

Investigation for Sustainable Development of Micro Agriculture through Hybrid Energy Systems (Solar and Biomass) in Remote Areas of Jharkhand: A Comprehensive Survey

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ABSTRACT

This comprehensive survey explores the potential for sustainable development of micro agriculture in remote areas of Jharkhand through the integration of hybrid energy systems. Focusing on the synergistic combination of solar and biomass energy, the study examines the technical aspects, benefits, and challenges of implementing these systems. The survey examines economic feasibility, environmental sustainability and the role of key stakeholders including the Jharkhand Renewable Energy Development Agency (JREDA). With emphasis on precision agriculture, this research highlights the transformative impact of hybrid energy solutions on energy access, agricultural productivity, and environmental protection in remote areas of Jharkhand. The findings advocate collaborative efforts between policymakers, researchers, and local communities to realize a greener and more resilient future for micro-agriculture in Jharkhand.

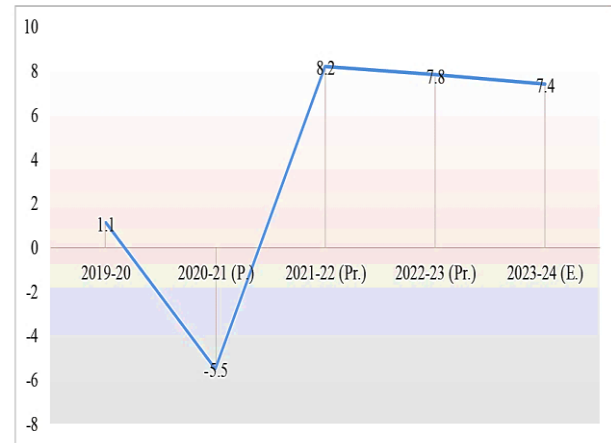
This work summarizes the important results of 34 research documents. These are primarily based on three focus areas (i) the potential of micro agriculture in Jharkhand, (ii) the deployment of hybrid energy (solar and biomass) based power generation, and (iii) the role of stakeholders. The review is expected to support upcoming researchers and power engineering practitioners working on operation and planning including hybrid energy (solar and biomass) based power generation and micro agriculture.

Keywords: Biomass, Hybrid Energy Systems, Jharkhand, JREDA, Micro agriculture, Smart Village, Solar.

1. INTRODUCTION

Jharkhand, a state in eastern India, has rich natural resources, diverse landscapes, and a unique cultural heritage. Established in 2000 after bifurcation from Bihar, Jharkhand has seen significant progress in various fields. Jharkhand is characterized by its ethnic diversity, with a significant tribal population contributing to its cultural richness. Jharkhand's economy is mainly dependent on mining and mineral-based industries. The state is known for its abundant coal, iron ore, copper, and bauxite reserves. The mining sector has significantly contributed to the state's gross domestic product (GDP). According to the Economic Survey of Jharkhand 2022-23, Gross State Domestic Product (GSDP) Projection for the FY 2022-23

and Forecast for the FY 2023-24 are depicted in Figure 1 [1].



(P-Provisional, Pr - Projected, E- Estimated)

Source: MoSPI, GoI and DES, GoJ.

Fig. 1. GSDP Projection for the FY 2022-23 and Forecast for the FY 2023-24 [1]

Furthermore, agriculture, another important component of the state's economy, supports a large section of the population. Primarily, rain-fed agriculture faces challenges such as low productivity, lack of modern technology and inadequate irrigation facilities. The government is implementing schemes to promote sustainable farming practices and increase the income of farmers [2]. Farming in Jharkhand is mainly done by small and marginal farmers adopting traditional farming methods. There is immense potential for horticulture and organic farming in the state of Jharkhand. According to the Jharkhand Economic Survey 2022-23, the government promotes horticulture through various schemes to diversify crops and increase farmers' income. Despite these efforts, challenges such as fragmented land holdings, lack of market access and vulnerability to climate change remain. Sustainable agricultural practices, technological interventions and market linkages are important to transform the agricultural landscape and ensure food security. The formulation of Jharkhand State Industrial Policy 2021 is an important step towards promoting industrial development. The policy emphasizes infrastructure development, skill enhancement and promotion of emerging sectors such as information technology and renewable energy [3], [4], [5], [6]. As per

information available in Jharkhand Economic Survey 2021-22, only 2% electricity is allocated for agriculture sector, represented in Figure 2 [1]. The data shows that the agriculture sector in Jharkhand required more support in terms of availability of power.

However, abundant in remote areas, Jharkhand faces significant challenges in providing consistent energy access for agricultural activities. Integrating hybrid energy solutions by leveraging solar and biomass resources is emerging as a promising avenue. The subsequent sections represent the outlining the importance of precision agriculture, energy demands and the imperative of sustainable practices.

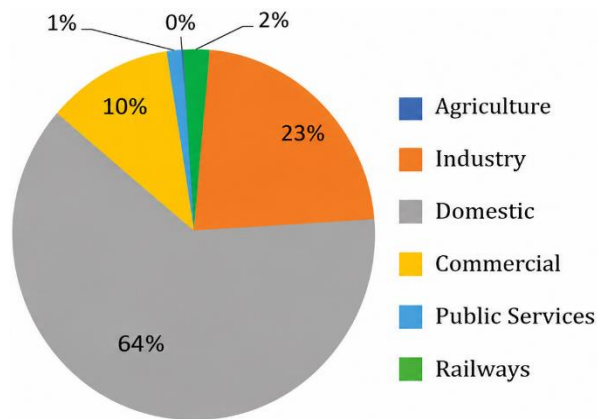


Fig. 2. Sector wise power consumption for FY 2021-22 [1]

II. MICRO AGRICULTURE AND RENEWABLE ENERGY INTEGRATION

Jharkhand has a predominantly agrarian economy, with a significant portion of its population living in rural villages. Integrating renewable energy-based power generation into micro-farming practices can emerge as a transformative force in meeting the energy needs of these villages while promoting sustainable development. In recent years, there has been an accelerated shift towards renewable energy sources such as solar and bio-gas energy, which provide viable solutions to the challenges posed by traditional energy sources. This section explores renewable energy's technical aspects, benefits, and impact on micro agriculture practices in Jharkhand villages [1], [6], [7], [8], [9], [10], [11], [12].

Implementing renewable energy-based power generation in villages of Jharkhand can include utilizing abundant solar and bio-gas resources prevalent in the area. Also, these systems can be integrated into microgrids, allowing decentralized power distribution, and reducing reliance on centralized grid infrastructure. Technical data shows that Jharkhand has an average of 300 sunny days annually, making solar energy an ideal source. Apart from this, forest resources can also be used in the state [13].

The adoption of energy-efficient technologies like energy-efficient pumps and drip irrigation systems powered by renewable energy can bring about a change in agricultural practices in these villages. A study by the Jharkhand Renewable Energy Development Agency

(JREDA) reported a 30% increase in crop yield and a 50% reduction in water consumption through integrating renewable energy into micro-farming practices. The technical efficiency of these systems is further supported by advances in energy storage solutions, enabling farmers to store excess energy for use during periods of non-sunlight or low gas unavailability. Integrating renewable energy into precision agriculture practices brings multifaceted benefits ranging from economic empowerment to environmental sustainability [1], [8], [14], [15]. Decentralization of power generation reduces transmission losses and ensures reliable and uninterrupted energy supply in rural areas. Farmers, who once depended on irregular grid connections or expensive diesel generators, now have access to a stable and affordable source of electricity in the form of renewable energy. This change not only improves the overall efficiency of agricultural operations but also enhances the quality of life of the rural population [16]. Furthermore, the economic impact of renewable energy integration extends to income generation through surplus power generation. The excess electricity farmers produce can be fed back into the grid, creating opportunities for them to become energy entrepreneurs. The revenue generated from selling surplus power can be reinvested in agriculture or other income-generating activities, contributing to the region's poverty alleviation and economic development. The environmental benefits of adopting renewable energy are paramount. Reducing dependence on fossil fuels reduces greenhouse gas emissions, thereby reducing the effects of climate change. Studies indicate that integrating renewable energy in villages in Jharkhand can significantly reduce carbon dioxide emissions, contributing to the state's commitment to the Sustainable Development Goals [2].

Therefore, integrating renewable energy-based power generation into micro-farming practices in villages of Jharkhand can be a game-changer for rural development. The technological efficiency of solar and bio-gas energy, combined with advances in energy storage, could usher in a new era of sustainable and resilient agricultural practices. Its benefits span from economic empowerment to environmental management, allowing Jharkhand to be established as a model for sustainable rural development through renewable energy integration. The villagers can integrate micro agriculture, solar and biomass energy, dairy and poultries at a common place for getting a cooperative and sustainable solution at local level as shown in Figure 3 [5], [17], [18].

A. Energy requirements for micro-agriculture

In the future, driven by technological advancements and sustainable practices, there is expected to be a transformational change in energy requirements for micro agricultural activities in the villages of Jharkhand. As global demand for food increases, especially in developing regions like Jharkhand, ensuring efficient and environment-friendly energy sources becomes paramount. The adoption of renewable energy solutions like solar and wind energy is projected to play an

important role in meeting the energy demands of micro agriculture. According to the International Renewable Energy Agency (IRENA), Jharkhand has immense untapped solar potential, with an average solar insolation of about 5 kWh/m²/day. Utilizing this solar energy through photovoltaic systems will provide a reliable energy source for agricultural activities and contribute to reducing carbon emissions. Additionally, bio-gas energy, with its promising potential in the state, can be harnessed using small-scale bio-gas generators designed for rural applications. Smart irrigation systems, sensor networks and automated machinery are expected to become integral parts of precision agriculture, optimizing resource utilization and improving crop yields. These technologies, powered by artificial intelligence (AI) and the Internet of Things (IoT), will require a reliable energy infrastructure. Microgrids designed for decentralized energy distribution will emerge as a key solution, ensuring a flexible and reliable power supply to support precision agriculture technologies. The Indian Ministry of New and Renewable Energy (MNRE) envisions widespread deployment of microgrids, and the government has already initiated pilot projects to evaluate their feasibility in rural areas[2], [5], [17], [18], [19], [20], [21], [22].

Furthermore, advances in energy storage technologies will be important in addressing the intermittent nature of renewable energy sources. Batteries with high energy density and long cycle life will enable efficient storage and use of surplus energy during peak production periods. This is particularly relevant for Jharkhand, where the grid infrastructure may not be as robust in remote villages. Cutting-edge battery technologies, such as lithium-ion and emerging options like solid-state batteries, are set to revolutionize energy storage in the context of precision agriculture.

The agricultural processes themselves will see a paradigm shift with the integration of sustainable energy solutions. Vertical farming, which maximizes space and resource efficiency, will gain prominence in villages in Jharkhand. LED lighting systems optimized for plant growth will be important in supporting year-round farming. Designed to operate on low power, these systems align with the energy-efficient ethos of future precision agriculture. Additionally, hydroponic and aquaponic systems requiring controlled environments will rely on energy-efficient heating, ventilation, and air conditioning (HVAC) systems, emphasizing the need for a reliable and sustainable energy infrastructure. Policy support and financial incentives will help advance the transition towards sustainable energy in Jharkhand's micro-agriculture sector. Government schemes like "Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan (PM-KUSUM)" aim to promote the use of solar energy for irrigation purposes. These initiatives and subsidies for adopting energy-efficient technologies will encourage farmers to invest in renewable energy solutions. Furthermore, collaboration between government bodies, non-governmental organizations (NGOs) and private enterprises will be essential in creating a holistic ecosystem that promotes integration of cutting-edge technologies into traditional agricultural practices. Hence, the future of energy requirements for micro agriculture in the villages of Jharkhand is poised for a sustainable and technology-driven transformation. The adoption of renewable energy sources, along with precision farming technologies and energy-efficient practices, will not only increase agricultural productivity but also contribute to environmental protection.



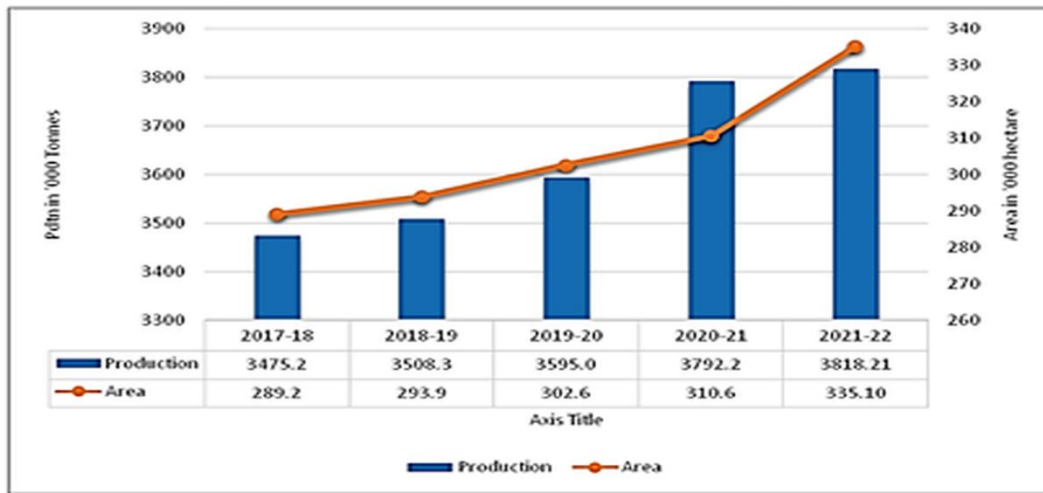
Fig. 3. Integration of micro agriculture-solar-biomass-dairy-poultry-compost

As Jharkhand strives for inclusive and sustainable development, the synergy between agriculture and renewable energy is key to fostering resilient rural communities. Through strategic planning, technological innovation and collaborative efforts, the vision of a greener and more productive agricultural landscape in the villages of Jharkhand can become a reality.

As per Jharkhand Economic Survey 2022-23 report, most farmers are engaged with production of Fruits and Vegetables about 83995 hectares (year 2020-21). Thus, it

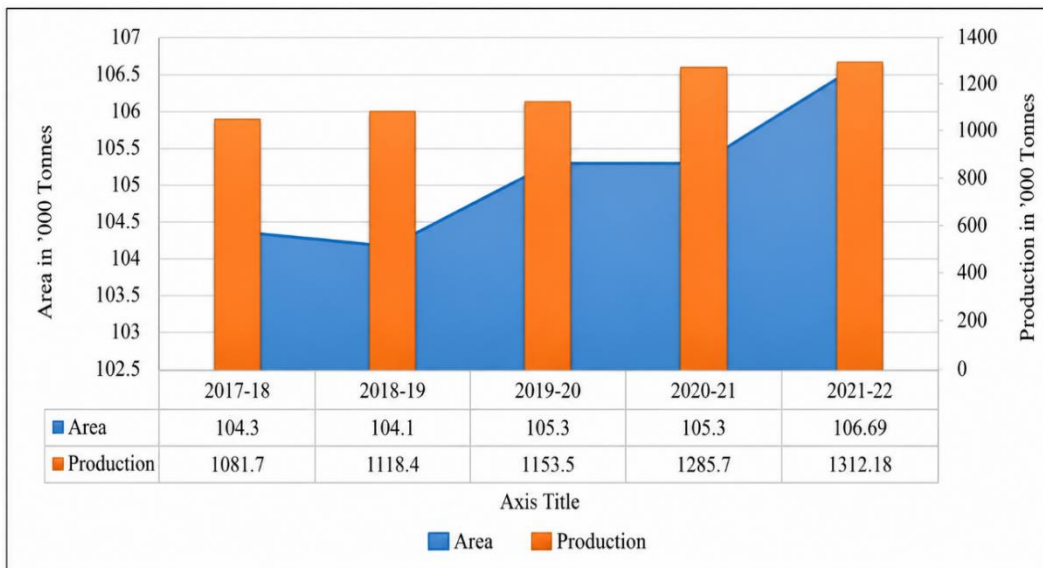
can be assumed that the villages of Jharkhand have potential to utilize the residue of these farms as biomass potential. The following figures 4 and 5 represent the agriculture production pattern of Jharkhand [23].

Similarly, a good number of people are engaged in the animal husbandry business. Which can be directly utilized to produce biogas and electrical energy. Following Table 1 represents the progress husbandry business in terms of animal's counts.



Source: Department of Agriculture, Animal Husbandry & Co-operative, Government of Jharkhand

Fig. 4. Year-Wise Area and Production of Vegetable [1]



Source: Department of Agriculture, Animal Husbandry & Co-operative, Government of Jharkhand

Fig. 5. Year-Wise Area and Production of fruits [1]

TABLE I
DELAY TOTAL LIVESTOCK AND POULTRY AND CHANGE
BETWEEN 2012 AND 2019 [1]

Category	2019	2012	% Change from 2012
Cattle	1,12,23,052	87,30,083	28.56
Buffaloes	13,50,313	11,85,942	13.86
Sheep	66,41,183	5,82,925	1,039.29
Goats	91,21,173	65,81,449	38.59
Horses and Ponies	1,378	5,706	-75.85
Mules	73	3,890	-98.12
Donkeys	400	381	4.99
Pigs	12,76,973	9,62,367	32.69
Total Livestock	2,36,14,545	1,80,52,746	30.81
Total Poultry	2,48,32,906	1,35,59,528	83.14

Source: 20th Livestock Census-2019, Ministry of Fisheries, Animal Husbandry & Dairying, Government of India.

B. Renewable energy initiatives and JREDA

Jharkhand Renewable Energy Development Agency (JREDA) has become a major player in promoting sustainable and environment-friendly energy solutions in Jharkhand, India. To harness the abundant renewable resources available in the region, JREDA has implemented several initiatives with a special focus on solar and biomass energy. Solar energy is a major component of JREDA's renewable energy portfolio. The agency has successfully implemented several solar projects across the state, ranging from small-scale rooftop installations to large-scale solar power plants. The technical data associated with these projects shows impressive efficiency and capacity factors. For example, the rooftop solar power plant with a capacity of 860 kW at Ranchi Railway Station is operating with an average annual capacity utilization factor (CUF) of more than

18%. The project contributes significantly to reducing the carbon footprint and demonstrates the feasibility of solar energy in meeting the region's power demands [4], [14], [16], [23], [24], [25], [26], [27].

Besides solar, JREDA has actively promoted biomass energy as a sustainable option. Biomass initiatives may utilize organic waste and agricultural residues for energy production. The successful integration of biomass energy into the region's power grid addresses environmental concerns and supports local farmers by creating additional revenue sources by selling agricultural residues.

JREDA's commitment to renewable energy is exemplified by its focus on decentralized solutions such as solar street lighting and water pumping systems. These initiatives not only increase energy access in remote areas but also contribute to reducing dependence on traditional energy sources. The technical parameters of these decentralized projects, such as the solar water pumping system in Palamu, underline their effectiveness in providing sustainable and reliable energy solutions to off-grid communities. To ensure the transparency and credibility of its initiatives, JREDA actively collaborates with reputed institutions and adheres to international standards. The agency often collaborates with the Ministry of New and Renewable Energy (MNRE) and the Indian Renewable Energy Development Agency (IREDA) to provide technical expertise and financial support. The technical guidelines provided by these organizations play a vital role in the design and implementation of JREDA's projects, ensuring that they meet the highest standards of efficiency and sustainability [27].

In addition, JREDA regularly publishes reports and documents detailing the performance and impact of its renewable energy initiatives. These reports serve as valuable references for researchers, policymakers and other stakeholders interested in renewable energy. By disseminating technical data and project results, JREDA contributes to the growing knowledge on renewable energy implementation, facilitating the replication of successful models in other regions [1].

C. Hybrid energy systems and micro-agriculture: Challenges and solutions

Hybrid energy systems (solar and biomass) integrated with micro-agriculture represent a promising opportunity for sustainable development, providing a synergistic approach to address energy and food security challenges. As the global population grows, energy and food resources demand increases. Integrating solar and biomass energy sources in a hybrid system presents an innovative solution to meet these demands in an environmentally friendly manner. Solar power harnesses the sun's energy through photovoltaic panels, while biomass uses organic materials such as agricultural residues to produce electricity. This integration not only diversifies the energy mix but also increases the overall efficiency and reliability of the system.

One of the major challenges in implementing hybrid energy systems for precision agriculture is optimizing the integration of solar and bio-mass components. The intermittent nature of solar power generation and variability in bio-mass feedstock availability require sophisticated control systems to ensure a stable and reliable power supply. Advanced energy management algorithms and smart grid technologies play a vital role in overcoming these challenges by intelligently balancing energy inputs from both sources. Researchers have explored various control strategies, such as predictive modelling and machine learning algorithms, to optimize the performance of hybrid systems based on real-time data, weather conditions and crop energy requirements.

Micro-agriculture, characterized by small-scale farming and precision farming techniques, further complicates the integration of hybrid energy systems. Energy demands in micro-agriculture settings are diverse, ranging from irrigation and greenhouse operations to post-harvest processing. Designing a hybrid energy system to meet these requirements requires a holistic understanding of agricultural processes and energy consumption patterns. Microgrid deployment within farming communities also increases energy access and promotes energy self-sufficiency, contributing to rural development.

In addition to the technical challenges, the economic feasibility of implementing hybrid energy systems in precision agriculture is an important consideration. Initial capital costs, maintenance and operating expenses must be balanced against long-term benefits, including energy cost savings and increased agricultural productivity. Government incentives, subsidies and favorable policies can play an important role in encouraging the adoption of hybrid energy systems in agriculture. Case studies of areas where such incentives exist demonstrate positive effects on both the economic viability of the system and the overall sustainability of farming practices. Furthermore, the environmental sustainability of hybrid energy systems in micro-agriculture depends on effective waste management and biomass utilization. Residues from agricultural activities, such as crop residues and organic waste, serve as a valuable feedstock for biomass energy production. Efficient conversion technologies, including anaerobic digestion and gasification, can convert these residues into bioenergy while reducing environmental impacts. Proper waste management practices contribute to reducing greenhouse gas emissions, aligning the hybrid system with the principles of a circular economy.

Successful implementation of hybrid energy systems in precision agriculture requires collaboration and knowledge exchange between stakeholders, including researchers, policymakers, and local communities. Interdisciplinary research efforts that combine expertise in agriculture, energy systems, and environmental sciences are critical to developing holistic solutions. Additionally, knowledge transfer programs and capacity-building initiatives can empower local communities to

harness the benefits of hybrid energy systems, promoting sustainable development at the grassroots level [5].

Micro agriculture, especially in the context of Jharkhand, faces a myriad of challenges ranging from irregular power supply to soil erosion. Integration of hybrid energy systems combining solar and biomass technologies can emerge as a promising solution to address these challenges and revolutionize the future of agriculture in the region. Jharkhand, due to its abundant sunshine, is suitable for solar applications. According to the National Institute of Solar Energy (NISE), the average solar insolation in the state is about 5.5 kWh/m²/day, making it favorable for solar energy production (NISE, 2022). However, solar energy alone may not be sufficient for energy-intensive agricultural processes. This is where biomass energy comes in handy. Biomass, derived from agricultural residues and organic waste, complements solar energy by providing a consistent and reliable energy source. The Central Pollution Control Board (CPCB) reported that Jharkhand generates substantial amounts of agricultural residues, which could make biomass energy production possible (CPCB, 2022).

However, integrating these systems has its own challenges. The intermittent nature of solar energy production and the variability in biomass availability require sophisticated control and storage systems. Energy storage technologies such as batteries become important to store excess energy during peak production periods for later use. Additionally, the development of efficient biomass processing units is required to convert agricultural residues into useful biomass fuel. To overcome these challenges and adapt hybrid energy systems for precision agriculture in Jharkhand, collaborative efforts are being made between research institutes, government agencies and private enterprises.

Furthermore, the economic feasibility of such systems needs to be carefully considered. Initial setup costs, maintenance and technological progress should be commensurate with the socio-economic conditions of the area. Government subsidies and financial incentives can play an important role in encouraging farmers to adopt these sustainable practices. The Ministry of New and Renewable Energy (MNRE) provides various schemes and subsidies to promote solar energy adoption in agriculture (MNRE, 2022). A similar approach can be extended to biomass energy, promoting holistic and integrated energy solutions for micro-farming in Jharkhand. Therefore, integrating hybrid energy systems combining solar and bio-mass technologies holds immense potential to transform precision agriculture in Jharkhand. Although challenges remain, strategic planning, technological innovation and collaborative efforts can pave the way to a sustainable and efficient future. Adoption of these solutions not only meets energy needs but also contributes to environmental protection and economic development in the region, linking with the broader goal of achieving a green and resilient agriculture sector.

III. MICROAGRICULTURE AND SUSTAINABLE DEVELOPMENT: A PROPOSED SOLUTION

Hybrid energy systems combining solar and biomass energy sources have emerged as promising solutions for increasing energy demand while reducing environmental impacts. Solar energy, derived from the Sun's abundant rays, and biomass energy, derived from organic matter, provide complementary benefits, providing a reliable and sustainable power supply. Integrating these two sources creates a synergy that increases energy production efficiency and ensures more consistent power generation.

Solar power, the cornerstone of renewable energy, plays a key role in hybrid systems. Photovoltaic (PV) panels convert sunlight into electricity, providing clean and abundant energy with minimal environmental impact. Technological advances in PV technology have significantly increased conversion efficiency, making solar energy a cost-effective and viable option for power generation. Additionally, concentrated solar power (CSP) systems use mirrors or lenses to focus sunlight onto a small area, generating high temperatures that can be used to produce electricity. The combination of PV and CSP technologies in hybrid systems allows for continuous power generation while addressing the intermittent nature of solar power [28], [29], [30], [31].

As a complement to solar energy, biomass energy contributes to the reliability and flexibility of the hybrid system. Biomass-derived from organic materials such as wood, agricultural residues and organic waste can be converted into biofuel or burned directly to produce electricity. Bioenergy systems provide dispatchable electricity, adjusting energy production based on demand. Gasification of biomass, a thermochemical process that converts organic matter into syngas, allows efficient and clean use of biomass resources. Advanced gasification technologies, such as fluidized beds and entrained flow gasifiers, increase overall efficiency and reduce emissions in hybrid energy systems [32], [33].

A notable example of the successful implementation of a solar-biomass hybrid energy system is the project in Varese, Italy, where a solar park has been integrated with a biomass power plant. The solar park, equipped with state-of-the-art PV panels, produces electricity during daylight hours, while the biomass power plant produces electricity continuously, providing a stable power supply. Integrating these two sources ensures stable and reliable energy production that meets local energy demand while reducing dependence on traditional fossil fuels. The success of such projects underlines the potential of hybrid energy systems in achieving sustainability goals. Technical data of hybrid energy systems demonstrate their efficiency and environmental benefits. A study by the International Energy Agency (IEA) highlights that integrating solar and biomass technologies in hybrid systems can achieve higher overall efficiency than standalone systems. Additionally, using solar and biomass resources optimizes energy production, resulting in a more reliable and consistent power supply. The study also

highlights the potential to reduce greenhouse gas emissions by deploying hybrid systems, contributing to global efforts to mitigate climate change. Figure 6 represents a proposed solution of hybrid systems

including different types of energy systems and their uses [33], [34].

Several notable biomass power projects contribute significantly to India's renewable energy landscape.

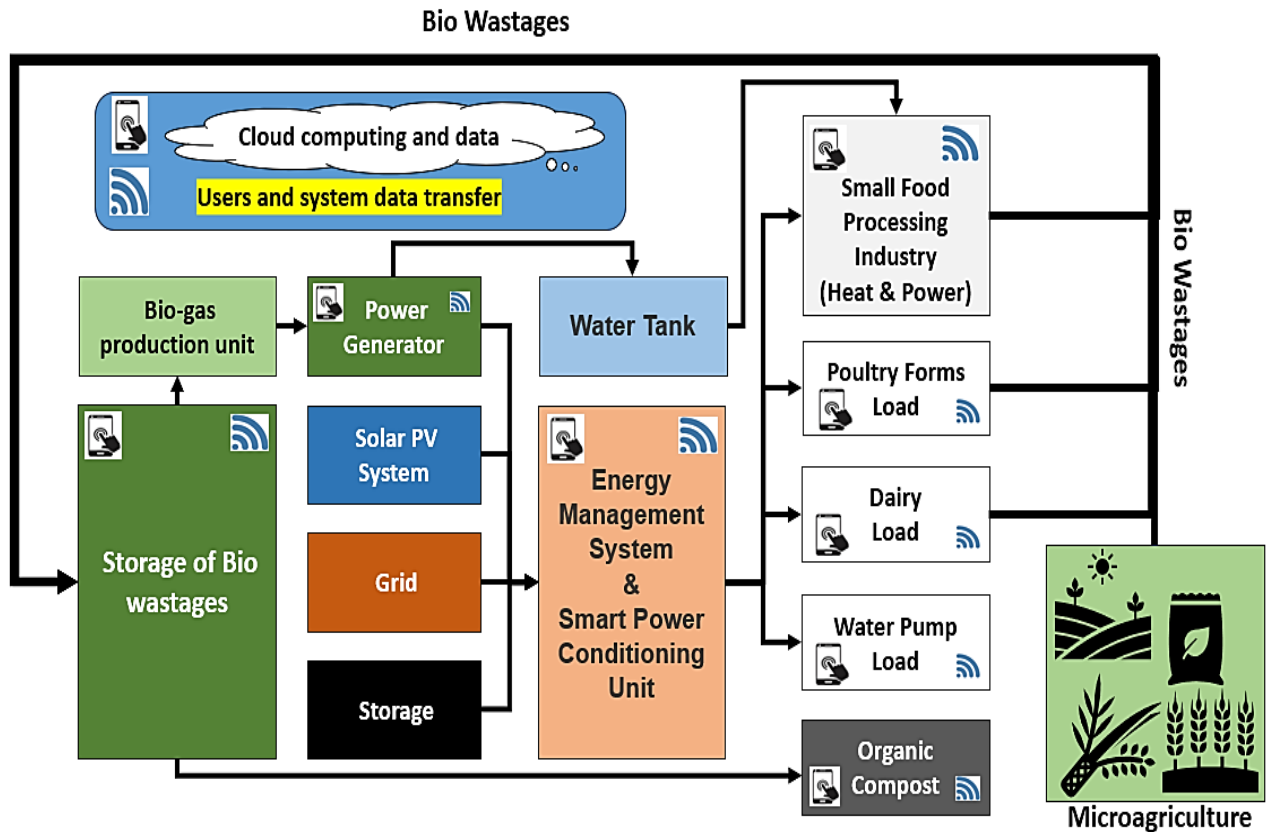


Fig. 6. Proposed solution of hybrid energy systems and their uses.

In Andhra Pradesh, Sembcorp Gayatri Power Limited operates a biomass-based power plant, increasing the region's renewable energy potential. Meanwhile, Moser Baer Clean Energy Ltd. in Punjab uses agricultural residues and biomass sources to generate electricity, contributing to the state's sustainable energy goals. Punjab Renewable Energy Systems Pvt. Ltd. is another major player in biomass power generation in the same state, further strengthening Punjab's renewable energy portfolio. Simhapuri Energy Limited in Andhra Pradesh generates electricity from locally available biomass resources through its power plant. Dalmia Bharat Sugar and Industries Limited in Uttar Pradesh uses bagasse and other biomass materials in collaboration with its sugar mill for biomass power generation. Rajasthan Biomass Power Limited in Rajasthan, Shalivahan Green Energy Limited in Maharashtra, Jindal Green Power Limited in Chhattisgarh, Vidarbha Industries Power Limited in Maharashtra, and Nandan Biomatrix Limited in Karnataka are collectively involved in sustainable energy production in various regions of India by using agricultural residues. These initiatives underline the country's commitment towards a diverse and environmentally friendly energy portfolio. The integration of solar and biomass energy in hybrid systems

not only addresses the problem of intermittent solar power but also contributes to the overall stability of the grid. The diversity of energy sources ensures a more robust and flexible energy infrastructure that can adapt to fluctuations in demand and supply. Furthermore, hybrid systems promote energy independence by diversifying the resource mix and reducing dependence on a single energy source. This diversification enhances energy security and reduces the impact of fluctuations in resource availability, thereby ensuring continuous power supply[30–32].

IV. FUTURE DIRECTIONS AND RECOMMENDATIONS: TRAJECTORY OF SUSTAINABILITY

It's abundant renewable energy resources and foster the future trajectory of sustainable micro agriculture, integrating solar and biomass energy, holds immense potential for the agricultural landscape of Jharkhand. The state, blessed with abundant sunlight and biomass resources, presents a unique opportunity to use renewable energy for agricultural practices. Key recommendations are important for policymakers, researchers, and stakeholders to ensure the successful integration of these technologies.

A multi-pronged approach is necessary for policymakers. First, encouraging the adoption of solar and biomass technologies through subsidies and favorable policy frameworks will catalyze the transition. A policy scenario that promotes decentralized energy production and distribution can empower farmers to become energy producers, thereby promoting energy self-sufficiency. Additionally, policymakers should focus on creating an enabling environment for micro-agriculture through land-use policies that support small-scale, sustainable farming practices. The initial financial burden on farmers can be reduced by collaborating with financial institutions to provide low-interest loans to purchase and install renewable energy systems.

The main recommendations for researchers include continuous innovation and adaptation of technologies to suit the specific needs of the agricultural landscape of Jharkhand. Research efforts should focus on developing efficient, economical and scalable solar and biomass solutions for smallholder farmers. Integrating smart technologies, such as precision agriculture, can increase the overall efficiency of agricultural operations. Furthermore, researchers should focus on developing robust storage solutions to address the intermittent nature of renewable energy sources, ensuring reliable power supplies for agriculture. Collaborative research initiatives with agricultural universities and institutes of technology can help create a knowledge-sharing ecosystem, promoting the development of context-specific solutions.

The main recommendations revolve around awareness and capacity building for stakeholders, including farmers and community-based organizations. Stakeholders should be educated on the benefits of sustainable micro-agriculture with emphasis on long-term economic and environmental benefits. Training programs on installing, operating and maintaining solar and biomass technologies should be implemented to empower farmers with the necessary skills. Collaborative platforms bringing together farmers, NGOs and private sector entities can facilitate the exchange of knowledge and experiences and foster a sense of community ownership and shared responsibility for sustainable development.

In this context, emphasis on scalability, affordability and inclusive growth is paramount. Scalability ensures that solutions can be expanded to reach larger audiences, maximizing impact. Affordability ensures that even resource-constrained farmers can access and adopt these technologies. Inclusive development ensures that the benefits of sustainable micro-agriculture reach all sections of society, including marginalized and small farmers, contributing to overall rural development. To facilitate scalability, investments in research and development should focus on creating modular and adaptable solutions that can be easily replicated across diverse agricultural settings in Jharkhand. Affordability can be increased through innovative financing models such as pay-as-you-

go systems, which allow farmers to pay for energy services incrementally. Inclusive development requires a proactive approach to address marginalized communities' specific needs and challenges, ensuring they are not left behind in the transition to sustainable micro agriculture.

Therefore, the future trajectory of sustainable micro agriculture integrating solar and biomass energy in Jharkhand depends on the collaborative efforts of policymakers, researchers, and stakeholders. By implementing these key recommendations, the state can harness a resilient and inclusive agriculture sector that aligns with the broader Sustainable Development Goals.

Envisioning the future trajectory of sustainable micro agriculture in Jharkhand, this section outlines key recommendations for policymakers, researchers, and stakeholders. Emphasis is placed on scalability, affordability, and inclusive development.

V. CONCLUSION

In conclusion, the comprehensive survey on the sustainable development of micro agriculture through hybrid energy systems in remote areas of Jharkhand highlights the important interrelationship of agriculture and renewable energy integration. This study highlights the transformative potential of hybrid systems, especially those combining solar and biomass energy, to meet the energy needs of micro-farming. It provides valuable insights into renewable energy initiatives led by the Jharkhand Renewable Energy Development Agency (JREDA). The survey highlights the challenges and solutions of integrating hybrid energy systems into precision agriculture, emphasizing the importance of advanced energy management algorithms and smart grid technologies. The proposed solution involves designing and developing hybrid energy systems ready for precision agriculture by leveraging solar and biomass technologies. Future directions and recommendations underline the need for a multi-pronged approach emphasizing scalability, affordability, and inclusive growth, guided by collaborative efforts between policy makers, researchers, and stakeholders. The path towards sustainability in Jharkhand's micro-agriculture depends on strategic planning, technological innovation, and a collective commitment to a greener and more resilient future.

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REFERENCES

- [1] Centre for Fiscal Studies P and DDG of J (2023) ECONOMIC SURVEY JHARKHAND 2022-23. Routledge
- [2] Khatri-Chhetri A, Aggarwal PK, Joshi PK, Vyas S (2017) Farmers' prioritization of climate-smart agriculture (CSA)

- technologies. *Agric Syst* 151:184–191.
<https://doi.org/10.1016/j.agvsy.2016.10.005>
- [3] Shabbir Alam M, Duraisamy P, Bakkar Siddik A, et al (2023) The impacts of globalization, renewable energy, and agriculture on CO₂ emissions in India: Contextual evidence using a novel composite carbon emission-related atmospheric quality index. *Gondwana Res* 119:384–401.
<https://doi.org/10.1016/j.gr.2023.04.005>
- [4] Elahi E, Khalid Z, Zhang Z (2022) Understanding farmers' intention and willingness to install renewable energy technology: A solution to reduce the environmental emissions of agriculture. *Appl Energy* 309:..
<https://doi.org/10.1016/j.apenergy.2021.118459>
- [5] Kothari R, Vashishtha A, Singh HM, et al (2020) Assessment of Indian bioenergy policy for sustainable environment and its impact for rural India: Strategic implementation and challenges. *Environ Technol Innov* 20:101078. <https://doi.org/10.1016/j.eti.2020.101078>
- [6] Takahashi K, Muraoka R, Otsuka K (2020) Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. *Agric Econ (United Kingdom)* 51:31–45.
<https://doi.org/10.1111/agec.12539>
- [7] Naveen S, Aravind S, Yamini B, et al (2023) A review on solar energy intensified biomass valorization and value-added products production: Practicability, challenges, techno economic and lifecycle assessment. *J Clean Prod* 405:137028.
<https://doi.org/10.1016/j.jclepro.2023.137028>
- [8] Majeed Y, Khan MU, Waseem M, et al (2023) Renewable energy as an alternative source for energy management in agriculture. *Energy Reports* 10:344–359.
<https://doi.org/10.1016/j.egy.2023.06.032>
- [9] Hernandez-Escobedo Q, Muñoz-Rodríguez D, Vargas-Casillas A, et al (2023) Renewable Energies in the Agricultural Sector: A Perspective Analysis of the Last Three Years. *Energies* 16:1–17.
<https://doi.org/10.3390/en16010345>
- [10] Udomkun P, Romuli S, Schock S, et al (2020) Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. *J Environ Manage* 268:110730.
<https://doi.org/10.1016/j.jenvman.2020.110730>
- [11] Aryal JP, Sapkota TB, Khurana R, et al (2020) Climate change and agriculture in South Asia: adaptation options in smallholder production systems. Springer Netherlands
- [12] Ridzuan NHAM, Marwan NF, Khalid N, et al (2020) Effects of agriculture, renewable energy, and economic growth on carbon dioxide emissions: Evidence of the environmental Kuznets curve. *Resour Conserv Recycl* 160:104879.
<https://doi.org/10.1016/j.resconrec.2020.104879>
- [13] Eliazar Nelson ARL, Ravichandran K, Antony U (2019) The impact of the Green Revolution on indigenous crops of India. *J Ethn Foods* 6:1–10.
<https://doi.org/10.1186/s42779-019-0011-9>
- [14] Waheed R, Chang D, Sarwar S, Chen W (2018) Forest, agriculture, renewable energy, and CO₂ emission. *J Clean Prod* 172:4231–4238.
<https://doi.org/10.1016/j.jclepro.2017.10.287>
- [15] Kumar S, Raut RD, Nayal K, et al (2021) To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP. *J Clean Prod* 293:126023.
<https://doi.org/10.1016/j.jclepro.2021.126023>
- [16] Soundarrajan P, Vivek N (2016) Green finance for sustainable green economic growth in india. *Agric Econ (Czech Republic)* 62:35–44.
<https://doi.org/10.17221/174/2014-AGRICECON>
- [17] Kapoor R, Ghosh P, Kumar M, et al (2020) Valorization of agricultural waste for biogas based circular economy in India: A research outlook. *Bioresour Technol* 304:123036.
<https://doi.org/10.1016/j.biortech.2020.123036>
- [18] Ugwoke B, Adeleke A, Corngati SP, et al (2020) Decentralized renewable hybrid mini-grids for rural communities: Culmination of the IREP framework and scale up to urban communities. *Sustain* 12:..
<https://doi.org/10.3390/SU12187411>
- [19] Syiem R, Raj S (2015) Access and Usage of ICTs for Agriculture and Rural Development by the tribal farmers in Meghalaya State of North-East India. *J Agric Informatics* 6:24–41.
<https://doi.org/10.17700/jai.2015.6.3.190>
- [20] Chetan Dwarkani M, Ganesh Ram R, Jagannathan S, Priyatharshini R (2015) Smart farming system using sensors for agricultural task automation. *Proc - 2015 IEEE Int Conf Technol Innov ICT Agric Rural Dev TIAR 2015* 49–53. <https://doi.org/10.1109/TIAR.2015.7358530>
- [21] Emerick K, Janvry A De, Sadoulet E, Dar MH (2016) Technological innovations , downside risk , and the modernization of agriculture Online Appendix Appendix A : Theoretical Model. *Am Econ Rev* 106:1537–1561
- [22] Mehdi BJ, Slim BY (2017) The role of renewable energy and agriculture in reducing CO₂ emissions: Evidence for North Africa countries. *Ecol Indic* 74:295–301.
<https://doi.org/10.1016/j.ecolind.2016.11.032>
- [23] García VC (2017) Optimal energy planning of a rural community in Jharkhand
- [24] Cai Y, Xu J, Ahmad P, Anwar A (2021) What drives carbon emissions in the long-run? The role of renewable energy and agriculture in achieving the sustainable development goals. *Econ Res Istraz* 35:4603–4624.
<https://doi.org/10.1080/1331677X.2021.2015613>
- [25] Aydoğan B, Vardar G (2020) Evaluating the role of renewable energy, economic growth and agriculture on CO₂ emission in E7 countries. *Int J Sustain Energy* 39:335–348.
<https://doi.org/10.1080/14786451.2019.1686380>
- [26] Mittal S, Ahlgren EO, Shukla PR (2018) Barriers to biogas dissemination in India: A review. *Energy Policy* 112:361–370. <https://doi.org/10.1016/j.enpol.2017.10.027>
- [27] Abaka JU, Olokede O, Ibraheem TB, et al (2017) Renewable Energy and Agriculture: A Partnership for Sustainable Development. *Int J Mod Eng Res* 7:37–44
- [28] Liu X, Zhang S, Bae J (2017) The impact of renewable energy and agriculture on carbon dioxide emissions: Investigating the environmental Kuznets curve in four selected ASEAN countries. *J Clean Prod* 164:1239–1247.
<https://doi.org/10.1016/j.jclepro.2017.07.086>
- [29] Mittal S, Mehar M (2016) Socio-economic Factors Affecting Adoption of Modern Information and

Communication Technology by Farmers in India: Analysis Using Multivariate Probit Model. J Agric Educ Ext 22:199–212. <https://doi.org/10.1080/1389224X.2014.997255>

- [30] Luthra S, Kumar S, Garg D, Haleem A (2015) Barriers to renewable/sustainable energy technologies adoption: Indian perspective. Renew Sustain Energy Rev 41:762–776. <https://doi.org/10.1016/j.rser.2014.08.077>
- [31] Mazid M, Khan TA (2014) Future of Bio-fertilizers in Indian agriculture: An Overview. Int J Agric Food Res 3:10–23. <https://doi.org/10.24102/ijafr.v3i3.132>
- [32] Dimpl E (2011) Small-scale Electricity Generation from Biomass Part I - Biomass Gasification. Biomass Gasif
- [33] Cardoen D, Joshi P, Diels L, et al (2015) Agriculture biomass in India: Part 2. Post-harvest losses, cost and environmental impacts. Resour Conserv Recycl 101:143–153. <https://doi.org/10.1016/j.resconrec.2015.06.002>
- [34] Cardoen D, Joshi P, Diels L, et al (2015) Agriculture biomass in India: Part 1. Estimation and characterization. Resour Conserv Recycl 102:39–48. <https://doi.org/10.1016/j.resconrec.2015.06.003>

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