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Just transition insights from India's 2050 MW Pavagada Solar Park

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues.

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HIGHLIGHTS

- Large-scale solar powerplants are widely considered beneficial due to their role in reducing emissions. However, their impact on local communities remains underexplored.
- This study addresses this gap by examining the differential effects of India's 2 GW Pavagada Solar Park on social groups in nearby villages. Using a combination of survey and qualitative data, we assessed the impacts on local livelihoods in villages around the solar park.
- The empirical evidence presents mixed outcomes. While larger farmers benefit from steady incomes by leasing their land to the solar park, smaller farmers, pastoralists, and landless laborers face the loss of stable livelihoods.
- Although one in five men in the solar villages worked at the solar park, no women were employed in the solar park. Security workers benefited from a fixed income while the wage workers did not. Moreover, all the workers were on informal contracts, limiting their ability to advocate for better working conditions.
- We find that, to ensure a just transition, it is crucial to include affected populations in planning processes to recognize their diverse socioeconomic needs and sustain their livelihoods.
- Future solar parks should also incorporate comprehensive environmental and social impact assessments to ensure that risks are anticipated and costs and benefits are equitably distributed.

EXECUTIVE SUMMARY

Background

A just transition away from fossil fuels must account for people affected at every step of the transition. The social context and characteristics of the population, such as caste, tribe, and gender, play crucial roles in planning a transition. Empirical evidence on how these effects are distributed across social groups is essential for understanding the context-specific needs to facilitate such a transition.

As countries build large-scale solar installations to transition to renewable power, understanding the effects of these projects on nearby communities is crucial. Solar energy significantly contributes to India's renewable power targets, mainly from large-scale solar power plants. However, research on the social aspects of this transition, particularly the local impacts of large solar installations in India, is limited.

About this working paper

This paper examines the Pavagada Solar Park, one of the largest solar parks in the world, to develop an empirical evidence base of its local socioeconomic impacts and situate these findings in the just transition narrative. Located in the southern Indian state of Karnataka, the solar park spans 13,000 acres of land leased from 2,300 farmers in five villages in Pavagada, where most people traditionally practice land-based livelihoods. As one of India's first utility-scale solar projects, learning from it can pave the way for similar future projects. This paper aims to enhance the existing discourse on energy transition using this evidence and to inform policymakers about the potential risks to communities and possible ways to ensure a just transition.

Research questions and methods

This paper tries to address the following questions:

- How has the solar park's impact on livelihoods and labor been distributed locally across socioeconomic groups and gender?
- What changes in vulnerabilities occurred before and after the installation of the solar park relative to similar villages without the solar park?
- How has access to resources, particularly water and land, been affected in villages with solar parks compared to similar villages without solar parks?

This study compared two groups of villages: those with and those without a solar park. A simplified version of the difference-in-differences technique was used to estimate the effect of solar parks by comparing changes in specific outcomes over time between these villages. The mixed-methods study used primary data from a survey of 300 households. To evaluate characteristics over time (2015–21), the survey collected information from respondents for the reference year through recall questions, supplemented by focus group discussions and interviews with key stakeholders. Data were collected in collaboration with our field partner, Thamate.

While the study examines changes in access to land and water, it does not cover local and long-term environmental impacts and related implications on livelihoods, acknowledging the need for further research on this subject.

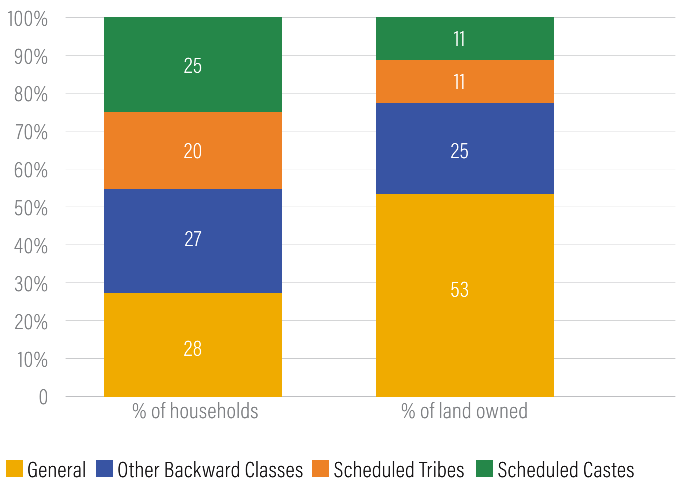
Findings

Differential impacts

The solar park increased the inequalities between landholding and landless households. Using land as the sole basis for compensation, without accounting for livelihoods, led to an uneven distribution of risks and benefits. This distribution mirrors landholding patterns in the region. Landowners benefit from the amount of land they have leased, but landless households do not.

The compensation mechanism exacerbated inequalities between marginalized caste groups and households from other social categories[1]. Land is deeply tied to caste. General category households, owning the most land (Figure ES1), benefited more, whereas scheduled caste (SC) households, owning less land, benefited less. If compensation mechanisms do not account for local social dynamics, they risk exacerbating inherent inequities.

Figure ES1 | **Proportions of households by social category and corresponding land holdings in solar villages**



Source: WRI India survey data.

Changing vulnerabilities

After the solar park installation, 20 percent of a agricultural laborers and 39 percent of pastoralists were unemployed. Over 80 percent of the locals relied on land-based livelihoods, with agricultural labor being the primary source of income. While cultivators[2] who leased out land to the solar park benefited from an assured yearly lease income, which is more secure than agricultural income that depends on weather conditions, landless workers were forced to seek work in other villages and cities or face unemployment.

The solar park employed 20 percent of working men in the solar villages. Salaried work at the solar park (even on informal contracts) provided more stability compared to agricultural activities. The employment potential of the park could be optimized by improving the nature of employment and quality of work for the villagers. Issues of job security, acceptable work environment, and fair wages remained critical for wage laborers and contractual workers.

Women did not gain new opportunities at the solar park, and nearly half of them lost employment in solar villages. Their vulnerabilities were exacerbated due to limited asset and land title ownership and dependency on agricultural labor. Women, who primarily worked as agricultural laborers, lost out due to limited options for travel or migration due to domestic responsibilities.

Opportunities at the solar park are not equally accessible. Eight-two percent of solar park workers came from landholding families. Therefore job quality directly correlated to land ownership and education level, which itself is linked to economic class.

Resource access

Pastoralists had to travel long distances for grazing land or sell their livestock due to reduced access to grazing areas. The solar park reinforced the ongoing shift away from land-based livelihoods. In solar villages, agriculture and livestock farming practices declined five times more than that in non-solar villages. Among former agricultural workers in solar villages, approximately 20 percent were unemployed, and 39 percent of former pastoralists were unemployed.

Conclusions and recommendations

Empirical findings from Pavagada highlight the need for energy transitions to consider potential impacts on local communities. A just and equitable transition must consider factors such as caste and gender, reflecting social realities. The unequal distribution of benefits is shaped by existing social and economic disparities. Even well-intentioned projects can have differentiated costs on local communities and exacerbate existing inequities. Responsible expansion of renewable energy is crucial for a just energy transition in India, and incorporating large-scale solar projects under the 2006 Environmental Impact Assessment (EIA) Notification could be a significant measure in mitigating potential socioenvironmental risks.

Compensation mechanisms should be reconsidered. The distribution of benefits based only on the amount of land leased does not consider the inherent disparity in land ownership in villages (Figure ES1) and the implications for landless laborers. Negotiated compensation mechanisms should equitably benefit the disadvantaged.

Quality of jobs should be enhanced. Workers at the solar park lack benefits, job security, and safety provisions. Mandating formal employment agreements can help workers negotiate better working conditions, wages, and job security.

Gender gaps in participation and employment opportunities should be addressed. Women's primary livelihood is agricultural work, yet they are underrepresented in decision-making and employment in solar parks. Conditions for their participation in decision-making and new jobs should be proactively facilitated through dedicated training for women displaced from their jobs.

INTRODUCTION

The rapid uptake of solar and wind power has driven the clean energy transition, constituting approximately 91 percent of the global installed renewable power capacity (IRENA 2021). In 2021, India added the third largest renewable power capacity (15.4 GW), after China and the US (REN21 2022). Solar power is a major contributor to this transformation. India's installed solar power capacity has risen from approximately 1 GW in 2012 (MNRE 2019a) to 59.3 GW in 2022 (MNRE n.d.). Approximately 77 percent of India's cumulative installed solar capacity is derived from utility-scale projects (JMK and IEEFA 2022). As of 2022, 57 solar parks have been approved across 13 states under the Development of Solar Parks and the Ultra-Mega Solar Power Projects scheme (MNRE 2023). The MNRE (2019b) defines a solar park as "a large area of land developed with all necessary infrastructures and clearances for setting up of solar projects of 500 MW and above." Large-scale renewable energy projects are exempt from an environmental impact assessment (EIA) as per government regulations.

Local trade-offs in the transition to renewable power

Technological transitions trigger corresponding socioeconomic and political transformations over time (Miller et al. 2013). The costs and benefits of the renewable energy transition cannot be measured only in terms of installed capacity, energy generated, and emissions avoided. It is also important to consider and respond to the social aspects of the transition to leverage its potential to mitigate existing inequities. With India's ambitious renewable power targets, the renewable energy sector is estimated to potentially employ 1 million people by 2030 (IRENA 2022).

Ground-mounted solar photovoltaic (PV) systems are land-intensive, requiring approximately 5 acres of land per MW (SECI n.d.). Approximately 67.6 percent of the country's utility-scale solar installations are on agricultural land (Ortiz et al. 2022). In a predominantly agrarian region, how have local communities been affected? Do utility-scale solar parks improve local job availability? How do the benefits from such interventions translate into local well-being? Apart from a few studies on local environmental impacts (Armstrong et al. 2013; Chowdhury 2021; *Pardikar* 2023), the subject remains under-researched. In the Indian context, it is crucial to understand the implications through the lens of caste, in addition to class and gender, given how these define the country's social structure and are intertwined with land ownership. This study examines the social dimension of the transition by focusing on the case of the Pavagada Solar Park.

This study aims to make an empirical contribution to spur discussions on a just transition in various contexts. Furthermore, it proposes that the concept itself must evolve to include those at the 'greener' end of the transition. Moreover, the interpretation of just and equitable transitions needs to be contextualized for countries such as India, to reflect their social realities.

Research objectives and questions

This study examined the distribution of socioeconomic impacts across social groups in local communities by capturing the changes in their lives and livelihoods due to the installation of the Pavagada Solar Park. We attempted to understand the nature of work generated at the solar park and who benefits from it. We also investigated whether these opportunities contributed to better livelihoods or decent work. Land is an inequitably distributed resource in India, deeply linked to caste (Srinivas 1986). Are existing inequities and vulnerabilities rooted in landholding mirrored or mitigated with this change in land use? How has the park impacted the occupations that people were engaged in before its establishment? Has there been a change in accessibility to resources and, consequently, livelihoods? The study examined these changes using a before-and-after comparison of livelihoods.

The study addressed the following research questions:

Differential Impacts: How are the impacts of the solar park distributed locally across different social groups? We studied the impacts through the lenses of social categories (including caste), land ownership, and gender, highlighting the need for intersectional analyses in the study of impacts.

Furthermore, the study focused on the aspects of resource scarcity and vulnerability in the context of the primary question.

- **Resource Scarcity: How has access to resources, particularly water and land, been affected?** This study aimed to examine the impacts on lives and livelihoods from a resource scarcity perspective, specifically land and water.
- **Vulnerability: How has the vulnerability of livelihoods changed over time as experienced by respondents in villages that are directly affected (those who leased land to the solar park) and neighboring villages?** The study examined the changes in vulnerability before and after the installation of the solar park.

METHODOLOGY

This study compared the situations in two sets of villages – 'solar' villages where land has been leased to the solar park and neighboring 'non-solar' villages. Observations from respondents in these categories over time (before and after the solar park installation) were gathered to contextualize the changes observed. Household surveys, with questions related to the before and after scenarios, were administered to gather responses allowing for disaggregation by socioeconomic characteristics.

A simplified difference-in-differences analysis was used to estimate the effect of the solar park by comparing changes in specific outcomes over time between solar and non-solar villages.

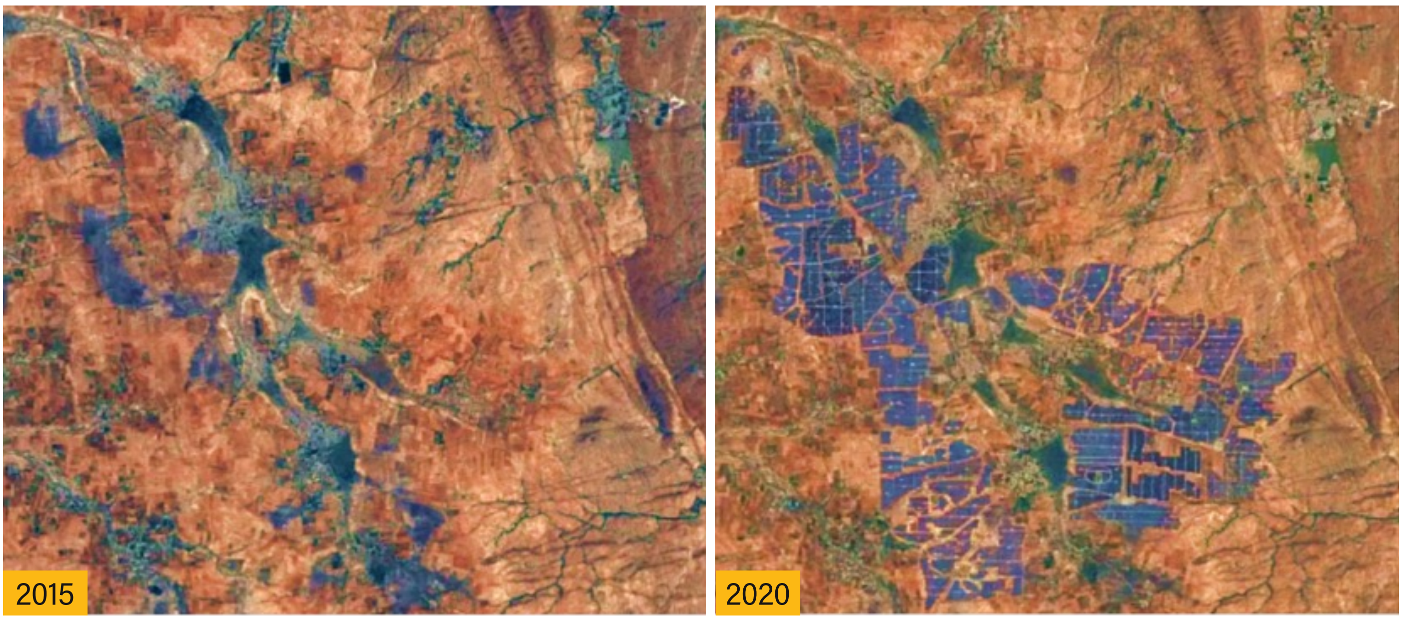
This research adopted a mixed-methods approach, using both qualitative and quantitative techniques for primary and secondary data collection and analysis. Qualitative data from interviews and discussions supplemented the quantitative data gathered through surveys. Data collection occurred in two stages. In the first stage, key informants and experts were interviewed to gather insights into the site and its subjects. The literature review and interviews informed specific research questions and the approach for the next stage. The second stage involved household surveys, focus group discussions (FGDs) and interviews with key informants.

Background to the Pavagada Solar Park

Pavagada is a taluka (subdistrict) in the Tumakuru District of Karnataka, India. According to the Dr. Nanjundappa Committee (2002), Pavagada is among the most socioeconomically backward talukas in Karnataka. Frequent droughts and a lack of economic growth opportunities have led residents away from Pavagada (The News Minute 2018). The region was considered suitable for a solar park due to its geography and weather conditions. The park is viewed as an opportunity to promote regional economic development (*Economic Times* 2018).

At its commissioning in 2019, the Pavagada Solar Park, also known as the Shakthi Sthala, was the largest in the world. The project was conceived in May 2015 by the Karnataka Solar Power Development Corporation Limited (KSPDCL). The land for the project was leased from 2,300 farmers for 28 years. KSPDCL subleases the land to private solar park developers (SPDs) and transfers the lease amount to the bank accounts of the land-leasing farmers. A lease amount of INR 21,000 per acre per year with a fixed increment of 5 percent every two years, was agreed upon after discussions between farmers and project authorities. The park covers over 13,000 acres of land across five villages in two panchayats (village

Figure 1 | **Satellite images showing the development of the Pavagada Solar Park**



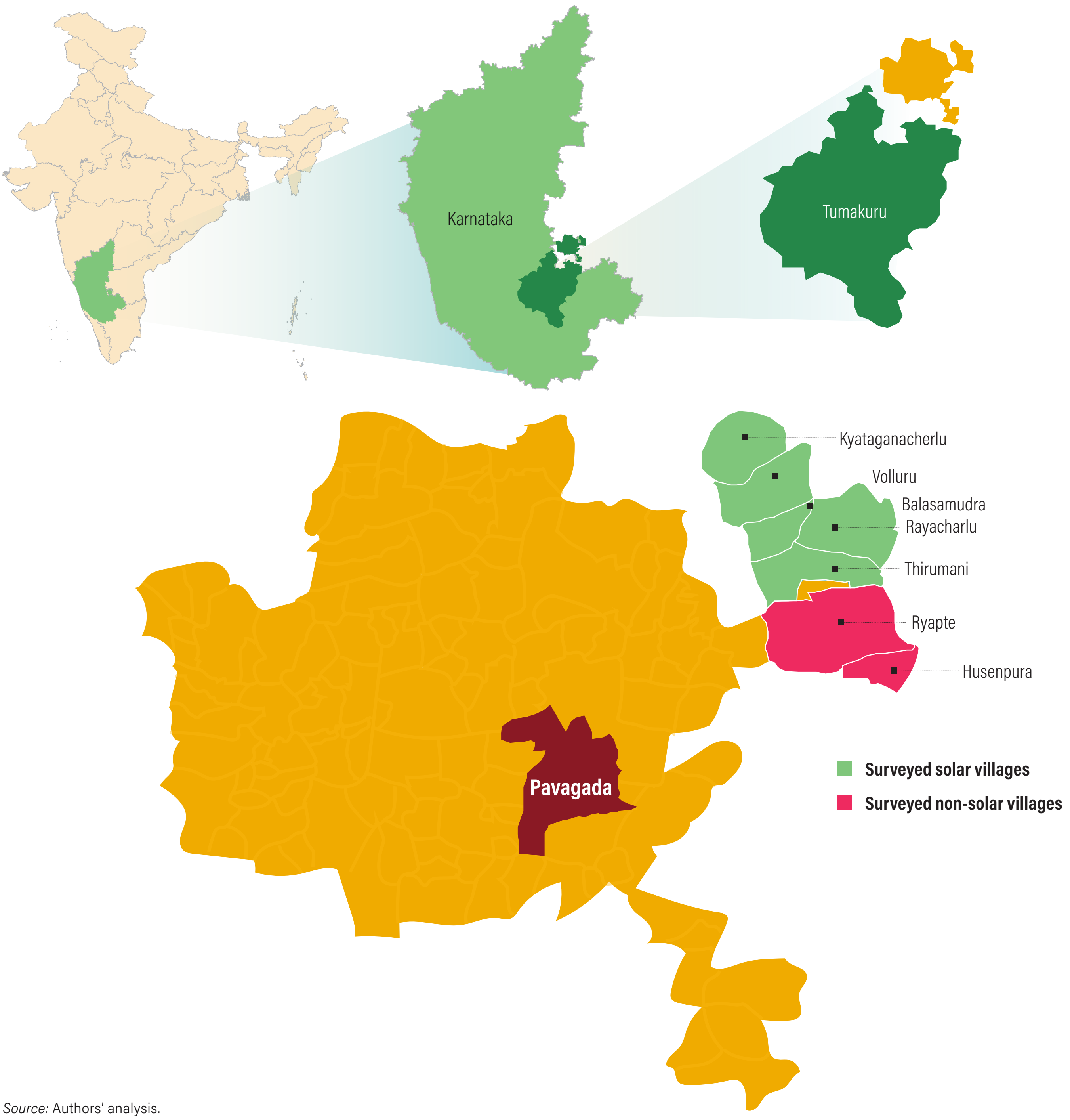
Source: Google Earth Engine.

administrative boundaries), Volluru and Thirumani. Figure 1 shows the change in the landscape with the development of the project.

Area of study

We classified the villages into 'solar' and 'non-solar' categories based on demographic and geographic similarities. The Pavagada Solar Park is spread across five solar villages, including Volluru, Rayacherlu, Kyataganacherlu, Balasamudra, and Thirumani. Surveys were conducted in Volluru, Rayacherlu, and Thirumani. Among the non-solar villages, Ryapte and Husenpura were chosen (marked in Figure 2) in consultation with our field partner, Thamate. This study compared the two sets of villages before (2015) and after (2021) the solar park installation.

Figure 2 | **Locations of villages surveyed in the study region**



Source: Authors' analysis.

Data on the population distribution and the number of households in the region were gathered by the field team from the respective Anganwadi[3] offices of the studied villages and verified by comparing with the 2011 census data.

Sampling technique and size

A stratified random sampling strategy was employed to select a statistically significant sample from the total number of households, capturing different social categories. Using data on the total number of households (N = 2,338), the sample size was calculated using the following formula:

$$n = (z2 \times N \times p \times (1-p)/(e2 \times N + z2 \times p \times (1-p))$$

n = sample size

N = population

z = critical value of the normal distribution at the required confidence level

p = sample proportion

e = margin of error

For a confidence level of 95 percent and a margin of error of 6 percent, the sample size was calculated to be 240 households. Accounting for a 20 percent nonresponse rate, the estimated sample size was 300 households across the five survey villages, and hence, 326 households were surveyed. The decadal population growth rate of Pavagada was assumed to be the same as between 2001–11 (–0.43 percent) (CGWB 2022).

Comparability between solar and non-solar villages was confirmed using a Chi-square test on social category and gender distribution (see Table 1). The null hypothesis stated no difference between the respective distributions for the two groups. With $p > 0.05$ in both tests, we failed to reject the null hypothesis, indicating no significant difference between the distributions of population by social category and gender in the two sampled groups, making them comparable.

Table 1 | **Chi-square test results**

	FOR SOCIAL CATEGORY	FOR GENDER
p value obtained from Chi-square test	0.101	0.069
Significance level	0.05	0.05

Research tools

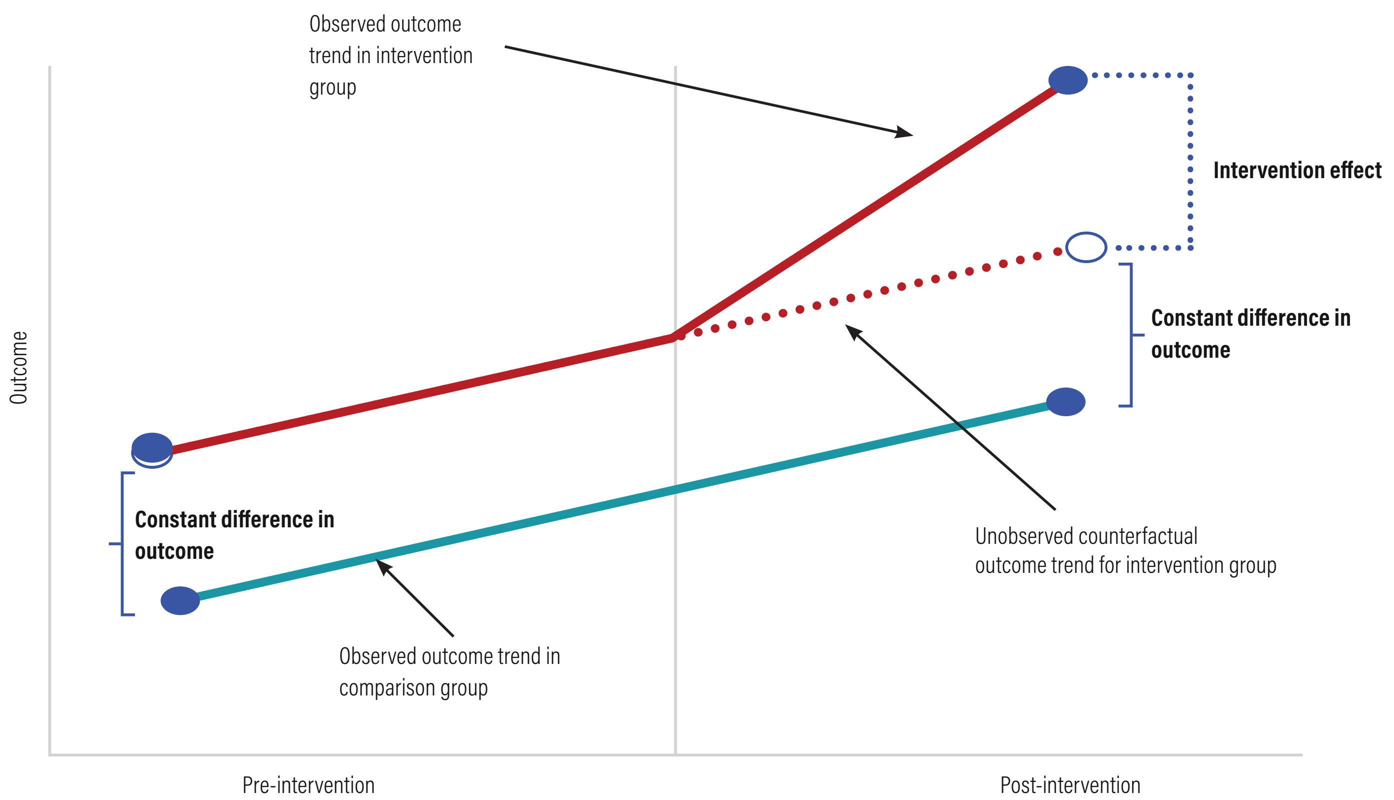
The standardized survey schedule (see Appendix B) included closed-ended questions to gather demographic and household-level data, including land ownership, agricultural practices, livestock farming, labor, and access to basic amenities. Data on social category and gender were gathered for disaggregation. The questionnaire covered two scenarios—before and after the installation of the solar park—to capture observed changes over time. The questionnaires were fed into a mobile application designed by contracted IT partners Dhwani RIS. Pilot surveys tested the questions, mobile application, and familiarized the field team with the application. The questions were translated into Kannada and Telugu and administered accordingly. The questionnaire was updated based on inputs received from the test survey and final surveys were conducted in October and November 2021.

Qualitative FGDs were conducted with subgroups of large and small farmers, landless laborers, pastoralists, and women to understand caste, land, and gender relations in the region. A semi-structured questionnaire guided the FGDs, moderated by Thamate. Eight FGDs were conducted in Volluru and Thirumani, complemented by in-depth interviews with community-level stakeholders. Detailed interviews with representatives from farmers' associations, scheduled castes, women activists, journalists, contractors, and KSPDCL aimed to gather varied perspectives.

Data description

Quantitative analysis of the household survey data was performed using Microsoft Excel. Data from household surveys provided a disaggregated analysis of details pertaining to land, occupation, and labor, based on the social categories of respondents and the village category. Landowners were classified into three groups: landless (no landholding), small farmers (≤ 5 acres) and large farmers (> 5 acres). Gender data for workers were used to analyze the gender dimension of occupation patterns in the villages. A "before-and-after" comparison between the solar and non-solar villages was conducted for applicable categories of information. A simplified difference-in-differences technique was used (Figure 3) to estimate the effect of the solar park by comparing changes in specific outcomes over time between solar and non-solar villages. This technique assumes that without intervention, the "unobserved" differences between the two groups of villages will remain the same over a time period (Columbia Public Health n.d.).

Figure 3 | **Graphical representation of differences-in-differences estimation**



Source: Columbia Public Health n.d.

Observations from the quantitative survey were supplemented by qualitative findings. The deductive method of narrative analysis was used to analyze qualitative data from in-depth interviews and FGDs. Key themes such as distribution of benefits across social groups and caste dynamics in the region emerged from initial consultations with experts and researchers. These were used to identify the story structures for our analysis.

Limitations

Although Kannada is the administrative language, Telugu is the spoken language of most families in the study area. The field team's proficiency in both languages mitigated the risk of translation losses, especially during the qualitative data collection process.

Household listing data were not readily available. The most recent demographic details available from Anganwadi offices were used. Many households were locked due to permanent migration for work, which slightly reduced the statistical population and potentially understating migration effects.

Data for the pre-intervention phase were based on recall, introducing the recall bias risk. This was mitigated by designing survey questions to gather data on nominal variables and parameters that were not subject to major changes over time (e.g., landholding). The difference-in-differences method assumes parallel trends in outcomes between treatment and intervention groups. For longitudinal studies, this is established by capturing observations at many time points. The shorter the period, the greater is the likelihood of the parallel trend assumption holding true. Qualitative information was collected to support this assumption and reduce the scope of bias in the deductions.

This research did not account for local environmental impacts, suggesting that socioeconomic impacts might be larger than the observations owing to their linkages with environmental factors.

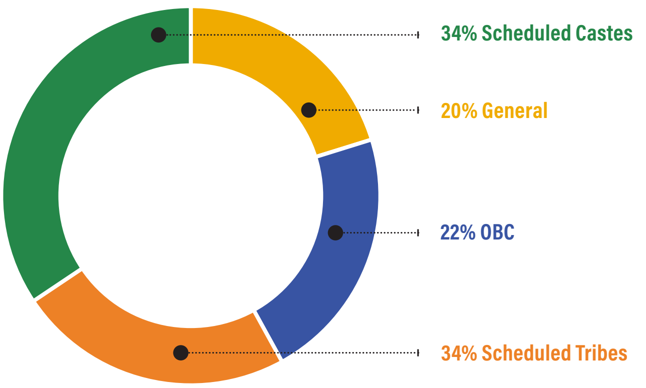
This paper is organized into the following sections: characteristics of the study area, findings, discussion, and conclusions and recommendations. The first section presents data on demography, land ownership, and occupations. The findings section addresses specific components of the research question by breaking down the gathered data. The discussion section, contextualizes the findings within broader study themes. The conclusions and recommendations section encapsulates key takeaways and presents specific and broad suggestions.

CHARACTERISTICS OF THE STUDY AREA: DEMOGRAPHY, LAND OWNERSHIP, AND OCCUPATIONS

Demography

The sampled households represented a mix of four social categories (Figure 4), proportional to the population data from local Anganwadi offices. The surveyed households consisted of 54 percent male and 46 percent female respondents. The median educational attainment of the population was fifth grade, with 30 percent having never attended school and only 7 percent holding a bachelor's degree or higher (see Appendix A for more information). Approximately 70 percent of the working population was engaged in land-based occupations (agriculture/pastoralism), and 21 percent were unemployed.

Figure 4 | **Distribution of population according to social categories**



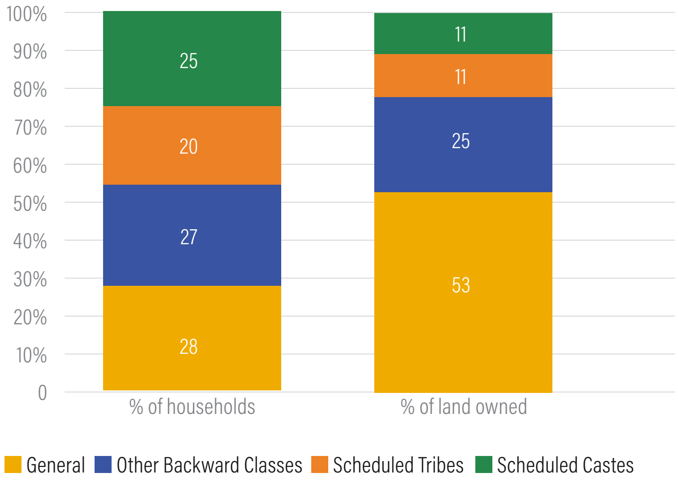
Note: OBC: other backward class.
Source: Authors' analysis.

Land

Over two-thirds of the households in the sample owned land. Of this land, 92 percent is cropland, with few households owning pasture lands for livestock grazing. Pastoral lands are commonly shared resources in the village. Approximately 90 percent of households had acquired land through inheritance, with a few cases of Shivasaguvali-bhoomi or Bagar-Hukum[4] land.

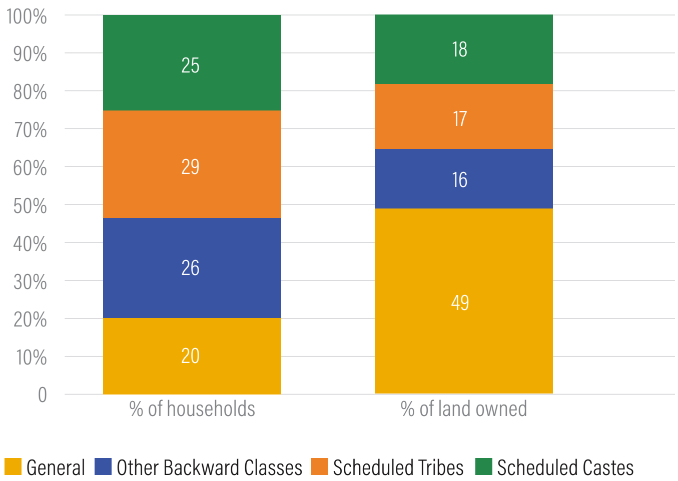
The average and median landholdings per household were 7 and 4 acres, respectively. There was a disparity in landholding, with general category households comprising 25 percent of the sample owning approximately half of the total land. Figures 5 and 6 show this distribution in solar and non-solar villages, respectively. Approximately 50 percent of SC households and 30 of scheduled tribe (ST) households did not own any land. Similar landholding patterns across social categories are evident in both village groups (Figure 7).

Figure 5 | **Proportions of households according to social category and their respective land holdings in solar villages**



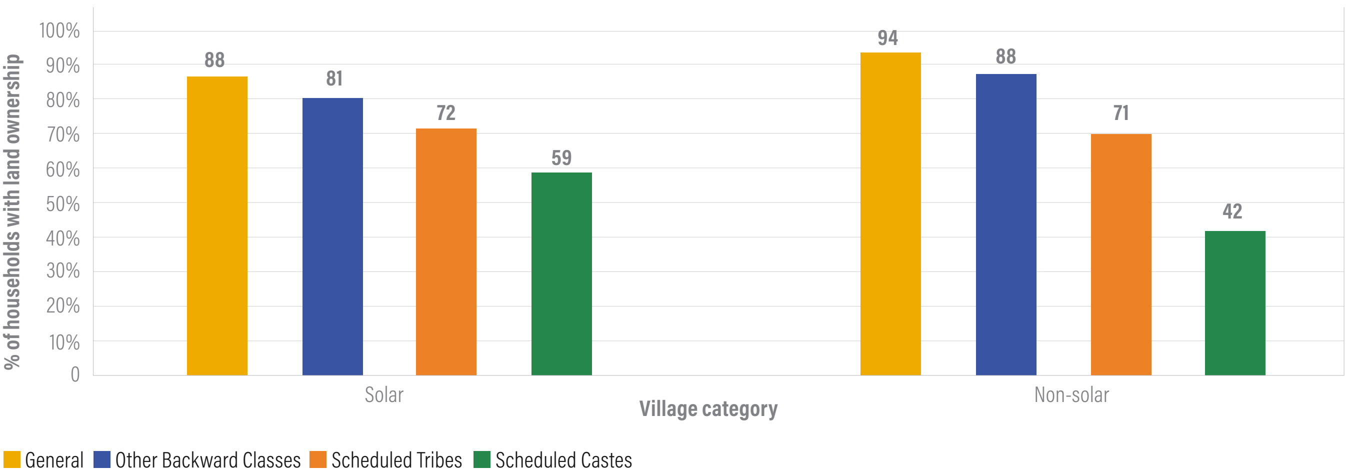
Source: Authors' analysis.

Figure 6 | **Proportions of households according to social category and their respective land holdings in non-solar villages**



Source: Authors' analysis.

Figure 7 | **Comparison of the proportions of households according to social category and their respective land holdings in solar and non-solar villages**



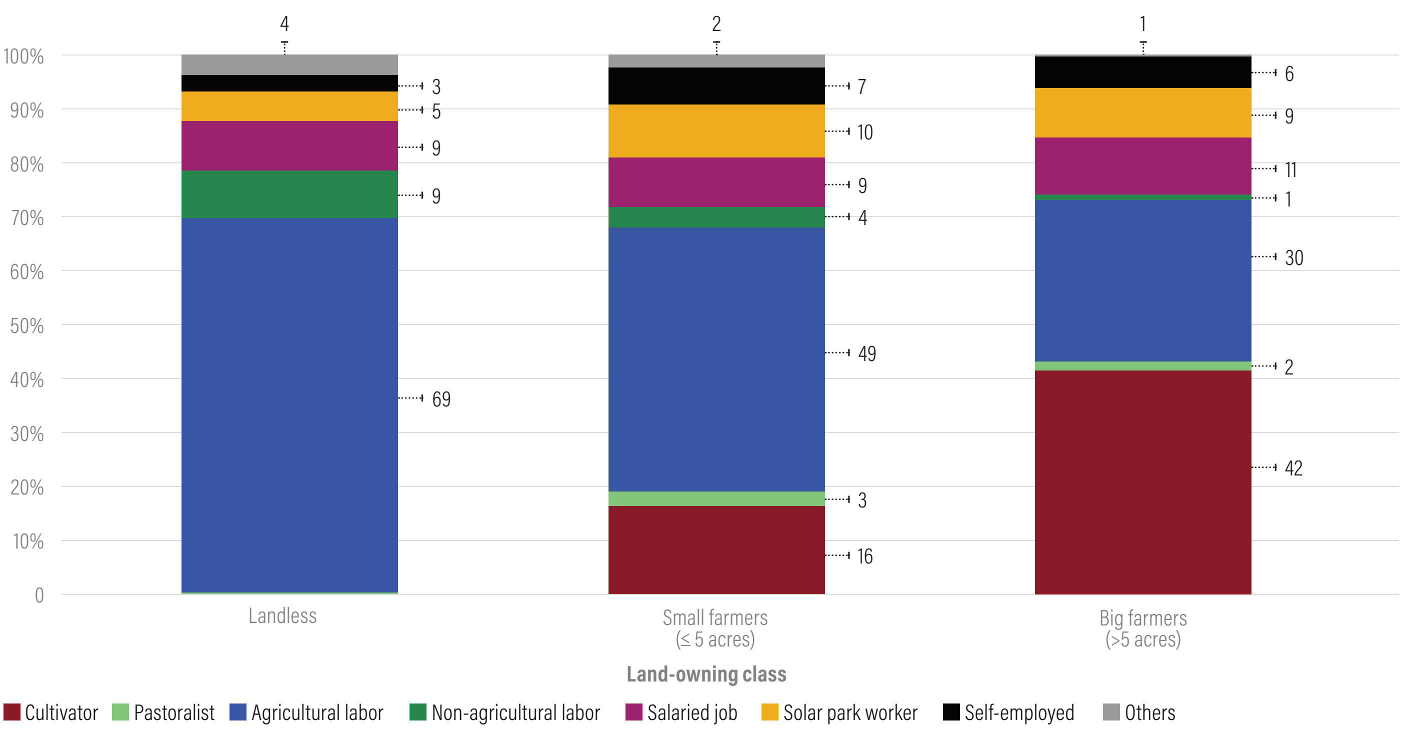
Source: Authors' analysis.

Occupations

Approximately 70 percent of the sampled population was engaged in agricultural labor and cultivation. Pastoralism was the other major land-based occupation. Landless workers and small landowners primarily engaged in agricultural labor. Workers from families with landholdings greater than 5 acres were mainly cultivators.[2] (Figure 8)

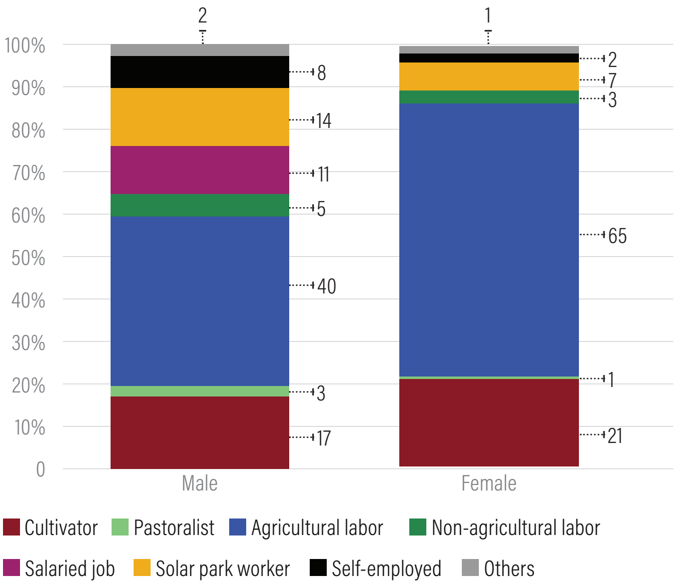
Agricultural labor was the primary occupation of 65 percent of the female working population. The livelihood options were more diverse for male workers (Figure 9).

Figure 8 | **Comparison of occupations of the population according to land ownership**



Source: Authors' analysis.

Figure 9 | **Comparison of occupations according to gender**



Source: Authors' analysis.

Despite declining productivity in the last few decades, the prominence of agriculture-related livelihoods indicates the lack of alternatives for local employment. Among the social categories, the SC community had the greatest share of agricultural laborers, with 66 percent of SC workers engaged in agricultural labor in the solar villages as opposed to 27 percent of the general category workers (Figure 10). The significance of agricultural labor as a source of livelihood for workers makes them more vulnerable to a change in land use.

Labor

The survey gathered information on labor, including the purpose of employment, nature of work, and place of work. Respondents were involved in activities, such as agricultural labor, tending to animals, operating agricultural machinery, domestic work, and nonagricultural labor. Agricultural laborers were employed for four months per year. Although agriculture is the primary occupation for most of the year, seasonal migration was common during non-cultivation seasons, with destinations including towns, such as Pavagada, Hindupur, and Ramagiri, and cities, such as Tumakuru and Bengaluru.

FINDINGS

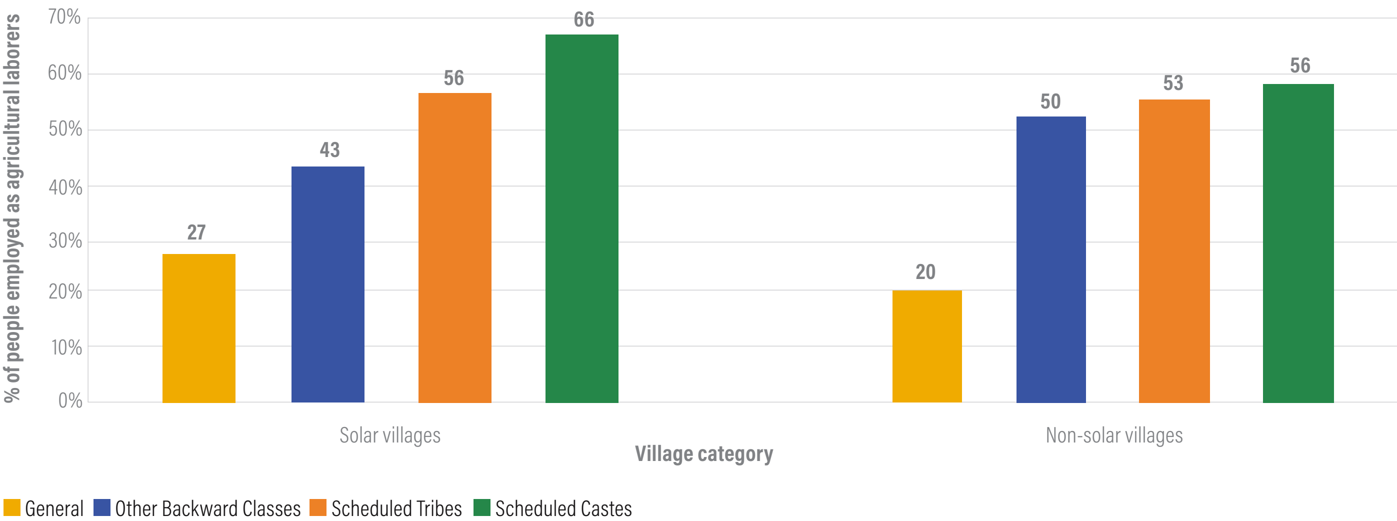
Differential impacts

Has the solar park created new jobs? If so, who is benefiting from these jobs?

The solar park has created new jobs, employing 8 percent of the total working population (60 out of 711).

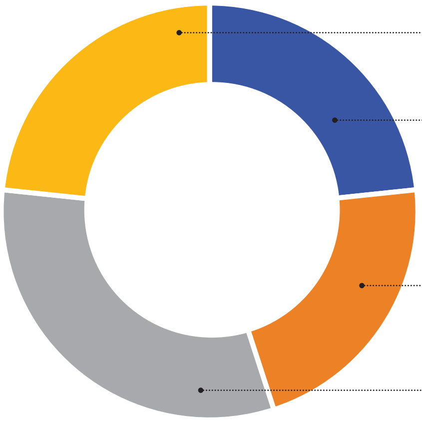
One in five working men in the solar villages was employed at the solar park. More than 60 percent of these work as security guards. The social category distribution of solar park workers was fairly even (Figure 11).

Figure 10 | **Comparison of proportions of agricultural labor according to social categories between the solar and non-solar villages**



Source: Authors' analysis.

Figure 11 | **Comparison of solar park workers according to social categories**



Source: Authors' analysis.

Table 2 | **Comparison of solar park workers according to social categories**

CASTE CATEGORY	PROPORTION OF WORKERS EMPLOYED AT THE SOLAR PARK
General	11%
OBC	9%
ST	10%
SC	6%

Source: Authors' analysis.
Note: OBC: other backward class; ST: scheduled tribe; SC: scheduled caste.

Table 2 shows that the SC community had the least representation in terms of employment at the solar park.

According to an agreement by the Government of Karnataka during the project's conception, "at least one employment per family" was to be provided to land-leasing households by KSPDCL (Government of Karnataka 2015). Mr. K shared[5] in an in-depth interview that land-leasing families were demanding preference for solar park employment to honor this agreement. In an FGD, landless laborers stated that they were not getting opportunities as they had not leased any land to the park. This study found that **82 percent of the solar park workers in our sample population belonged to landholding families.**

No woman in the sample population was employed at the solar park. Ms. M, an Anganwadi worker, shared that women were told that "there is no work for them at the solar park." From an FGD with women in Volluru, it emerged that a couple of women from the village were employed for "cement work" during the construction stage but none since the park's commissioning. Private SPDs were not keen to take up "additional" responsibilities to ensure the safety of female laborers at the solar park (Jain 2020). In the same interview, Ms. M claimed that women would willingly line up to work as soon as they had opportunities at the solar park.

What kinds of jobs has the solar park created?

The solar park employs a range of workers, including engineers, supervisors, managers, technicians, security guards, grass cutters, module/panel cleaners, and drivers. Mr. R, a KSPDCL official, shared that qualified locals are always given preference during hiring for skilled jobs. For operations and maintenance work, private SPDs generally appointed workers through contractors. Owing to the low levels of educational attainment in the surveyed villages, most locals were not eligible for skilled jobs. Mr. A, who joined an SPD as a technician after completing his education at an Industrial Training Institute, mentioned that applicants had to wait for several months and needed a recommendation from an "influential" individual. Mr. K from Rayacherlu informed us that though a "Suryamitra" training program was conducted, no jobs were given thereafter. Other job options included security guard positions and unskilled labor.

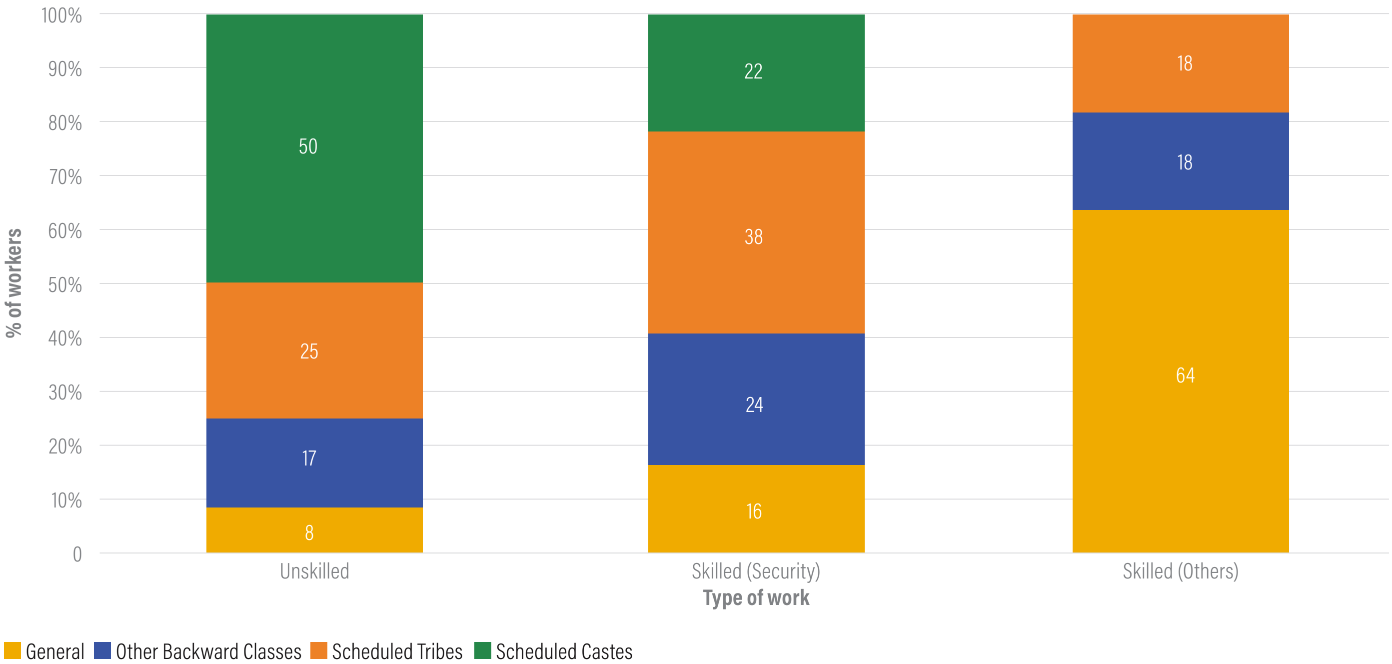
All solar park workers in the sample were contractual workers. This study found that **72 percent of the solar park workers were engaged in skilled work, with over 85 percent of them employed as security guards.** Unskilled laborers (28 percent) were engaged in grass cutting, module/panel cleaning, and driving.

Disaggregation of solar jobs

Figure 12 shows the social category distribution of the workers engaged in each type of work. Unskilled work includes grass cutting and panel cleaning. Skilled workers include technicians, supervisors, and contractors. This study found that **50 percent of unskilled workers belonged to the SC community whereas 64 percent of the most skilled workers belonged to the general category.**

This study found that 82 percent of the solar park workers belonged to landowning families. The average landholding and average education of unskilled laborers was the lowest (see Table 3). Nineteen percent of general category adults had studied up to 12th grade or higher compared to 8 percent of SC adults. The underlying linkages between these aspects (low wealth and asset ownership and low educational attainment) highlight reduced opportunities for the socioeconomically underprivileged classes.

Figure 12 | **Comparison of type of work according to social categories**



Source: Authors' analysis.

Table 3 | **Comparisons between type of work, land holding, and education**

TYPE OF WORK (SOLAR PARK)	AVERAGE LANDHOLDING (ACRES)	AVERAGE EDUCATION (GRADE)
Unskilled	2.40	8
Skilled (Security)	4.91	11
Skilled (Others)	12.00	12

Source: Authors' analysis.

Has the solar park created better livelihoods and decent work?

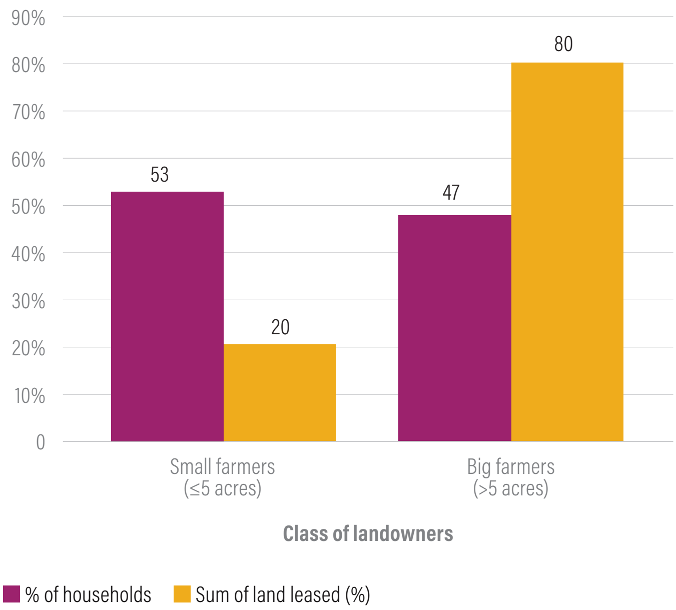
At least 32 percent of solar park workers were agricultural laborers before the installation of the solar park. Overall, 86 percent of the total workers were daily wage workers before the commissioning of the solar park, which has now fallen to 63 percent, with a corresponding increase in the number of salaried workers. The creation of salaried jobs in solar parks has partly contributed to this increase. **A group of solar park workers in Volluru shared that the solar park had improved their situation.** Working as security guards offered them a sense of job security and a stable income in their own village (approximately INR 12,000 per month). This has reduced uncertainty of agricultural labor availability and income.

While a KSPDCL security employee[6] expressed satisfaction with the formal contract and timely payments, workers at the solar powerplants (i.e., a part of the solar park being developed by private developers) had contrary experiences. They were hired via informal contracts and lacked agency to demand better working conditions or wages. Some grass-cutting workers expressed concerns about the lack of safety equipment suitable for work under low-light conditions. Wages were fixed by contractors, with no regulations for formal grievance redressal mechanisms. Delayed payments and irregular work availability added to the plight of contractual workers.

Livelihoods and landholding: perpetuation of land-based inequities

Small farmers represent over 50 percent of the families in the solar villages but contribute only 20 percent of the land used by the solar park (Figure 13). The annual compensation of INR 22,000–23,000 per acre was the main benefit for land-leasing farmers. The plot represents the distribution of benefits between the two landowning classes, with the mechanism benefiting those who own more land. The smallest landowners (owning ≤ 2.5 acres) constituted 21 percent of the sample and contributed 5 percent of the total land leased to the solar park. At the other extreme, the largest landowners (owning > 10 acres) constituted approximately 24 percent of the sample but contributed 58 percent of the land leased to the solar park.

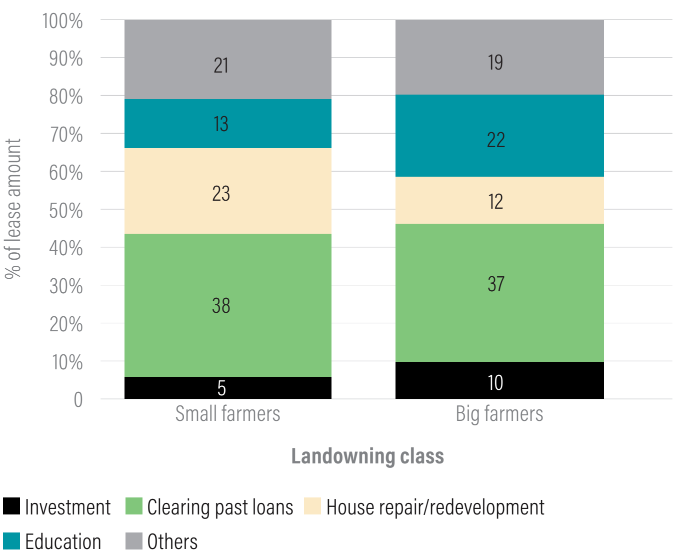
Figure 13 | **Comparison of land leased to the solar park by small and large farmers**



Source: Authors' analysis.

The lease amount was mostly used to clear past loans, fund children's education, and cover household expenses. Figure 14 provides an overview of how members of both landowning classes spent the lease money. Major expenses were similar to both classes, highlighting the general economic conditions of farmers in the region. The main expenses in both cases were clearing loans and 'other expenses' (domestic expenses) and, in some cases, marriages.

Figure 14 | **Comparison of spending of lease amount received from the solar park by small and large farmers**



Source: Authors' analysis.

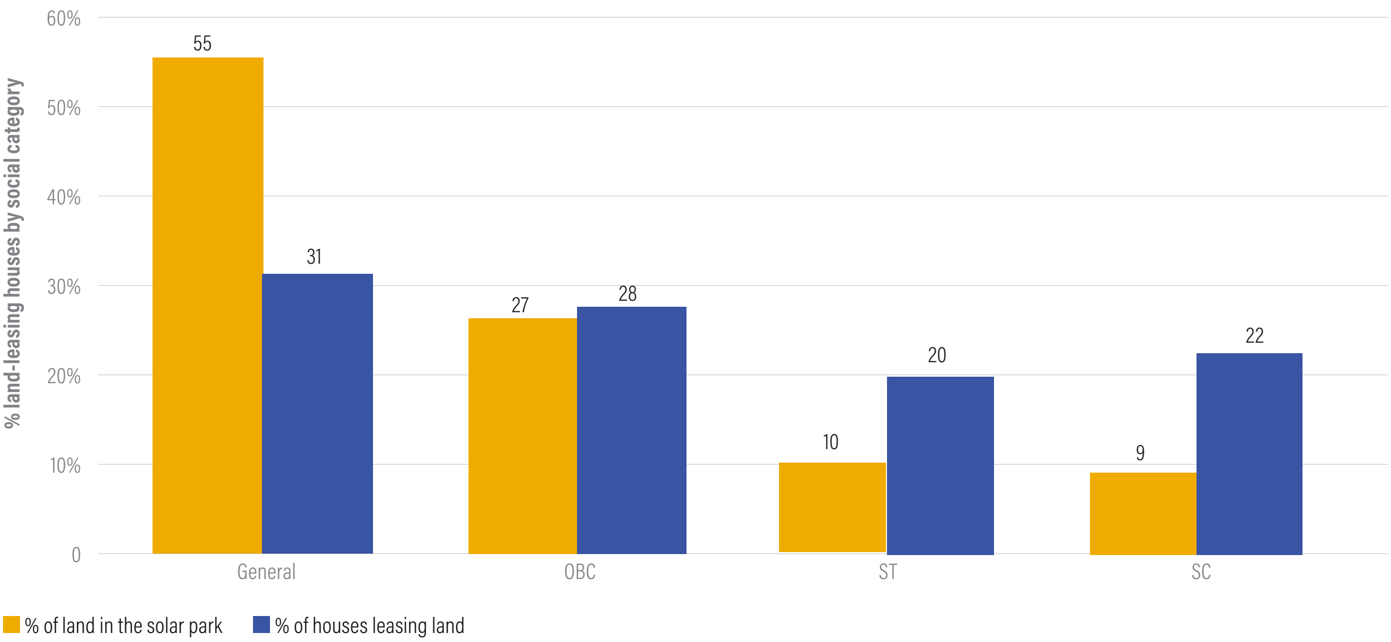
Large farmers spent more on children's education and investments, while small farmers spent more on house repairs. Thirty-nine houses were constructed/repaired after 2015 (in our sample) using money from the lease arrangement. The biggest landowners (with > 10 acres) spent the highest share (14 percent) of their lease income on investments.

The large landowners primarily focused on cultivation, whereas small landowners relied more on agricultural labor (Figure 8). Before the solar park installation, small landowners cultivated their land for subsistence and worked as agricultural laborers on others' lands to supplement their income. Although the lease income from the solar park offered some financial certainty, it was insufficient for small farmers to sustain their livelihoods. Previously, they met their domestic consumption needs from their own cultivation and used their earnings from agricultural labor for other expenses. Now, they must rely on the market for all essentials, making them more vulnerable to price changes. Consequently, they have had to seek alternative income opportunities outside their villages.

Large farmers reported that the solar park has improved their financial situation compared to previous years, when cultivation was not profitable. However, they argued that the lease amount be increased, as a mere INR 1,000 increment (per acre) over two years did not keep pace with the rise in living costs. Initially, land-leasing families were verbally promised jobs at the solar park, but they either did not receive these jobs or were only offered unskilled labor positions despite their qualifications. Large farmers also compete among themselves for operation and maintenance contracts handed out by SPDs. Mr. KR, a large farmer, noted that vendors from other states were often awarded these contracts instead of local vendors.

More than 50 percent of the land leased to the solar park came from general category households (Figure 15), who not only benefited from monetary compensation but also played a crucial role in negotiations due to their social standing. They led local farmers' associations and represented other farmers during consultations, while landless laborers were not adequately represented. Over half of the large farmers belonged to the socioeconomically well-off members of the general category
Contractors hired laborers for the solar park at their discretion, further entrenching the existing social hierarchy.

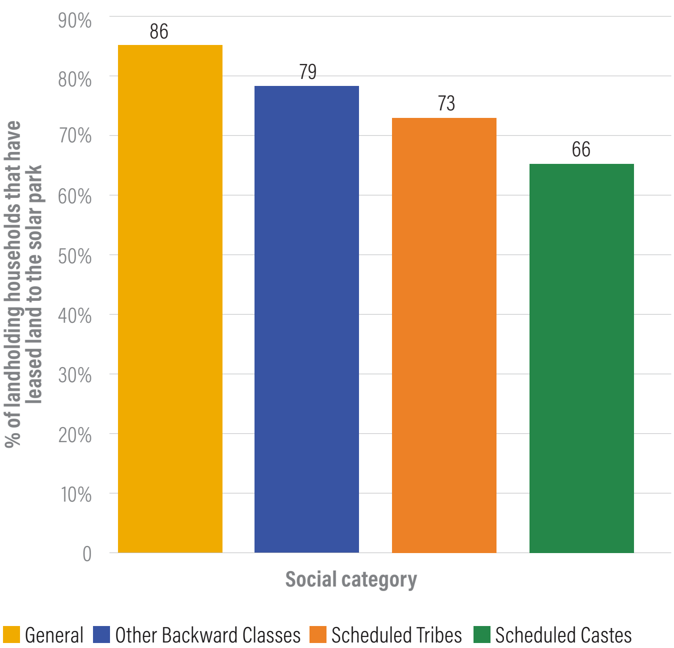
Figure 15 | **Comparison of land leased to the solar park and households leasing land to the solar park according to social categories**



Note: OBC: other backward class; ST: scheduled tribe; SC: scheduled caste.
Source: Authors' analysis.

According to Mr. H, a local civil society leader, land belonging to the SC community was often fragmented and disconnected, making it unsuitable for the solar park, which required continuous stretches of land, thus preserving existing class distinctions. Figure 16 shows that only 66 percent of landholding SC households leased their land to the solar park.

Figure 16 | **Comparison of households leasing land according to social categories**



Changing vulnerabilities of livelihoods

How has the solar park impacted the traditional occupations of the local people? Approximately 70 percent of the working population in the surveyed villages engaged in land-based livelihoods, including cultivation, agricultural labor, and livestock farming. Approximately 80 percent of the land in the project villages is agricultural rainfed cropland (Knight Frank India 2016). The development of the solar park had direct effects on communities that were dependent on agriculture and related activities.

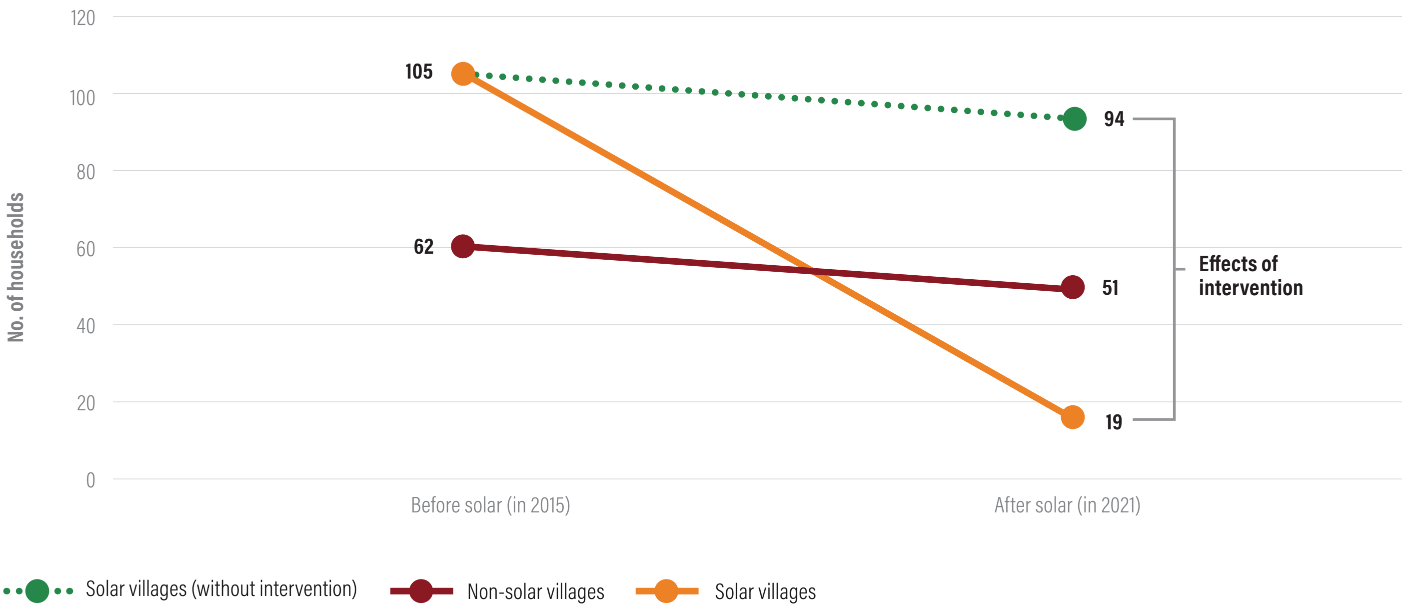
AGRICULTURE

Land previously used for cultivation was leased for the development of the solar park. Since 2015, cultivated land in solar villages has decreased by 65 percent. Approximately 24 percent of the households did not lease their lands to the park for reasons such as unevenness of land or lack of contiguity with other plots.

Agriculture in Tumakuru is highly vulnerable to climate change (Rama Rao et al. 2022), and persistent drought-like conditions have affected productivity in recent decades, causing workers to seek reliable livelihood options in nearby towns or cities. A comparison with non-solar villages, showed that the number of households engaged in cultivation in solar park villages decreased by 81.9 percent, whereas non-solar villages experienced a 17.7 percent reduction. This suggests that the solar park installation caused a reduction seven times higher than that projected for villages without installation (Figure 17). Figure 18 shows the corresponding reduction in land under cultivation.

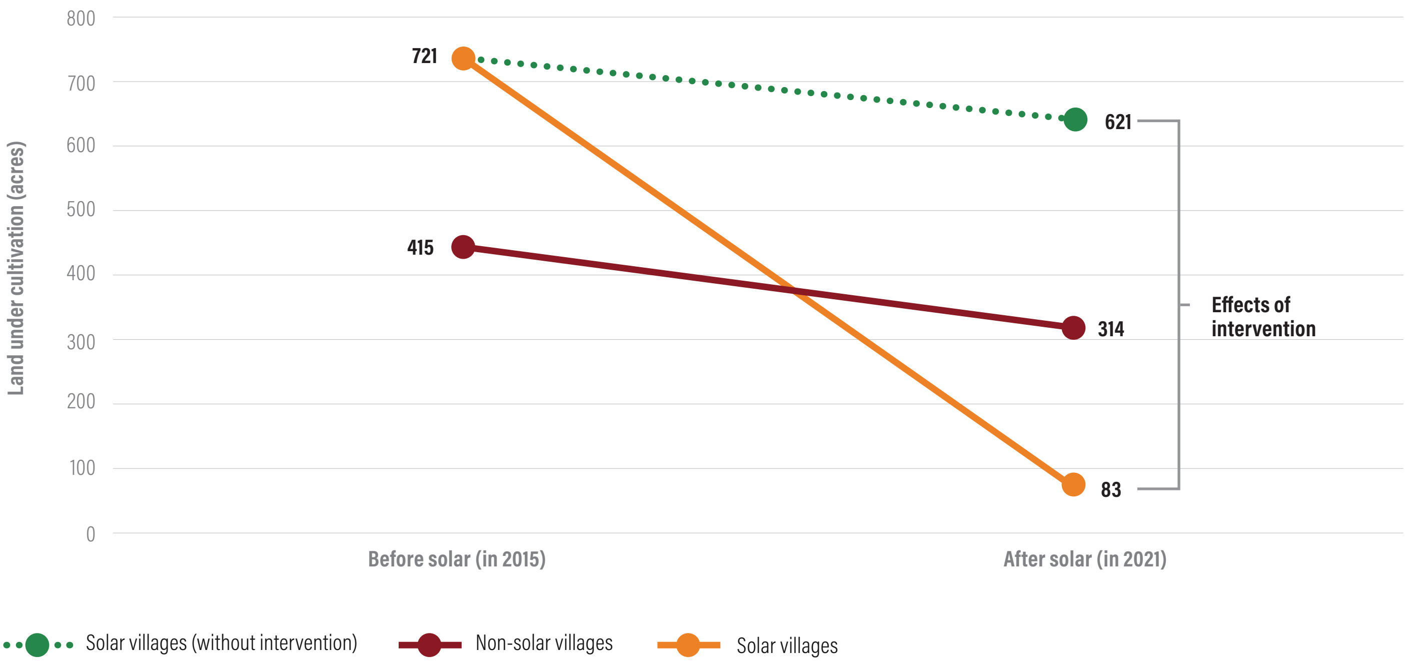
Table 4 shows the corresponding changes in cultivated land and agricultural employment. Approximately 20 percent of former agricultural workers in solar villages were unemployed, with most working on land cultivated in their own or nearby villages, adding pressure on the declining area of cultivated land.

Figure 17 | **Comparison of households practicing cultivation before and after the installation of the solar park**



Source: Authors' analysis.

Figure 18 | **Comparison of land under cultivation before and after the installation of the solar park**



Source: Authors' analysis.

PASTORALISM

Livestock farming is common in Karnataka, with Pavagada having one of the highest livestock populations in Tumakuru District (Government of Karnataka 2015). The loss of grazing land has created new challenges for pastoralists. In non-solar villages, there was only a reduction of 8 percent in pastoralists, whereas it was approximately 60 percent in solar villages, six times higher than that projected for villages without the solar park (see Figure 19 for absolute figures). In our sample, among the pastoralists who had stopped rearing livestock, 39 percent were unemployed, while 44 percent had transitioned to agricultural labor. The average age of those continuing pastoralism is 57.5 years, compared to 45 years for those who quit, as older pastoralists found traveling for wage labor was unfeasible given their physical conditions.

Table 4 | **Changes in cultivators and persons employed by them before and after the installation of the solar park**

	OBSERVED REDUCTION SINCE THE SOLAR PARK INSTALLATION (2015–21) (%)	
Variable	Solar villages	Non-solar villages
Number of cultivating households	81.9	17.7
Land under cultivation	88	24
Workers employed by cultivators	82	12

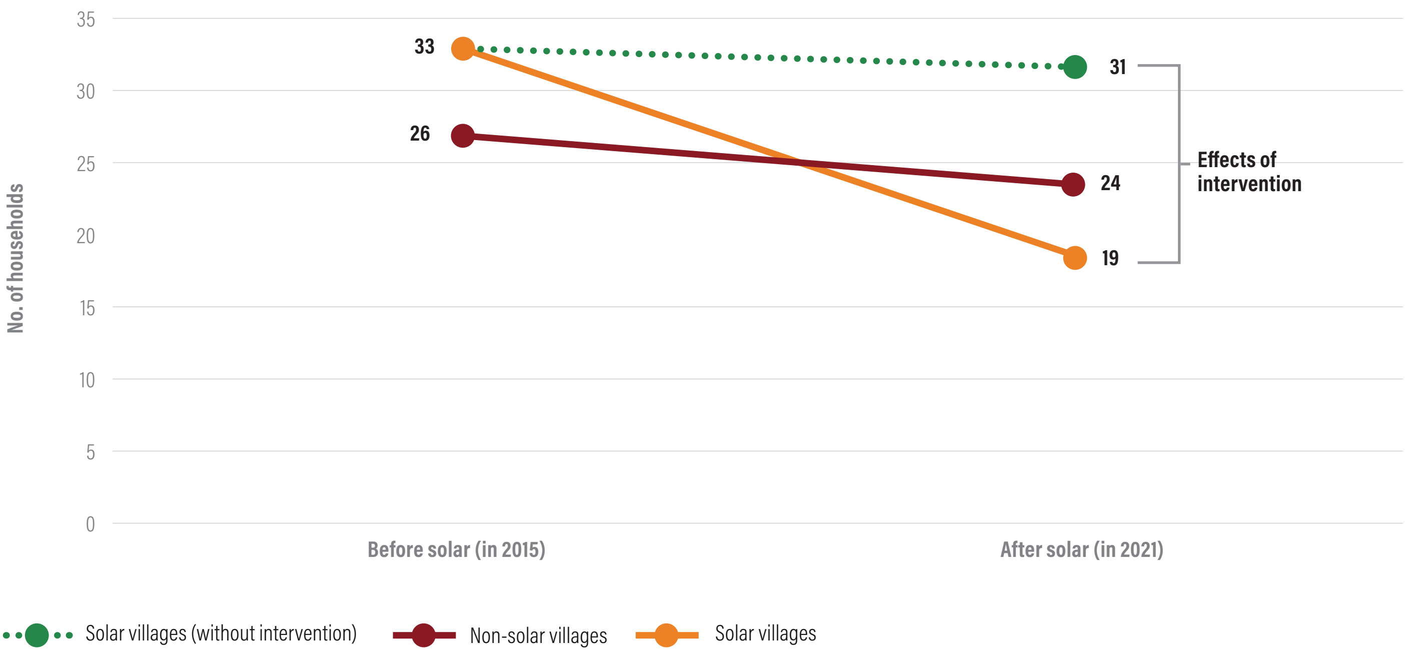
Source: Authors' analysis.

Labor and migration

The study found that 21 percent of the labor force in the surveyed villages is unemployed, with a higher unemployment rate among women (33 percent) compared to men (11 percent). In solar villages, these figures are slightly lower at 28 percent for women and 10 percent for men. There has been a reduction of 69 percent and 45 percent in male and female agricultural workers, respectively, following the establishment of the solar park. Two factors likely contributed to this disparity. First, women in the village had fewer livelihood options, with more than 85 percent engaged in agricultural labor or cultivation. Additionally, several women could not migrate to distant locations for work due to domestic care-taking responsibilities, as highlighted in FGDs. Ms. M noted that women have organized themselves through sessions with Stree Shakti Sanghas, fostering solidarity among working-class women and leading to demands for decent working hours and conditions.

The average number of months of employment increased from six to seven months per year in the solar villages. Security guard positions offered year-round employment, which was not the case when relying on agricultural or nonagricultural labor activities.

Figure 19 | **Comparison of households practicing livestock farming before and after the installation of the solar park**



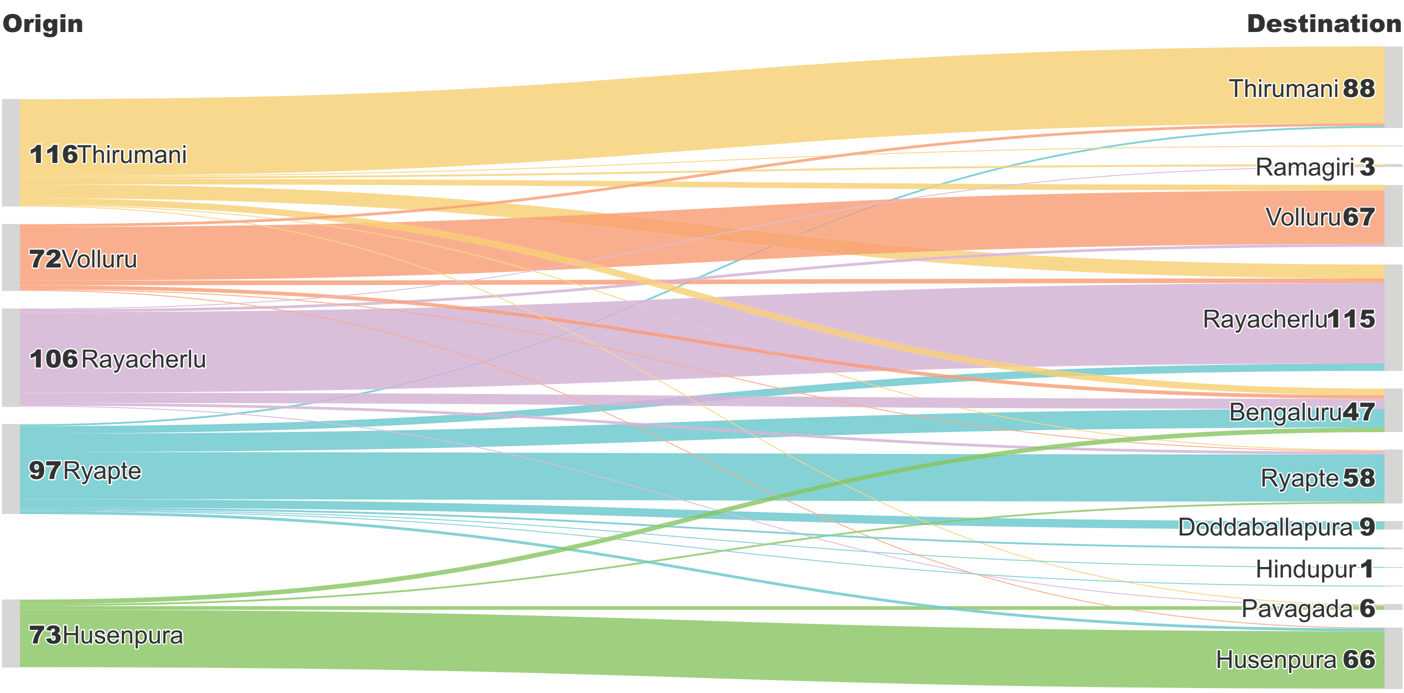
Source: Authors' analysis.

However, there was an 11 percent reduction in the overall working population during this period, indicating a further exacerbation of existing inequities owing to the solar park.

During nonagricultural months, workers would travel to neighboring towns or cities in search of work. Mr. G, a community worker in Pavagada, shared that seasonal migration for construction, painting, and other jobs was common. The general lack of economic activity in the villages and declining agricultural productivity have led to an increase in permanent migration, particularly among landless families. The limited employment opportunities in the solar villages have nudged more families toward migration in search of better subsistence alternatives.

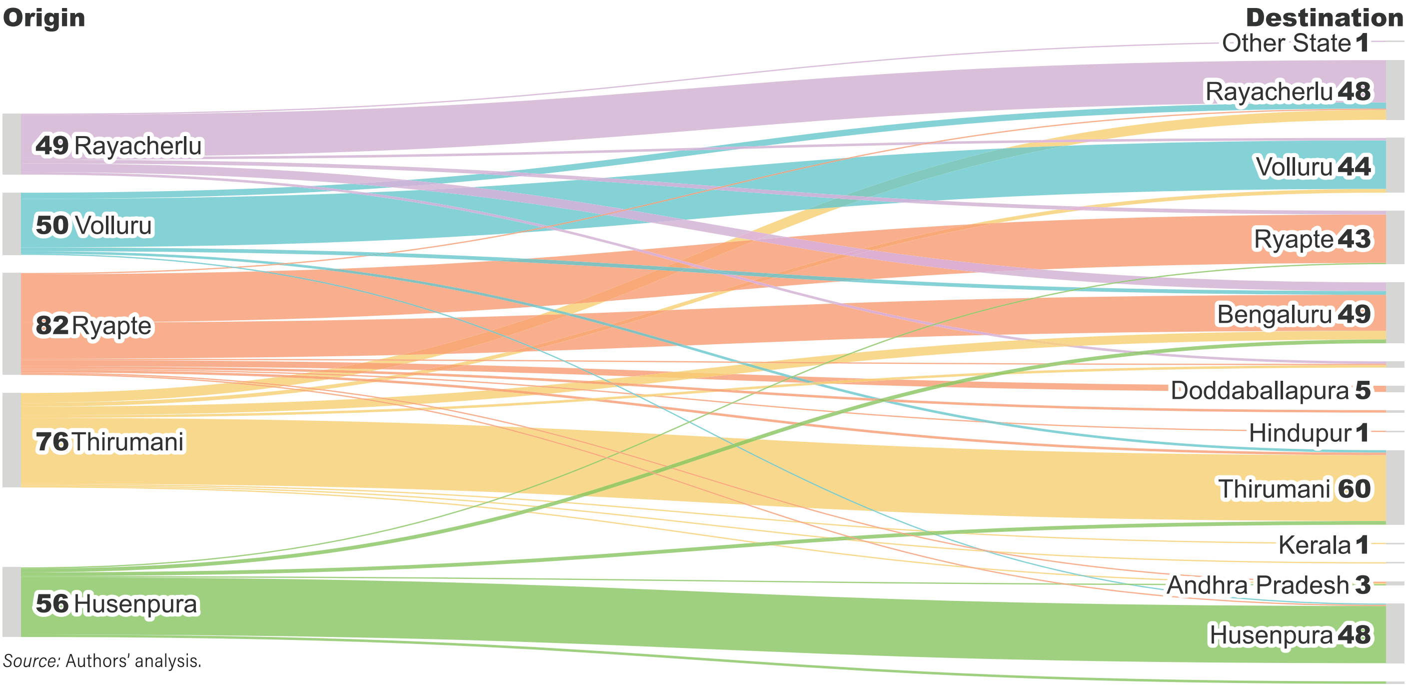
Figures 20 and 21 depict the movement between the surveyed villages and from the surveyed villages to other locations. In 2015, at least 15 percent of workers were employed outside the five surveyed villages. This number has since increased to 20 percent of the working population. Families that permanently relocated could not be included in the survey, implying that this figure is conservative and potentially not capturing the full extent of the migration. Several houses in each village were found to be locked. An interview with a person whose family had moved away permanently to Bengaluru revealed several factors influencing their decision. Landless families and those from the SC community were the most vulnerable due to their limited resources (little or no land or other assets) and social mobility within the village. Without means to sustain a living locally, migration was their only alternative for reliable income sources. These families were also impacted by the lack of access to informal credit streams from landowners for whom they worked several months each year. The breakdown of such relationships within the community and their connection to the land could have lasting effects, including loss of livelihood, changes in community dynamics, erosion of traditional practices and knowledge systems, and increased social conflicts.

Figure 20 | **Place of work before the installation of the solar park**



Source: Authors' analysis.

Figure 21 | **Place of work after the installation of the solar park**



Source: Authors' analysis.

Resource access

Access to land, water, and electricity

Access to grazing land is a crucial for pastoralists. The lack of available grazing land in the village has forced livestock farmers to seek alternatives, often traveling over 40 km with their livestock to neighboring villages, where they can stay for weeks or months. In these situations, pastoralists must compete and negotiate with the farmers for access to common grazing land. Mr. R stated that those who found this unfeasible would pay others to take care of their livestock. Some households could not afford this and were forced to sell their livestock. Those who continued rearing livestock faced challenges in accessing pastures and water, affecting livestock health and their income. This scarcity of land resources threatens the traditional livelihoods of local pastoralists.

This study also gathered data on households, access to water, finding no significant change in water supply after the installation of the solar park. Pavagada is considered to be in a "semi-critical" state in terms of groundwater resources (CGWB 2021, 2022). Solar power plants require approximately 75 L of water per MWh of power generation for cleaning, with approximately 60 percent sourced from groundwater borewells (Rustagi 2018; Verma 2019). Despite the large-scale installation of solar panels in a water-scarce zone, 96 percent of surveyed households reported no change in water supply since the installation of the solar park. During the first phase of the solar park (600 MW), developers dug the borewells to meet the water requirements for cleaning. The second phase followed the MNRE guidelines to adopt robotic cleaning technologies, reducing water demand (MNRE 2019c). A KSPDCL official stated that this method mitigated the potential strain on water resources in the region (Interview with KSPDCL Official, 2021).

While all surveyed households had electricity connections, they experienced regular power cuts, especially during monsoons. Mr. V, a social worker in Pavagada, highlighted the irony that Pavagada lacked a reliable electricity supply despite generating power for other parts of the state. Approximately 95percent of households reported no change in the quality of electricity supply since the installation of the solar park.

Local area development

Local community discussions emphasized the need for local infrastructure development. The solar park gained social approval partly due to anticipated funds for the improvement of local amenities. A Local Area Development Fund collected INR 1 billion from private SPDs over five years for village infrastructure projects, including the construction of roads, schools, hospitals, and drainage systems. As of 2022, funds have been released for several projects according to public records (Tables 5 and 6).

Table 5 | **Work in progress based on the Local Area Development Fund**

PURPOSE (WORK IN PROGRESS)	AMOUNT ALLOCATED (MILLION INR)
RO plants	6
Reviving purification plants in schools	5.4
Construction of school toilets	4
Pavagada General Hospital	13.6
Afforestation	14.7

Note: RO: Reverse Osmosis
Source: Authors' analysis.

Table 6 | **Proposed works based on the Local Area Development Fund**

PURPOSE (WORK IN PROGRESS)	AMOUNT ALLOCATED (MILLION INR)
Construction of school buildings	132
Construction of roads	275.6
Other improvements	73.2

Source: Authors' analysis.

DISCUSSION

Differentiated impacts

Land is the primary source of income in agrarian societies. The solar park's reliance on land poses the risk of exacerbating existing land distribution inequities. The caste system, with dominant castes holding more land and the other castes depending on them (Kumar 2020), positions the SC community at a historical disadvantage. Landless families and women are similarly vulnerable because of their reliance on agricultural labor. Larger land holders, who had greater visibility in negotiations, benefited more from the solar park, relative to the marginalized sections, including SC workers and the landless.

Women disproportionately exited the workforce (Jain 2020) due to limited migration options owing to domestic responsibilities. Socially restricted gender roles in Pavagada meant that women are often excluded from public meetings, and even elected women representatives often had their male partners attend meetings or make decisions on their behalf. Preexisting social structures have traditionally deprived women of fair participation in socioeconomic processes and informed decision-making. This persisted with the solar park, as evidenced by the absence of female workers and their lack of alternative employment options.

It is important to note that the solar park itself has not perpetuated these issues. Underlying societal conditions play a significant role. Underprivileged social groups need guided access to training and vocational education to prepare for solar park jobs and alternative employment forms. Providing marginalized sections, such as women, SC, and the landless, with such means is the first step toward challenging and undermining the social hierarchies that have held them back. Scaling up renewables has the potential to improve the livelihoods of everyone, but this will require deliberate interventions.

Changing vulnerability of livelihoods

The existing vulnerability of socioeconomically underprivileged communities has been compounded by changes in land use, leaving them without alternative sources of livelihood. The study shows that the communities benefiting the least from the solar park are the SC and landless households that are already socioeconomically marginalized. Their livelihoods were already precarious due to their dependence on rainfed agriculture in the semiarid region of Pavagada. They were ill-prepared for the shift in land use brought about by the solar park, lacking the skills or means to undertake nonagricultural activities or find alternative livelihood options. Many workers from these communities (SC and landless) have migrated away from the villages in search of unskilled labor opportunities (Interview with Gangaraju 2021).

Women who largely relied on agricultural labor and had limited or no land titles, faced further constraints in income-generating opportunities when agricultural activities were reduced. Sociocultural norms limited their options, preventing them from traveling to other locations for work due to domestic responsibilities. They are also not considered for work at the solar park because employers do not want the "added" responsibility of safeguarding women in male-dominated workspaces (Jain 2020). This perpetuation of vulnerability is rooted in inequalities in power relationships.

In Pavagada, caste and gender continue to influence participation in decision-making and availability of opportunities. Landlessness adds to vulnerability, and landless women from disadvantaged castes are at the most vulnerable intersection. To ensure that they benefit fairly from interventions, such as the solar park, their vulnerabilities must be recognized, and they should be represented and included in decision-making. Projects of this scale present an opportunity to address the structural causes of these inequalities.

Renewable energy jobs and decent work

The potential of solar power to generate jobs is well recognized. Approximately 20 percent of the male working population in the solar villages work in some capacity at the Pavagada Solar Park. These jobs have provided livelihood security to the workers. According to security guards at the park, the fixed monthly wage from the solar park brought a sense of 'nemmadi' (Kannada: peace of mind), making work at the solar park worthwhile. More than the number of jobs created, the improvement in well-being and quality of life accentuates its significance.

While the security personnel at KSPDCL were directly paid by the state enterprise on time with decent working conditions, some workers at private solar blocks were employed through contractors, had longer working hours, and received delayed payments. Workers at private solar blocks wanted direct employment by either the state or SPD to ensure better accountability.

Decent work emphasizes the generation of quality jobs that are meaningful and sustainable and provide fair wages and social protection. Employment of unskilled workers on informal contracts for tasks, such as grass cutting or panel washing, implied no job security or agency to demand better working conditions or wages. These workers were paid daily or weekly wages based on work availability. Women are not employed at the solar park. Hiring based on the amount of land leased and recommendations of influential villagers created additional barriers for marginalized communities.

The potential of solar power to generate jobs must evolve to create quality jobs. This requires collaboration among multiple stakeholders: workers (considering their skills and needs), SPDs (considering quality and quantity of skills needed), and the government (to improve enforcement of decent work programs and labor laws).

The co-utilization of land is an interesting alternative that can retain local land-based livelihoods while generating solar power. Co-utilization refers to the dual land use for cultivation ("agrivoltaics") or grazing ("solar grazing") along with solar power generation. This arrangement, tried in several European countries and gaining popularity in India, benefits cultivators, pastoralists, farm-based workers, and SPDs (NSEFI 2021; Solar Energy Technologies Office, DOE 2022; Trommsdorff et al. 2021). This optimization of land use promotes diversified and stable livelihoods for local communities.

Comparison with control villages

A comparison of solar and non-solar (control) villages helped identify the solar park's impact over the years. Surveyed landholding farmers in non-solar villages were keen to lease their land to a solar plant, as agricultural income was uncertain compared to the secure income from land leasing. Landless laborers hoped to benefit from jobs at such solar plants. Non-solar villagers viewed the solar park as an opportunity for a better life. In solar villages, the general perception was that the solar park has benefits, but these benefits have not been distributed evenly, and anticipated developments arising from the allocation of the Local Area Development Fund have not materialized. The comparison highlights the disparity in perceptions and aspirations between solar and non-solar villages.

Enabling a fair and green transition

The clean energy transition involves shifting from sources, such as coal and gas, toward "greener" alternatives, such as renewable power. Utility-scale installations, such as the Pavagada Solar Park, are central to India's energy transition. A just transition must consider the people affected by these renewable power installations. Deep-rooted local social contexts and characteristics, including caste/tribe and gender, are intrinsic to conceptualizing a just transition at these sites.

Evidence from the Pavagada Solar Park shows how the inequitable distribution of risks and benefits between different classes of landowners and the landless and between social categories and across genders, reinforces existing inequities. The lack of targeted measures to address the diverse needs based on social differentiation led to an accumulation of benefits with landholding classes and dominant caste groups, while marginalized communities benefited less or lost access to livelihoods. A just transition to greener alternatives need to focus on vulnerable and dispossessed populations, including women and landless communities.

The case of the Pavagada Solar Park illustrates how decision-making and governance processes have led to differentiated impacts on local communities. While the unique land-leasing arrangement allowed farmers to retain ownership of their land, it bypassed the Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (RFCTLARR) Act, 2013, which requires public hearings, social impact assessments, and economic rehabilitation for those affected by land acquisition. Landless laborers and women were not adequately represented during the initial consultations and negotiations with project proponents, with large landowners from dominant caste groups leading the discussions (Reddy 2021). Meaningful inclusion of the people affected by the project will empower them to advocate for their needs.

In cases such as that of the Pavagada Solar Park, where intervention impacts are already observable, the principles of restorative justice should inform actions to address unintended consequences. Large-scale interventions, such as the Pavagada Solar Park, can significantly benefit local communities through job creation, local infrastructure development, and economic improvement. Achieving these goals would promote a just transition for the local community by addressing existing marginalities. Marginalized sections of the population require more than equal treatment, as equality can inadvertently preserve existing differences and keep them at the margins.

CONCLUSIONS AND RECOMMENDATIONS

Recommendations for solar parks

Rethinking compensation mechanisms

Compensation mechanisms should be negotiated and operationalized to equitably benefit those at an inherent disadvantage owing to disparities in land ownership patterns. Retrospectively acknowledging the disadvantaged social groups and compensating them based on their needs would benefit local communities.

Promoting skill development and vocational training

Displaced workers need skill development and vocational training to prepare for employment at the solar park. The low average educational attainment rendered most of the population ineligible for technical and formal jobs at the solar park. Providing dedicated training for such workers, in addition to ensuring the implementation of existing schemes, will improve their opportunities for alternative employment.

Ensuring job opportunities for women

Skilling as well as workplace conditions suitable for women should be facilitated through inclusive discussions, and enforceable measures should be explored to encourage contractors to provide equal opportunities for women.

Improving the nature and quality of work

Solar park workers were employed on temporary contracts without benefits, job security, or health and safety provisions. Formal agreements to mandate respectable working conditions and wages would introduce accountability for employers. The enforcement capacity of labor laws should be improved to ensure that green jobs provide decent work for all.

Participatory planning for the utilization of the Local Area Development Fund

Develop local infrastructure through planned, transparent, and efficient utilization of the Local Area Development Fund collected from SPDs and additional corporate social responsibility funds. Participatory budget planning for public priorities will help achieve community development and promote economic activity in the region. For example, the development of an ecotourism site could sustainably contribute to the local economy. Investing the fund in social infrastructure development will be the key to unlocking the transformative potential of this transition.

Setting up a research and evidence base

Conducting post-project impact assessments and routine audits to take stock of local development around the solar park, focusing on affected communities will be necessary. This must be complemented by continued engagement with communities to hear their voices and identify their needs to help reduce negative socioenvironmental outcomes. Research to create a robust evidence base for environmental impacts, including questions pertaining to end-of-life management, is also required to ensure a sustainably just transition.

General recommendations

The decision to exempt solar parks from Environmental and Social Impact Assessments should be reconsidered. The study finds that while the park generates employment and provides a secure alternative to underproductive agricultural activities for some, others, particularly women, landless workers, and pastoralists, cannot reap all the benefits. The EIA in India has been an important mechanism to balance environmental safeguards and development. Mandating an EIA for large-scale renewable power projects would help policymakers and developers proactively anticipate risks and build resilience rather than react to unintended and unanticipated consequences.

Public consultations and needs-assessment studies can help identify potential risks and areas of intervention to mitigate undesirable outcomes. These can be preceded by the selection of appropriate sites using scientific tools to minimize socio-economic and environmental costs.

The conversion of less productive agricultural land to host solar parks is well-intentioned and mitigates economic risks for cultivators. However, facilitating irrigation and water supply to revive agriculture should also be considered where possible. **Promoting climate-resilient agriculture in such regions to protect local livelihoods should be explored.** The tradeoffs between livelihoods and energy security will be interesting to explore further, especially when similar questions arise in other sites. This is where **agrivoltaics could be a productive alternative,** potentially preserving existing sociocultural relations while promoting the productive use of renewable energy and enhancing livelihoods and energy services in rural areas.

The **potential of rooftop or distributed solar energy must be fully explored** through regulatory incentives and innovative financing mechanisms. This will reduce the dependence on land-intensive utility-scale solar energy to meet renewable energy targets and climate goals. Furthermore, it offers the possibility of democratizing energy infrastructure, making local communities stakeholders in power generation. Mechanisms, such as power purchase agreements with local cooperatives and/or governments to make them part-owners of the power produced, can be explored. For a just energy transition to materialize, deliberate planning is required to ensure that all social groups benefit equitably.

Conclusions

India's energy transition presents an opportunity for long-term transformative changes. This paper highlights the unintended local consequences of the transition to renewable power. As observed in the case of the Pavagada solar park, differentiated impacts can reinforce existing socioeconomic inequities and those at the intersections of marginalized social identities require special attention.

Achieving a just transition requires planning, focusing on developing social infrastructure and the local economy and attention to differentiated needs, adaptive capacities, and priorities across social groups. This study provides an evidence base for the impacts observed by local communities. Further research on local environmental impacts will help understand the ecological dimensions of such interventions. A longitudinal study will be useful for tracking changes in the social landscape and local area development over time.

Finally, the interpretation of just energy transitions must be expanded to account for transformations at the sites of clean energy projects, especially large-scale projects, and the people affected by renewable power installations. In the Indian context, this includes acknowledging how caste, tribe, class, and gender shape social relations. A just transition framework must include methods to build resilient livelihoods at the 'greener' end of the transition across these intersections.

APPENDIX A: SUPPLEMENTARY TABLES

Table A-1 | **Demographics of the surveyed villages**

CASTE CATEGORY	NO. OF HOUSEHOLDS	NO. OF MEMBERS	NO. OF MEMBERS (%)
General	58	255	20
OBC	67	275	22
ST	70	298	24
SC	104	434	34
Total	299	1262	100

Note: OBC: other backward class; ST: scheduled tribe; SC: scheduled caste.
Source: Authors' analysis after data cleaning.

Table A-2 | **Land ownership according to social categories**

LAND OWNED (ACRES)	GENERAL (%)	OBC (%)	ST (%)	SC (%)
Landless	7	13	23	58
≤ 5.0	8	30	29	33
> 5.0	52	21	15	12

Source: Authors' analysis.

The following table confirms the skewed nature of the distribution of landholding, a key asset for rural communities.

Table A-3 | **Descriptive statistics of landholding according to social categories (acres)**

LANDHOLDING (ACRES)	MAXIMUM	MINIMUM	AVERAGE	MEDIAN	TOTAL
General	80	0.15	14.4	10	746.2
OBC	20	0.03	5.5	4	310.6
ST	10	0.02	4.0	3	198.1
SC	32	0.40	3.8	2	199.9

Source: Authors' analysis.

Table A-4 | **Proportions of landholding houses that have leased land to the solar park according to social categories**

CASTE CATEGORY	% OF HOUSES
General	86
OBC	79
ST	73
SC	66

Note: OBC: other backward class; ST: scheduled tribe; SC: scheduled caste.
Source: Authors' analysis.

Table A-5 | **Number of households practicing agriculture before and after the installation of the solar park**

DO YOU PRACTICE AGRICULTURE?	NO. OF HOUSEHOLDS	
	BEFORE SOLAR	AFTER SOLAR
Yes	166	69
No	131	228

Source: Authors' analysis.

Table A-6 | **Number of households practicing agriculture before and after the installation of the solar park in the solar and non-solar villages**

VILLAGE CATEGORY	BEFORE SOLAR	AFTER SOLAR
Non-solar	55	43
Solar	111	26

Source: Authors' analysis.

Table A-7 | **Number of households practicing livestock farming before and after the installation of the solar park**

DO YOU PRACTICE LIVESTOCK FARMING?	NO. OF HOUSEHOLDS	
	BEFORE SOLAR	AFTER SOLAR
Yes	58	43
No	239	254

Source: Authors' analysis.

Table A-8 | **Number of households practicing livestock farming before and after the installation of the solar park in the solar and non-solar villages**

VILLAGE CATEGORY	BEFORE SOLAR	AFTER SOLAR
Non-solar	27	25
Solar	31	18

Source: Authors' analysis.

Table A-9 | **Laborers (Agricultural laborers employed by surveyed cultivators)**

DID YOU EMPLOY WORKERS OR MANAGERS FOR YOUR WORK LAST YEAR?	NO. OF HOUSEHOLDS	
	BEFORE SOLAR	AFTER SOLAR
Yes	62	20
No	235	277

Source: Authors' analysis.

Table A-10 | **Number of households employing agricultural laborers before and after the installation of the solar park in the solar and non-solar villages**

VILLAGE CATEGORY	NO. OF HOUSEHOLDS	
	BEFORE SOLAR	AFTER SOLAR
Non-solar	18	15
Solar	44	5

Source: Authors' analysis.

Table A-11 | **Gender-wise status of employment in the solar and non-solar villages**

VILLAGE CATEGORY	GENDER	WORKING POPULATION (%)	UNEMPLOYED/NON-WORKING POPULATION (%)
Non-solar Villages	Female	40	60
Non-solar Villages	Male	61	39
Solar Villages	Female	52	48
Solar Villages	Male	67	33

Source: Authors' analysis.

Table A-12 | **Gender-wise status of employment at the solar park in the solar and non-solar villages**

VILLAGE CATEGORY	GENDER	NO. OF WORKERS AT THE SOLAR PARK	PROPORTION OF WORKERS (OUT OF THE TOTAL WORKING POPULATION) (%)
Non-solar Villages	Female	0	0
Non-solar Villages	Male	6	4
Solar Villages	Female	0	0
Solar Villages	Male	54	20

Source: Authors' analysis.

Table A-13 | **Occupation profile according to landholding**

CASTE CATEGORY	CULTIVATOR (%)	PASTORALIST (%)	AGRICULTURAL LABOR (%)	NONAGRICULTURAL LABOR (%)	SALARIED JOB (%)	SOLAR PARK WORKER (%)	SELF-EMPLOYED (%)	OTHERS (SPECIFY)
0	0	0.49	69	9	9	5	3	4
< 2.5	17	2	51	4	7	7	8	3
2.5–5.0	15	3	45	3	12	13	6	1
5.0–7.5	37	0	37	0	11	8	6	0
7.5–10	30	2	37	2	4	14	11	2
> 10	55	3	18	1	15	6	1	0

Source: Authors' analysis.

Table A-14 | **Percentage of working population in the total sample surveyed [(no. of working persons)/(total persons surveyed)] in the solar and non-solar villages**

VILLAGE CATEGORY	VILLAGE	WORKING POPULATION (SHARE OF TOTAL PERSONS SURVEYED)(%)	TOTAL WORKING POPULATION	WORKING POPULATION - FEMALE (%)	WORKING POPULATION - MALE (%)
Solar	Rayacherlu	63	188	54	70
Solar	Thirumani	68	154	64	70
Solar	Volluru	48	96	36	57
Non-solar	Ryapte	51	177	40	63
Non-solar	Husenpura	55	103	48	62
	Total	57	718	48	65

Source: Authors' analysis.

Table A-15 | **Percentage of unemployed in total sample surveyed [(no. of unemployed)/(total number of persons surveyed)]**

VILLAGE CATEGORY	VILLAGE	UNEMPLOYED (SHARE OF TOTAL PERSONS SURVEYED)(%)	TOTAL UNEMPLOYED	UNEMPLOYED - FEMALE (%)	UNEMPLOYED - FEMALE (%)
Solar	Rayacherlu	7.4	22	14	2
Solar	Thirumani	4.8	11	6	4
Solar	Volluru	30	61	42	20
Non-solar	Ryapte	20	69	29	11
Non-solar	Husenpura	16	30	24	9
	Total	15	193	23	8

Source: Authors' analysis.

Table A-16 | **Agricultural labor. Percentage of agricultural laborers in the total working population [(no. of agri-laborers)/(working population)]**

VILLAGE CATEGORY	VILLAGE	AGRICULTURAL LABOR (SHARE OF TOTAL WORKING POPULATION (%)	TOTAL AGRICULTURAL LABOR	AGRICULTURAL LABOR - FEMALE (%)	AGRICULTURAL LABOR - MALE (%)
Solar	Rayacherlu	53	99	73	40
Solar	Thirumani	54	83	60	49
Solar	Volluru	44	42	85	22
Non-solar	Ryapte	40	71	46	36
Non-solar	Husenpura	59	61	74	49
	Total	50	356	65	40

Source: Authors' analysis.

Table A-17 | **Comparison of wages of agricultural laborers before and after the installation of the solar park in the solar and non-solar villages**

VILLAGE CATEGORY	MALE WORKERS		FEMALE WORKERS	
VILLAGE CATEGORY	BEFORE SOLAR (INR/DAY)	AFTER SOLAR (INR/DAY)	BEFORE SOLAR (INR/DAY)	AFTER SOLAR (INR/DAY)
Non-solar	169.4	393.3	98.6	185.3
Solar	165.7	400.0	101.9	250.0

Source: Authors' analysis.

Table A-18 | **Percentage of solar park workers in the total working population [(no. of solar park workers)/(working population)]**

VILLAGE CATEGORY	VILLAGE	SOLAR WORKERS (SHARE OF WORKING POPULATION)(%)	WORKERS AT SOLAR PARK	SOLAR WORKERS - FEMALE (%)	SOLAR WORKERS - MALE (%)
Solar	Rayacherlu	9	16	0	14
Solar	Thirumani	9	14	0	15
Solar	Volluru	25	24	0	38
Non-solar	Ryapte	3	5	0	5
Non-solar	Husenpura	1	1	0	2
	Total	8	60	0	14

Source: Authors' analysis.

Table A-19 | **Ownership of land according to the type of work at the solar park**

PARK WORKER CATEGORY	AVERAGE LAND OWNERSHIP (ACRE)
Overall	4.67
Solar park worker - Module cleaner	1.33
Solar park worker - Grass cutting	1.57
Solar park worker - Security guard	4.38
Solar park worker - Technician	6.00
Solar park worker - Supervisor	12.00

Source: Authors' analysis.

Table A-20 | **Type of work at the solar park according to social category**

SOCIAL CATEGORY	UNSKILLED (NO. OF WORKERS)	SKILLED (NO. OF WORKERS)	TOTAL (NO. OF WORKERS)
SC	4	9	13
ST	5	15	20
OBC	3	9	12
General	5	10	15
Total	17	43	60

Note: OBC: other backward class; ST: scheduled tribe; SC: scheduled caste.
Source: Authors' analysis.

APPENDIX B: SURVEY TOOL USED FOR DATA GATHERING

[A] Survey schedule

S. No. Title (in English)

1. Personal Details

1.1. Name

1.2. Age (in completed years)

1.3. Caste/Tribe

1.3.1. What formal caste category would this fall under?

1.4. Religion

1.5. Gender

1.6. Relation to the head of the household?

1.7. Household general information:

1.7.1. Members of the family (Name)

1.7.2. Gender

1.7.3. Relation to the head of the household

1.7.4. Age (in completed years)

1.7.5. Education level

1.7.6. Primary Occupation

1.7.7. Place of work (Primary occupation)

1.7.8. Secondary Occupation

1.7.9. Place of work (Secondary occupation)

1.8. Year of migration to the village (If applicable)

1.9. What kind of a dwelling does the respondent live in?

1.10. Year of original construction of the dwelling

1.11. Year of last reconstruction/repair, if applicable

1.12. What government cards do you possess?

1.13. What do you avail from these cards?

2. Land

2.1. Did/Do you own land?

2.2.1. Type of land owned

2.2.2. Amount of land owned (specify units)

2.2.3. What is the land used for?

2.2.4. Mode of acquisition

2.2.5. Since when have you owned this land?

2.2.6. Amount of land leased (specify units)

2.2.7. Amount of land leased/sold to the solar park (specify units)

2.2.8. Monetary compensation received from lease/sale agreement (for solar park), INR/year

2.3. Have you received any in-kind compensation for leasing/selling land to the solar park? (specify units)

2.4. How do you plan to use this money/what have you used this on, so far? Tick categories that apply.

3. Agriculture

3.1. Do you practice agriculture?

3.2. Do you practice agriculture as a primary occupation or a secondary occupation?

3.3. If Yes, extent of land under cultivation? (specify units)

3.3.1. Who owns the land under cultivation? (Whether the cultivated land is owned by self/leased from someone/owned by others?)

3.4. What crops are cultivated on this land?

3.5. Share of produce used for household consumption? (%)

3.6. Share of produce sold in the market? (%)

3.7.1. Approximate earnings from sale of produce last year (if applicable) (INR/year)

3.7.2. Share of crop produce provided (as payment/compensation) to workers, if applicable (specify units)?

4. Livestock farming

4.1. Do you practice livestock farming?

4.2. Do you practice livestock farming as a primary occupation or a secondary occupation?

4.3.1 Where is the livestock reared? (classification of land based on ownership)

4.3. Specify, if other

4.4. Which animals do you rear on this land?

4.5. Share (percentage) of produce used for household consumption? (specify units)

4.6. Share (percentage) of produce sold in the market? (specify units)

4.7. Approximate earnings from livestock farming in the last year in INR (if applicable)

5. Labor: Employees

5.1. Were you or any of your household members employed for work?

5.2.1. Name of the member

5.2.2. Purpose of employment

5.2.3. Type of labor

5.2.4. No. of months employed (in the last year)

5.2.5. Place of work

5.2.6. Annual earnings (INR)

5.2.7. Earnings in kind

5.2.8. Employer details: Village of residence

5.2.9. Employer details:

5.2.9.1 Caste

5.2.9.2 Occupation

5.2.9.3 Landholding, if known (specify units)

5.3. Are members of the family free to work for wages for an employer of choice?

5.3.1. If no, are there any cases of compulsion/coercion/restrictions?

5.4. Are there any obligations to perform any traditional caste duties?

6. Labor: Employers

6.1. Did you employ workers or managers for your work last year?

6.2.1. Number or proportion of male workers

6.2.2. Number or proportion of female workers

6.3.1. Number of SC workers

6.3.2. Number of ST workers

6.3.3. Number of other workers

6.4.1. Purpose of employment

6.4.2. Number of months that workers were employed?

6.4.3. Type of wage/contract:

6.4.4. Typical wages: Male workers (specify units)

6.4.5. Typical wages: Female workers (specify units)

6.4.6. Any compensation/payment made in kind to employees (specify units)

7. Access

7.1.1. What is the primary source of water for your household? (for drinking and domestic use)

7.1.2.1. What is the source of water for purposes other than household/domestic use (agriculture, livestock use, etc.), if applicable?

7.1.3. What is the type of ownership of the primary water source?

7.1.4. How far is this water source from your house?

7.1.5. Has there been any change in the water supply or accessibility of water after the installation of the solar park?

7.1.6. How much do you spend on average per month on water? (INR/month)

7.2.1. Are there any cases of fluorosis in the household?

7.2.2. Has this led to any long-term disabilities/illness?

7.2.3. Has the expenditure on healthcare changed in the last two years? (if applicable)

7.2.4. If Yes, by how much? (INR/year)

7.3.1. Main source of lighting

7.3.2. Has there been any change in the electricity supply after the installation of the solar park?

7.3.3. How much do you spend on average per month on electricity? (INR/month)

ENDNOTES

1. Social categories: SC: Scheduled Castes, ST: Scheduled Tribes, OBC: Other Backward Classes, General – includes everyone who does not fall under the aforementioned groups. SC and ST are communities officially recognized by the Constitution of India as among the country's most disadvantaged socioeconomic groups.

2. *Cultivators* refers to persons who own land and are involved in farming activities.

3. Anganwadi Services is one of the flagship programmes of the Government of India providing early childhood care and development of the beneficiaries; i.e., children in the age group of 0-6 years, pregnant women, and lactating mothers through a large network of Anganwadi workers (AWW) and Helpers (AWH).

4. This refers to government land allotted to landless persons for cultivation without any transfer of legal titles.

5. Shared by Mr. K from Rayacherlu in an in-depth interview with the research team.

6. Employed at the KSPDCL Terminal, Thirumani.

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ABOUT THAMATE

Our Field Partner

Thamate, originally based in Pavagada, has been working on rural empowerment for over two decades. Familiarity with the local context helped to build trust among potential respondents and identify key information pertaining to a range of perspectives.

Under the guidance of Dr. K.B. Obalesha, Mr. Venkatesha and Mr. Gangaraju coordinated our field efforts across the five study villages. The field team from Thamate included Akshay Kumar, Baba Fakruddinruba, Babu Pothaganahalli, Madhu, Nagaraju Appajihalli, Nagaraju Davadabetta, Nagaraju Ponnasamudra, and Prathima.

Research Ethics

WRI India has a rigorous human-subject protection protocol. Potential risks associated with data collection activities were identified before the field visits, and control measures were adopted to reduce them. These risks included identifiability, sensitivity related to social categories, and safety concerns, which were mitigated by altering the questionnaires and methods (by moving questions to FGDs rather than individual surveys involving local field partners). The field team included a mix of men and women from local villages who helped familiarize the respondents with information related to the study and created a safe space for data collection exercises. All data were collected with due consent from the respondents, informing them about the objectives of the research and clarifying their queries before conducting surveys, interviews, or discussions. The responses were anonymized to protect their identities. Data were collected using a digital tool and housed on a secure Amazon cloud server that followed code-level security protocols and was protected by the necessary security certifications.

ABOUT WRI INDIA

WRI India, an independent charity legally registered as the India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Our work focuses on building sustainable and liveable cities and working towards a low carbon economy. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being. We are inspired by and associated with World Resources Institute (WRI), a global research organization. Know more: www.wri-india.org

Our challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to inform government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

DISCLAIMER: All maps used in this publication are for illustrative purposes and do not imply the expression of any opinion on the part of WRI India, concerning the legal status of any country or territory or concerning the determination of frontiers or boundaries.