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Profiling the Solar Transition in Odisha's Agriculture – Adoption Patterns and Socio-Economic Perceptions Among Tribal Farmers

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ABSTRACT

In the contemporary era, climate change has emerged as a major global concern, with agriculture being a significant contributor due to its heavy reliance on mechanization and fossil fuel consumption. In India, this dependence has led to increased greenhouse gas emissions, particularly carbon dioxide and methane, along with accelerated depletion of natural resources such as water, thereby raising serious concerns about environmental sustainability. In this context, renewable energy-especially solar power-offers a viable pathway toward promoting sustainable agricultural practices. Recognizing its importance, the Government of India has introduced several subsidized programmes to facilitate the adoption of solar energy in agriculture.

This study examines the adoption of solar energy in agricultural production systems, its socio-economic impacts on farming communities, and its overall efficiency and sustainability. Using primary data collected from 502 tribal farm households across five blocks each in Koraput and Nabarangapur districts of Odisha, the study reveals that solar energy plays a significant role in enhancing the socio-economic well-being of farming households. Solar energy is primarily utilized for crop production, irrigation, processing, value addition, and storage. Nearly 99% of the respondents reported a highly positive socio-economic impact, resulting in an average additional annual income of approximately ₹50,000 per household.

Despite these benefits, several operational challenges were identified, including low voltage supply, pump set inefficiencies, damage caused by wild animals, and the lack of locally available maintenance and repair services. Addressing these constraints, the study proposes key policy recommendations, including the development of localized maintenance ecosystems, enhanced subsidy support, promotion of group-based solar models, and provision of training and exposure programmes for farmers to ensure effective adoption and long-term sustainability of solar energy in agriculture.

Key Words: Solar Energy, Agriculture, Sustainability, Environment, Socio-Economic Impact

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INTRODUCTION

Sustainable development is a multinational mission often linked to reducing climate change and ensuring energy security (Adom, 2024; Bierbaum & Matson, 2013). The issues of energy poverty and climate change are very severe in India, especially in the agricultural sector. Agriculture is a central part of the rural income and food safety in developing countries like India, which is also a primary user of water and energy (Dalla Fontana et al., 2020; Yue & Guo, 2021). Here, solar energy as a renewable energy source is a significant mechanism, which can separate agricultural development from high dependency on fossil fuels. This shift from non-renewable energy to renewable energy constructs resilience to the climate and reduces carbon pollution (IEA, 2022; Pietrzak et al., 2025). The combination of agriculture and solar energy often goes well together. Likely, the high potential of

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agricultural fields is helping to generate more solar power (Adeh et al., 2019). This initiates the possibilities for agrivoltaics that increase the land use for food and energy production (Dupraz et al., 2011).

Such green technologies are urgently required among the tribal communities in India, who have traditionally faced marginalization, low socio-economic development, and limited access to resources (Xaxa, 2005; Balgir, 2006). Odisha is a state with a high number of Scheduled tribe population (62), and the Particularly Vulnerable Tribal Groups (13) across India, is the prime location of problems (GoI, 2022). Koraput and Nabarangapur districts of Odisha are selected for the study as more than 50% of the total district population belongs to tribes. Also, these districts are known for poor literacy rates, high Multidimensional Poverty Index scores, and high dependency on rain-fed agriculture (Census, 2011; NMPI, 2021). These communities are facing energy poverty challenges because of frequent grid failures and poor infrastructure. This drives post-harvest processing and dependency on costly diesel pumps, which reinforces a cycle of poverty and low productivity (Campana et al., 2013; Djanibekov & Gaur, 2018).

The use of solar power in agriculture is a revolutionary solution in remote areas. Research shows that decentralized solar systems, such as dryers, irrigation pumps, processing units, and cold storages, can supply a clean, secure and low-cost energy for agriculture (Aliyu et al., 2018; Guno & Agaton, 2022). The use of solar irrigation instead of diesel can lower the costs of operation in agriculture. Also, it is increasing the cropping intensity as well as offering access to water on time (Hoque et al., 2016; Islam & Hossain, 2022). In addition, solar drying and cold storage can significantly minimize post-harvest losses. This makes value addition possible and enables farmers to obtain improved prices in the market (Hin et al., 2024). The cost savings and increased income that follow can be consequently channelled into healthcare, education, and improved farm inputs. This directly contributes to Sustainable Development Goal for poverty eradication (SDG 1), zero hunger (SDG 2), and clean and affordable energy (SDG 7) (Li et al., 2020; Auci & Pronti, 2023).

Seeing the potential, the Government of India and non-governmental institutions have introduced initiatives for the installation of solar-powered systems in agricultural fields. Schemes such as the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) encourage solar irrigation and other decentralized uses (MNRE, 2023). In Odisha, institutions like the Odisha Renewable Energy Development Agency (OREDA), the SELCO Foundation and many other such agencies have been playing a crucial role. They pilot and scale solar-based livelihood initiatives tailored for tribal farmers (Dash et al., 2024).

Nonetheless, a major imbalance occurs between the technical potential of solar energy and a realistic comprehension of its actual adoption and effects from the tribal farmer's point of view. While numerous studies analyze the techno-economic viability of solar systems (Khalid et al., 2023; Merida García et al., 2021) and their general socio-economic implications (Güre et al., 2025; Thapa et al., 2022), and in-depth descriptive studies are rare. There are limited studies that identify the real users, list out the specific usage patterns, and elaborate on the perceived challenges and benefits in the tribal areas of India (Nkhoma et al., 2024; Ukoba et al., 2024). While designing the long-run and successful energy interventions, it is important to understand who is using what technology, what the challenges are and the key effects.

Moreover, the study provides an exhaustive descriptive overview of renewable solar energy used among tribal farmers of Odisha. Next, the study emphasizes the theoretical framework to give a deeper understanding of solar energy use in contemporary times. Basically, the study focuses on three important goals, where it emphasizes socio-economic contexts of the tribals, documents the adoption patterns, and determines the perceived benefits and challenges to operate the technologies. The findings will give effective suggestions to development officers, policymakers, and researchers to control solar energy for equitable and sustainable development in tribal regions of India.

LITERATURE REVIEW

This discussion highlights three thematic areas in the literature to set the research within context. It covers the tribe's socio-economic context, the use and benefits of the solar system in the agricultural field, and the ongoing problems associated with it and its sustainability in the long term.

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The Socio-Economic Context of Tribal Communities

Tribals or Adivasis or Scheduled Tribes (STs) are considered to be the most socio-economically disadvantaged population (Xaxa, 2005). Even though many development interventions and constitutional safeguards have emerged in favour of tribes, these groups are still experiencing challenges like low literacy rates, limited access to resources, and limited integration into the mainstream economy (Jain et al., 2015). Among them, PVTGs are a sub-group characterized as more vulnerable to poverty and primitive cultivation practices (GoI, 2022).

Odisha is the prime location of STs and PVTGs in India (GoI, 2022). The two districts - Koraput and Nabarangapur are known for poor literacy rates, high Multidimensional Poverty Index scores, and high dependency on rain-fed agriculture (Census, 2011; NMPI, 2021). Research shows that more than 70% of the rural population's livelihood is highly impacted by rain-fed irrigation, energy poverty, and low productivity (Census, 2011; GoO, 2018). It illustrates that tribal households are likely to engage more in different informal economic practices and wage employment, which is making them economically poor (Nkhoma et al., 2024). In order to examine the use of solar energy, its benefits, and any developmental interventions, it is crucial to understand the socio-economic context.

Solar Energy as an Agent in Agricultural Systems

The encouragement of the use of solar energy in the agricultural field is a crucial strategy to influence productivity and sustainability. Many studies have supported its efficacy and feasibility in the agricultural sectors. For instance, SPIS is used during the cultivation stage, which is proven to be more economical and technically feasible as compared to grid electricity and diesel pumps (Aliyu et al., 2018; Campana et al., 2013). The research conducted in India and Bangladesh shows that SPIS helps in ensuring on-time water supply for irrigation, reduces the production cost, and enhances the cropping intensity, resulting in directly rise of agricultural incomes (Hoque et al., 2016; Jethani et al., 2023).

Apart from irrigation, solar energy is also considered for loss prevention and extensive value addition. For instance, solar dryers give sun drying to high-value produce like fish, vegetables, and fruits, which create new market opportunities and lower post-harvest losses (Hin et al., 2024; Mostafaeipour & Nasiri, 2020). Similarly, cold storage avoids distress sales, helps in storing perishables, and helps farmers to generate better income (Amer et al., 2022; Zhang et al., 2018). Moreover, agrivoltaics-co-deployment of land in agriculture, is offering microclimatic crop benefits and high land-use efficiency (Adeh et al., 2019; Dupraz et al., 2011).

Further, better access to clean solar energy can empower women SHGs by generating income for them and improving livelihood diversification (Guno & Agaton, 2022). Solar energy is also cost-saving and provides income benefits that can generate better farming inputs, health, and education, contributing to social empowerment and wider poverty reduction (Li et al., 2020; Lin & Kaewkhunok, 2024). Solar energy has socio-economic impacts that facilitate community resilience and network dynamics (Güre et al. 2025)

Adoption and Sustainability Challenges

There are significant challenges for the sustainable and large-scale application of solar power in tribal regions. Economically, the major challenge for small farmers is the initial capital cost, even though they receive government subsidies (IRENA, 2021; MNRE, 2023). The bureaucratic lag and administrative inconvenience in accessing the subsidy can challenge access by the small farmers (Kafle et al., 2024). Another major challenge could be the operation and maintenance of the solar power.

The use of a reliable solar-powered storage system is unpredictable as it has a short lifespan and is expensive (FAO, 2023). In remote areas, a solar system downtime is weakening the confidence of the users due to a lack of spare supply chains and technical competencies (Habib et al., 2023). Additionally, dust on PV panels in agricultural settings can affect the efficiency of the system if not cleaned on time (Tamoor et al., 2022). Apart from this, socio-behavioural factors can also affect the early adoption of solar systems. For instance, the lack of awareness and technical knowledge among farmers can restrict the early adoption (Chindasombatcharoen et al.,

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2024). However, solar technologies can be effective if proper training is given with providing post-installation support, and generating local entrepreneurships to develop a sustainable platform for repair and maintenance of solar systems (Ukoba et al., 2024).

Synthesizing the Gap

The literature highlights the technical potential of the solar system and its relevance in the socio-economic context. However, the research has not given more focus on PVTGs who have distinct vulnerabilities and socio-cultural environments. Hence, it is crucial to document the adoption of solar power (including dryers, pumps, fencing, etc.) among tribal farmers, source of getting solar systems (NGO, Government), operating challenges in their regular life and specific benefits they have enjoyed.

This study bridges this gap by employing a descriptive research technique to develop a rich description of the existing situation of solar energy uptake in the Koraput and Nabarangapur districts. With a focus on the user's end, this study will provide empirically based findings that will enable the design of more targeted, effective, and sustainable programs and policies for clean energy transition among tribal farming.

METHODOLOGY

Study Area

The research was conducted in the Scheduled Tribe-majority districts of Nabarangapur and Koraput in Odisha State, India. The districts were purposively chosen because of their dense population of Scheduled Tribes (STs), high dependence on agriculture, and their recognition as being areas with very high socio-economic and energy poverty problems. The two districts are dominated by rain-fed agriculture and have been the target of different government and non-governmental activities encouraging solar energy.

The survey was stratified among ten administrative blocks, five blocks in each district, to provide geographical representation. In the Koraput district, the selected blocks were Boipariguda, Nandapur, Lamtaput, Kotpad, and Koraput. The selected blocks in Nabarangapur district were Kosagumuda, Jharigam, Raighar, Umerkote, and Nabarangapur Sadar.

Data Source and Collection

The research used primary cross-sectional data that had been gathered for the study, "Sustainability of Solar Energy in the Socio-Economic Development of Tribal Farmers of Koraput and Nabarangapur Districts, Odisha, India". A structured questionnaire is used to gather data. This detailed instrument was implemented through face-to-face interviews carried out by enumerators who were trained and local dialect conversant. The survey tool captured quantitative and qualitative data in various domains such as household demographics, livelihood assets, farming practices, and extensive modules on solar technology adoption.

Sample Size and Sampling Strategy

The sample used in this analysis is 502 tribal farmers who have adopted solar technology for agricultural use. The sampling approach followed under this study was multi-staged and stratified. First, the ten blocks in the two districts were chosen purposively based on the concentration of tribals and the use of solar power systems in the agriculture production by the tribes. Similarly, the selection of Gram Panchayat and villages were made as per the list provided by the Odisha Lift Irrigation Corporation, Odisha Agro Industries Corporation Limited and SELCO Foundation.

Total 45 Gram Panchayats were covered under data collection, which includes Boipariguda(10), Nandapur (04), Lamtaput (03), Kotpad (06), Koraput (07) from Koraput district and Kosagumuda (03), Jharigam (03), Raighar (02), Nabarangapur (01), Umerkote (06) from Nabarangapur. Unlike the selection of Gram Panchayats, a total 77 villages were selected from the two sample districts for data collection, which includes Boipariguda (12), Nandapur (05), Lamtaput (03), Kotpad (08), Koraput (18) from Koraput district and Kosagumuda (05), Jharigam (11), Raighar (07), Nabarangapur (01), Umerkote (07) from Nabarangapur district.

A total of 502 tribal households consist of 190 from Koraput and 312 from Nabarangapur districts, engaged in agriculture, were selected from the two sample districts. For identification of sample households, the list of farmers provided by Odisha Lift Irrigation Corporation (OLIC), Odisha Agro Industries Corporation Limited (OAIC) and SELCO Foundation were followed, and the short fall were completed by following snowball sampling methods (Table 1).

Table 1: **Sample profile**

S. No.	Districts	Blocks	GP (No)	Village (No)	Total HH (No)
1	Koraput	Boipariguda	10	12	25
2		Nandapur	04	05	43
3		Lamtaput	03	03	45
4		Kotpad	06	08	24
5		Koraput	07	18	53
6	Nabarangapur	Kosagumuda	03	05	31
7		Jharigam	03	11	38
8		Raighar	02	07	122
9		Nabarangapur	01	01	54
10		Umerkote	06	07	67
Total		**10**	**45**	**77**	**502**

Source: Compiled by the authors from filed survey 2025

Variables for Analysis

The household schedule data were classified into separate categories of variables for descriptive purposes:

Socio-Demographic Profile

Variables in this category are the age and sex of the respondent, formal education years achieved, family type (nuclear or joint), total landholding (in acres), and economic status (BPL/APL).

Adoption Patterns

This type records the details of solar technology adoption. The most significant variables are the adopted solar system type (e.g., irrigation pump, dryer, fencing), year of adoption, source of the system (Government, NGO, Private), ownership model (Individual or Group), and its major nature of utilization in the agro-value chain (Production, Processing, or Storage).

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Perceived Benefits

This measures the reported outcomes by families. Indicators are the increase in crop area (in acres) due to solar irrigation, self-reported enhancement in crop production (in kilograms), economic gain per year (in Indian Rupees), and better social standing (e.g., membership in a Self-Help Group, possession of a bank account). Overall satisfaction rated on a Likert-type scale is also surveyed.

Operational Challenges

This dimension deals with the hurdles in long-term use. It encompasses the number of system repairs, cost of annual maintenance (in INR), presence of local technicians, availability of formal training, and distance to the nearest service centre (in kilometres).

Data Analysis Methods

The statistical analysis for this paper is based solely on descriptive statistics. The aim is to describe and summarize the major features of the sample without drawing statistical inferences to a wider population.

The data will be represented in the following manner:

For categorical variables (such as system type, source of supply, level of satisfaction), results will be displayed as percentages and frequencies by use of tables and visualizations such as bar charts and pie charts.

For continuous variables (e.g., landholding, system cost, economic benefit, cost of maintenance), measures of central tendency (mean, median) and spread (standard deviation) will be computed and tabulated in summary tables. Histograms may also be plotted to show the distribution of these variables.

This research method gives a distinct and structured picture of solar-energy adopting tribal farmers, describing who they are, how they utilize the technology, and what benefits and difficulties they face.

Data Analysis

Socio-Demographic Profile of Adopting Households

The analysis begins with a profile of the tribal farmers who have adopted solar technologies. The data, summarized in Table 1, reveals a predominantly middle-aged, male-led household structure with basic education levels primary schooling (78.5%). Out of the total 94.2% were married and 2.4% reported to be Widow/Widower/Divorce. Except 8% members remaining are falling under the working age group of 25 to 55 years.

Table 1: **Socio-Demographic Characteristics of Respondent Households (N=502)**

S. N.	Attributes	F	Total	S. N.	Attributes	F	Total
Sex of Respondent				**Marital Status**			
1	Male	Count	408	1	Married	Count	473
2		%	81.30%	2		%	94.20%
3	Female	Count	94	3	Unmarried	Count	17
4		%	18.70%	4		%	3.40%
Total		Count	502	5		Count	12

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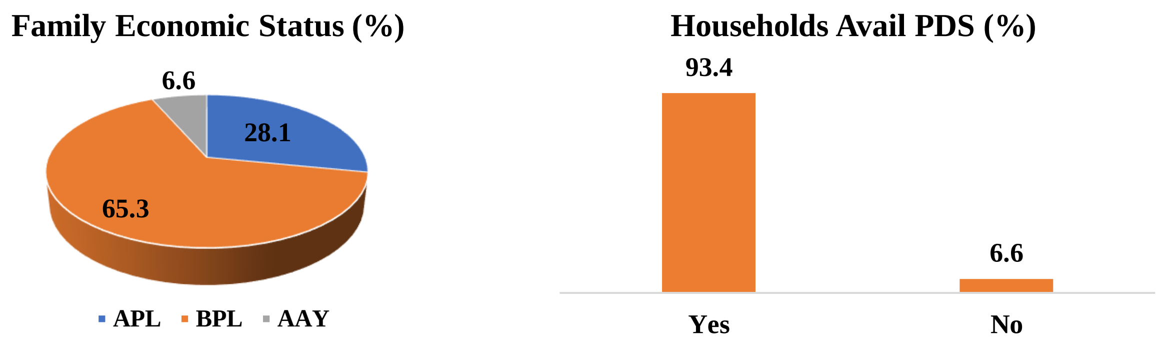
		%	100.00%	6	Widow/ Widower /Divorce	%	2.40%
Education				**Total**		Count	502
1	Illiterate	Count	78			%	100.00%
2		%	15.50%	**Age of the Respondent**			
3	Primary	Count	394	1	Below 25 Year	Count	2
4		%	78.50%	2		%	0.40%
5	Upper Primary	Count	8	3	25 - 35 Year	Count	97
6		%	1.60%	4		%	19.30%
7	Secondary Education	Count	11	5	36 - 45 Year	Count	200
8		%	2.20%	6		%	39.80%
9	Higher Secondary	Count	5	7	46 - 55 Year	Count	163
10		%	1.00%	8		%	32.50%
11	Graduation & above	Count	6	9	56 Year and Above	Count	40
12		%	1.20%	10		%	8.00%
Total		Count	502	**Total**		Count	502
		%	100.00%			%	100.00%

Source: Compiled by the author from the field survey 2025

A significant majority of the households (65.3%) were classified as Below the Poverty Line (BPL), and 6.6% families were reported to be critically poor and covered under Antyodaya Anna Yojana (AAY). Underscoring the economic vulnerability of the community and the importance of subsidized technologies. Under the National Food Security Act 2013, the government of India has created a provision for the distribution of cereals among households living in poverty. Tribals, being the most backward community, are entitled to the scheme of the government. Of the total sample, 93.4% family's avail PDS benefit. (Figure 1).

Figure 1: Family Economic Status and Households Avail PDS (%) (N-502)



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Source: Compiled by the author from the field survey 2025

Land and Agriculture

In common parlance, tribal communities are either small holder and landless. However, in the sample area, 16.5% families are found to be marginal farmers having up to one hectare of land holding, with 20.8% families from the non-solar households. Similarly, among others, 56.2% families are small holders having 1.0 - 1.99 hectares of land, which percentage is higher (58.0%) in the case of solar households. A total of 26.6% families covered under the survey are semi-medium farmers holding 2.0 - 3.99 hectares of land, and 0.7% are medium land holders with 4.0-9.99 hectares of land. However, none of the households under survey are large farmers in either of the categories (Table 4.7).

Table 2. Land Holding Classification (N-502)

S. N.	Farmer Category	Frequency	Total
1	Marginal (Below 1.0 hectare)	Count	61
2		%	12.2%
3	Small (1.0 - 1.99 hectares)	Count	291
4		%	58.0%
5	Semi-Medium (2.0 - 3.99 hectares)	Count	145
6		%	28.9%
7	Medium (4.0 - 9.99 hectares)	Count	5
8		%	1.0%
Total		Count	502
		%	100.0%

Source: Compiled by the author from the field survey 2025

Cropping Area, Crop Production and Sale

In the sample area, the total cropping area was 1817.2 acres for Paddy, Millet (109.5 acres), Maize (1203.4 acres), Til (11.5 acres), Vegetables (198.65 acres) and orchard crop (11 acres) for the entire season. In the Kharif season, the area covered under crop production was 1797.8 acres, which was 1553.5 acres in the Rabi season. Paddy is the most dominant crop among all cultivated crops in the Kharif season. However, during the Rabi season, maize dominates paddy, showing the importance of maize in Koraput and Nabarangapur (Table 3).

Table 3. Cropping Area in Acre (N-502)

S. N.	Crop	Frequency	Kharif Total	Rabi Total	Grand Total
1	Paddy	Count	1752.2	65	3468.2
2		%	50.5	1.9	100.0

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3	Millet	Count	6	103.5	138.5
4		%	4.3	74.7	100.0
5	Maize	Count	27.6	1175.8	2045.4
6		%	1.3	57.5	100.0
7	Til	Count	1.5	10	13.5
8		%	11.1	74.1	100.0
9	Vegetable	Count	10.5	188.15	477.65
10		%	2.2	39.4	100.0
11	Orchard crop	Count	0	11	18
12		%	0	61.1	100.0

Source: Compiled by the author from the field survey 2025

Since paddy covers the highest area of land during the Kharif season, it is the highest produced crop and provides 39453 quintals of production in a year. Surprisingly, 38162 quintals of paddy were produced alone during the Kharif season out of the total production. Next to paddy, the other major produced crop was maize, which was produced in 26551 quintal per year. Other than the two major crop like paddy and maize, the farmers of Koraput and Nabarangapur were also producing Millet (1757 quintal), Til (258 quintal), vegetables like brinjal, guar, tomato, ladies-finger, cabbage, curly flower, etc., (3715 quintals) and Orchard crops like mango, litchi, jackfruit, banana, etc., (164 quintal) (Table 4).

Table 4. Crop Production in Quintal (N-502)

S. N.	Crop	Frequency	Kharif Total	Rabi Total	Grand Total
1	Paddy	Count	38162	1291	39453
2		%	54.9	1.9	100
3	Millet	Count	94	1663	1757
4		%	4.4	78.2	100
5	Maize	Count	460	26091	26551
6		%	1.1	62	100
7	Til	Count	18	240	258
8		%	6.2	82.2	100
9	Vegetable	Count	156	3559	3715
10		%	2	46.5	100

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11	Orchard crop	Count	0	164	164
12		%	0	64.8	100

Source: Compiled by the author from the field survey 2025

Patterns of Solar Technology Adoption

The use of solar powered systems in agriculture is varied. It is being used for both production and processing and value addition such as irrigation systems, rice mills, hullers, dryers, threshers, cold storages, etc. The details relating to the varied usage of solar powered systems are given in Table 5. Solar irrigation pumps were the most widely adopted technology, followed by solar fencing and dryers. This indicates that production-stage applications are the primary entry point for solar adoption in these communities. The government was the predominant source of these technologies, highlighting the critical role of public schemes like PM-KUSUM and OREDA initiatives. Furthermore, a mix of individual and group ownership models was observed in the study area, with a notable proportion of community-level assets like cold storage and large processing units being managed by SHGs or FPOs.

Table 5: Use of Solar Energy in Agricultural Production Systems (N-502)

Agricultural Stage	Solar Energy Use	Specific Application in Tribal Regions	Potential Impact
1. Production	• Solar-powered irrigation pumps • Solar fencing • Solar lights in fields • Solar sprayer	• Replacing diesel pumps and manual sprayers in districts like Koraput, Rayagada. • Night farming	• Reduced input cost • Increased cropping intensity • Wildlife crop protection
2. Processing	• Solar grinders, threshers, hullers • Solar dryers, Oil mill, Dal mill, etc.	• Millet, Maize, Ginger and Turmeric processing. • Leaf plate making	• Improved product quality • Employment for women • Local enterprise generation
3. Value Addition	• Solar dehydration units • Solar cookers	• Drying mango, jackfruit, amla, mushrooms	• Shelf-life extension • Premium pricing for organic products
4. Storage	• Solar-powered cold storage • Solar refrigeration for perishables	• Pilots in Malkangiri and Nabarangapur for vegetable & fish storage	• Post-harvest loss reduction • Improved food security and price negotiation power

Source: Compiled by the author from the field survey 2025

The study shows that the dominant use of solar power is irrigation, with 85.9% tribal household responded its overall usage (Figure-2). This indicates that solar power primarily supports the essential needs of crop production. It has found that Nabarangapur has the highest irrigation use with 89.4% households' response, which suggests high dependence on solar pumps. On the other hand, Koraput has 80.0% of households with diversified usage (Figure-2). Research reflects those value-added activities like millet processing, paper plate

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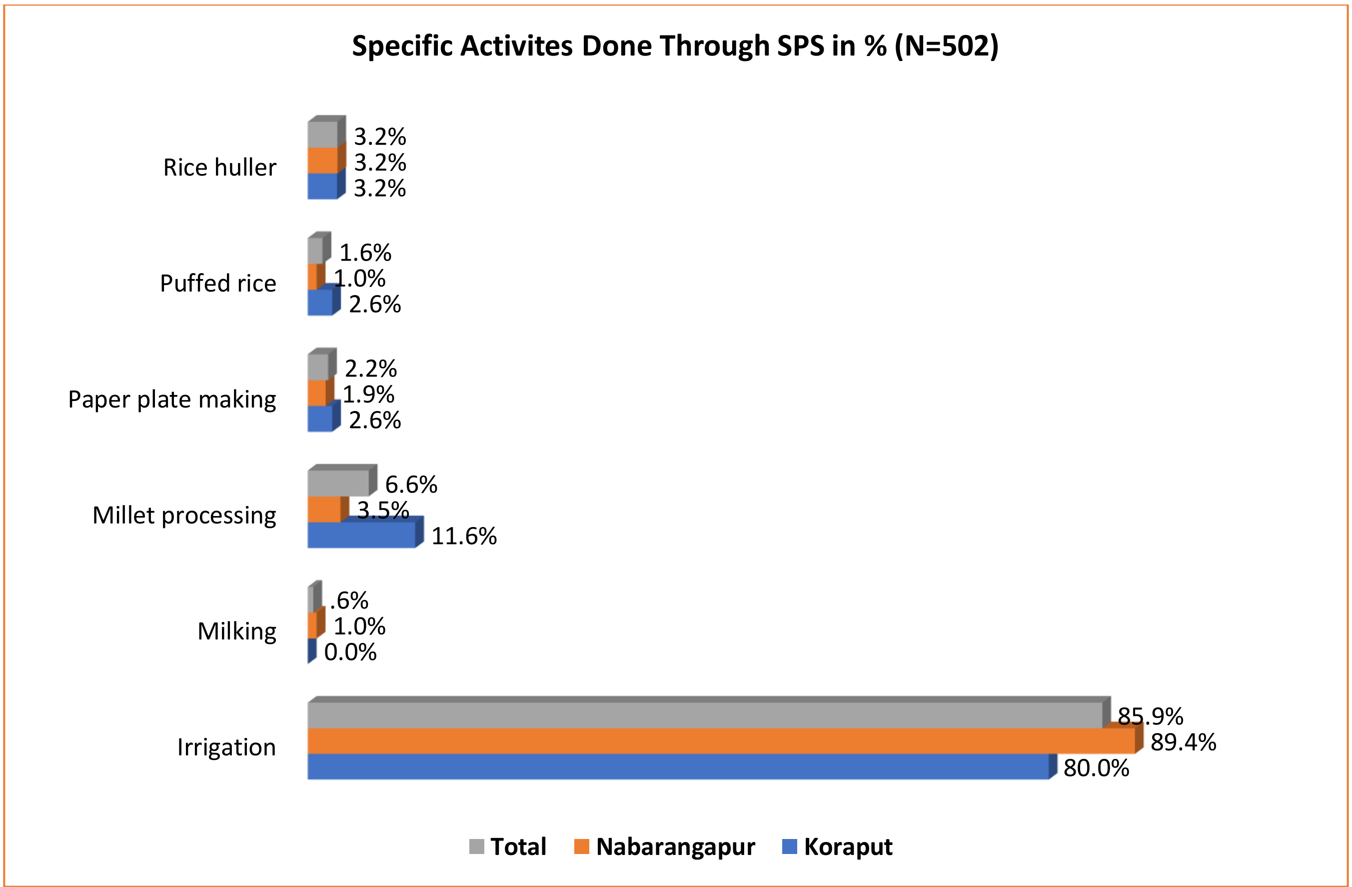
making, rice hulling, and puffed rice preparation remain limited, which reflects constraints in market access, technology, and skills. This trend shows that adoption of solar power is largely production-centric with a modest shift toward income-generating activities. The same pattern has been observed in the adoption of rural renewable energy studies (MNRE, 2024).

Figure 2. Actual use of the solar system



Source: Compiled by the author from the field survey 2025

Perceived Socio-Economic Benefits and Challenges

Households reported significant benefits from adopting solar technologies. The most direct impact was economic, with an average annual financial benefit of ₹ 50000/- per household. This was driven by a reported average increase in cropped area by 2 to 5 acres and a reduction in post-harvest losses. As shown in table 6, when asked to rate their overall satisfaction, a strong majority of users reported "Good" to "Excellent" experiences.

Table 6. Benefits of Solar Power System for Agriculture (N-502)

S. N.	Attributes	%	District		Total
			Koraput	Nabarangapur	
1	Yes	Count	188	308	496
2		%	98.9%	98.7%	98.8%
3	No	Count	2	4	6
4		%	1.1%	1.3%	1.2%

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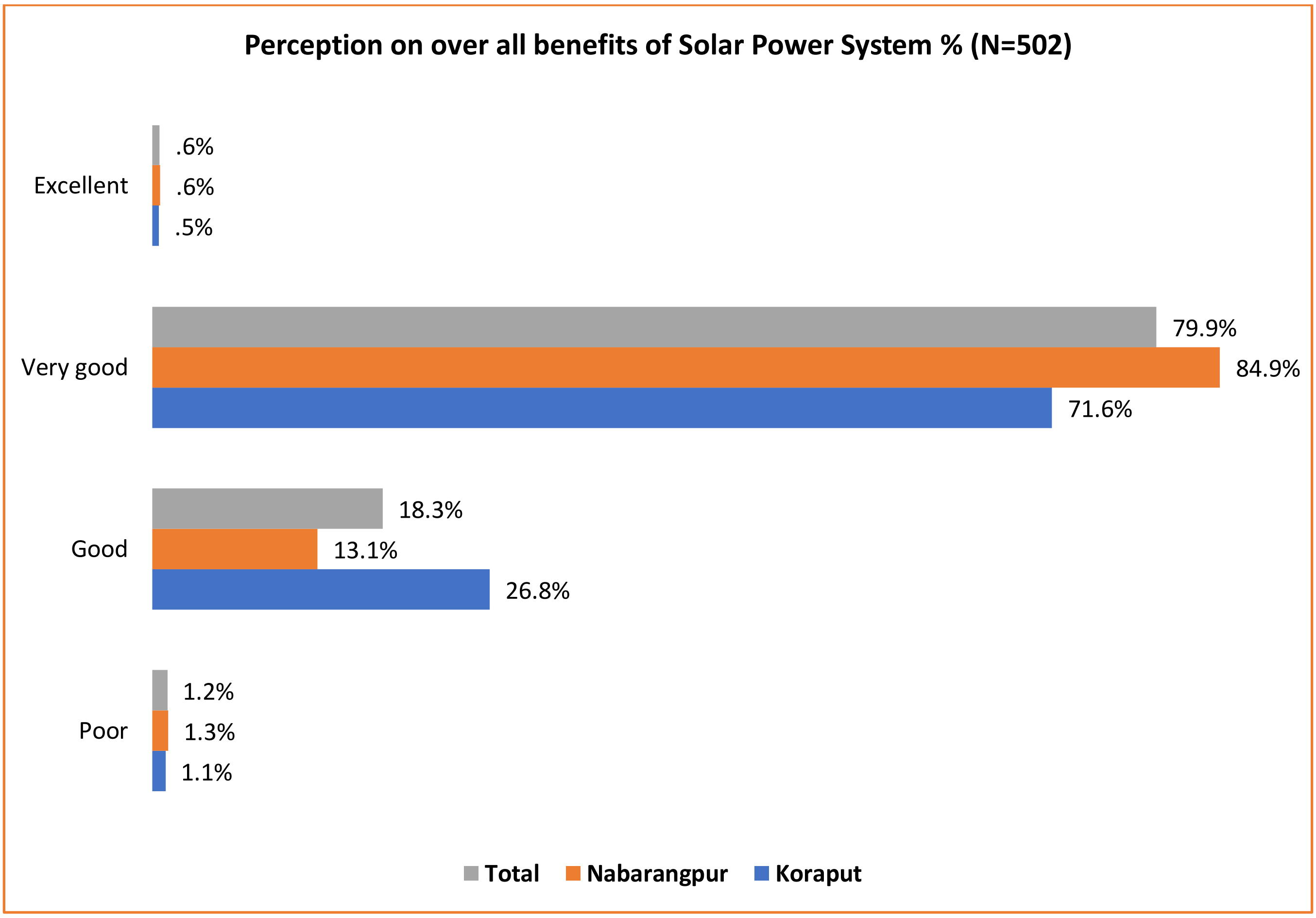
Total	Count	190	312	502
	%	100.0%	100.0%	100.0%

Source: Compiled by the author from the field survey 2025

The data shows that most respondents (79.9%) rated solar power systems as "very good" in Koraput, with a small proportion rating them "good" (18.3%). In Nabarangapur, 84.9% respondents said "very good" rating for its overall benefits. This indicates a high level of satisfaction with solar power benefits in Nabarangapur and Koraput, which reflects improved reliability and productivity (Figure 5.6).

Figure 3: User Satisfaction with Solar Power Systems



Source: Compiled by the author from the field survey 2025

Major issues associated with Solar Power System

The adoption journey of SPS was not without challenges. Maintenance emerged as a critical issue. Even though the average annual maintenance cost incurred by households was very less ₹1000 to ₹5000/-, which is due to coverage of repair and maintenance under the installation, still the farmers face numerous challenges. The frequency of repairs varied, with a notable proportion of users requiring multiple services per year. A significant barrier was the lack of local service infrastructure, with the average distance to the nearest technician being minimum 10 km.

The data reflects that issues with water pumps are the primary concern for users of solar power systems, which is impacting 75% of households in total. Koraput (78.7%) has a slightly greater percentage than Nabarangapur (61.5%). Attacks from wild animals affect 20% of households, with a higher rate in Nabarangapur (30.8%)

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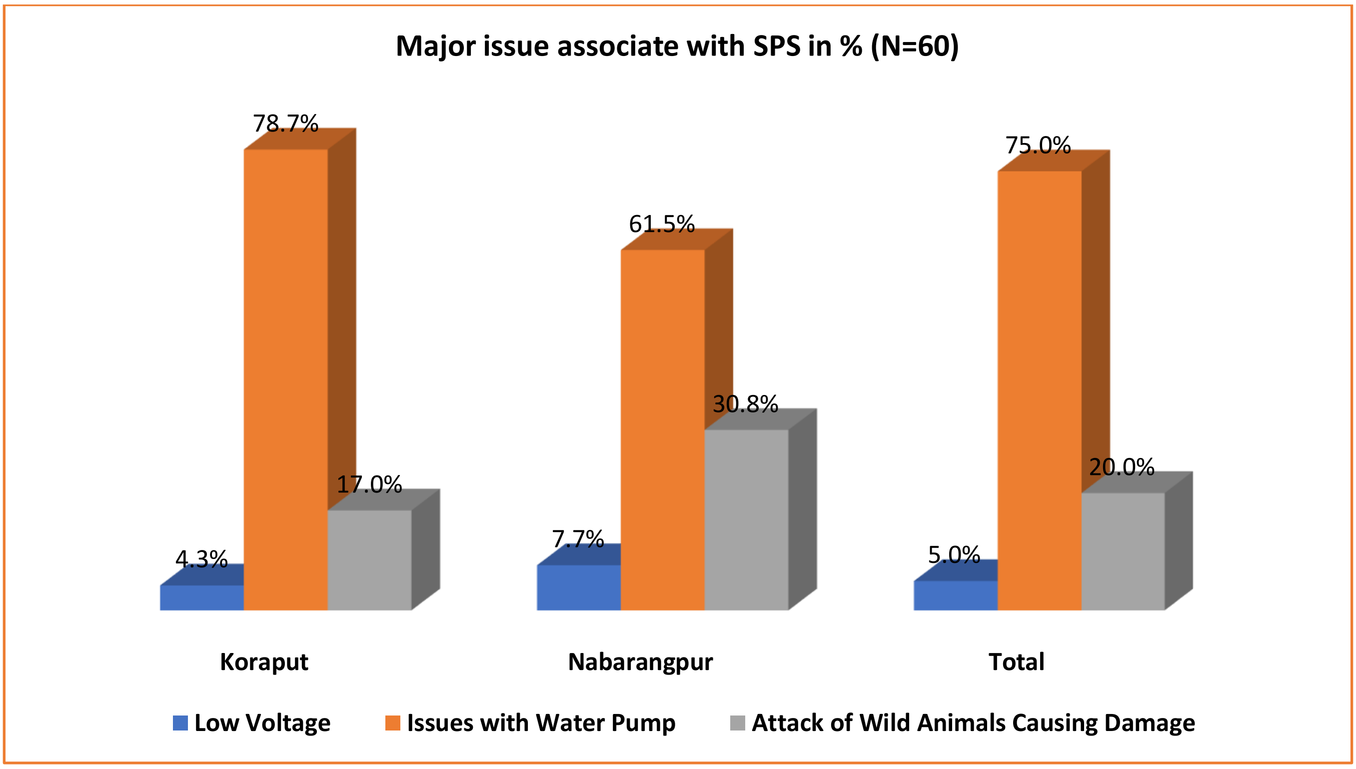
compared to Koraput (17%), whereas low voltage issues are less common (5%). This suggests that technical upkeep and ecological factors are major obstacles, and specific actions like safeguarding against wildlife and pump maintenance can enhance the dependability and efficiency of solar energy systems (Figure 4 & 5).

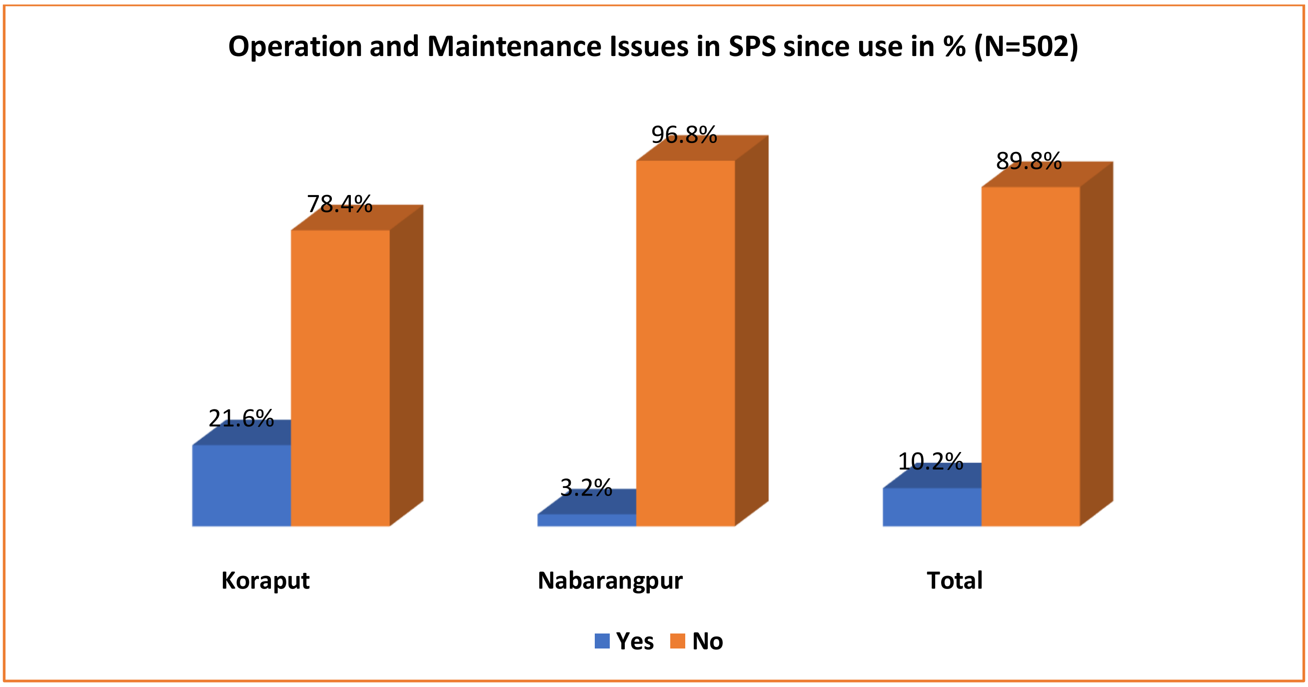
Figure 4. Major issues faced by farmers from SPS



Source: Compiled by the author from the field survey 2025

Operation and maintenance issues of the solar power system

Figure 5. Operation and maintenance related issue of SPS since use (502)



Source: Compiled by the author from the field survey 2025

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DISCUSSION

This study gives a deeper understanding of the solar energy used among the tribal farmers of Odisha, emphasizing a number of significant observations and patterns. Research shows that the socio-economic adopters, like small-scale farmers and middle-aged people from BPL, are the consistent beneficiaries of government subsidy initiatives like PM- KUSUM (MNRE, 2023). It shows that the policy initiatives are connecting successfully with most of the economically disadvantaged people. However, a gender disparity is also observed while adopting the solar system, where men are more prevalent in decision-making and technology ownership (Nkhoma et al., 2024). Here, more focused interventions should be a pervasive rural technology diffusion challenge.

The study shows that the most commonly adopted renewable energy system is solar irrigation pumps. This shows the extreme significance of access to water in the rain-fed production systems. The dominance of solar systems shows that it is a strategic prioritization of production-stage obstacles, which is the first step in the agricultural shift (Campana et al., 2015). The public policy plays a critical role in helping to facilitate market creation and close the affordability gap in tribal or rural regions (Ukoba et al., 2024). For instance, a good initiative could be the complementary existence of group and individual ownership structures for more expensive cold storage systems that can accumulate social capital and enhance economic sustainability, which aligns with the Sustainable Livelihood Approach (DFID, 1999).

The study states significant socio-economic impacts of solar systems among small farmers. Solar power system has the capability of increasing revenue and productivity, which provides immediate economic benefits in terms of minimized post-harvest losses and expanded cropping area (Guno & Agaton, 2022; Mostafaeipour & Nasiri, 2020). Moreover, it has strong user satisfaction, which means that technology is observed as a net benefit. However, it is crucial for word-of-mouth dissemination and long-run sustainability in such communities. The association with SHG membership and financial inclusion shows that the adoption of solar system has the potential to bring more socio-economic development (Li et al., 2020).

Further, this positive trend may be hampered due to operational barriers. The literature illustrates that the high maintenance of the solar system, theft, damage by wild animals, and common repair needs reflect worries about the sustainability of solar projects in rural areas (Habib et al., 2023). In the maintenance landscape, there are some key challenges, like distance to service hubs and the unavailability of local technicians. However, this has the potential to create downtime in extending the solar system in rural areas. The findings also suggest that the focus on existing policy and establishing a localized, strong, and low-cost solar installation service network.

CONCLUSION AND POLICY IMPLICATIONS

The adoption of a solar energy system has strong potential to boost the socio-economic status of tribal farmers in Odisha by processing crops, creating economic gains, increasing agricultural output, providing a proper storage system, and overall development. Solar energy technology is well accepted in rural regions. However, the sustainability of this solar technology depends on overcoming deeper challenges linked with maintenance and operation, which are hindering the maximum use in the present context.

The research paper identified some significant findings and accordingly posed some policy recommendations that are highlighted below:

- **Emphasize Local Maintenance ecosystems**: The policymakers and development agencies are required to emphasize the deployment and training of technicians at the local village level. This can also contribute to the present skill development missions. Moreover, developing solar entrepreneur networks at the block or panchayet level can reduce the repair expenses and time.
- **Better Subsidy Programs**: It has found that capital subsidies are beneficial for solar adoption, but there is a need to focus on providing extended warranties and subsidizing up-front maintenance expenses. Also, these subsidy programs could promote service contracts with dealers at the local level to ensure better maintenance.

- **Promote Group Models for Enhanced Technologies**: It is important to encourage group ownership under SHG and FPOs for advanced, sophisticated, and costly solar systems like large processing units and cold storage systems. As a result, it can divide the risk, split the costs, and encourage community capacity for management.
- **Enhance Targeted Training and Awareness**: There is a need for ongoing training of the technicians in the field of preventive maintenance and elementary troubleshooting. The focus must be given to the awareness campaign that provides benefits to non-users and encourages them to adopt a solar system.

In general, the idea of integrating sustainable solar energy into tribal agriculture is beneficial. In future, longitudinal designs must be used to enhance the inferential techniques and long-term sustainability of solar systems. This way, it will be easy to find out factors associated with adoption success and failure.

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