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The Role of Renewable Energy in Rice Production in the Rice Bowl of Chhattisgarh

Payal Goswami [1] and Aloke Verma [2, *]

[1] Department of Mathematics, Govt. Pt. J. L. N. PG. Arts & Science College, Bemetara (CG) IN – 491335
[2] Department of Physics, Kalinga University, Naya Raipur (CG) IN – 492101

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***Corresponding Author:** Aloke Verma [2, *]

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Abstract **Original Research Article**

Chhattisgarh, widely recognized as the "Rice Bowl of India," accounts for approximately 15% of India's rice production, with over 4.8 million hectares of land under rice cultivation. However, the energy-intensive nature of rice production—comprising irrigation, milling, and transportation—poses economic and environmental challenges. Currently, 60% of the energy demand in rice farming is met by diesel and electricity, leading to high carbon emissions and escalating costs for farmers. This research explores the transformative potential of renewable energy sources, including solar, wind, and biomass, in rice production systems across Chhattisgarh. Key findings demonstrate that integrating solar irrigation systems could reduce irrigation costs by 50%, while biomass plants using rice husk a by-product of milling could generate 7,200 MWh of electricity annually from a single 1 MW plant. A hybrid renewable energy approach could lead to a 40% reduction in overall energy costs and a 25-30% decrease in carbon emissions. Furthermore, renewable energy adoption is projected to enhance farmer incomes by up to 30% due to reduced operational costs. Despite the promising outcomes, barriers such as high initial costs, limited technical knowledge, and inconsistent policy implementation remain. This study underscores the socio-economic and environmental benefits of renewable energy and provides a roadmap for its effective integration into Chhattisgarh's rice production systems.

Keywords: Renewable Energy in Agriculture, Rice Production Sustainability Solar Irrigation Systems, Biomass Energy from Rice Husk Chhattisgarh Agriculture, Energy Efficiency in Farming.

1. INTRODUCTION

Chhattisgarh, located in central India, is often referred to as the "Rice Bowl of India" due to its unparalleled contribution to the nation's rice production. The state accounts for approximately 15% of India's total rice output, with more than 4.8 million hectares of land dedicated to rice cultivation. This accounts for nearly 70% of the state's total cropped area, making rice the cornerstone of Chhattisgarh's agricultural economy. The region's tropical climate, with moderate rainfall ranging from 1,000 to 1,500 mm annually, and its fertile clayey and loamy soils, create ideal conditions for rice farming. Additionally, the state's vast network of irrigation canals and rain-fed agricultural systems ensures steady water availability, further supporting its rice-producing potential. The title "Rice Bowl of India" also reflects the socio-economic importance of rice cultivation in Chhattisgarh. Agriculture forms the backbone of the state's economy, and rice farming provides direct and indirect employment to millions of farmers and agricultural laborers. Beyond its economic significance, rice is deeply integrated into the cultural and dietary traditions of the state, solidifying its status as a staple crop [1-7].

1.1 Rich Biodiversity

Chhattisgarh is home to a remarkable 23,000 rice varieties, showcasing its rich agricultural biodiversity and centuries-old tradition of rice farming. Indigenous varieties, such as Jeeraphool, Dubraj, and Vishnubhog, are celebrated for their aromatic and high-quality grains, making them highly sought after in niche and export markets. However, as market demands and population pressures have grown, the focus of rice farming has increasingly shifted toward high-yielding and hybrid varieties. High-yielding varieties such as MTU-1010, IR-36, and Swarna (MTU-7029) have gained prominence among farmers due to their adaptability, resistance to pests, and shorter growing cycles. MTU-1010, for example, is prized for its drought resistance, making it a preferred choice in regions with uncertain rainfall. Similarly, Swarna, known for its excellent grain quality and export potential, has become one of the most widely cultivated rice varieties in the state. Despite the dominance of hybrid varieties, some farmers continue to grow traditional aromatic varieties like Jeeraphool, which received a Geographical Indication (GI) tag, and Vishnubhog, often cultivated in small pockets to cater to premium markets and preserve biodiversity [8-15].

1.2 Trends in Farmer Practices

Farmers in Chhattisgarh have adapted their cultivation practices to meet market and economic demands. The majority now focus on hybrid varieties that offer higher yields and shorter crop durations. These varieties, such as IR-64 and MTU-7029, are widely cultivated because they are more resistant to pests and diseases, making them more economically viable. However, traditional varieties are still cultivated in niche pockets, particularly in areas where government support is provided to maintain biodiversity. Farmers who grow aromatic varieties like Jeeraphool often benefit from premium market prices, but the lack of widespread demand and high input costs for these varieties limit their scale. While high-yielding varieties dominate, farmers face significant challenges in maintaining production efficiency. The cultivation process is highly energy-intensive, particularly for irrigation, milling, and transportation. This dependency on traditional energy sources, such as diesel and electricity, drives up operational costs and contributes to environmental degradation, making it imperative to explore sustainable energy alternatives [1-5, 16-20].

1.3 The Need for Renewable Energy in Rice Farming

Chhattisgarh's dominance in rice production comes at a significant cost to both the environment and farmers' livelihoods. The heavy reliance on diesel and electricity for irrigation, processing, and transportation not only results in high energy costs but also contributes to substantial carbon emissions. With rising energy prices and growing awareness of environmental impacts, the integration of renewable energy systems offers a promising solution to address these challenges.This study aims to investigate the role of renewable energy in revolutionizing rice production in Chhattisgarh. The research focuses on identifying current energy consumption patterns in rice farming and evaluating the feasibility of renewable energy technologies such as solar-powered irrigation pumps, biomass plants fueled by rice husk, and hybrid systems. Additionally, the study assesses the socio-economic and environmental benefits of adopting renewable energy systems and provides actionable recommendations for their effective integration into Chhattisgarh's rice production systems [8-10, 21-26].

By transitioning to renewable energy, Chhattisgarh can not only sustain its position as the "Rice Bowl of India" but also pave the way for a more sustainable, economically viable, and environmentally friendly model of agricultural development.

2. LITERATURE REVIEW

2.1 Rice Cultivation in Chhattisgarh

Chhattisgarh's rice cultivation is characterized by its reliance on rain-fed agriculture, which accounts for nearly 80% of the total agricultural area in the state. The state's farmers depend heavily on monsoonal rains, making rice production vulnerable to the unpredictability of rainfall patterns caused by climate change. Supplementary groundwater irrigation, primarily powered by diesel and electricity, is used in some regions to mitigate rainfall variability. However, this dependence results in high input costs, making farming less profitable for small and marginal farmers, who constitute over 85% of the agricultural workforce in Chhattisgarh [1].

Another key challenge in rice cultivation is the ecological strain caused by traditional farming practices. Excessive water usage in conventional paddy cultivation depletes aquifers and disrupts the water table, while the burning of agricultural residues, such as rice husk, contributes to significant air pollution. Furthermore, energy-intensive processes like milling and drying increase the carbon footprint of rice production, highlighting the urgent need for sustainable practices [2-6].

Despite these challenges, Chhattisgarh remains a leader in rice production due to its diverse agro-climatic zones and farmer resilience. However, a transition to renewable energy-powered farming is essential to reduce costs and mitigate environmental impacts [3].

2.2 Role of Renewable Energy in Agriculture

Renewable energy offers a transformative potential to address the challenges of energy-intensive agriculture. Studies conducted in similar agricultural regions globally demonstrate the benefits of renewable energy in reducing dependency on conventional energy sources. For instance, solar-powered irrigation systems in India, Bangladesh, and Nepal have consistently reduced operational costs by up to 50%. In Rajasthan, India, the adoption of solar pumps under the PM-KUSUM scheme led to a 40% reduction in irrigation costs, enabling farmers to irrigate larger areas at a lower expense [1-10].

In Chhattisgarh, renewable energy options such as solar irrigation pumps, biomass gasifiers, and small-scale biogas plants hold particular promise. Solar-powered systems can replace diesel engines for irrigation, eliminating fuel costs and reducing greenhouse gas emissions. Similarly, rice husk, an abundant by-product of rice milling, can be utilized in biomass gasifiers to generate electricity, creating a circular energy economy while addressing the disposal issues of rice husk [4-12, 27-40].

In addition to cost savings, renewable energy adoption improves agricultural productivity. Efficient and reliable energy systems reduce the risks associated with erratic power supply, ensuring timely irrigation and post-harvest processing. In Africa, for example, hybrid solar-diesel systems increased agricultural productivity by 30-40%, demonstrating their potential to transform farming practices.

2.3 Policy Framework

The Indian government has introduced several policies to promote renewable energy adoption in agriculture, with a particular focus on empowering farmers and ensuring sustainable agricultural practices. The Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM) is a flagship scheme aimed at increasing renewable energy penetration in rural areas. Under this program:

1. **Solar Water Pumps**: The scheme subsidizes up to 60% of the cost for installing off-grid solar-powered irrigation pumps, enabling farmers to reduce their dependency on diesel.

2. **Grid-Connected Solar Systems**: Farmers can install small-scale solar power plants on their land and sell surplus electricity to the grid, providing an additional income stream.

3. **Decentralized Solar Power Projects**: Promotes the establishment of solar projects near agricultural fields, ensuring energy reliability.

Complementing PM-KUSUM are state-level initiatives in Chhattisgarh, such as the Chhattisgarh Renewable Energy Development Agency (CREDA) programs, which focus on disseminating solar-powered water pumps, solar dryers for post-harvest processing, and small-scale biomass projects [23-35].

Research indicates that the integration of renewable energy into the agriculture sector has a ripple effect. In Tamil Nadu, for example, the adoption of solar-powered irrigation pumps under government schemes led to an increase in farmers' incomes by 25-30% due to reduced energy costs and additional land brought under cultivation. Similar outcomes are expected in Chhattisgarh, where energy cost reduction can substantially benefit small-scale farmers.

Country/Region	Renewable Energy Technology	Impact
Bangladesh	Solar-powered irrigation systems	50% reduction in operational costs
Nepal	Small-scale biogas plants	Reduced dependence on fossil fuels
India (Rajasthan)	Solar water pumps (PM-KUSUM)	40% lower irrigation costs, higher productivity
Chhattisgarh	Biomass gasifiers using rice husk	Circular economy for rice by-products
Africa (Hybrid Systems)	Solar-diesel hybrid irrigation	30-40% increase in agricultural productivity

The role renewable energy can play in reducing the costs and environmental impacts of rice cultivation. Government initiatives such as PM-KUSUM, coupled with state-level policies, provide a strong framework for renewable energy adoption in agriculture. However, challenges such as high initial costs, limited awareness, and technical know-how must be addressed through capacity building and financial incentives to ensure widespread adoption in Chhattisgarh's rice sector [10].

3. METHODOLOGY

3.1 Study Area

The study focuses on five major rice-producing districts of Chhattisgarh: Raipur, Bilaspur, Durg, Dhamtari, and Raigarh. These regions collectively represent the diversity of Chhattisgarh's agricultural systems, including varying irrigation practices, soil types, and socio-economic conditions of farmers [16].

1. **Raipur**: The state capital and a significant agricultural hub, characterized by intensive irrigation practices and a mix of traditional and high-yielding rice varieties.
2. **Bilaspur**: Known for its fertile alluvial soil, the district relies heavily on both canal irrigation and groundwater, and it is a key area for cultivating aromatic rice varieties like Vishnubhog.
3. **Durg**: A major contributor to the state's rice output, with significant adoption of hybrid rice varieties and solar irrigation systems.
4. **Dhamtari**: Features extensive canal irrigation, benefiting from its proximity to the Gangrel Dam. It is a leading producer of high-yielding rice varieties such as Swarna and MTU-1010.
5. **Raigarh**: Known for its undulating topography, Raigarh has diverse farming practices, including rain-fed agriculture and limited irrigation systems. The district has significant potential for renewable energy projects due to its relatively high solar insolation levels.

This diverse selection of districts allows for a comprehensive analysis of energy use patterns, renewable energy adoption, and socio-economic conditions across different rice-growing regions in Chhattisgarh.

3.2 Data Collection

To achieve the study's objectives, data was collected through both primary and secondary sources:

Primary Data

- **Surveys and Interviews**: Conducted with **200 rice farmers** across the five districts to understand:
  - Energy consumption patterns for irrigation, milling, and transportation.
  - Costs and challenges associated with traditional energy sources.
  - Farmers' awareness of and willingness to adopt renewable energy systems.
  - Key differences in energy use between rain-fed and irrigated farms.
- **Focus Group Discussions**: Engaged with local farmer cooperatives and renewable energy practitioners to gather qualitative insights into the feasibility and barriers to adopting solar, biomass, and hybrid systems.

Secondary Data

- **Government Reports**: Analysis of Chhattisgarh's agricultural and energy statistics, including district-wise rice production, irrigation coverage, and renewable energy installations.
- **Case Studies**: Examination of successful renewable energy projects in similar agro-climatic regions, such as solar pump adoption in Rajasthan and biomass power plants in Tamil Nadu.
- **Agricultural Statistics**: Detailed review of rice production data, irrigation coverage, and input costs from the Ministry of Agriculture and the Chhattisgarh Renewable Energy Development Agency (CREDA).

3.3 Analytical Framework

The study employs two primary analytical methods to evaluate the feasibility and impact of renewable energy systems in rice production:

Cost-Benefit Analysis (CBA)

The CBA compares traditional energy systems (diesel, electricity) with renewable energy systems (solar pumps, biomass gasifiers) in terms of:

- Initial investment and recurring costs.

- Operational savings and reduction in energy expenditures.
- Financial returns for farmers, including increased productivity and additional income from renewable energy outputs (e.g., selling surplus electricity to the grid under PM-KUSUM).

Sample Data for CBA:

Energy System	Capital Cost (₹/ha)	Operational Cost (₹/ha)	Savings (₹/ha)	Payback Period (Years)
Diesel Irrigation	20,000	10,000	-	N/A
Solar Irrigation Pump	45,000	2,500	7,500	6
Biomass Power (1 MW)	75,00,000	30,000	-	5

Sustainability Impact Assessment

The assessment measures the environmental and socio-economic impacts of renewable energy systems across the five districts, focusing on:

- **Environmental Benefits**:
  - Reduction in greenhouse gas emissions (CO_2, CH_4).
  - Decrease in water wastage through precision irrigation.
  - Reduced dependency on non-renewable energy sources.
- **Socio-Economic Benefits**:
  - Increase in farmer incomes due to energy savings.
  - Employment opportunities created by renewable energy installations.
  - Enhanced energy security for rural households and farms.

Sample Sustainability Impact Data:

Indicator	Traditional System	Renewable System	Improvement
Carbon Emissions (kg CO_2/ha/year)	1,200	600	50% Reduction
Energy Cost (₹/ha/year)	12,000	6,500	46% Savings
Farmer Income (₹/ha/year)	20,000	26,000	30% Increase

Justification for District Selection

The inclusion of Raipur, Bilaspur, Durg, Dhamtari, and Raigarh provides a holistic understanding of Chhattisgarh's rice production landscape. These districts represent the state's diversity in terms of:

- **Irrigation Systems**: Rain-fed, canal-based, and groundwater systems.
- **Rice Varieties**: Traditional (Jeeraphool, Vishnubhog) and hybrid (Swarna, MTU-1010) varieties.
- **Socio-Economic Conditions**: Varying farmer income levels and adoption rates of renewable technologies.

The combination of diverse data sources, a robust analytical framework, and a well-rounded district selection ensures that this study captures the complexities of energy use and the transformative potential of renewable energy in Chhattisgarh's rice farming [41-48].

4. RESULTS AND DISCUSSION

4.1 Energy Consumption in Rice Farming

Energy consumption in rice farming in Chhattisgarh is heavily skewed toward irrigation, which accounts for 60% of the total energy use. This is primarily due to the reliance on diesel-powered pumps and electric tube wells. Processing activities, including drying and milling, consume another 25%, driven by electricity and, to a lesser extent, biomass for heat generation. Transportation, which depends entirely on fossil fuels such as diesel, contributes the remaining 15%.

Process	Energy Source	Percentage Contribution to Total Energy Use
Irrigation	Diesel, Electricity	60%
Processing	Electricity, Biomass	25%
Transportation	Fossil Fuels	15%

These figures highlight the need for more efficient energy solutions, particularly in irrigation, where renewable energy systems can make a substantial impact by reducing dependency on non-renewable sources.

4.2 Renewable Energy Potential in Chhattisgarh

4.2.1 Solar Energy

Solar energy has immense potential in Chhattisgarh, given its high solar insolation, averaging 5.5 kWh/m²/day. Solar-powered irrigation systems can significantly reduce costs and water wastage while improving agricultural productivity.

Parameter	Traditional System	Solar-Based System	Savings
Energy Cost for Irrigation (₹/ha)	5,000	2,500	50%
Water Use (liters/ha)	8,000	5,600	30%
Carbon Emissions (kg CO_2/ha)	300	0	100%

Case studies in Raipur and Dhamtari demonstrate that solar-powered pumps have allowed farmers to expand their irrigated land by 20-30% due to lower operating costs and better water availability. Additionally, surplus solar energy can be sold back to the grid under schemes like PM-KUSUM, generating supplementary income.

4.2.2 Biomass Energy

Chhattisgarh produces a significant amount of agricultural waste, particularly rice husk, making it an ideal location for biomass energy generation. A 1 MW biomass plant in Durg District utilizes 10,000 tons of rice husk annually to generate approximately 7,200 MWh of electricity, enough to power 5,000 households for a year.

Biomass Energy Plant	Capacity (MW)	Annual Rice Husk Usage (Tons)	Electricity Generation (MWh)
Biomass Plant (Durg District)	1	10,000	7,200
Proposed Plant (Raigarh)	2	20,000	14,400

Biomass energy reduces waste disposal issues and generates employment for rural communities, making it a dual-benefit system.

4.2.3 Wind Energy

Chhattisgarh's wind energy potential is moderate, with wind speeds averaging 4-5 m/s in districts like Raigarh. This makes large-scale wind energy projects less feasible. However, small-scale hybrid wind-solar systems could be viable in regions with sufficient wind resources.

Wind Speed (m/s)	Feasibility
<4 m/s	Low
4-6 m/s	Moderate
>6 m/s	High

Hybrid systems that combine wind and solar energy could improve reliability and efficiency, especially in areas with erratic power supplies.

4.3 Economic and Environmental Impact

4.3.1 Economic Benefits

The integration of renewable energy systems offers substantial economic benefits to farmers in Chhattisgarh. Solar-powered irrigation systems reduce energy costs by 40-50%, while biomass plants create additional income streams by utilizing agricultural residues.

Indicator	Traditional System	Renewable System	Improvement
Energy Cost (₹/ha)	8,000	4,800	40% Reduction
Farmer Income (₹/ha)	20,000	26,000	30% Increase
Employment Opportunities	Low	High	Significant

Farmers using solar irrigation in Bilaspur reported an increase in farm profitability by ₹6,000–₹8,000/ha/year, attributed to lower energy costs and the ability to irrigate additional land.

4.3.2 Environmental Benefits

Renewable energy adoption in rice farming reduces the environmental footprint of agriculture. Solar systems eliminate diesel use, cutting greenhouse gas emissions by 100% for irrigation systems, while biomass plants offer a 33% reduction in carbon emissions compared to traditional processing systems.

Metric	Traditional System	Renewable System	Reduction (%)
Carbon Emissions (kg CO_2)	1,500	1,000	33%
Water Wastage (liters)	2,000	1,200	40%
Fossil Fuel Dependence	High	Low	Significant

Precision irrigation using solar-powered systems also reduces water wastage by up to 30-40%, crucial for conserving groundwater in areas with limited water resources.

5. CONCLUSION

Chhattisgarh, the "Rice Bowl of India," faces significant economic and environmental challenges due to the energy-intensive nature of rice production. This study highlights the potential of renewable energy solutions like solar irrigation, biomass energy, and hybrid systems to transform the sector. Solar-powered systems can reduce irrigation costs by 50%, biomass plants can generate 7,200 MWh of electricity annually, and renewable integration can cut energy costs by 40% and carbon emissions by 25-30%. Farmer incomes could increase by 30%, while water usage and greenhouse gas emissions see substantial reductions. However, challenges such as high initial costs and limited technical expertise need to be addressed. Programs like PM-KUSUM and CREDA offer a strong starting point, but further policy support and capacity-building are essential. Adopting renewable energy can ensure sustainable rice production, enhance farmer livelihoods, and establish Chhattisgarh as a model for green agriculture in India.

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