh	MegaWatt Hour
MWCD	Ministry of Women and Child Development
NGO	Non-Governmental Organization
NISE	National Institute of Solar Energy
NRDC	Natural Resources Defense Council
NSM	National Solar Mission
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan
PMKVY	Pradhan Mantri Kaushal Vikas Yojana
SAUBHAGYA	Pradhan Mantri Sahaj Bijli Har Ghar Yojana
SEWA	Self Employed Women's Association
SDG	Sustainable Development Goals
SHG	Self Help Group
SSDP	Suryamitra Skill Development Programme
STEP	Support to Training and Employment Programme
tCO_2	Metric tons or tonnes of Carbon Dioxide
TREAD	Trade Related Entrepreneurship Assistance and Development
W	Watt

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EXECUTIVE SUMMARY

Over 60% of India's population lives in villages.[1] With more than 900 million people, rural communities, that continue to lack access to affordable and reliable electricity, are central to India's goal of holistic and equitable development with prosperity for all. India balances its climate development goals with the need to provide access to affordable, reliable, sustainable, and modern energy for all, as envisaged in the United Nations Sustainable Development Goals (SDG) 7. With flagship initiatives like Pradhan Mantri Sahaj Bijli Har Ghar Yojana (SAUBHAGYA), the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY), National Solar Mission (NSM) and others, India has made remarkable progress in electrification, bringing power to nearly every household.[2] However, challenges persist in ensuring continuous and reliable electricity for remote and underserved areas, where geographical and infrastructural barriers disrupt grid supply.

Credit: NRDC

Use of cool roofs in Fangani village, Gujarat

As India makes progress on both rural development and climate action, initiatives that effectively integrate the two will be essential: The **Hariyali Gram initiative** (Green Village Initiative) represents a holistic model of sustainable rural development through the integration of clean energy solutions. Launched in 2019, it is a collaborative effort by the **Natural Resources Defense Council (NRDC)**, the **Self-Employed Women's Association (SEWA)**, and the **Association of Renewable Energy Agencies in States (AREAS)** under the Ministry of New and Renewable Energy (MNRE). NRDC engages in policy advocacy, technical inputs and overall project management, SEWA supports on awareness generation, capacity building of rural communities and on-ground deployment of technologies and AREAS brings in comprehensive sub-national network to build the capacity of state government officials on Decentralized Renewable Energy (DRE) technologies. The Hariyali Gram initiative aims to demonstrate a replicable, scalable model of clean energy adoption in rural India, addressing energy equity, environmental sustainability, and social inclusion.

Despite robust evidence of the need for climate action (that is, actions to reduce emissions of carbon dioxide and other greenhouse gases), research on the potential benefits of climate action for rural communities remains relatively underexplored in India. To contribute new knowledge and to gauge the initiative's success, NRDC and partners evaluated the impact of interventions implemented over the past five years in two Hariyali Gram villages - Nagano Math in Gujarat and Beraniya in Rajasthan. This report presents the outcome of that evaluation, assesses the impact of adopting climate-friendly solutions on rural households, and provides case studies to illustrate these impacts. It also looks at the Greenhouse Gas (GHG) emissions reduction potential of the Hariyali Gram initiative, explores the landscape of governmental programs that support clean energy technology initiatives, and provides recommendations on how to scale implementation and impact of similar villages-based climate initiatives.

KEY FINDINGS

The Hariyali Gram Initiative provides significant benefits for rural households—from reduced fuel and electricity expenditure to co-benefits like time savings, reduced drudgery, higher crop yields and water savings. Key learnings are below:

- In the past five years, household income and savings have increased significantly. A portion of this increase can directly be attributed to a reduction in money spent on fossil fuels, traditional fuels and electricity apart from additional income sources.
- The adoption of climate-friendly technologies such as biogas plants, solar water pumps, solar-based precision irrigation systems, energy efficient appliances like LED bulbs and fans, solar trap lights and solar fencing has allowed households more time to engage in other income-generating or leisure activities, which have increased the purchasing power capacity of the households.
- With higher income and savings, overall appliance ownership increased across

rural households signifying rising purchasing power among them.

- Albeit small per village, the carbon emission reduction potential of such distributed climate-friendly and clean energy technologies, when scaled, can significantly contribute to India's climate goals while also supporting vulnerable rural communities in building resilience and adaptive capacity in dealing with climate change and its adverse impacts.

At a village level, limited implementation of climate-friendly interventions can avoid an average of 280 tonnes CO_2 (tCO_2) emissions annually (for a small village with just 200-300 households), which is equivalent to an individual taking 480 Delhi-Mumbai roundtrip flights.[3] Scaling this to a mere 5 percent of India's over 600,000 villages, can potentially avoid CO_2 emissions of nearly 8.4 million tonnes annually.

KEY RECOMMENDATIONS

The findings from this assessment suggest that scaling up Hariyali Gram interventions across rural India can deliver significant and sustained direct and indirect benefits, as well as strengthen resilience to environmental threats. As climate change exacerbates challenges in India's rural communities, implementing climate mitigation and adaptation measures can yield substantial co-benefits, including improved health outcomes, enhanced economic security, better environmental quality, and increased gender equity. Key recommendations are below.

Connecting villages to central and state initiatives and opportunities

Local organizations have limited capacity and need more support to scale such projects. Hence, it is essential to work with central and state government departments and nodal agencies to integrate initiatives such as the Hariyali Gram into existing policies and programs complemented by supportive climate-friendly policymaking.

Climate is an overarching and cross-cutting theme requiring focused actions from sectoral departments and government agencies in states. Convergence of schemes, policies and goals of relevant state government departments and agencies such as (but not limited to) environment, agriculture, energy, water and rural development, and regular coordination amongst them will ensure state-level efforts are concerted as well as desired levers of cross-sectoral initiatives such as Hariyali Gram are regularly addressed to achieve the intended impact that align with needs of the rural communities.

Adopting a tailored implementation strategy and engaging local partners

Scaling impact requires tailoring the approach for the specific locale. For example, with reference to the Hariyali Gram initiative, the project began with understanding the energy needs of the local communities and introducing suitable climate-friendly solutions accordingly. Another key aspect was acknowledging and incorporating the different income and prosperity levels between the villages of Gujarat and Rajasthan. To ensure this, partnering with local and regional partner organizations is important.

Developing accessible financial mechanisms

Based on the ground survey, we learned that easy and low-cost financing is a barrier to clean energy access in rural areas, especially for the many rural women who do not own assets in their name. Furthermore, with limited purchasing power capacity, the cost of clean technologies is certainly high for the rural households. With considerable limitation of access to credit, specifically from mainstream lenders at affordable cost, investing in climate-friendly solutions becomes a big challenge.

Therefore, designing accessible, low-cost, innovative financial mechanisms providing guarantees and interest subvention (lower interest rates for loans), blended financing with combination of grants, debts, equity and other user-friendly products for rural households is needed to ensure women access finance to effectively support the energy transition.

Building strong partnerships with relevant stakeholders

The success of the Hariyali Gram initiative so far has hinged on collaborative work among relevant stakeholders and partners, including grassroots-level implementing organizations, government agencies, vendors and technology suppliers, and financial institutions. This ensured timely on-ground implementation and scaling up of the program.

Ensuring monitoring, verification and post implementation support

It is essential to continue support for these initiatives beyond the initial implementation phase. For instance, by:

- Building capacity for repair and servicing of appliances and technologies in the program design components for a substantial period (~3 years),
- Strengthening capacities of district offices to ensure continuous usage and adoption of solutions,
- Supporting Community Based Organisations that provide skilling and capacity building of local leaders,
- Supporting climate entrepreneurs who can help increase demand and adoption of green technologies, and
- Enabling women to take on the role of planners, users and managers of climate-friendly solutions.

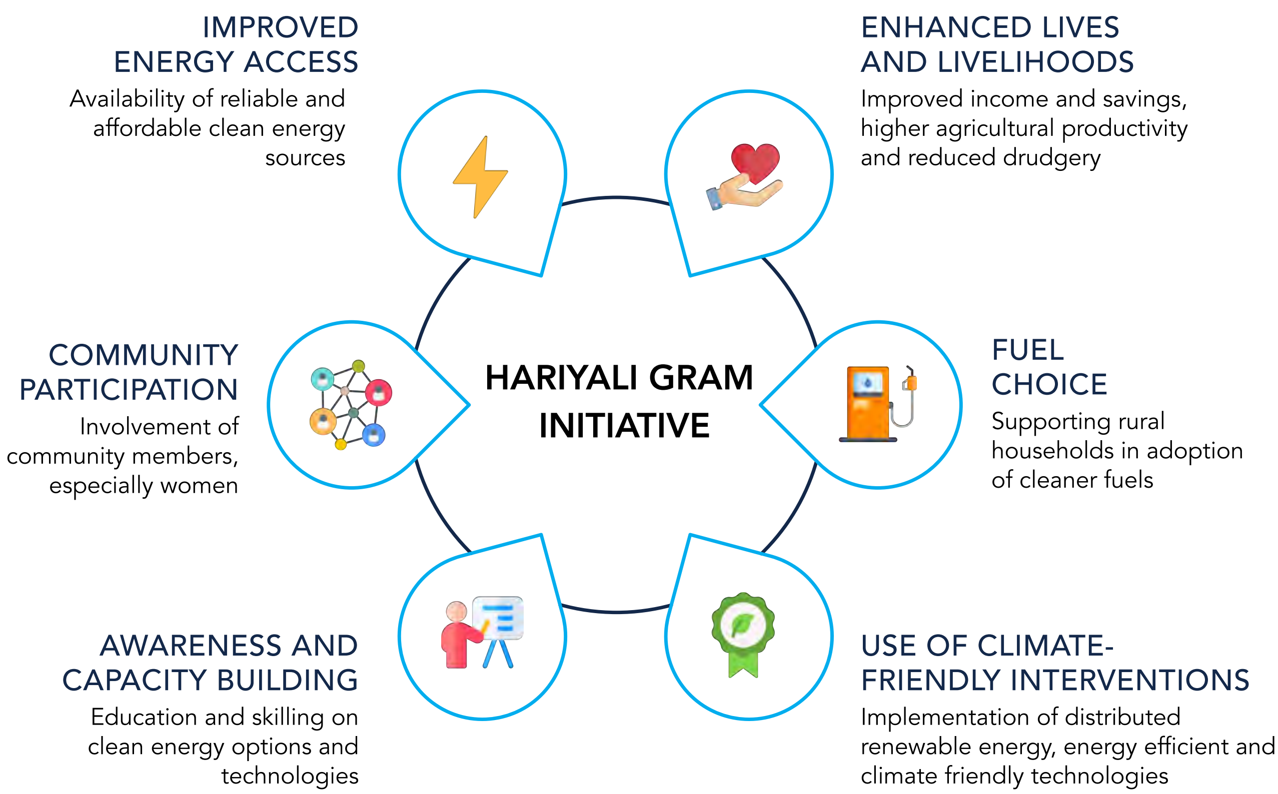
Strengthening skilling and capacity building and role of market actors

Education, skilling and capacity building are the cornerstones of ensuring an initiative’s long-term impacts. Grassroots-level initiatives should provide training and capacity building of grassroots leaders, as well as local agencies involved in the implementation, to ensure desired skills are being imparted for a sustainable impact. The private sector could also partner with rural communities/ local agencies to promote climate entrepreneurship opportunities to address the skill gaps.

1 ABOUT THE HARIYALI GRAM INITIATIVE

1.1. INTRODUCTION

Decentralized and off-grid renewable energy solutions have a key role in mitigating energy access challenges and achieving socio-economic equity at the last mile, especially for the most remote and geographically challenging areas, typically in rural communities, where connecting people to the power grid is particularly difficult and expensive, often due to dispersed populations and poor infrastructure. Decentralized, or small-scale, locally generated renewable energy systems like rooftop solar panels, small wind turbines, micro-hydropower, and bioenergy are not connected to the main power grids. Instead, they generate energy independently and closer to the point of consumption. The **Hariyali Gram initiative** exemplifies this approach, leveraging clean energy and climate-friendly technologies to enhance energy access, improve rural livelihoods, and contribute to India's climate and development goals.



Villages designated as "Hariyali Grams" are characterized by a focus on **decentralized clean energy and climate-friendly technologies** tailored to local needs; **community participation**, particularly by women, in decision-making, technology selection, and energy system management; and tangible **improvements in energy access, awareness** of alternative energy sources, **choice of fuels** used for daily chores, **agricultural productivity**, and overall **quality of life**. This Hariyali Gram initiative aims to demonstrate a replicable, scalable model of clean energy adoption in rural India, addressing energy equity, environmental sustainability, and social inclusion.

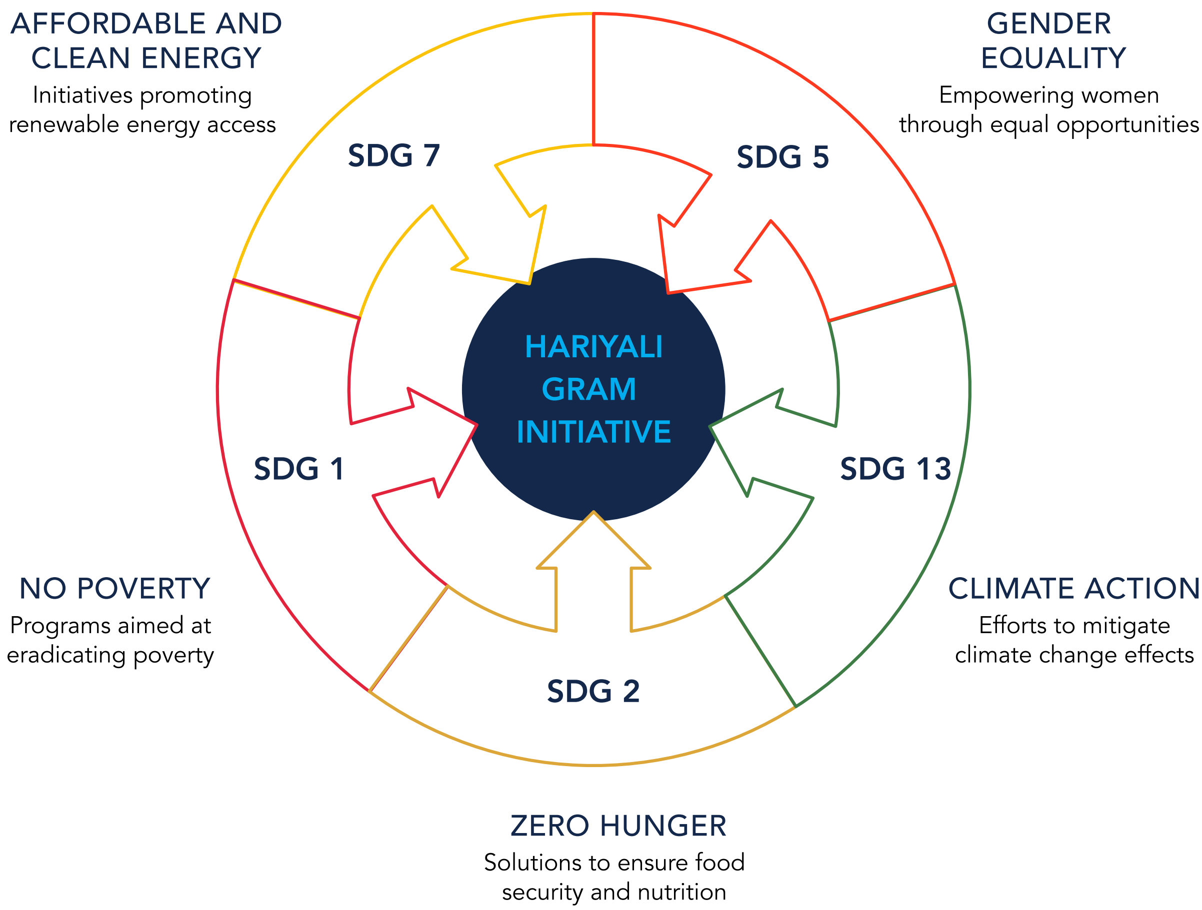
To gauge the initiative's success, NRDC and partners evaluated the impact of interventions implemented over the past five years in two Hariyali Gram villages with which we initiated this project - Nagano Math in Gujarat and Beraniya in Rajasthan. Using both qualitative and quantitative data, the team looked at the original Hariyali Gram approach and baseline surveys, follow-up survey data, as well as community discussion and engagement, and a review of existing government initiatives and support, to come up with analysis and recommendations to scale such initiatives across the country. In this 2024 review, we also looked at two new aspects, in particular– technology-specific impact at household and village economy levels and the impact of clean technologies adoption on the health of rural communities, a detailed finding of which is presented in the later chapters of this report.

1.2. APPROACH

The Hariyali Gram initiative adopts a holistic and community-centric approach, emphasizing inclusivity and sustainability to ensure long-term impact. It begins with comprehensive needs assessments, including household surveys and community consultations, to identify local energy challenges and developmental priorities. Based on these insights, clean energy solutions are tailored to align with community needs, ensuring both relevance and scalability. A defining feature of the initiative is its women-led framework, where women actively participate in decision-making, technology selection (brief of the climate-friendly technologies in the following section), and financial planning, fostering ownership and sustainability. Additionally, capacity-building programs equip community members, particularly women, with the skills to manage energy systems, create local employment opportunities and address drudgery associated with traditional energy use such as reducing time for collecting traditional fuels such as firewood, spending less time in tending to crops in the fields, and reducing their exposure to extreme heat and indoor air pollution due to traditional cooking practices. This participatory model not only enhances energy access but also supports climate resilience, gender empowerment, and improved living standards in rural communities.

Advancing Sustainable Development Goals

The Hariyali Gram initiative significantly contributes to multiple Sustainable Development Goals (SDGs) through its multifaceted interventions. By expanding rural energy access with clean, decentralized solutions, the initiative directly advances **SDG 7 (Affordable and Clean Energy)**, ensuring that underserved communities have access to reliable and sustainable energy. Its strong focus on empowering women through active participation, decision-making, and capacity-building programs promotes **SDG 5 (Gender Equality)**, enabling women to take on leadership roles and benefit from new economic opportunities. The adoption of clean technologies, such as biogas plants and solar-powered systems, reduces greenhouse gas emissions and dependency on fossil fuels, aligning the initiative with **SDG 13 (Climate Action)**. Moreover, the improved access to energy fosters better agricultural productivity and supports livelihoods, directly addressing **SDG 1 (No Poverty)** and **SDG 2 (Zero Hunger)**. By integrating these goals into its framework, the initiative exemplifies how clean energy interventions can drive comprehensive and sustainable rural development.



1.3. TECHNOLOGIES DEPLOYED

The Hariyali Gram initiative integrates a range of climate-friendly technologies to address the unique challenges faced by rural communities around agriculture and irrigation, cooking, power and lighting, mobility, thermal comfort and livelihood generation activities. The solutions that have been implemented are outlined below.

Solar-Powered Solutions:

Solar-powered solutions such as water pumps and precision irrigation systems for irrigating crops, solar fencing to protect crops, and solar trap lights for improved safety have been deployed to enhance agricultural productivity and reduce losses. Solar rooftop systems, solar lanterns and solar fans are helping households with reliable and clean energy and improving community well-being.

Energy-Efficient Appliances:

Energy-efficient appliances, including LED bulbs, energy-efficient ceiling fans, and solar fans, are helping households achieve better lighting and thermal comfort while reducing electricity consumption and enhancing overall monetary savings.

Biogas Plants:

Biogas plants have been introduced as clean cooking solutions, reducing dependency on traditional fuels like firewood and fossil fuels like Liquefied Petroleum Gas (LPG), increasing income through the use of biogas slurry as a bio fertilizer and pesticide, and mitigating reported health risks from indoor air pollution, resulting in long-term health benefits among nearly one third of households sampled.

Cool Roofs:

Cool roofs, or low-cost, energy-efficient roofing systems designed to provide thermal comfort in homes, were implemented.

Clean Mobility Solutions:

Electric two-wheelers have been introduced, which reduce petrol/diesel usage, improve livelihoods and access to market and lower expenditure on fossil fuels.

Over the last five years to date more than 900 units of 9W LED bulbs and more than 200 units each of 50W fans and 35W Brushless Direct Current (BLDC) fans have been deployed. More than 1000 households have adopted biogas plants, and a cool roof has been implemented in more than 50 households with varied roof areas. Adoption of solar fencing and solar trap lights are continuously gaining traction to counter animal and pest attacks, leading to more than 150 fencing installations (in varied farm sizes) and adoption of nearly 120 solar trap light units so far. For irrigation, 16 solar water pumps have been deployed, and more than 80 solar based precision irrigation systems are installed. Solar lanterns have gained the maximum traction during the project duration with more than 5000 units deployed so far. These climate friendly technologies are adopted across the Indian states of Gujarat, Rajasthan and Maharashtra.

Each technology promoted in this initiative is carefully selected to improve energy access, reduce greenhouse gas emissions, improve household economy and enhance community resilience against climate change.

Solar Powered Solutions

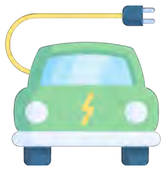
Solar water pumps and precision irrigation improve farming, solar fencing and trap lights protect crops. Solar rooftops, lanterns, and fans provide clean energy at home, reducing electricity costs.

Cool Roofs

Low-cost, reflective roofing keeps homes cooler, reducing heat stress and AC usage. (e.g., urban households adopting white-coated roofs for better insulation)

Energy-Efficient Appliances

LED bulbs, energy-saving fans, and solar fans enhance lighting and cooling while cutting electricity bills. (e.g., households switching to LED lights for lower power consumption)



Clean Mobility Solutions

Electric two-wheelers cut fuel costs, reduce emissions, and improve access to markets. (e.g., vendors using e-scooters for deliveries)

Biogas Plants

Biogas plants offer clean cooking, reduce firewood and LPG use, and provide organic fertilizer, improving health and income. (e.g., families using biogas slurry for crop growth)

1.4. DETAILS OF THE 2019 BASELINE SURVEY

In 2019, the Hariyali Gram initiative employed a comprehensive, multi-step approach to identify and design clean energy interventions at the village level.[4] The process began with selecting two pilot villages—Nagano Math in Gujarat and Beraniya in Rajasthan—based on criteria including SEWA's presence, low electricity access, high reliance on solid cooking fuels, low asset ownership, limited banking access, climate vulnerability, and a prevalence of small and marginal farmers. Following village selection, research was conducted to identify clean energy opportunities through literature reviews and interviews with stakeholders, including government officials, technical experts, and financial institutions. This research explored potential solutions like solar water pumps, efficient appliances, cool roofs, and microgrids while aligning with national and state policies and SEWA's existing activities.

Figure 1: Flowchart of Survey Methodology (NRDC, 2021)

STEP 1	Select criteria were applied to identify two villages to conduct the pilot.
STEP 2	Government programs and market opportunities for clean energy were identified through primary and secondary research.
STEP 3	Household energy use surveys and research were conducted to determine the key energy uses for both domestic and productive uses in the villages.
STEP 4	Based on the available research and data collected, key interventions for increasing energy access were identified for implementation in the two pilot villages.

Extensive household energy surveys were conducted between May and July 2019, covering 177 households (35% of the population of the two villages combined). These surveys assessed energy use, expenditures, appliance ownership, and willingness to adopt clean energy solutions. Key insights from this survey were: limited annual income and household savings, heavy reliance on fossil fuels (such as diesel and kerosene) and traditional fuels such as firewood, high electricity bills, limited appliance ownership, and limited knowledge of climate-friendly solutions. Semi-structured community discussions validated survey findings, ensuring a holistic understanding of local needs. Based on the collected data, a comprehensive energy plan was developed, incorporating short, medium, and long-term interventions aimed at affordability, enhanced energy supply, and improved living conditions. The plan focused on expanding clean energy use, reducing GHG emissions and toxic air pollutants, and promoting health, air quality, and sustainability, with continuous community feedback through SEWA's engagement. Steps followed during implementation were:

- SEWA started with awareness generation campaigns in the villages on the various climate-friendly technologies identified under the village energy plans.

- This was followed by discussions with technology providers to identify relevant, affordable and quality climate-friendly solutions that can be deployed in these villages. Research was carried out simultaneously on central and state policies and programs on DRE to understand their applicability to rural households.

- Demonstrated pilots of climate-friendly technologies in villages for a few months.

- Aggregated demand for these technologies based on the positive results from the pilots. Simultaneous discussions were held with households on their purchasing power capacity and financing mechanisms. This included reviewing documentation requirements of government schemes to avail subsidies, other than bank requirements for loans.

- Worked with technology providers on implementation and on-ground Operations & Maintenance support.
- Lastly, along with deployment of technologies, we ensured training of households on equipment operation, maintenance and doing basic troubleshooting.

This methodical process ensured tailored interventions that addressed energy access challenges while boosting livelihoods and environmental quality. The project implementation began in 2021 with pilot projects in **Nagano Math, Gujarat**, and **Beraniya, Rajasthan**. As of **2025**, the initiative has expanded its operations to various districts in the states of Gujarat, Rajasthan, Uttar Pradesh, Maharashtra, and Assam, with implementation penetrating more than 500 villages and addressing diverse energy and developmental challenges. In addition, capacity building and awareness generation sessions have been organized with more than 30,000 rural people so far.

Importance of women-led clean energy initiatives

Adoption of climate-friendly solutions offer several direct benefits to households and communities at large. This report covers three case studies of how adopting climate-friendly technologies has impacted people's lives and livelihoods. Below are some of the benefits such initiatives could offer:

Direct benefits:

Women-led adoption of clean energy solutions in rural areas directly benefits the community in the form of – improved access to clean energy, reduced energy bills, reduced fossil fuel consumption and greenhouse gas emissions, more thermal comfort and reported improved health, reduced drudgery, time savings and higher women asset ownership.

Indirect benefits:

Key indirect benefits include greater rural energy independence, women empowerment, improved livelihoods and quality of life, employment generation, informed policy-making and improved financial access, improved gender equity and greater climate resilience.

2 | IMPACT ASSESSMENT

In 2024, the NRDC team, along with partner SEWA, revisited the initial villages of Nagano Math in Gujarat and Beraniya in Rajasthan to conduct another detailed energy survey in the villages - in the same sample of households that were part of the 2019 baseline study survey for the Hariyali Gram initiative. This assessment aimed to evaluate the impact of climate-friendly interventions implemented over the past five years. Below is an outline of the survey approach used for the 2024 impact assessment.

2.1. SURVEY APPROACH & METHODOLOGY

2.1.1. Sample Size

The 2024 survey covered 86 households in Nagano Math and 84 in Beraniya, representing a slight reduction in the number of surveyed households compared to 2019. This decline may reflect demographic shifts, migration patterns, or sample variations. Despite this, the surveyed households provided a robust dataset for analyzing the socio-economic and environmental changes attributed to the initiative.

About Nagano Math Village, Gujarat

Nagano Math is a predominantly tribal village located 50 km from the block centre of Bayad town in the Aravalli district of Gujarat. It has 256 households, each typically comprising 4-6 family members. The village has a primary school within walking distance but is about 7 km from the nearest bank and health care centre. The village has no bus service other than a school bus that started operating recently. The villagers largely use private shared taxis or three-wheelers to travel. There is no major industry or factory in the vicinity of Nagano Math. SEWA started a dairy co-operative in the village a few years back to support many households engaged in animal husbandry.

Agriculture is the primary source of livelihood in Nagano Math. Most village households have small landholding (less than 5 bigha/~2 acres) and either rent or share large farm equipment (such as tractors and threshers). The major crops grown in the village include wheat, cotton, corn, castor, pearl millet, peanuts and vegetables. Most of these crops are for consumption by households, other than cotton and peanuts, which are sold in the market.

In addition to agriculture, the main occupations include animal husbandry, daily wage labour, and other services. Household electricity supply in Nagano Math is nearly universal and available for most of the day, but the village has no streetlights.

About Beraniya Village, Rajasthan

Beraniya is a village with about 250 households, with most households consisting of six to nine family members. Agriculture is the primary occupation, and most households engage in marginal farming or work as agricultural or manual labourers. Farming is largely rainfed with major crops being soybean, corn and lentils during monsoon, and wheat, gram and paddy during winters. Farmers with better irrigation facility and water availability grow groundnut in the summer season. Other occupations include animal husbandry and wage labor.

Public transport connectivity in Beraniya is limited, and the community largely relies on private taxis or three-wheelers for transport. Roads leading to and within Beraniya are now paved. Most households have electricity connection and the electricity supply is intermittent, with an average of nine hours per day. Beraniya has no streetlights.

2.1.2. Survey Approach

The 2024 survey built upon the 2019 baseline by incorporating additional research dimensions and a more comprehensive questionnaire structure. The survey retained core sections from the previous assessment to enable longitudinal comparisons while introducing new sections to capture evolving challenges and impacts. Data collection employed both quantitative and qualitative methodologies, with structured questionnaires supplemented by semi-structured interviews. Trained interviewers, predominantly women, conducted the surveys in local languages (Gujarati and Hindi), ensuring cultural sensitivity and data accuracy. A detailed analysis was conducted to identify trends, impacts, and areas for further improvement.

The 2024 questionnaire introduced new subsections and focused on the following key areas:

Indoor Emissions and Health Impacts

A new section focused on assessing indoor (residential) air pollution emissions associated with cooking and heating practices. Questions evaluated respondents' awareness of the health impacts of indoor air pollution (IAP) and their understanding of the health benefits of transitioning to cleaner cooking technologies. This section provided insights into the role of cooking methods in exacerbating reported IAP-related health risks and tracked the adoption of biogas and other cleaner fuels.

Adoption and Performance of Clean Energy Technologies

The survey evaluated the performance and user satisfaction of technologies implemented under the Hariyali Gram initiative, including Solar Precision Irrigation Systems, Solar rooftop systems, Solar Trap Lights, Solar Fodder Systems, Solar Fencing, Solar Lanterns, and Solar Water Pumps. The research sought to determine whether these technologies reduced household energy consumption, expenditures, and reliance on fossil fuels while enhancing productivity and environmental sustainability.

Biogas and Cooking Fuel Shifts

A dedicated section examined changes in cooking fuel use since 2019, emphasizing reductions in firewood and kerosene dependency. Data was collected on changes in household fuel expenditures and time saved from firewood collection which was used to estimate reductions in annual GHG emissions, and co-benefits of biogas plants, such as income from selling or using slurry as a bio fertilizer and pesticide.

Longitudinal Comparisons

The 2024 survey included the same questions from the 2019 baseline, enabling a direct comparison of changes over five years. Key focus areas included household energy use, expenditures, appliance ownership, and livelihood activities. This comparative analysis was crucial in identifying the progress made and areas that required further attention.

Thermal Comfort and Cool Roofs

The cool roofs intervention was assessed for its effectiveness in enhancing thermal comfort and reducing energy demand. Additional questions focused on co-benefits, including reduced roof seepage and improved indoor living conditions, especially during extreme heat events.

2.2. COMMUNITY ENGAGEMENT

The survey process was complemented by regular community discussions and focused group discussions (FGDs). These discussions, conducted after the survey, brought together Panchayat leaders, male and female community groups, and SEWA members to validate and refine survey findings. FGDs played a pivotal role in corroborating survey data, contextualizing results, and ensuring that the interventions and outcomes resonated with community realities. These discussions also allowed the research team to identify any unanticipated impacts and gather actionable feedback for future program iterations.

CASE STUDY 1:

ADOPTION OF CLIMATE-FRIENDLY SOLUTIONS PROVE CATALYTIC IN STRENGTHENING HIRAL BEN'S SAVINGS

Hiral ben Solanki has been associated with SEWA for seven years. For over three years, she has been working as an Aagewan—a rural sister who work towards understanding the issues and needs of her community, brings in the solutions, and educates and promotes sustainable livelihoods in her community. Over the past few years, Hiral ben has invested in several climate-friendly technologies, positively impacting her savings in the range of INR 78000 per annum and reducing time spent on purchasing cattle fodder and tending to crops in the field by approximately 50 hours per month. The impact of each of the technologies is listed below.

Impact of Specific Climate Interventions on Her Life

SOLAR FODDER SYSTEM

Prior to adopting the solar fodder system (a hydroponic system that uses solar power to grow fodder for livestock), Hiral ben would travel to the fields and depend on local dairy to collect high-protein fodder for her cattle. In this process, she spent half a day on travel and around INR 1500-1600 to purchase cattle feedstock for 10 days. For the regular fodder, she spent an additional INR 10,000 per month. She purchased the solar-powered fodder system (costing INR 60,000) with an initial down payment of INR 10,000, and with the help of SEWA, she secured a bank loan amount of INR 50,000. She now pays a monthly installment of INR 1500 for three years. The fodder system, in turn, has cut down her expenditure on high-protein fodder, yielding monthly savings of approximately INR 4500. In addition, the quality of fodder grown in the solar-based system has increased milk production from 3 litres per day to 4 litres per day from two cows, thereby increasing her daily earnings from selling this milk.

LED BULBS AND ENERGY-EFFICIENT CEILING FANS

Hiral ben also replaced her old 75W fan and five incandescent bulbs with a 50W energy-efficiency fan and five energy-efficient LED bulbs, which are brighter. Through this replacement, she saves INR 600 on every electricity billing cycle, which is almost INR 300 per month. Through her savings, she could pay back the cost of these appliances in just three installments.

COOL ROOF

Hiral ben and her family faced extreme indoor heat during summers as they lived in a pucca house (built with bricks and cement) house with a roof size of 900 square feet.

Indoor heat caused heat stress and inconvenience to elders in the family, who required constant medical attention, and the family couldn't sleep comfortably at night or during the day. To escape this extreme heat and for enhanced thermal comfort, her family poured water on the roof, which proved ineffective. Hiral ben has now switched to cool roofing strategy, which cost her approximately INR 9400 to purchase solar reflective paint. Due to this shift, her family now experiences significant thermal comfort inside the house and can sleep more comfortably. She underwent training led by SEWA on painting her roof white, which saved on labor costs.

Credit: SEWA

Figure 2: Cool roof on Hiral ben's home

SOLAR TRAP LIGHT

Hiral ben also procured a Solar Trap Light (a device designed to attract and trap insects using light) and has used it for over a year on her 1 bigha farm plot. Through this light, she is avoiding pest infestation on her farm during the cropping cycles, and thus saving money spent on pesticides - INR 3000-4000 per month for two months during the first cropping season and INR 2000-3000 per month for 2-3 months during the second cropping season. The trap light protects the crops from nocturnal insects during the late evening and night hours. Her initiative also encouraged other women in her village to invest in this technology.

Credit: SEWA

Figure 3: Solar trap light in Hiral ben's farm

3 SURVEY FINDINGS

The study involved a detailed assessment of key parameters and aspects impacted in the last five years across the two villages of Nagano Math in Gujarat and Beraniya in Rajasthan. This section elaborates on how adopting climate-friendly solutions has impacted the rural households and continues to transform the lives of rural households. An overview of key findings is listed below:

- Household income and savings have gone up in all the surveyed households. A portion of this increase can directly be attributed to the reduction in money spent on fossil fuels, as well as the fact that the households are now also engaged in other income generating activities (such as animal husbandry) with the time saved from engagement in drudgery such as collecting firewood, spending more time in the field tending to crops and exposure to indoor air pollutants due to traditional cooking and heating methods.

- Fossil fuel usage patterns have seen a stark change. Consumption of fuels like diesel and kerosene have decreased considerably. LPG usage saw an increase as more families switched from firewood to LPG based cooking.

- Overall, firewood usage increased considerably in Nagano Math due to an increase in animal husbandry related activities. Further investigation revealed that 75% of the firewood was used for preparing cattle fodder, and only 13% was used for household cooking and 11% for heating water.

- Time spent on collecting fuels has reduced significantly for fuels such as coal, cow dung, kerosene, LPG and firewood which can be attributed to various reasons such as reduced consumption of fuels such as kerosene, cow dung and coal and better distribution of fuels like LPG. For firewood, though the consumption quantity increased, many households switched from collection to purchase of firewood, leading to lesser time spent on firewood collection activities.

- With higher incomes and savings, overall appliance ownership increased across rural households, signifying increased purchasing power capacity.

- The health-related analysis involving perception-based qualitative responses indicates that climate-friendly interventions can bring multidimensional benefits including better indoor and outdoor air quality, enhanced thermal comfort, and improved health outcomes.

- Albeit small per village, the carbon emission mitigation potential of such distributed climate-friendly and clean energy technologies, when scaled, can have significant impact in contributing to India's climate goals while also supporting vulnerable rural communities in building resilience and adaptive capacity in dealing with climate change and its adverse impacts.

Overall, this analysis shows that adoption of climate-friendly technologies has supported the economic growth and improved quality of life of rural households by supporting them in reduced expenditure on fuels and electricity, along with co-benefits like time savings, reduced drudgery by cooking with cleaner fuels and reducing exposure to toxic air pollutants, higher crop yields and water savings. Detailed analysis of survey results is outlined in the sections below.

3.1. HOUSEHOLD INCOME AND SAVINGS

The financial analysis revealed a remarkable improvement in average household incomes and savings across both Nagano Math village in Gujarat and Beraniya village in Rajasthan (Table 1). In Nagano Math, over 95% of households reported annual incomes exceeding INR1,20,000 in 2024, a significant rise compared to just 10% in 2019. A focused group discussion conducted by NRDC & SEWA with the village community highlighted that this substantial financial progress was attributed to multiple factors, including an increase in the number of earning members within households. Many individuals who were pursuing education in 2019 are now employed in higher-paying jobs, such as government positions, or have engaged in alternative income-generating activities. Further, many households which had 2-3 cattle in 2019 now have 5-7 cattle, leading to higher income from animal husbandry as they sell milk to the local dairy cooperative, a livelihood that has seen major increase in the Aravalli district of Gujarat where the village is located.

Table 1: Comparative analysis of average household income in INR for both the villages

	Average annual household income in 2019 (NR)	**Average annual household income in 2024 (INR)**
Nagano Math, Gujarat	66,839	3,25,050
Beraniya, Rajasthan	91,218	1,54,568

It is worth noting that some households in Nagano Math reported exceptionally high incomes, skewing the average results upwards. In Beraniya, the economic resilience was equally notable, with over 70% of households earning more than INR1,35,000 annually in 2024, compared to only 21% in 2019. This growth underscores the economic progress and improved livelihood opportunities in this village in Rajasthan.

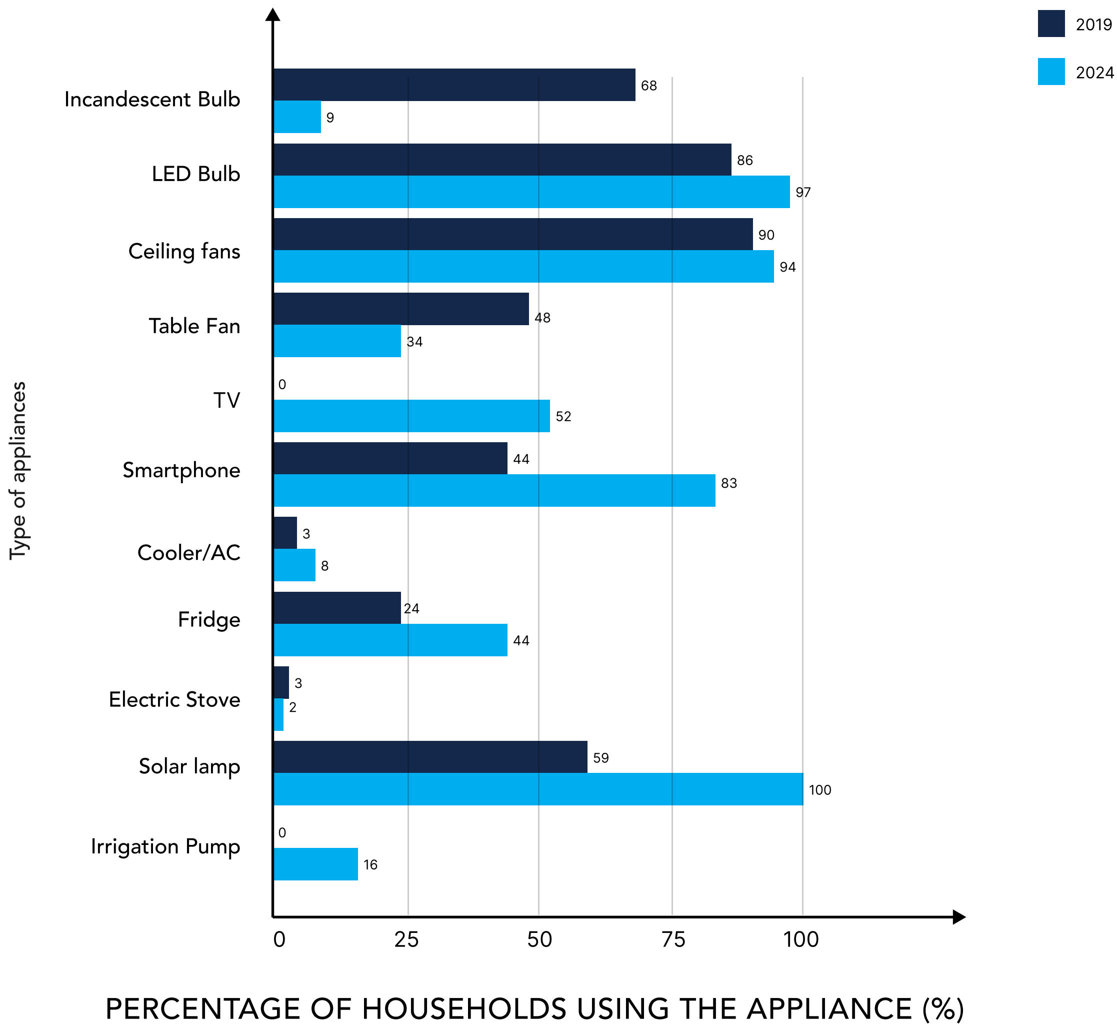
Savings patterns also reflected positive trends, with households demonstrating more efficient income management and reduced energy expenditures because of Hariyali Gram's implementation. In Nagano Math, annual income saved increased from 11% in 2019 to 29% in 2024, indicating improved financial planning and stability. Beraniya showed a relatively consistent trend, with household savings increasing marginally from 12.6% in 2019 to 12.7% in 2024. This modest growth in savings can be attributed to a simultaneous rise in household incomes and expenditures, which likely offset potential increases in savings.

3.2. OVERVIEW OF APPLIANCE OWNERSHIP AND COOLING STRATEGIES

Ownership of household appliances significantly increased, reflecting improvements in living standards and access to modern conveniences.

In Nagano Math, there was a significant shift towards energy-efficient appliances, with 97% of households reporting using LED bulbs in 2024. This marks a near-complete phasing out of incandescent bulbs, a testament to the successful adoption of energy-efficient lighting solutions. Ownership of ceiling fans also saw an increase, while the use of old and inefficient table fans decreased from 48% in 2019 to 34% in 2024. Moreover, ownership of air coolers, air conditioners (ACs), and smartphones more than doubled during the same period. This trend can be attributed to improved living standards and rising household incomes, indicating a positive shift towards modern and prosperous living (Figure 4a).

(a)



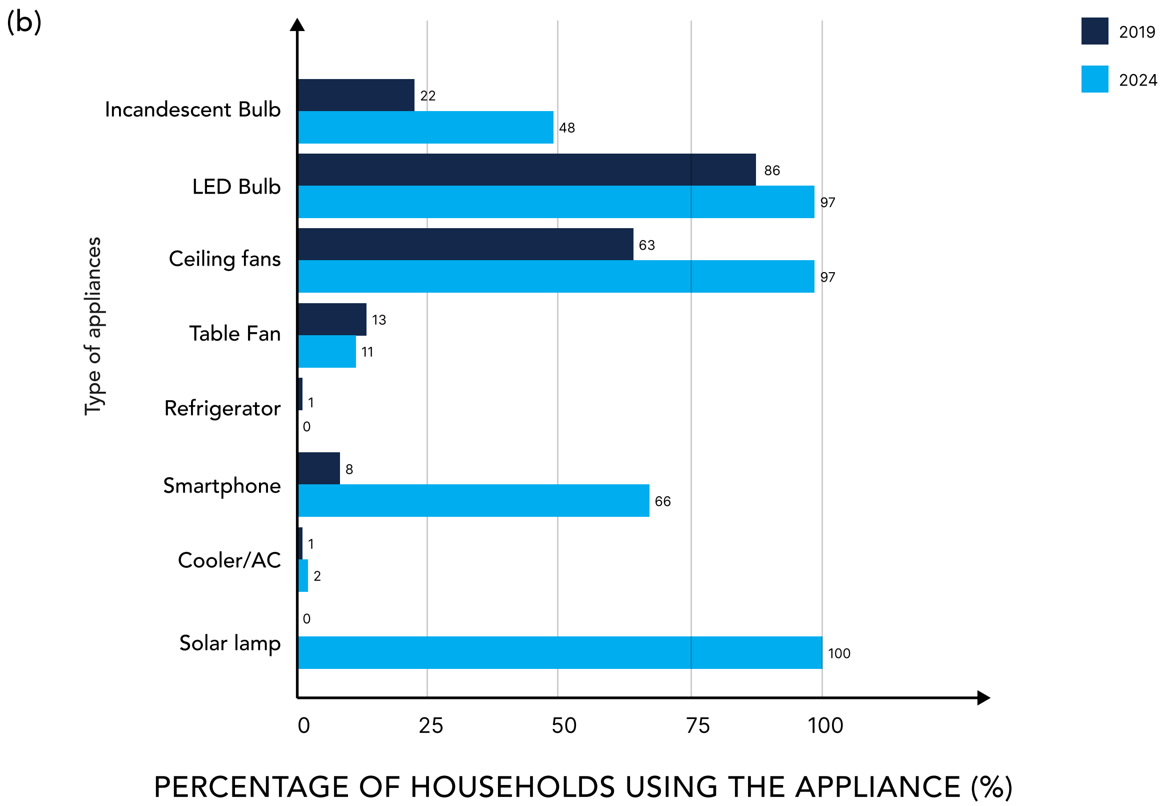


Figure 4: Comparative analysis of difference in ownership of appliances between 2019 v/s 2024 for (a) Nagano Math & (b) Beraniya

Beraniya displayed similar advancements, reflecting a growing preference for energy-efficient technologies. While LED bulb usage rose significantly, there was also an unexpected increase in the use of incandescent bulbs. This anomaly is linked to a lack of awareness regarding the benefits of energy-efficient appliances within the community as well as less cost and easy availability of incandescent bulbs. But at the same time there was a rise in the number of solar lamps as well, with every surveyed household having at least one solar lamp. Ceiling fan ownership in Beraniya rose from 63% in 2019 to an impressive 97% in 2024, with a marginal decline in table fan usage. Furthermore, smartphone penetration soared, particularly in Beraniya, where 66% of households now report owning smartphones, underscoring the rapid adoption of modern technologies and their integration into daily life (Figure 4b).

These findings highlight the dual role of rising income levels and targeted energy-efficiency initiatives in transforming household energy usage patterns. However, the persistence of incandescent bulbs in Beraniya emphasizes the need for enhanced community-based awareness campaigns to maximize the impact of these transitions.

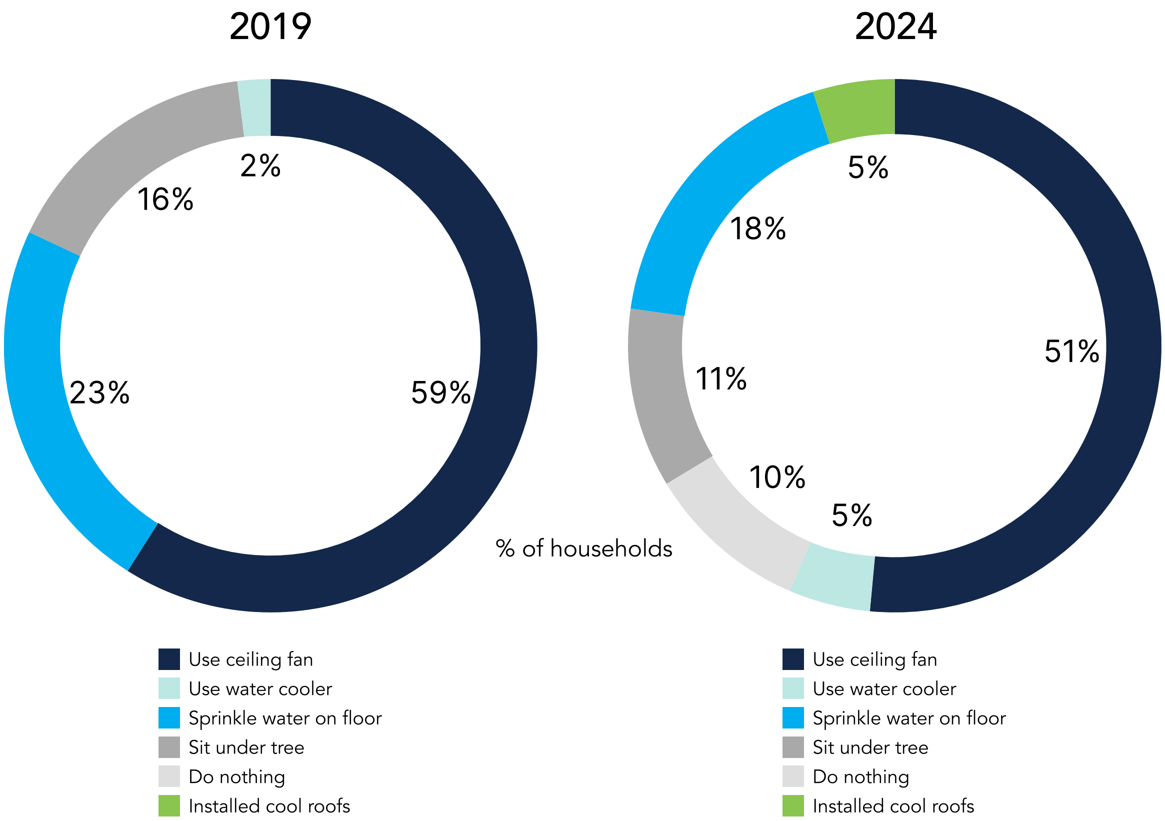


Figure 5: Comparative analysis of percentage of households adopting different cooling strategies for Nagano Math – 2019 v/s 2024

Data on the use of different **cooling strategies** was shared (Figure 5) only by the respondents from Nagano Math village. Based on the data received from Nagano Math households, ceiling fans remain the predominant cooling strategy, followed closely by sprinkling water and sitting under trees as secondary measures. This trend highlights a continued reliance on low-cost, accessible cooling methods. However, the use of cool roofs as a technology to improve thermal comfort is slowly emerging in this village.

3.3. ELECTRICITY EXPENDITURE AND TRENDS

Electricity expenses revealed contrasting trends between the two regions. In Nagano Math, expenditure on electricity in 2024 increased by 36.21% compared to 2019, which can largely be attributed to higher ownership of electric appliances (Figure 6). While this indicates a rise in living standards and modern energy use within rural communities, it also reflects an increased energy

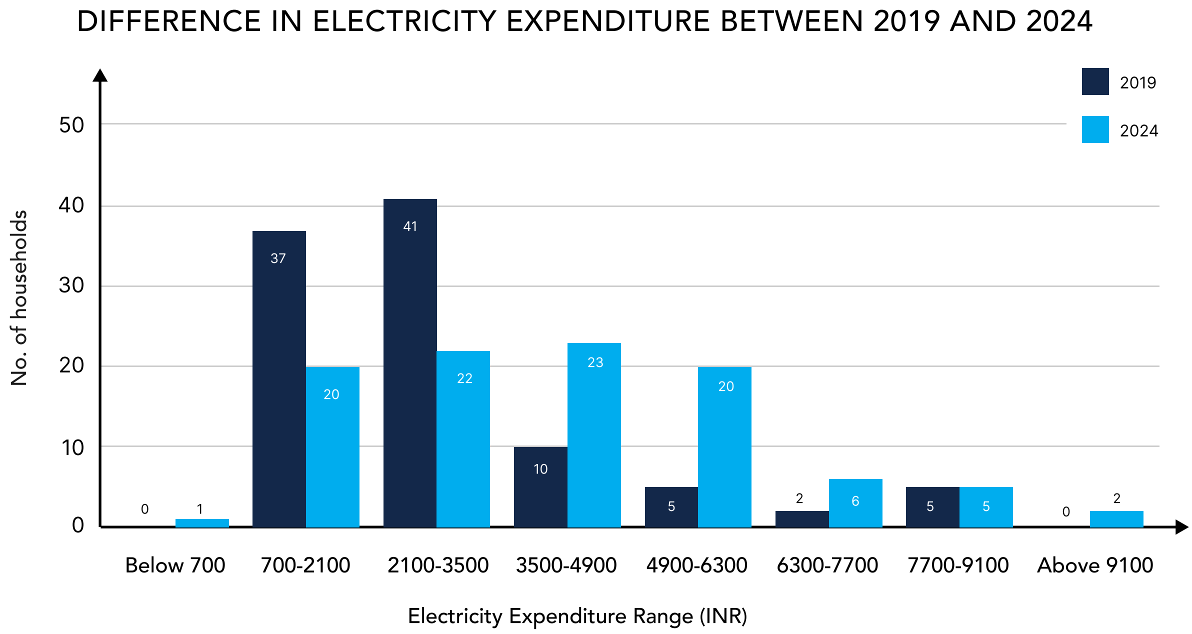


Figure 6: Comparative analysis of Average Annual Electricity Bill per household for Nagano Math in Gujarat

demand. In contrast, Rajasthan's progressive state policy of providing 100 free electricity units per household per month significantly reduced the financial burden on residents.[4] As a result, households in Beraniya reported no expenditure on electricity bills in 2024, further contributing to their economic resilience.

These findings highlight the transformative impact of increased income opportunities, efficient energy management, and supportive policies on household financial well-being in both Nagano Math and Beraniya. The data reflects improved economic conditions and underscores the role of state-level interventions in driving equitable growth and reducing energy poverty.

3.4. FUEL USAGE AND TIME SAVINGS

The study revealed substantial changes in energy usage patterns and time spent on fuel collection.

NAGANO MATH, GUJARAT FUEL USAGE:

In Nagano Math, significant progress was observed in adopting cleaner energy sources by 2024, with LPG emerging as the dominant fossil fuel. The increased adoption of LPG reflects its growing affordability and accessibility, driven by targeted interventions and awareness campaigns promoting its benefits of clean cooking. The expenditure on LPG surged by 20% compared to earlier periods, signalling a major behavioural and technological shift towards cleaner energy alternatives and moving away from firewood used in the cooking sector (Table 2). Expenditure on diesel for non-irrigation purposes was eliminated, while expenditure on diesel usage for irrigation purposes decreased by an impressive 65%. These advancements lowered household energy expenses and reduced the carbon footprint associated with diesel usage, further supporting the transition towards sustainable and energy-efficient rural livelihoods.

Table 2: Comparative analysis of Average Annual Expenditure on fuels for Nagano Math village in Gujarat

Type of fuel	Annual expenditures on fuel per household in 2019 (INR)	Annual expenditures on fuel per household in 2024 (INR)	Percentage change in expenditure on fuel consumption
Diesel (non-irrigation)	10,753	-	-100%
Diesel (for irrigation/season)	9802	3344	-65.88%
Firewood	4715	35084	+644%
Kerosene	3360	-	-100 %
LPG	3656	4388.12	+20.03 %

The survey findings revealed a 644% increase in expenditure on firewood between 2019 and 2024, indicating its continued prevalence as a fuel source in rural households (Tables 2 and 3). NRDC and SEWA conducted a focused group discussion with the Nagano Math village households to verify this. Insights from the FGD highlighted that this is a localized issue within the village where increased firewood usage is largely attributed to a rise in cattle ownership (Table 3), as firewood is primarily used to prepare cattle feed outside the house.

Table 3: Comparative analysis of Quantity of Firewood used weekly and Cattle Ownership in households of Nagano Math village in Gujarat

Average quantity of firewood used by a rural household (kg/week)			Average cattle ownership per rural household (number of cattle)		
2019	2024	% Change	2019	2024	% Change
58.9	134.4	**+128%**	3.5	5.1	**+47%**

Upon further investigation, it was found that only 13% of the firewood was used for household cooking purposes, and 11% for heating water reassuring the positive impact of switching from traditional fuels like firewood to biogas plants for household cooking purposes (Figure 7). Preparation of cattle fodder emerged as the main activity which attributed towards 75% of the firewood usage. Discussions with Nagano Math households revealed that due to increase in the number of cattle, many households switched from buying cattle feed from the local dairy to producing cattle feed inhouse using agricultural waste (mainly corn cobs). This reduced their spending on cattle fodder, but has significantly increased their use of firewood, which was considerably far less in 2019. Since cattle feed is prepared in large quantities, most households have set up bigger traditional cookstoves (chulhas) outside the house.

FIREWOOD USAGE ACTIVITY IN NAGANO MATH

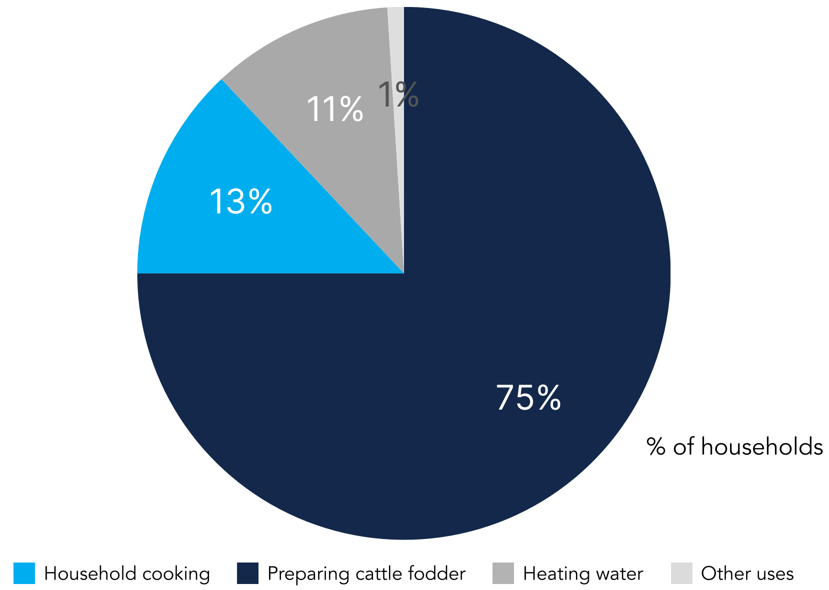


Figure 7: Firewood usage by activity for Nagano Math in 2024

While, to some extent, this reflects a positive development in livestock-driven livelihoods, it raises concerns about the broader environmental impact. On the one hand, households are moving towards cleaner cooking options like LPG and biogas for residential cooking and, in turn, moving away from firewood usage; however, increased cattle ownership has significantly shot up firewood usage. This higher demand for firewood could potentially contribute to increased emissions of greenhouse gases and toxic air pollutants, undermining the overall emission reduction goal and environmental sustainability under similar rural climate initiatives.

Another interesting outcome of this analysis was a discernible shift toward the purchase of firewood rather than its collection, which resulted in a 50% reduction in time spent gathering firewood (Figure 8). This time savings is particularly significant, as it allows households, especially women, to reallocate their efforts towards more productive activities, such as income-generating tasks or education.

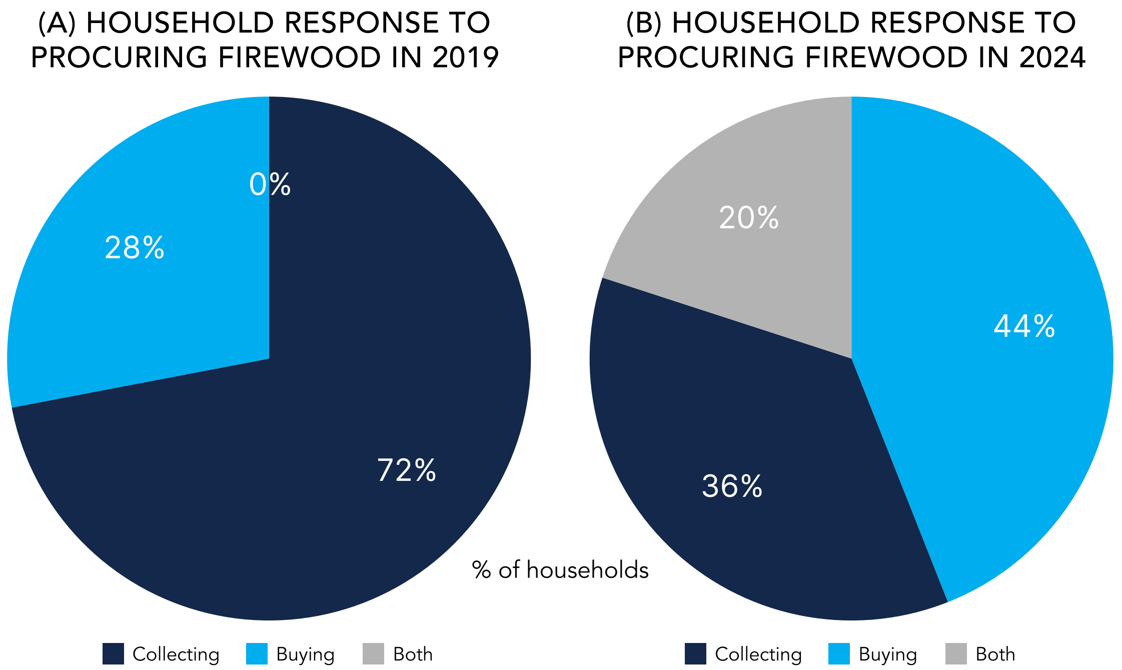


Figure 8: Comparative analysis of difference in procurement of firewood; (A) In the year 2019 the collection was more than buying; (B) In the year 2024, respondents were buying more firewood

This issue requires further investigation and targeted interventions to ensure that sustainable energy solutions extend to activities like cattle feed preparation, mitigating the adverse environmental effects of firewood dependency.

BERANIYA, RAJASTHAN FUEL USAGE:

Even though the state of Rajasthan is demonstrating significant progress in transitioning toward cleaner energy sources, not all the respondents in Beraniya had specific details available against each fuel. This limited the fuel-related analysis under this survey to Nagano Math village in Gujarat.

Overall, fuel expenditures are declining in both states, reflecting the success of interventions promoting cleaner energy options.

TIME SPENT ON COLLECTING FUEL

The data indicates a significant reduction in the time households spend collecting various fuel types, reflecting the impact of the Hariyali Gram initiative on streamlining energy access and reducing dependency on traditional fuels (Figure 9). The weekly time spent collecting traditional fuels like firewood decreased from 8 hours in 2019 to 6 hours in 2024. Though the consumption for firewood increased, discussions with the community revealed that the time spent collecting firewood reduced as many households are now purchasing it to save time. Similarly, there was a sharp decline in the time spent on dung cake collection, dropping from 7 hours per week in 2019 to just 1 hour per week in 2024. This reduction can likely be attributed to the decreased use of dung cakes as fuel, facilitated by the shift to cleaner cooking alternatives like LPG and biogas.

TIME SPENT ON COLLECTION OF FUELS IN 2019 AND 2024

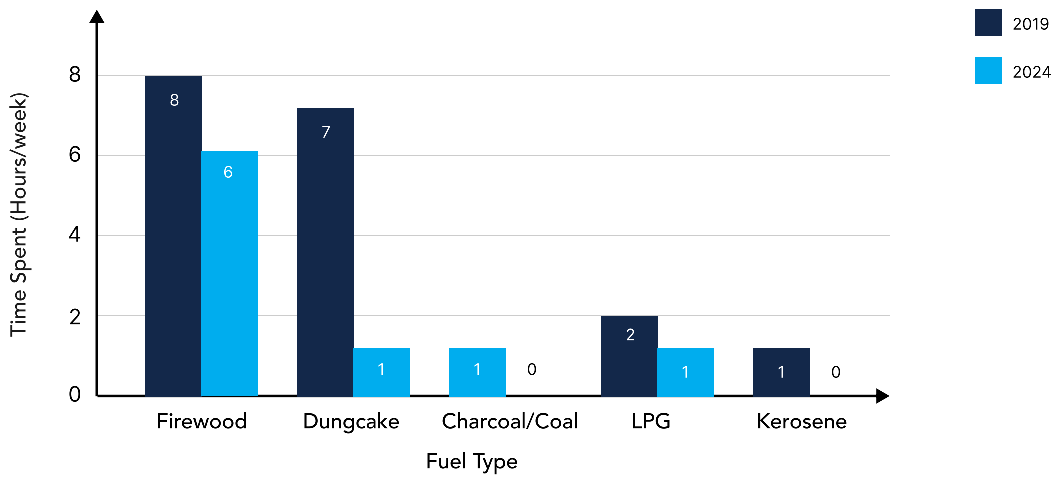


Figure 9: Comparative analysis of difference in time spent in collection of various fuels – 2019 v/s 2024 for Nagano Math

The collection time for LPG also showed a noteworthy reduction, with households in Nagano Math reporting a decrease from 2 hours per week in 2019 to a negligible level in 2024. This trend highlights improved access to LPG, possibly through better distribution and transportation networks or increased affordability.

Additionally, traditional fuels such as charcoal/coal and kerosene, which previously required collection or procurement efforts, have been completely phased out. This total elimination saves time and signifies a critical shift toward cleaner and more sustainable energy sources.[6]

3.5. DETAILED ANALYSIS OF SPECIFIC CLIMATE-FRIENDLY TECHNOLOGIES

This section explores the quantitative and qualitative impacts of individual technologies and their co-benefits for rural households.

The adoption of climate-friendly technologies brought notable benefits to Nagano Math households in Gujarat. The household sample size for this analysis was limited to 10-20 households in Nagano Math and nearby villages due to several key constraints. Firstly, data availability was limited since the technologies being assessed were implemented only in a few select households, and widespread adoption had not yet occurred during the survey. Given the early stage of implementation of these technologies, the study focused on these initial households to evaluate feasibility, effectiveness, and user experience before scaling up. While a larger sample size would have provided more robust statistical insights, the findings from these initial pilot households still offer valuable preliminary evidence on the potential benefits and challenges associated with these technologies.

3.5.1. BIOGAS

The adoption of biogas significantly reduced the reliance on traditional fuels such as firewood and LPG among the respondents. This shift not only addressed environmental concerns but also had a profound economic impact on households. Monthly costs associated with firewood and LPG usage saw a substantial decline—58% for firewood and a complete 100% elimination for LPG. These cost savings underline the financial benefits of transitioning to biogas as a sustainable energy source.

In addition to the monetary savings, the time spent collecting firewood and LPG also experienced a dramatic reduction. Respondents reported an 80% or more decrease in the time required to gather these fuels, a shift attributed to the reduced consumption of firewood and the complete elimination of LPG for cooking purposes (Table 4; Figure 10). This time-saving aspect not only lightens the workload, especially for women in rural households but also allows families to allocate time to other productive or leisure activities, thereby improving their overall quality of life.

The results emphasize the dual benefits of biogas adoption in terms of cost-efficiency and labor reduction, reinforcing its role as a sustainable alternative to conventional energy sources in rural and semi-urban settings. These findings highlight the need for broader awareness and support for biogas initiatives to ensure their widespread adoption and sustained impact.

The adoption of **biogas as a clean cooking fuel** has led to a **reported reduction in indoor air pollution**, which is a major contributor to respiratory illnesses and other health complications. Biogas minimizes household exposure to harmful pollutants such as particulate matter (PM2.5), carbon monoxide (CO), and other health-harming emissions by replacing traditional biomass fuels like firewood and dung. Respondents reported that this transition has resulted in **notable health benefits**, including **reduced respiratory infections, chronic obstructive pulmonary disease (COPD), and eye irritation**, among others. The specific health improvements reported and supporting evidence are detailed in the next section.

Table 4: Comparative analysis for a Biogas Plant

Variables Before & After Installation of Household Biogas Plant									
	Monthly expenditure on fuel (INR)			Quantity of fuel used per month			Time spent on procuring the fuel per month		
Fuel Type	Before	After	% Change	Before	After	% Change	Before	After	% Change
Firewood	1133	475	-58.07%	433.5 kg	83.88 kg	-80.65%	33.8 hours	6.4 hours	-81.06%
LPG	12950	0	-100%	1 cylinder	0 cylinder	-100%	1.3 (hrs/ refilling)	0	-100%

CHANGE IN FIREWOOD AND LPG USAGE ADOPTION OF BIOGAS

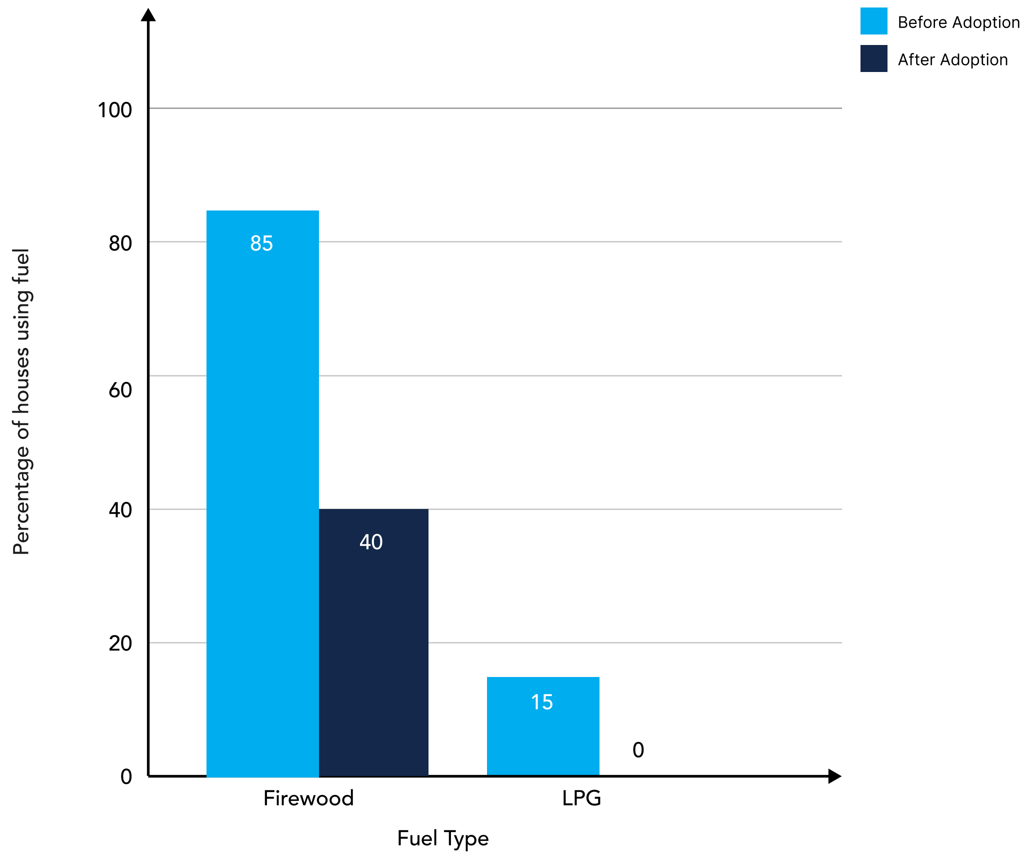


Figure 10: Change in firewood and LPG usage after adoption of Biogas

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3.5.2. SOLAR PRECISION IRRIGATION

A solar precision irrigation system is an agricultural irrigation system that uses solar power to operate a water pump and precisely deliver water to crops. This type of system is beneficial for areas with limited water availability or for farmers who do not own a water pump and rent it for use or purchase water for irrigation. Due to this micro irrigation method, water usage is reduced significantly, minimizing waste while maximizing crop yield.

Before the adoption of the solar precision irrigation system, nearly 60% of respondents relied on renting water pumps and purchasing water to irrigate their fields (Figure 11). This dependency not only increased costs but also posed challenges related to the timely availability of resources. The introduction of solar-powered precision irrigation systems addressed these challenges by streamlining irrigation practices and reducing the time and labor required for agricultural activities.

IRRIGATION OF LAND BEFORE ADOPTION OF SOLAR PRECISION IRRIGATION

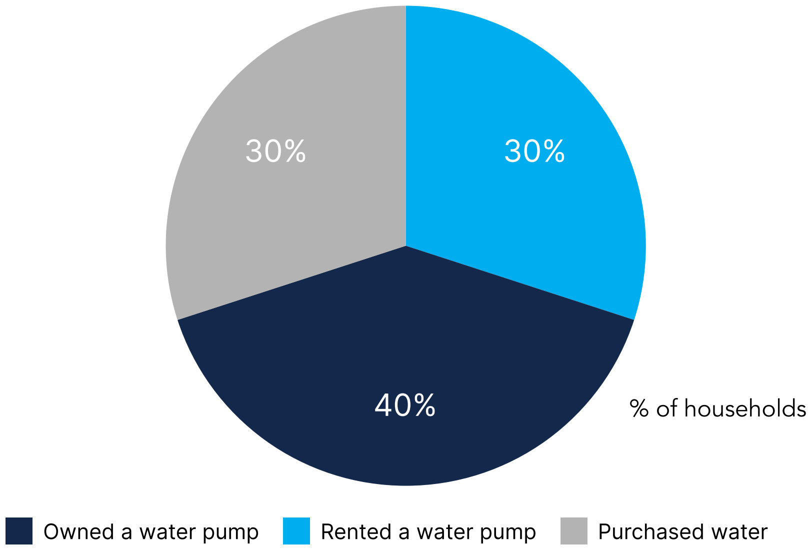


Figure 11: Irrigation of land before adoption of solar precision irrigation

All respondents reported that the precision irrigation system significantly minimized the time spent on irrigation. This reduction in irrigation time translated into tangible economic benefits, with respondents reporting an average savings of INR 7030 per year (Table 5). These savings and reduced operational challenges contributed to improved agricultural productivity and enhanced annual incomes.

Furthermore, the time saved through the solar precision irrigation system had a broader impact on livelihoods. Approximately 90% of respondents reported utilizing the additional time for other livelihood-enhancing activities (Figure 12) such as selling processed agricultural products, working as daily wage labourers, spending more time on their other businesses, engaging in sewing and tailoring work. This shift not only diversified income streams but also empowered households to improve their overall standard of living. Households reported that they were able to save an average of INR 1825 per month leading to annual savings on approximately INR 21900 (Table 5). By reducing costs, saving time, and enhancing productivity, such systems can play a critical role in improving the resilience and economic stability of farming communities. These findings highlight the potential of these systems to address the dual challenges of resource scarcity and economic vulnerability, making them a valuable tool in the broader context of sustainable development.

Table 5: Savings through Solar Precision Irrigation System

Annual expenses saved on irrigation	INR 7030
Annual increase in income due to households utilizing time saved by precision irrigation in other livelihood activities	INR 21900

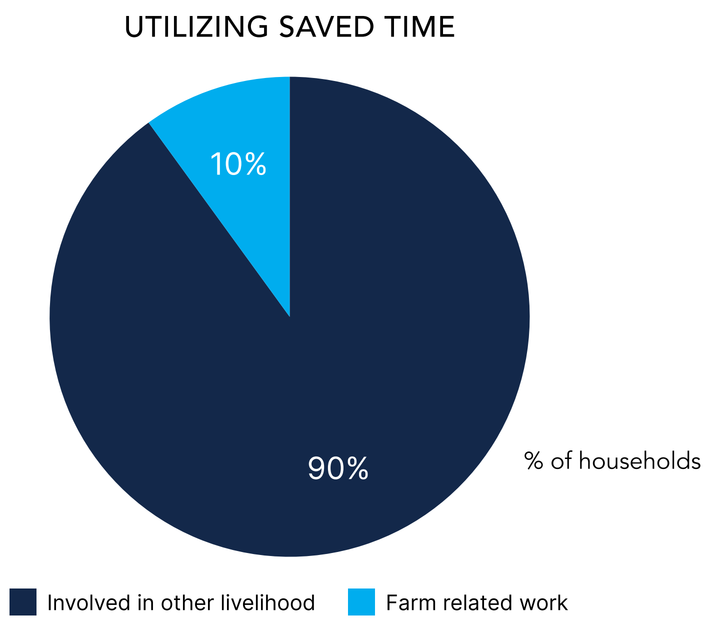


Figure 12: Utilization of time saved by respondents after adoption of solar precision irrigation

3.5.3. COOL ROOFS

The implementation of cool roofs has significantly improved thermal comfort across all user groups, offering a practical and energy-efficient solution to mitigate the effects of extreme heat. Cool roofs have effectively reduced indoor temperatures by reflecting more sunlight and absorbing less heat compared to traditional roofs, creating a more comfortable living environment, especially during peak summer months.

Additionally, the adoption of cool roofs has contributed to lowering energy costs for households. By reducing operating hours of energy-intensive cooling appliances such as air coolers and fans, families have experienced savings in electricity bills. This financial benefit not only enhances household's purchasing power but also contributes to reduced energy demand, aligning with broader sustainability goals.

Another critical advantage of cool roofs has been their ability to address water seepage issues. In nearly 70% of households, cool roofs mitigated water leakage, thus providing a durable and cost-effective solution to a persistent structural challenge (Figure 13). This dual functionality—improving thermal comfort and protecting homes from water damage—has further enhanced its appeal among rural users.

REDUCTION OF WATER SEEPAGE AFTER COOL ROOF INSTALLATION

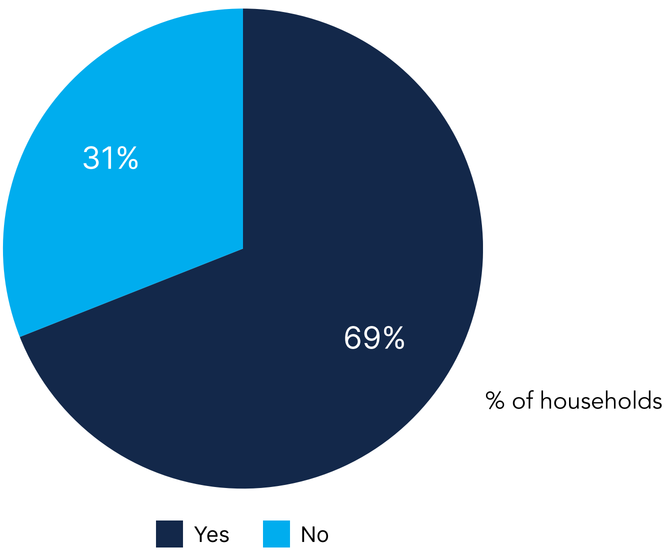


Figure 13: Plot depicting percentage of households reporting reduction in seepage after cool roof installation

The findings underscore the multifaceted benefits of cool roof technology, demonstrating its potential as a key intervention for improving climate resilience in rural areas. Cool roofs offer a comprehensive approach to building sustainability and enhancing the quality of life for communities by simultaneously addressing thermal discomfort, energy efficiency, and structural integrity.

3.5.4. SOLAR TRAP LIGHTS

Before installing solar trap lights, pest attacks posed a significant challenge to agricultural productivity, with 87% of respondents reporting that their harvests were consistently damaged by pests (Figure 14). To mitigate this, the same 87% of respondents spent three or more hours per month applying chemical pesticides to their crops to protect them from pest infestations (Figure 15). This reliance on pesticides consumed valuable time increased input costs and raised concerns about environmental and health impacts.

HARVEST DESTROYED BECAUSE OF PEST ATTACKS

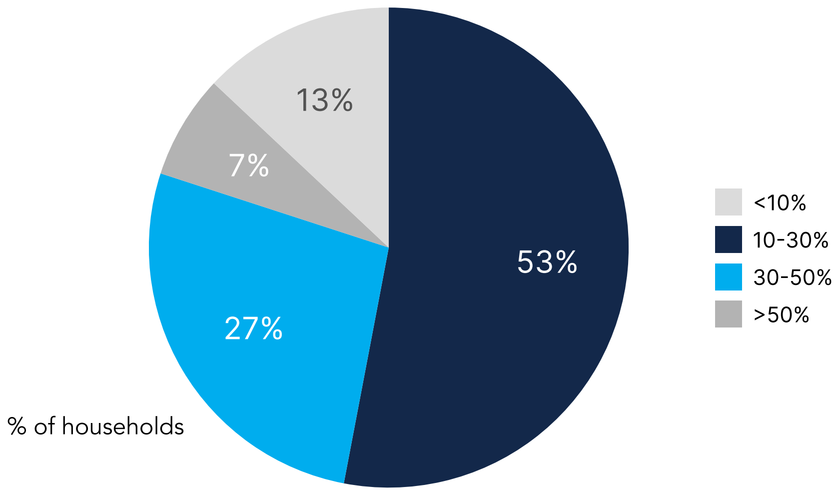


Figure 14: Plot depicting percentage households reporting the extent of damage to harvest due to pest attacks

TIME INVESTED PER MONTH BY HOUSEHOLDS TO REDUCE HARVEST DAMAGE BY PEST ATTACKS (HRS)

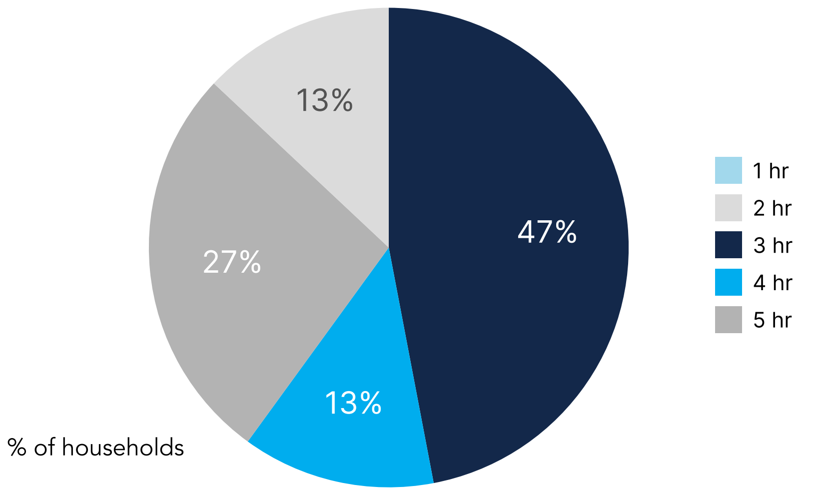


Figure 15: Plot depicting time invested per month by households to save the harvest from being destroyed due to pest attacks

The introduction of solar traplights brought about transformative changes. Following their installation, all respondents (100%) reported no longer needing to use chemical pesticides on their crops. Solar trap lights effectively attract and trap pests, providing an eco-friendly and sustainable alternative to conventional pest control methods.

The elimination of pesticide application resulted in significant time savings, which respondents utilized for productive activities. Among them, 53% reported redirecting this saved time to other livelihood opportunities, while 40% used it for additional farm-related tasks (Figure 16).

Moreover, adopting solar trap lights improved crop safety by reducing chemical exposure and decreasing input costs associated with purchasing pesticides. These benefits highlight the dual advantages of solar traplights as a sustainable agricultural solution and cost-reduction technology.

UTILIZED SAVED TIME AFTER ADOPTION OF SOLAR TRAP LIGHTS

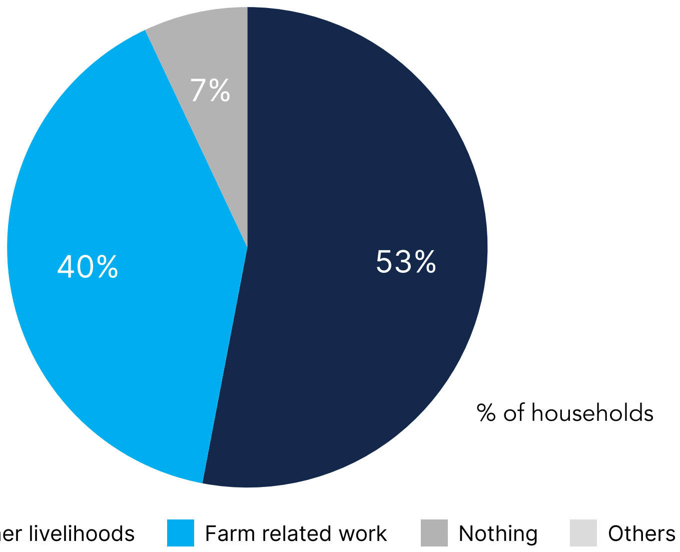


Figure 16: Plot depicting time utilized after adoption of Solar Traplight

3.5.5. SOLAR FENCE

The installation of solar fencing emerged as a highly effective solution to prevent animal-induced (commonly Nil Gai, monkeys, elephants and grazing cattle) crop damage, delivering both financial and operational benefits to farming households. On average, households saved approximately INR8,000 annually due to reduced crop losses.

Before the adoption of solar fencing, protecting crops from animals was a persistent and labour-intensive challenge. A significant 80% of respondents reported being physically present in their fields to safeguard their crops from animal intrusions, often spending long hours away from other productive activities. Meanwhile, 20% of respondents relied on hired labor for crop protection, which added an additional financial burden to their households (Figure 17).

MECHANISMS TO SAFEGUARD CROPS BEFORE SOLAR FENCING

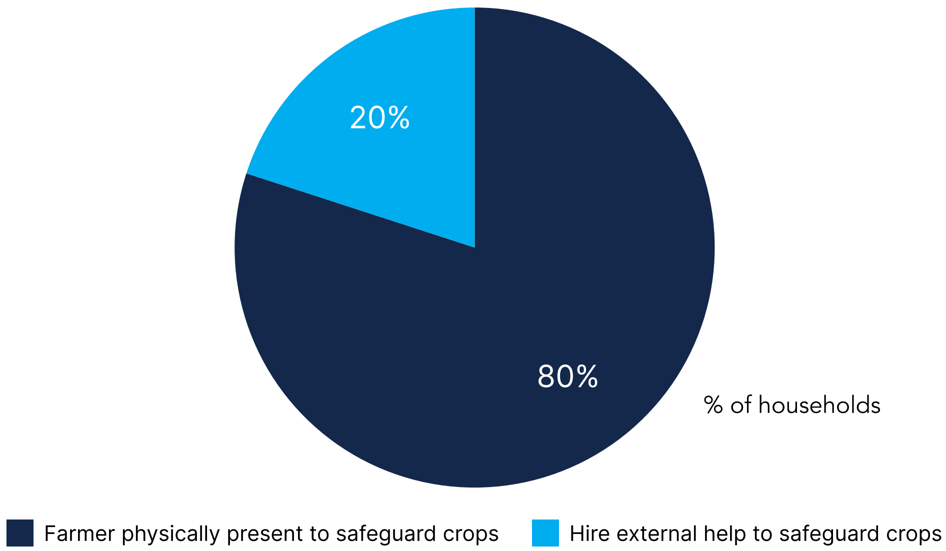


Figure 17: Mechanisms to safeguard crops before Solar Fencing

Despite these efforts, crop damage from animals was a daily occurrence for all respondents (60% of the total households responded to this), demonstrating the limitations of traditional guarding methods. After the installation of solar fencing, the results were transformative. All respondents (100%) reported a complete cessation of crop damage caused by animals. The solar fencing provided a reliable, low-maintenance barrier that effectively deterred animals from entering agricultural fields, thereby protecting the crops without requiring continuous human supervision.

This intervention improved agricultural outcomes by ensuring undamaged harvests and freed up time for respondents to focus on other livelihood activities or farm management tasks. Additionally, by eliminating the need for hiring guards or spending hours monitoring fields, households experienced reduced operational costs and labor demands.

3.5.6. SOLAR LANTERN

A notable 32% of respondents reported that using solar lanterns allowed them to dedicate more time to livelihood activities (Figure 18). Furthermore, 42% of respondents highlighted a significant improvement in mobility during nighttime and early mornings, as solar lanterns effectively removed constraints caused by darkness. Another 16% of respondents indicated that solar lanterns provided essential backup lighting during power outages, ensuring uninterrupted access to basic energy needs. Additionally, many respondents shared that solar lanterns increased household safety by reducing the risk of accidents, such as falls or injuries, during dark hours. The lanterns also provided their children with extended hours to study.

BENEFITS OF USING SOLAR LANTERN

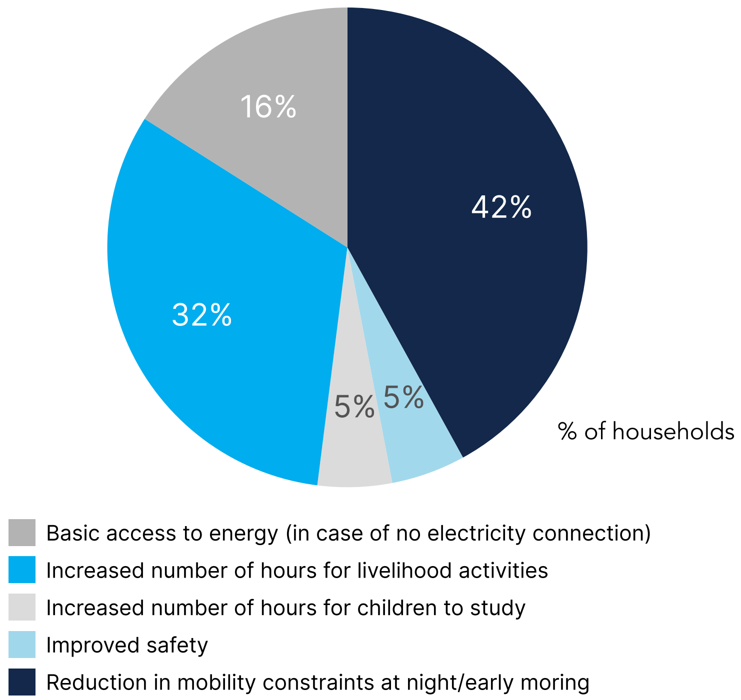


Figure 18: Benefits of using Solar Lantern

Overall, solar lanterns played a pivotal role in fostering socioeconomic progress and improving living standards for the respondents. By offering a cost-effective, sustainable lighting solution, solar lanterns helped bridge the energy gap, enabling communities to thrive and adapt to challenges associated with limited access to electricity. Through focused group discussions, it was found that solar lanterns are particularly useful during power cuts during the rainy season.

3.5.7. SOLAR WATER PUMPS

Solar water pumps are primarily used to provide a reliable water supply in areas without grid electricity access, particularly for irrigation in agriculture, livestock watering, and supplying clean drinking water to communities in remote regions, by drawing water from underground sources or surface bodies like rivers, lakes, and ponds using energy generated from sunlight. A notable 83% of the respondents that switched to solar water pumps reported that they were earlier using a diesel water pump for irrigation purposes (Figure 19). The rest 17% respondents were using electrical pumps before installing solar water pumps.

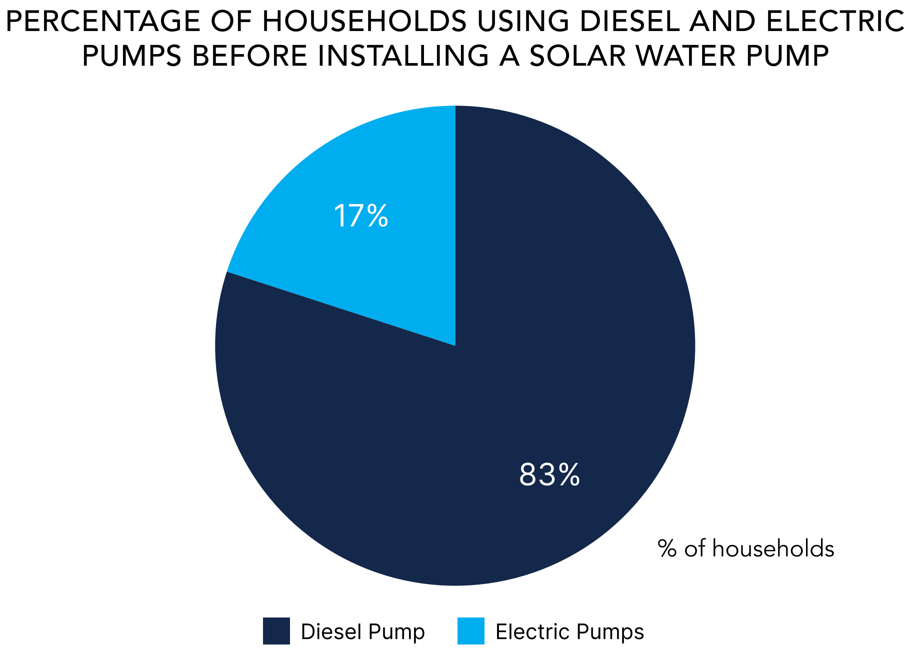


Figure 19: : Plot depicting percentage households using diesel and electric pumps before adoption of solar water pumps

The analysis also revealed that households that used diesel for pumping water were able to save an average of 200 liters of fuel annually, which amounted to approximately INR 20,000 of annual expense (Table 6). These households also reported a small quantity of motor oil usage which was eliminated after switching to solar water pumps. Respondents that used electric pumps were able to save INR 3500 per annual on electricity expenses after the adoption of solar water pumps.

Table 6: : Savings through adoption of Solar Water Pumps

Average quantity of diesel saved annually	200 litres
Annual expense on diesel before adoption of solar water pumps	INR 20000
Average quantity of motor oil saved annually	4 litres
Annual expense on motor oil before adoption of solar water pumps	INR 616
Annual electricity expense saved annually for households that shifted from electric pumps to solar water pumps	INR 3500

Collectively, these technologies saved time and money, enabling households to diversify their livelihood activities and reduce environmental impacts.

3.6. HEALTH IMPACTS

Air pollution has emerged as the second largest global risk factor for premature mortality, with South Asia experiencing among the highest burdens of air pollution-related disease.[7] Expanding access to sustainable household energy sources in rural communities can significantly reduce indoor air pollution and its associated health impacts.

Over the past decade, applied research has highlighted the significant health benefits of climate action in Indian cities, since cleaner energy sources emit less heat-trapping greenhouse gases and fewer health-harming air pollutants.[8] However, while much of this research has concentrated on climate-sensitive risks in urban areas, there is a substantial evidence gap regarding the intersection of climate and health in rural areas. Rural areas face unique challenges, including economic limitations, lower levels of educational attainment, and inadequate infrastructure, which significantly constrain their adaptive capacity.[9] Addressing these challenges requires urgent action to implement and scale renewable energy interventions specifically designed for rural villages and informal settlements to mitigate adverse health impacts.

A notable outcome of this survey was data and discussion with participants on the impact of climate-friendly interventions on participant health. Due to data limitations, the health impact on the households of Beraniya village in Rajasthan could not be studied. The following findings are from responses gathered from 86 out of 90 sampled households for Nagano Math, Gujarat. This underscores the transformative potential of climate-friendly interventions for enhancing indoor thermal comfort, improving air quality, and delivering health benefits. The preliminary findings here highlight these multidimensional advantages

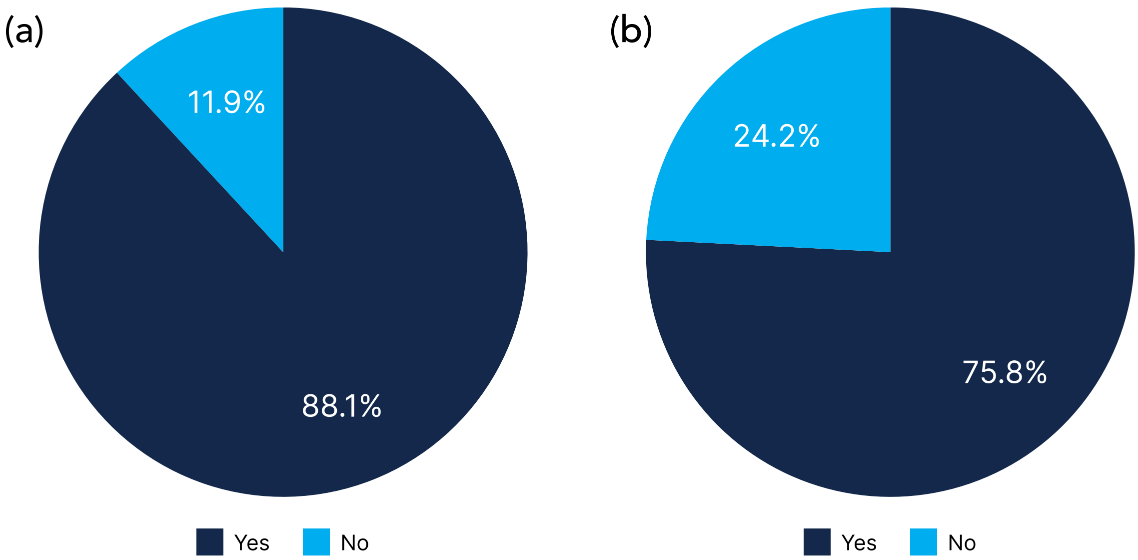


Figure 20: Pie Charts depicting (a) % of households acknowledging the link between traditional cooking methods and the health risks of Indoor Air pollution; (b) % of households reporting reduction in air pollution after switching to cleaner cooking energy sources

and underscore the need for further research in other rural contexts.

A significant majority (88%) of surveyed households acknowledged the link between traditional cooking methods and the health risks of indoor air pollution (Figure 20a). This widespread awareness indicates that rural communities recognize the detrimental effects of conventional cooking practices on their living environments. Following the implementation of cleaner energy technologies, 76% of households reported that switching to cleaner cooking energy sources had significantly reduced indoor air pollution in their homes (Figure 20b). While many households perceived the benefits of these cleaner cooking solutions, not all explicitly connected these improvements to reduced health risks, air pollution hazards, or broader climate change policy objectives.

Beyond the household level, the survey findings also highlight the impact of these interventions on outdoor air quality. Notably, 66% of households surveyed observed noticeable improvements in outdoor air pollution after adopting cleaner energy solutions in Nagano Math (Figure 21). This suggests that the benefits of cleaner cooking technologies and other interventions extend beyond individual households, contributing to enhanced ambient air quality in the broader community.

The survey also shed light on the chronic health challenges faced by rural households and the potential health benefits of adopting cleaner energy technologies. Half of the surveyed households reported family members suffering from chronic health conditions, including heart disease, asthma, and other respiratory illnesses. These findings reflect the significant burden of disease in rural India, which is further exacerbated by poor air quality. Among households that adopted cleaner, climate-friendly cooking solutions, 29% perceived tangible health benefits attributed to reduced indoor air pollution. However, another 31% were uncertain about whether any health benefits were realized, pointing to the need for further awareness-building and sustained engagement.

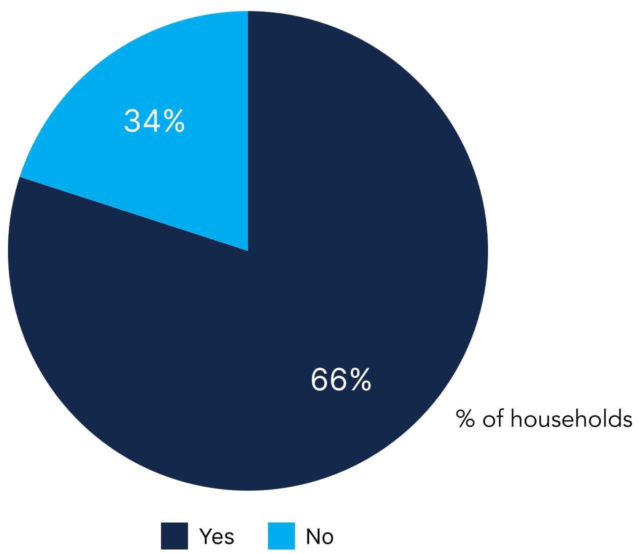


Figure 21: Pie Chart depicting improvements in outdoor air pollution after adopting cleaner energy solutions

In addition to cleaner cooking technologies, other climate-resilient interventions, such as cool roof installations, also demonstrated promising results. Of the 50 households that benefited from cool roofs, nearly 47% reported improved thermal comfort indoors, a critical factor in enhancing overall well-being, particularly in regions facing extreme heat.
Overall, these findings indicate that climate-friendly interventions can bring multidimensional benefits to rural Indian households, including better indoor and outdoor air quality, enhanced thermal comfort, and improved health outcomes. The results highlight the importance of scaling such interventions and signal the need for continued monitoring, awareness-building, and research to maximize their impact and sustainability.

These findings highlight the potential of Hariyali Gram interventions to deliver significant co-benefits for climate mitigation, air quality improvement, and public health in small, low-income villages. However, to ensure these interventions address the needs of vulnerable populations such as women, children, the elderly, economically marginalized individuals, and those with chronic health conditions, future evaluations must assess outcomes across demographic variables such as gender, occupation, income, and age.

3.7. EMISSION REDUCTION POTENTIAL OF HARIYALI GRAM INITIATIVE

Analyzing the data from our surveys in 2024 indicates that if one family transitions from using firewood for cooking to a household-level biogas plant, they can save approximately 3000 kg of firewood annually, avoiding approximately nine tonnes of carbon dioxide (tCO2) emissions. Switching to more efficient appliances, just 100 fans and 100 LED bulbs in a village, can save approximately 21 MWh of electricity every year. This accounts for 15 tonnes of avoided carbon dioxide (tCO2) emissions. Transitioning families from kerosene lamps to solar lanterns equals 12 tCO2 emissions for replacing 100 lamps. Similarly, 10 solar rooftop systems with 1kW capacity can save 14 MWh of electricity annually, corresponding to 10 tCO2 emissions. Using one solar pump (instead of a diesel pump) can lead to 3 tonnes of avoided CO2 emissions. Cool roofs that provide thermal comfort and reduce energy demand for cooling can lead to a one-time offset of 3 tCO2 for 300 square meters of roof area.

Though some technologies led to significant reductions in carbon emissions, many others with limited carbon impact displayed notable co-benefits in increasing household income, saving time, reducing drudgery, reducing water usage, etc. For example, technologies like solar fencing and solar trap lights significantly impact crop yield and quality, thereby enhancing the livelihoods of rural farmers. A precision irrigation system has a limited impact in terms of reducing diesel consumption. Still, it has been proven to reduce irrigation water consumption by up to 80%, proving an important intervention for water-stressed areas or for farmers who do not own a water pump and must purchase irrigation water regularly.

A major finding from this work is that the requirement of climate-friendly technologies varies from village to village and depends on the specific needs of the household and various other factors such as the demographics of the area, livelihoods that the household is engaged in, ownership of cattle, purchasing power capacity etc. For instance, households in hilly areas that engage in agriculture may prefer solar powered precision irrigation to save diesel usage and reduce water runoff. Similarly, a household with cattle ownership may be interested in shifting to biogas for cooking since animal manure is regularly needed as an input to run the biogas plant.

To estimate the impact that such an initiative can have at a village level, a few selected technologies have been considered that have the potential of wider adoption in villages or are backed by government programs and thus may see scaled adoption across Indian villages. Therefore, to gauge the GHG emission reduction impact at the village level, the analysis considers a small village with just 200-300 households and assumes that 400 LED bulbs, 100 ceiling fans, 150 solar lanterns, 10 solar water pumps and solar rooftop systems and 20 biogas plants are installed in the households. This limited implementation of climate-friendly interventions can avoid an average of 280 tCO_2 emissions annually (Table 7), which is equivalent to an individual taking 480 Delhi-Mumbai roundtrip flights. Scaling this to a mere 5% of India's over 600,000 villages can potentially avoid CO_2 emissions of nearly 8.4 million tonnes annually.

Credit: NRDC

Women who have adopted climate-friendly solutions in Dungarpur, Rajasthan

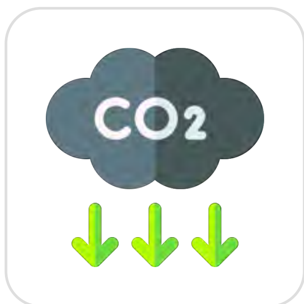
EMISSION REDUCTION FROM CLIMATE FRIENDLY TECHNOLOGIES

 One household level biogas plant can save 3000 kg firewood and avoid 9 tCO_2 emissions annually	 Switching to 100 LED bulbs and efficient fans can save 21 MWh of electricity and 15 tCO_2 emissions annually	 Transitioning from kerosene to solar lamps can avoid 12 tCO_2 emissions for replacing 100 lamps
 10 solar rooftop systems of 1kW capacity can save 14 MWh of electricity and 10 tCO_2 emissions annually	 Switching from diesel to solar pump can avoid 3 tCO_2 emissions annually	 Cool roofs can lead to a one-time offset of 3 tCO_2 for 300 square meters of roof area.

EMISSION REDUCTION FROM ONE GREEN VILLAGE

1

HARIYALI GRAM VILLAGE



280

tCO_2 EMISSIONS

OR

480

DELHI-MUMBAI ROUNDTRIP FLIGHTS

Table 7: Emission reduction potential of climate-friendly technologies for one village

List of technology	Carbon emissions saved annually (tCO_2)*	Assumptions and Data Sources
100 Ceiling fan	5.82	Ceiling fans run for 8 hours for 250 days a year[11]
400 LED bulb	37.89	LED bulbs are used for 7 hours on all days of the year[12]
150 solar lantern	18.26	Solar lanterns are replacing kerosene lamps that consume 400ml of fuel per household per day[13]
10 solar rooftop systems	10.47	1kW rooftop solar systems are considered here which on average can generate 1440 kWh of electricity annually[14]
20 biogas plants	179.38	Calculations are done for a 2 cubic meter household-level biogas plant. It is assumed that all households adopting the technology are transitioning away from firewood usage.
10 solar water pumps	28.27	Calculations are based on 5HP solar water pumps, and it is assumed that the farmers are transitioning away from diesel pumps and that the systems are off-grid.
Total emission reduction	280.09	

*Emission factors for the calculations (for fuels and electricity grid) are taken from IPCC and Central Electricity Authority, Government of India. Calorific values of fuels are taken from energy statistics from the Ministry of Statistics and Programme Implementation, the Government of India, and the IPCC.[15]

Moreover, with higher penetration of climate-friendly technologies within these villages, the estimated impact will increase further, leading not just to energy and cost savings but reduced drudgery from collecting traditional fuels and spending more time in the field tending to crops, reduced exposure to air pollution, improved health, and further improved livelihood and well-being of the rural communities while empowering rural India to lead this transition.

3.8. LIMITATIONS OF THE STUDY

The study dealt with a wide range of demographic and socio-economic factors across both the villages in Gujarat and Rajasthan with varying profiles and needs. Acknowledging this, below are some of the limitations and shortcomings of the study as certain impact indicators cannot be entirely attributed to the interventions under Hariyali Gram.

INCREASE IN INCOME/ SAVINGS IN NAGANO MATH, GUJARAT

Beyond the adoption of climate friendly technologies, households in Nagano Math also attributed increase in yearly income or savings to the rise in the number of earning members in a family. Family members for some households that were studying in 2019 are now employed in well-paying jobs, leading to a rise in the disposable income of the family. Also, with the set-up of dairy cooperative in the region, many households increasingly engaged in animal husbandry related activities and selling milk further leading to higher incomes levels.

REDUCTION IN ELECTRICITY EXPENDITURES IN BERANIYA, RAJASTHAN

A big contributor to the reduction in electricity expenditures in Beraniya, Rajasthan is the state's electricity subsidy policy (providing first 100 units of electricity free of charge to the residents), rendering the impact of adoption of energy efficient appliances on the electricity bills difficult to accurately ascertain.

HEALTH FINDINGS

Though the team tried to assess the role of clean cooking technologies like biogas plants on the indoor air pollution and health risks on the households, it is important to note that the responses to the questions were self-reported, with no medical basis to underpin the health impacts reported in this study. Also, only one third of the sample households in Nagano Math reported health improvements, and another 31% were uncertain about the relation of clean cooking technologies to health outcomes, pointing to the need for greater awareness-building and sustained engagement with the community to enhance their understanding on the linkage between improved indoor air quality and better health.

Credit: NRDC

Use of clean cooking solutions to reduce indoor air pollution

CASE STUDY 2:

ARTI BEN'S JOURNEY: OVERCOMING CHALLENGES WITH SUSTAINABLE TECHNOLOGY SOLUTIONS

Arti ben lives in a small hamlet - Nagano-math, in the Aravalli district of Gujarat. As part of a rural household with her mother and brother, she relied on farming and cattle rearing for her livelihood. She has had a three-year-long association with SEWA (Self-Employed Women's Association) and the Hariyali Gram Project, which she credits with helping to support her resilience and growth.

Prior to her work with SEWA, Arti ben faced daunting challenges. The scant electrification of her village and household impeded everyday tasks. Moreover, the high expenses linked to LPG usage and the labour-intensive gathering of firewood posed significant obstacles. She also had significant financial hardships. Prior to her engagement with SEWA, her household total income was limited: Her brother earned INR 100 for eight hours of labor, while her mother's daily income was a modest INR 80 (it has since increased to INR 180/day).

Over the past 1.5 years, her life has profoundly transformed her living conditions and her agricultural and animal husbandry practices. After assuming leadership as an Aagewan within SEWA, Arti ben underwent rigorous training in agriculture and animal husbandry and acquired valuable skills that transformed her way of life. With financial assistance in linkages through SEWA, she was able to build a new home.

Impact of Specific Climate Interventions on Her Life

SOLAR OFF-GRID SYSTEM

Arti ben faced limited and intermittent access to reliable electricity, often relying on shared connections, which resulted in high utility bills. Frequent power outages led to communication disruptions, as phones lose charge without access to consistent power. With the help of SEWA Bank's loan facility, she purchased a solar off-grid system at INR 40,000 with zero interest. Arti ben could then completely save the INR 2,500 she

Credits: SEWA

Figure 22: Arti ben with her solar off-grid system

used to spend every two months on electricity bills. The new, reliable access to electricity has substantially lowered her energy costs and eliminated communication disruptions during adverse weather conditions.

SOLAR PRECISION IRRIGATION SYSTEM

Arti ben struggled with high costs from labour-intensive irrigation and inefficient water management, which reduced her crop yield. She invested in a solar-powered precision irrigation system for INR 55,000, with a loan of INR 25,000 from SEWA Bank. This adoption boosted crop yield, increased her income by INR 1,000 per month, and lowered labor and water rental costs, saving her INR 2,500 per month. The time spent on irrigation was reduced from 30 hours per month to 10 hours.

COOL ROOF

Arti ben implemented cool roof technology, or a reflective paint coating on the roof, for INR 8000. Previously, extreme summer heat had negatively impacted her household's health. Since the cool roof was installed, indoor temperatures have decreased by up to 5 degrees Celsius compared to the outdoors, significantly enhancing comfort and mitigating heat-related health issues.

SOLAR TRAP LIGHT

Arti ben experienced significant crop damage from pests, spending 30 hours per month protecting her fields. She invested in a solar trap light for INR 5,500, paid in six installments. This reduced her pest management time from 30 hours per month to 7.5 hours a month, lowered her pesticide costs, and minimized insect-related crop damage, ultimately preserving her harvest and increasing her income by INR 500 per month.

Credits: SEWA

Figure 23: Solar trap light in Arti ben's farm

BIOGAS PLANT

Previously, Arti ben was tasked with time-consuming, tedious firewood collection and growing LPG usage expenses. To address this, she purchased a biogas unit for INR 9,000. It was paid in four installments, with a loan from SEWA Bank, and after adopting biogas, the time spent collecting firewood was reduced from 60 hours per month to just 15 hours, saving her time and cutting down on LPG expenses. The biogas by-product, organic slurry, also serves as manure, improving soil quality and crop yields. The reduction in indoor pollution has also contributed to better household health.

SOLAR FENCING

Arti ben experienced significant crop damage from intruding animals, which resulted in financial losses and required extensive labor to mitigate. To address this, she purchased solar fencing for INR 30,000 with support from SEWA Banks loan facility. This solution reduced the time spent safeguarding her crops from 90 hours per month to 30 hours and saved INR 500 monthly. The solar fencing has completely stopped animals from destroying her crops, resulting in improved harvests and increased income.

4 STRENGTHENING SUPPORTIVE POLICIES TO SCALE UP ADOPTION OF WOMEN-LED CLIMATE ACTION IN RURAL INDIA

India's goal of achieving 500 GigaWatt (GW) of non-fossil fuel-based generation capacity by 2030 offers a unique dual advantage: addressing clean employment gaps while driving climate action.[16] Various studies highlight that access to decentralized renewable energy (DRE) can boost productivity in agriculture and textiles, potentially impacting 37 million livelihoods.[17] It also creates employment opportunities while significantly improving education, healthcare, and local economies in rural areas. Additionally, equipping women with green technologies challenges traditional societal norms and empowers them to contribute to household income and take on a leadership role within their communities.

DRE systems, including solar-based technologies, biogas units, etc., hold transformative potential for localized energy solutions. By reducing dependency on fossil fuels and centralized grid systems, DRE catalyzes green job creation and skill development in installation, maintenance, and renewable energy manufacturing. These systems also empower rural households, especially women, by enabling clean cooking solutions, reducing drudgery by saving time spent on collecting traditional fuels like firewood or protecting crops from pests and animals, and creating entrepreneurial opportunities in technology product assembly, distribution, implementation and service and maintenance.

The Indian government has introduced numerous schemes and programs to support marginalized communities in dealing with the severe impacts of climate change. These initiatives aim to enhance technical capabilities, foster entrepreneurship, and create pathways for inclusion in critical sectors like renewable energy. For countries like India, DRE integration is more than an energy solution—it is a comprehensive strategy to uplift underserved communities, bridge gender disparities, and build climate resilience, driving the country towards a more equitable and sustainable future.

To advance rural development through clean energy and climate-friendly interventions, the national and state governments have developed various policies and schemes that align renewable energy adoption with rural development, reinforcing the Hariyali Gram Initiative. The Ministry of New and Renewable Energy (MNRE) has introduced the **PM Surya Ghar: Muft Bijli Yojana Scheme**, which promotes 10 million rooftop solar installations.[18] **The National Bioenergy Program** supports biogas plants and biomass projects, directly impacting rural communities.[19] The DRE Framework by MNRE provides a structured approach for integrating decentralized renewable energy solutions into rural areas (but with no financial allocation). At the same time, the **PM Kusum Scheme** encourages solar irrigation and energy access for farmers, reducing dependency on diesel pumps.[20]

Other notable initiatives include the Ministry of Drinking Water and Sanitation's **GOBARdhan Scheme**, which facilitates waste-to-energy projects and creates livelihoods in biogas unit installation and operation.[21] The **National Rural Employment Guarantee Act (NREGA)** supports climate-resilient development in rural areas with infrastructure projects related to afforestation, soil conservation, water conservation, and renewable energy.[22] The Ministry of Panchayati Raj (MoPR) has introduced the **Sooraj Scheme**, focusing on solar energy adoption in villages with training for local youth, and the **Clean and Green Village initiative**, which aims to create eco-friendly villages with renewable energy, sanitation, and waste management solutions.[23]

Skilling Rural Women to Lead India's Clean Energy Transition

India's rapid economic growth and ambitious sustainability goals underscore the pressing need for robust skill development policies tailored to its diverse workforce. The nation's predominantly unorganized and undertrained labor force faces a significant gap between industry requirements and existing skills, particularly in emerging sectors like renewable energy.[24] With approximately 30% of India's youth either unemployed or underemployed and women making up only 32.8% of the workforce, this disparity perpetuates poverty, entrenches social inequities, and underutilizes the country's vast human resource potential.[25]

Bridging the skill gap necessitates a multifaceted approach. The Government of India has introduced numerous schemes to foster skill development and create employment opportunities, particularly for rural and urban women.[26] These initiatives aim to uplift women economically and socially, address systemic inequities, and enable them to participate in India's growth story.

Programs such as the **Deen Dayal Upadhyaya Grameen Kaushalya Yojana (DDU-GKY)** and the **National Rural Livelihood Mission (NRLM)** have played pivotal roles in transforming rural women's lives.[27] The reservation of 33% seats for women under DDU-GKY and the self-help group (SHG) model under NRLM have successfully brought women into the fold of skill development and financial independence.[28]

Similarly, the **Suryamitra Skill Development Programme** and the **Green Skill Development Programme (GSDP)** have opened new avenues in renewable energy and environmental management, enabling women to contribute to sustainable development.[29] The **Pradhan Mantri Kaushal Vikas Yojana (PMKVY)** has introduced financial literacy and entrepreneurial skills, equipping rural women with the tools to manage businesses.[30]

Additionally, the **Mahila Shakti Kendra (MSK)** initiative offers a grassroots-level platform to support women's empowerment through training, counseling, and legal aid.[31] Meanwhile, sector-specific schemes like the **Support to Training and Employment Programme (STEP)** target employment in traditional and emerging sectors, such as agriculture, dairy, and handicrafts.[32]

Despite notable advancements, rural women in India face persistent challenges in fully benefiting from developmental initiatives due to entrenched social and cultural barriers, inadequate awareness, and infrastructural shortcomings. Gender norms often restrict women's mobility, decision-making, and access to resources, while families prioritize men for opportunities in education and employment. A lack of localized communication strategies and low digital literacy leaves many women unaware of government benefits, further compounded by insufficient training centers, inadequate childcare facilities, and limited transportation options. Financial constraints, procedural complexities, and lack of collateral limit women's access to credit and subsidies, undermining schemes like Trade Related Entrepreneurship Assistance and Development (TREAD) by the Ministry of Micro, Small and Medium Enterprises (MoMSME).[33] Employment opportunities often lack sustainability due to weak market linkages and limited post-placement support.[34] Moreover, gender-specific objectives in policies remain secondary or underreported, reducing accountability.[35] Bridging these gaps requires localized awareness campaigns, expanded training accessibility, community engagement to challenge patriarchal norms, policy, financial and market support, and strengthened implementation through regular monitoring and targeted reforms.[36] Integrating these efforts with initiatives like the Hariyali Gram underscores a commitment to sustainable, inclusive growth, making the vision of an equitable future a reality.

Credits: SEWA

Focus group discussion with community members

CASE STUDY 3:

TRANSFORMING RURAL LIVES: BHARTI BEN'S JOURNEY WITH CLIMATE-FRIENDLY TECHNOLOGIES

Bharti ben Vishnu Vaghela resides in Anand, Mehlao village, Gujarat, where her parents, five sisters, and brother are engaged in agriculture and animal husbandry. Financial struggles were a constant challenge. Often, her family faced additional expenses due to crop losses and high electricity bills caused by unreliable connections.

Through SEWA's Hariyali Gram program, Bharti ben received training in agriculture and gained knowledge about renewable energy for the first time. Through her continued association with SEWA, she has gradually gained control over her family's economic situation, providing them with a better lifestyle today.

The adoption of climate-friendly technologies has yielded significant positive impacts on Bharti ben’s agricultural practices and overall livelihood, increasing her agricultural profits by INR 18000 and savings by INR 13000 per year with a significant reduction in irrigation and pest control time.

Impact of Specific Climate Interventions on Her Life

SOLAR PRECISION IRRIGATION SYSTEM

Previously, she was dependent on labour-intensive irrigation, which drove up costs. Inefficient water management negatively impacted both crop quality and yield. To address this, she invested INR 52,000 in a solar-powered precision irrigation system. This upgrade has significantly improved crop yield, increased her monthly income by INR 1,500, and cut labor and water rental expenses, saving her INR 12,000 annually. The time spent on irrigation has dropped from 120 hours per month to just 30 hours. Additionally, the improved system allows for zero-tillage

Credit: SEWA

Figure 24: Solar-powered precision irrigation system at Bharti ben's farm

farming, eliminating the need for time-consuming field preparation.

SOLAR LANTERN

Previously, limited access to reliable electricity and frequent communication disruptions during power outages created significant challenges. Shifting to portable solar lanterns has provided consistent lighting during outages, ensuring safety from snakes in the dark. The lantern's portability adds convenience, allowing it to be used anywhere as needed. Additionally, the built-in mobile charging port has eliminated communication issues during adverse weather, ensuring uninterrupted connectivity and enhancing overall safety.

Credit: SEWA

Figure 25: Solar lantern in Bharti ben's home

LED BULBS AND ENERGY-EFFICIENT CEILING FAN

An investment of INR 2,000 in LED bulbs and an energy-efficient ceiling fan has significantly reduced electricity expenses. The switch has lowered monthly energy bills by INR 200, while improved lighting from the LED bulbs has eased eye strain, enhancing comfort and well-being.

SOLAR TRAP LIGHT

Pest-related crop damage resulted in financial losses, and she had to spend 60 hours per month protecting her fields. To tackle this, she invested INR 5,000 in a solar trap light. This investment has reduced her pest management time to just 4.8 hours per month, cut pesticide costs by INR 600 per season, and minimized insect-related crop damage, helping to preserve her harvest and boost her income.

Credit: SEWA

Figure 26: Bharti ben cleaning the solar trap light

5 RECOMMENDATIONS TO SCALE WOMEN-LED RURAL CLEAN ENERGY INITIATIVES

The analysis of climate action co-benefits in a rural Indian village highlights the transformative potential of mitigation and adaptation strategies in addressing environmental challenges. Climate-friendly solutions, such as those implemented under the Hariyali Gram initiative, have shown promise in improving access to clean energy and thermal comfort, reducing indoor air pollution, greenhouse gas emissions and drudgery, strengthening livelihoods and rural economy, empowering women and enhancing overall health outcomes. These findings underscore the importance of targeted interventions in rural settings, where communities often face unique vulnerabilities that require tailored approaches to sustainable development. By prioritizing actions that improve socio-economic conditions, including health, such initiatives can serve as a blueprint for broader climate action in rural India.

As the Hariyali Gram program expands, it is essential to balance mitigation and adaptation strategies to maximize health, energy, and economic benefits for rural communities. While mitigation efforts—such as reducing reliance on fossil fuels and traditional sources of energy—are crucial for addressing long-term socio-economic, environmental and health impacts, adaptation measures offer immediate, tangible benefits to the community. For example, cool roof installations have proven effective in moderating indoor temperatures and reducing energy demand for cooling. Integrating these efforts with government initiatives, local capacity-building, and long-term financing mechanisms is critical to ensuring the sustainability and scalability of these interventions.

There are also many learnings from designing the Hariyali Gram survey such as:

1. Design the survey in simple language and translate it in the local dialect. For Nagano Math and Beraniya villages, using surveys translated in Gujarati and Hindi worked well.
2. Train the surveyors so that they clearly understand the outcome of the survey and the survey questions and can gather the required data while answering any questions that the respondents may have.
3. Build the capacity of the surveyors on technology related questions and the type of response requested.
4. Conduct interviews at a time when the respondent is relatively free during the day. For example, the rural women in Nagano Math preferred afternoon hours when they were done with household chores and were able to devote time to provide adequate responses.
5. Conduct focused group discussions with the community members in addition to individual in-person interviews to better understand statistical outliers and data points that are significantly outside the usual range of responses, as well as the community perception to adopting or refraining the use of a particular climate solution.

Despite robust evidence of the need for climate action, the ancillary benefits for rural communities remain relatively underexplored in India. The findings from this assessment suggest that scaling up Hariyali Gram interventions across rural India can deliver significant and sustained direct and indirect benefits to the community at large, improving the living/ economic conditions of households and strengthening resilience to environmental threats. Inclusive implementation strategies that prioritize the holistic development of a region involving vulnerable populations and marginalized communities are essential for ensuring long-term equitable economic development across both urban and rural areas in India and other similar geographies.

The section below explores key learnings and recommendations from the Hariyali Gram initiative. It highlights a few key areas that are essential for scaling such gender-focused climate interventions in vulnerable and rural communities.

KEY LEARNINGS AND RECOMMENDATIONS

CONNECTING VILLAGES TO CENTRAL AND STATE INITIATIVES AND OPPORTUNITIES

After setting up Hariyali Gram in two states, it was learnt that local organizations are limited in capacity and need more support to scale such projects. Hence, it is essential to work with central and state government departments and nodal agencies to integrate the initiatives such as Hariyali Gram approach into existing policies and programs. This needs to be complemented by supportive climate-friendly policymaking (for example, a dedicated policy to support the adoption of women-led DRE solutions) following a bottom-up approach involving consultations with communities and performing holistic needs assessment.

ADOPTING A TAILORED IMPLEMENTATION STRATEGY AND ENGAGING LOCAL PARTNERS

It is key to have a holistic understanding of the local context to design a tailored approach and achievable milestones across any program. For example, with reference to the Hariyali Gram initiative, income and prosperity levels varied between the villages of Gujarat and Rajasthan. Both regions also bear unique cultural nuances, socio-economic status and overall readiness, which called for tweaking our engagement methods for each stakeholder group. For this, it is important to collaborate with experienced grassroots and local level organizations working in the specific geography with strong community connections, to ensure effective implementation starting from survey design to household adoption stage.

STRENGTHENING CONVERGENCE BETWEEN GOVERNMENT DEPARTMENTS AND INTER-DEPARTMENTAL COORDINATION AT THE STATE LEVEL

The climate is an overarching and cross-cutting theme requiring focused actions from sectoral departments and government agencies in states. To catalyze scaling up a multi-sectoral program such as Hariyali Gram, a convergence of schemes, policies and goals of relevant government departments and agencies in states such as (but not limited to) environment, agriculture, energy, water and rural development, and regular coordination amongst them is needed. This will ensure state-level efforts are coordinated, with leverage of cross-sectoral initiatives to achieve the intended impact.

DEVELOPING ACCESSIBLE FINANCIAL MECHANISMS

Based on the ground survey, we learned that lack of easy and low-cost financing is a barrier to women-led clean energy access in rural areas since many women do not own assets in their name. Designing accessible, low-cost, innovative financial mechanisms and user-friendly products for rural households is needed to ensure that associated risks are reduced, for women to effectively support the energy transition on the ground. To address this, government, private players and financial institutions, in collaboration with grassroots-level organizations, can work collaboratively to design financial tools and products to better serve underserved communities - mainly rural women- and empower them to adopt climate-friendly solutions.

BUILDING STRONG PARTNERSHIPS WITH RELEVANT STAKEHOLDERS

Collaboration is the fuel that keeps the engine of any initiative working. The Hariyali Gram initiative ensures collaborative work among relevant stakeholders and partners, including grassroots-level organizations, government agencies, vendors and technology suppliers, financial institutions, etc., to ensure timely on-ground implementation and scaling up of the program. Therefore, initiatives targeting vulnerable rural communities should have components of policy support, awareness generation, skilling and capacity building, access to finance and technology support for successful implementation.

ENSURING MONITORING, VERIFICATION AND POST-IMPLEMENTATION SUPPORT

It is essential to continue support for these initiatives beyond the initial implementation phase. For instance, by:

- Building capacity for repair and servicing of appliances and technologies in the program design components for a substantial period (~3 years)
- Strengthening capacities of district offices to ensure continuous usage and adoption of solutions
- Supporting Community Based Organisations that provide skilling and capacity building of local leaders
- Supporting climate entrepreneurs who can help increase demand and adoption of green technologies, and
- Enabling women to take on the role of planners, users and managers of climate-friendly solutions.

STRENGTHENING SKILLING, CAPACITY BUILDING AND ROLE OF MARKET ACTORS

Education, skilling and capacity building are the cornerstones of ensuring an initiative's long-term impacts. The Hariyali Gram initiative continues to put emphasis on regular awareness generation campaigns and workshops with relevant stakeholders, including building local climate entrepreneurs. Grassroots-level initiatives should embed training of grassroots leaders and capacity building among local agencies involved in the implementation, to ensure desired skills are being imparted for a sustainable impact. Here the role of market actors is also crucial: the private sector could partner with rural communities and local agencies to jointly design and promote climate entrepreneurship opportunities, to address the skill gaps.

FOSTERING KNOWLEDGE EXCHANGE AND PEER-TO-PEER LEARNING

For wider replication and amplification of these efforts, it is critical to disseminate success stories and profile the work across communities, states, and regions via case studies, as well as amplify the voices of the beneficiaries in dedicated forums and platforms.

Credit: NRDC

SEWA sisters attending a capacity building and awareness session

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HIGHLIGHTED REPORTS

Technology Guidebook: A Compendium of Resources for End Users of Climate-Friendly Technologies

Hariyali Green Villages: Women-Led Climate and Clean Energy Solutions for Prosperity in Rural India

It Takes a Village: Advancing Hariyali Clean Energy Solutions in Rural India

Worth Their Salt: Building Skills and Improving Livelihoods of Women Salt Farmers in Gujarat through Clean Energy Solutions

India's Expanding Clean Energy Workforce: 2022 Update

Creating Jobs and Income: How Solar Mini-Grids Are Making a Difference in Rural India