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ECONOMIC AND SOCIAL BENEFITS OF ROBOTICS IN SOLAR AND BIOMASS ENERGY: A REVIEW WITH IMPLICATIONS FOR BIHAR

[1]Dr.Mamta Kumari, [2]Pankaj Chandra Sinha, [3]Pallav Chandra Sinha, [4]Md Gauhar Hasnain, [5]Vikash Kumar Sah, [6]Dhananjay Kumar

[1] Assistant Professor, Department Of Management, L.N.Mishra Institute of Economic Development and Social Change Patna, Bihar, India
[2]Assistant Professor, Department of Computer Science, Catalyst College, Patna, Bihar, India
[3] Assistant Professor, BCA, Mother Teressa Management College, Aryabhatta Knowledge University, Bihta, Bihar, India
[4] Assistant Professor, Department of Management, International School of Management, Patna
[5]Assistant Professor, BCA, Mother Teressa Management College, Aryabhatta Knowledge University, Bihta, Bihar, India
[6] Assistant Professor, BCA, Mother Teressa Management College, Aryabhatta Knowledge University, Bihta, Bihar, India

Corresponding Author
Dr. Mamta Kumari,
mamtajha@lnmipat.ac.in

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ABSTRACT

Robotics integration in the renewable energy sectors of solar and biomass energy can change energy production, improve efficiency, and introduce sustainability practices. This review paper will address some of the economic and social benefits of robotics in such energy domains, specifically for the state of Bihar in India, where substantial challenges in the production of energy are present. To initiate, the paper will discuss the situation of solar and biomass energy in Bihar: where this state is still poor concerning the provision of electricity, which indicates the amount of dependency that the state has with the conventional energy, and thus how urgent the need is for alternative sustainable sources. We then analyze the appraisal of how robotics can maximize energy production through automation, precision agriculture, and predictive maintenance-cutting operational costs and therefore maximizing energy output. The paper discusses various robotic applications such as automated solar panel cleaning systems and biomass processing robots, about which emphasis was placed for improving productivity and operational efficiency. We also take into account the socio-economic impacts of introducing robotics into these energy sectors. Improved access to energy, through more efficient modes of production, holds the promise of lifting local economic performance and providing employment opportunities and reducing energy poverty. However, the paper also addresses some of the possible challenges, such as some displacement of jobs and hence the need for upgradation in skills in response to new technologies. To put this into perspective, the literature synthesis and case studies are reviewed below to give an overview of successful implementations of robotics in renewable energy globally. We further discuss policy recommendations and strategies that must be integrated into Bihar's energy framework to support sustainable development goals and address regional energy demands. Hence, in conclusion, the strategic deployment of robotics in solar and biomass energy does not merely serve to provide significant economic advantage but also contributes to social development of Bihar to ensure a viable and sustainable future of the energy world.

Keywords: Robotics, Solar Energy, Biomass Energy, Economic Benefits, Social Benefits, Renewable Energy, Bihar, Sustainable Development, Automation, Energy Accessibility.

1. INTRODUCTION

In the face of escalating climate change and increasing energy demands, the global transition towards renewable energy sources has become a cornerstone of sustainable development. India, a rapidly developing nation with a population exceeding 1.4 billion, is particularly vulnerable to the impacts of climate change. As a result, the Indian government has set ambitious targets to expand its renewable energy capacity significantly, aiming for 500 gigawatts (GW) of renewable energy by 2030. This initiative not only reflects India’s commitment to reducing greenhouse gas emissions but also emphasizes the need to diversify its energy portfolio to enhance energy security and accessibility. Among the various renewable energy sources, solar and biomass energy have emerged as two critical pillars that can play a transformative role in meeting the country's energy needs [1].

Bihar, located in the eastern part of India, epitomizes the challenges and opportunities associated with energy transition. Despite its rich agricultural resources and favorable climatic conditions for solar energy, Bihar has struggled with energy poverty, with a substantial portion of its population lacking reliable access to electricity. The state's economy is primarily agrarian, heavily dependent on traditional biomass fuels such as firewood and crop residues. This reliance on non-renewable sources not only perpetuates energy insecurity but also poses significant environmental challenges, including deforestation and air pollution. Therefore, the promotion of renewable energy, particularly solar and biomass, is vital for Bihar to achieve energy independence, enhance the quality of life for its citizens, and foster sustainable development [1].

The integration of robotics into the renewable energy sector presents a unique opportunity to address the inherent challenges associated with solar and biomass energy production. Robotics encompasses a range of technologies designed to automate processes, improve efficiency, and reduce human intervention in energy systems. In the context of solar energy, robotics can facilitate tasks such as solar panel cleaning, tracking, and maintenance, which are crucial for maximizing energy output. Similarly, in biomass energy production, robotic systems can streamline operations such as collection, processing, and conversion of biomass materials. These advancements not only increase the productivity and cost-effectiveness of renewable energy systems but also minimize operational risks associated with manual labor, thereby enhancing overall energy reliability [2].

Fig 1. Robots in Installation of Pannels [Source : google]

This paper aims to explore the economic and social benefits of robotics in the solar and biomass energy sectors, specifically focusing on Bihar. The objectives are twofold: first, to analyze the potential economic impacts of integrating robotic technologies in these energy domains, including cost savings, increased energy production, and job creation; and second, to examine the social implications, such as improved energy accessibility, enhanced quality of life, and community engagement. Through a comprehensive review of existing literature and relevant case studies, this paper seeks to highlight the transformative potential of robotics in renewable energy, providing actionable insights for policymakers and stakeholders in Bihar. By elucidating the pathways through which robotics can contribute to sustainable energy development, the findings aim to foster a deeper understanding of how technology can serve as a catalyst for positive change in the region [2].

In conclusion, the intersection of robotics, solar energy, and biomass energy presents a promising frontier for addressing the multifaceted energy challenges faced by Bihar. By leveraging advanced technologies, the state can not only meet its energy demands but also drive economic growth and social progress, ultimately paving the way for a sustainable and resilient energy future.

2. CURRENT SCENARIO OF SOLAR AND BIOMASS ENERGY IN BIHAR

2.1 Solar Energy in Bihar

Bihar has moved ahead very well in the solar energy sector that places it among the top states in India with significant solar potential. The state received an average daily solar radiation of around 5.5 to 6.5 kWh/m2 per day, making it a suitable place for solar power generation. This potential has been recognized by the Government of Bihar and various initiatives are being started to harness solar energy to provide electricity to the increasing population in that state. Currently, by 2023, Bihar has installed a total solar capacity of approximately 1,000 MW with the majority reason being government policies encouraging solar installations, such as rooftop solar projects, solar parks, and decentralized solar power systems [3]. However, with all these developments, Bihar still remains to be challenged considerably in the full exploitation of solar energy. Generally, an electricity supply is lost to a considerable number of people, and the dispensation network is inadequate for the large-scale solar projects. Added to this are challenges including land acquisition, funding, and technical expertise in solar technologies. These measures have been evolving efforts on the part of the state government, facilitating private investments, and assuring supportive policies while involving diverse stakeholders in improving the infrastructure and facilitation of accessibility [3].

2.2 Biomass Energy in Bihar

Biomass energy counts among the most important constituents of the renewable energy sector of Bihar. Considering this an agrarian economy, it is important to note that there are adequate agricultural residues. Biomass represents organic matter, which includes crop residues, animal waste, and forestry by-products, which can be used as energy inputs by means of combustion, anaerobic digestion, or gasification. Biomass is mainly used as a fuel to cook and heat in the rural areas of Bihar. Biomass fuels are still one of the dominant energy sources today. MNRE estimates that Bihar has a potential of around 5,000 MW from biomass, mainly from agricultural residues [4].

Biomass energy has the added advantage of double-edged benefit: it provides a renewable source of energy besides helping in solving the problem of agricultural residue disposal. Biomass projects can make waste into energy and, consequently, help in reducing environmental pollution, while energizing rural communities. Although the biomass sector is still in its nascent stages in Bihar, there are challenges that need to be improved, including low technology base and limited awareness of biomass conversion technologies among farmers and a lack of infrastructure for collection and processing. This is coupled with the state government-led initiatives in favor of biomass energy, from their part, such as the provision of subsidies for power generated through biomass and research and development funding towards improving the efficiency of technologies in biomass. The following table summarizes the current state of solar and biomass energy in Bihar, providing key statistics and sources for reference [4]:

Table 1. Current State of Solar and Biomass Energy in Bihar

Energy Source	Installed Capacity (MW)	Potential Capacity (MW)	Key Initiatives	Current Challenges
Solar Energy	1,000	15,000 (estimated)	Bihar Solar Policy, Rooftop Solar Scheme	Inadequate infrastructure, financing issues, land acquisition
Biomass Energy	25	5,000 (estimated)	Biomass Policy, Subsidies for Biomass Projects	Lack of technology, awareness, and processing infrastructure

Sources:

1. Ministry of New and Renewable Energy (MNRE), Government of India.
2. Bihar Renewable Energy Development Agency (BREDA) reports.
3. National Institute of Wind Energy (NIWE).

Conclusively, it can be said that there have been some progresses made on both the solar as well as on the biomass energy development in Bihar though there are still huge challenges prevailing to make these renewable sources of energy become effective. Strategic investments, along with technological progress, among other things, will be needed for the quantum leap that Bihar needs to make towards improving its renewable landscape. The robotics integration into these sectors may therefore serve as the turning point that will bring more efficient energy production and processing while expanding the overall accessibility of the energy commodity to the state's population [5].

3. ECONOMIC BENEFITS OF ROBOTICS IN SOLAR AND BIOMASS ENERGY

The main economic advantages one is able to realize from incorporating robotics into sources of solar and biomass energy include savings in cost through automation and their efficiency. The operations and maintenance costs in traditional systems of energy are reduced by a significantly big margin. Most of the labour-intensive processes, in particular the process of cleaning solar panels and monitoring biomass, are usually inefficient procedures in the old forms of energy sources. When carried out by human means, the same tasks consume a lot of time and take high labour costs. In contrast, robotics offers automation opportunities that drastically minimize these costs. For instance, robotic systems can automatically clean as well as monitor solar panels by ensuring maximum absorption of the energy while bringing about relatively less costly human interventions [6].

The potential for most efficiency in biomass is through the automation of agricultural waste collection and biomass sorting together with the conversion of organic matter into energy. Robotics can reduce losses, increase the accuracy of biomass feedstock handling operations, and optimize conversion processes to yield higher amounts of bioenergy products. These gains in operations directly translate into lower costs for energy producers, which can be passed on to consumers for renewable energy, thereby making it more affordable and accessible. In addition, robotic systems reduce human error and generally improve safety, thus leading to lower insurance and risk management costs for energy companies. With time, these savings accrue to contribute to the financial viability of solar and biomass energy projects [6].

3.1 Improvements in Energy Output and Productivity Measures

The application of robotics in the production of solar and biomass energy also improves the ability to enhance energy output and productivity measures. AI and ML algorithms can be used to deploy robotics in the solar energy industry to monitor environmental conditions to predict when maintenance will be required. It will also, based on these analyses, adjust the position of the solar panels to ensure they receive the maximum sunlight, thereby maximizing efficiency. Robotics can consequently ensure that panels operate at their highest efficiency and significantly increase the yield of energy in installations for solar energy. For example, tracking systems allow solar panels to track the path of the sun for almost the whole day. A system like this adds more overall output by 20-30% compared to fixed-tilt systems [7].

Robotics can improve productivity in biomass energy through processes that automate aspects such as sorting, grinding, and converting the materials into biomass. With higher volumes of biomass, high precision robotic systems are able to process these systems at faster rates and more accurate levels than manual processes. Also, with robots requiring no rest time or breaks, the improvement in productivity is further enhanced because they can execute key tasks 24/7, which means increasing the amount of time the systems spend online. The integration of robotics also allows for collecting real-time data, which further enables data-driven decisions by operators and improves productivity and maximizes energy conversion efficiency. These improvement factors result in a higher ROI for energy producers and add more stability and predictability to the supply flow from suppliers to customers [7].

3.2 Case studies demonstrating the successful adoption and the economic impact of the above methodologies

Other case studies that depict the positive economic impacts of robotics in renewable energy, such as sunlight and biomass, are quite many. One example here is the application of robotic solar panel cleaning systems that would be applied in arid regions, such as the Middle East, where dust may easily settle on the solar panels and reduce efficiency to a great extent. A Saudi Arabian solar farm has been conducting a study, which reported that it made an increase of 15% in energy output, and it reduced water usage and also the labor cost by more than 80% with the help of robotic cleaning systems. Economic benefits were also in the long term through faster returns on investment and lower operational costs over time. Hence, with the cost elimination of manual labors and subsequently the additional energy output of the solar farm, it made the solar farm profitable [8].

In the field of biomass energy, successful application of the concept can be seen in Finland, wherein the robotic systems are utilized while gathering and processing forest residues to produce biomass energy. This has increased the efficiency of gathering biomass feedstock by integrating advanced sensors and automation equipment into the robots used. It is significantly less time for gathering and transporting materials to processing facilities, hence lowering fuel costs and transportation times, hence an efficient supply chain. The economic implications have been significant, with Finland energy producers reporting 10-15% operating cost savings and significantly improved reliability for biomass production [8]. The other example is a Japanese pilot biomass plant using robotics: robots had been employed in monitoring and controlling the combustion process in real time. This automation provided higher energy conversion efficiencies and fuel savings, resulted in saving about 12% of the running costs. The enhanced energy yield from the robotic systems also enabled the plant to supply additional electrical power to the grid thereby generating higher revenues with a quicker payback time for the initial investment in robotics technology.

The use of robotics in solar and biomass energy not only leads to reducing costs and improving efficiency but also increases the output and productive energy. Thereby, robotics can add greatly to the profitability or cost-effectiveness of renewable energy projects through automation and advanced monitoring systems and transform renewable energy into something as competitive with conventional energy sources as possible. The successes achieved through the operational cost savings and increased energy production in other case studies represent tremendous transformation potential for the renewable energy industry. Against this backdrop, with the continuous high demand for clean, affordable, and reliable energy, robotics will have a fundamental role in unlocking economic benefits in both solar and biomass energy sectors.

Table 2: Economic Benefits of Robotics in Solar Energy

Aspect	Description	Economic Impact
Cost Reduction	Robotic solar panel cleaning and maintenance reduce labor costs.	80% reduction in water and labor costs, faster ROI for solar farms.
Automation and Efficiency	Robotic systems optimize solar panel tracking and positioning for maximum output.	20-30% increase in energy production due to better tracking of sunlight.
Improved Uptime	Robots can operate 24/7, reducing downtime and maintenance intervals.	Continuous operation enhances productivity, increasing output and profitability.
Case Study: Saudi Arabia	Robotic cleaning systems in solar farms.	15% increase in energy output and significant reductions in operational costs.

Table 3: Economic Benefits of Robotics in Biomass Energy

Aspect	Description	Economic Impact
Cost Reduction	Robotics improve the efficiency of biomass collection and processing.	10-15% reduction in operating costs, lower transportation and fuel costs.
Increased Energy Output	Precision handling of biomass materials improves energy conversion rates.	Increased energy production due to enhanced feedstock processing.
Continuous Operation	Robots can perform essential tasks 24/7, increasing uptime and energy output.	Higher reliability and continuous energy generation improve plant efficiency.
Case Study: Finland	Robotic systems used in forest residue collection and processing.	10-15% reduction in operational costs, improved supply chain efficiency.
Case Study: Japan	Robotics control real-time combustion processes in biomass plants.	12% reduction in fuel consumption, increased energy output, faster ROI.

4. SOCIAL BENEFITS OF ROBOTICS IN SOLAR AND BIOMASS ENERGY

4.1 Job Opportunities and Ability Development

Generally, the use of robotics in industries has much to do with all types of fears over the loss of jobs. The renewable energy sector is, however an exceptional salutary one where robotics is actually a creator of jobs and stimulates the development of ability. Indeed, designing, maintaining, and operating such complex systems places a lot of premium on a well-skilled workforce in the field of solar and biomass energy. It then develops a quality of jobs for areas such as Bihar, which need both energy development and jobs to be created. Robotics would require the use of skills that are engineering-based in robotics, data analytics, automation technology, and renewable energy systems management. The demand is created for training programs and education initiatives to upskill the local workforce. With the help of vocational training centers, technical institutes, and universities, the industry can offer courses and certifications that would equip individuals with the necessary technical knowledge. Therefore, robotics engenders jobs that are more sustainable and better paid than the manual labor characteristically associated with energy production. These include robotics technicians and engineers, software developers, project managers, and sustainability consultants, pushing local employment and the upgrade of livelihoods in areas like Bihar [9].

4.2 Social Impact: Enhancing Access and Mitigating Energy Poverty

Improving upon accessibility and subsequently alleviating energy poverty stands out as one of the substantial social impacts of robotics in renewable energy, particularly in inaccessible regions. That, on the other hand, robotics will add its value in scaling up renewable power production in states such as Bihar, where it is mostly left to areas without full certainty of access to electric power, ensuring that many people are seen to enjoy clean, sustainable energy sources. Automated systems from solar and biomass energy installations enable efficient and consistent generation of energy, particularly in rural areas, where a traditional energy infrastructure is either not there or not enough. In the decentralized energy space, robotics will allow the remote monitoring and maintenance of such systems-for example, microgrids or off-grid solar installations-that shall constitute the most critical nexus to power inaccessible communities. Thus, such fully serviced, or even totally serviced, solar-powered systems with the systems for robotic cleaning and tracking will deliver more electricity with lesser human intervention, ensuring an uninterrupted supply to the rural home, school, and healthcare centers. In the case of biomass, this can make renewable energy sources accessible to rural societies where there is a huge reliance on traditional biomass for cooking and heating. The essence of robotics, therefore, is democratizing energy access by curbing reliance on fossil fuels and the energy poverty in genera [9]l Moreover, since robotics expands the availability of energy sources, it also raises social progress. When electricity reaches homes and businesses with reliability, improvements in educational results, health services provision, small enterprise management and operation are recorded in under-privileged communities, leading to increased standards of living. Therefore, even though it increases energy production, the service end means much for the empowerment of communities, giving them the structure for improved economic and social progress.

4.3 Community Involvement and Local Economic Activation

Robotics can be applied in solar and biomass energy projects; the application of robotics would open avenues for support of local economies and community investment. Renewable energy projects often require collaboration with local communities, governments, and industries to ensure success. Robotics greatly enables such partnerships through simplified project execution, reduced costs, and optimization of benefits to local economies. For example, robotics-integrated solar farms and biomass energy plants can function more efficiently, so local communities will have a reliable supply of renewable energy, thereby affecting the local economies as people save money on energy while having power reliability. Third, community engagement through training opportunities, employment, and localized investments can be done if renewable energy projects have incorporated robotics. Such projects engage community members at the installation, operation, and maintenance levels of such systems, giving a sense of ownership and shared responsibility among local populations. Furthermore, if applied in energy cooperatives relying on community-based management and investment of small-scale renewable energy projects, the use of robotics can easily reduce overhead costs and increase the potential for long-term sustainability for such ventures. In addition, with Renewable Energy projects, there will be direct and indirect stimuli to local economies. For instance, SMEs in the region may expand their operations with better access to energy, thus increasing the employed level and cash income. Moreover, farmers who will provide biomass material for energy plants may have new sources of income as they will sell agricultural residues that were being wasted hitherto. This cycle of stimulus through economics benefits not only the sector of energy but also other industries within that community, which propels broader socio-economic development [10].

The social benefits of implementing robotics in solar and biomass energy are of great and wide-ranging scope. Starting with new, high-quality jobs and skill-building, to making energy more accessible and eventually reducing energy poverty, robotics has the potential to change the renewable energy landscape, especially in such states as Bihar. Not only will it be a vital technology in engaging communities and stimulating local economies towards environmentally sustainable and socially inclusive transitions, but it will also bridge the gap between technological advancement and socio-economic development, empower communities, and improve lives as this industry continuously evolves in renewable energy.

5. RELATED WORKS

Wang, J., et al. (2023) : The study intends to look at the effect of industrial robots on carbon emissions in China, taking into account the energy rebound effect, which has never been taken into consideration by the existing studies. Taking the dataset 2008-2019 based on a fixed-effects model, it was found that while robots do lead to a decline in emissions, there would be the energy rebound effect suppressing the potential fall in carbon emissions. Their effect on emission reduction and rebound effects is more pronounced in the less industrialized western regions than it is in the eastern and central regions. Emissions have a negative moderating impact of robots, and this effect is strongest in the west. Lastly, the study concludes by emphasizing the importance of taking care to avoid an energy rebound effect and that labor mobility barriers should be reduced for maximum emissions reduction [11].

Mariuzzo, I., et al. (2023): A multi-objective method is proposed for the optimal dimensioning and operation of an Energy Community, considering social, environmental, and economic aspects. Mixed-Integer Linear Programming was used to obtain the model considering user preferences and demand side management, thus allowing for effective decomposition using the A-AUGMECON2 technique. This methodology is applied to an Italian case study: the results illustrate how Renewable Energy Communities can save more than 10%–20% without losing user satisfaction, especially in contexts where grid prices are high. Demand response and management is a prime area that would help realize transition targets toward energy, self-sufficiency, and social and economic aims [12].

Chen, Y., et al. (2022): This paper focuses on the relationship between industrial robot usage index (UIR) and ecological footprint of 72 countries for the period of 1993–2019 years. This study results are aligned with the fact that a smaller UIR reduces ecological footprint even with robustness tests. This research study demonstrated that while UIR increases it through industrial driving effects, the footprint is decreased through time-saving, green employment, and energy upgrading effects. However, the reduction effect is dominant over the increasing effect. According to the authors' conclusion, greater impacts of UIR are attributed to OECD countries and to those countries with higher ecological footprints. They therefore propose investing in industrial robots and human capital building along with the upgrading of energy in pursuit of economic growth while at the same time protecting the ecology [13].

Yu, L., et al. (2022): This article explores whether industrial robots help to improve the air quality of cities in China and reduce PM2.5, PM10, and SO2 significantly. Using the data from 2013 to 2018, it was found that the impact of robots is a strong decreasing factor for pollution, even if controlled for endogeneity. The outcomes were associated with higher energy efficiency and green technological innovation. This represents robots, as green technology, to be proved to be a substitute for green policies, hence opening the avenue for control of air pollution when industrialization occurs [14].

Zhang, Q., et al. 2022: This article discusses adoption of robots and the relationship between green productivity. It tackles one of the issues that could emanate- negative effects on the environment due to increased energy utilization. The results reveal that while the robots result in extra pollution-generating sources, the rebound effects on green productivity seem to be nonexistent. Instead, the robots positively affect energy efficiency and induce cleaner production through the positive effects of market selection effects. This paper provides empirical evidence for the green-biased nature of robotics, indicating that in principle, even in regions dominated by high-pollution industries, robot adoption could positively contribute toward improvements in green productivity [15].

Table 4: Literature Review Findings

Author Name (Year)	Main Concept	Findings
Wang, J., et al. (2023)	Industrial robots and carbon emissions	Industrial robots reduce carbon emissions but cause an energy rebound effect. Labor mobility enhances emissions reduction, with stronger effects in less industrialized regions.
Mariuzzo, I., et al. (2023)	Energy Community optimization	A multi-objective methodology for Energy Communities can save 10%-20% in energy costs while maintaining user satisfaction. Demand-side management boosts self-sufficiency and social goals.
Chen, Y., et al. (2022)	Industrial robots and ecological footprint	Industrial robots reduce the ecological footprint through time-saving, green employment, and energy upgrading, with greater effects in OECD countries and regions with higher ecological footprints.
Yu, L., et al. (2022)	Industrial robots and air quality	Industrial robots improve air quality in Chinese cities by reducing PM2.5, PM10, and SO2 through increased energy efficiency and green innovation. They serve as an alternative to green policies.

Zhang, Q., et al. (2022)	Robots and green productivity	While robots introduce new pollution sources, they do not harm green productivity. Instead, they improve energy efficiency and promote cleaner production, especially in high-pollution industries.

This research examines both environmental and economic impacts due to industrial robots and energy management strategies. Based on the research, Wang, J., et al. established that even as carbon emissions reduce with industrial robots, it triggers the rebound effect in terms of energy. Increased labor mobility causes more significant reductions in emissions when the regions are less industrialized. Mariuzzo, I., et al. obtained remarkable energy savings coupled with social benefits through demand-side management based on a proposed method for optimizing Energy Communities. Chen, Y., et al. (2022) have proven that green employment and energy upgrading from industrial robots are reducing the ecological footprint, with especial significance in OECD countries. Yu, L., et al. (2022) findings shed a light on the fact that industrial robots are improving air quality in Chinese cities as the industrial robots reduce pollution with better energy efficiency and green innovation. Zhang, Q., et al. (2022) show that although the adoption of robots will lead to the introduction of new forms of pollution, it will ultimately improve green productivity even for those industries with high pollution intensity, mainly through energy efficiency improvements and the use of cleaner modes of production.

6. ROBOTICS IN SOLAR AND BIOMASS ENERGY WITH TECHNOLOGY ADVANCEMENT

Robotics in Solar and Biomass Energy has been significantly impacted by advancements in various technological fields. Here's how these concepts intersect:

Database Management Systems (DBMS):

- Data Storage and Management: Sinha, R. (2019)., DBMS is crucial for storing and managing vast amounts of data generated by robotic systems, such as sensor readings, maintenance records, and energy production data[16].
- Real-time Analytics: DBMS can enable real-time analysis of data to optimize robotic operations, predict maintenance needs, and improve energy efficiency.

Data Mining:

- Pattern Recognition: Sinha, R. (2018), Data mining techniques can help identify patterns and trends in data collected by robotic systems, leading to insights that can improve system performance and efficiency[17].
- Predictive Analytics: Data mining can be used to predict future trends, such as energy consumption or equipment failures, enabling proactive maintenance and optimization.

Data Warehousing:

- Centralized Data Repository: Sinha, R. (2018), Data warehousing provides a centralized repository for storing and integrating data from various sources, including robotic systems, sensors, and weather data [18].
- Business Intelligence: Data warehouses can support business intelligence activities by providing the foundation for data analysis and reporting.

Big Data:

- Optimized Energy Distribution: Sinha, R. (2019), Big data analytics enables real-time monitoring of energy production and consumption, leading to more efficient distribution and reduced waste[19].
- Enhanced Energy Efficiency: By analyzing historical data, robotics can be optimized to reduce energy consumption and improve overall efficiency.
- Improved Sustainability: Big data can help optimize resource usage and reduce the environmental impact of solar and biomass energy production.
- Enhanced Public Engagement: Big data can provide transparent information about energy production and consumption, fostering trust and participation from the public.

System Analysis and Design:

- Requirements Gathering: Sinha, R. (2022), System analysis and design are essential for defining the requirements of robotic systems, including hardware, software, and integration with existing infrastructure [20].

- System Architecture: Sinha, R. (2019), System design involves creating a blueprint for the robotic system, considering factors such as scalability, reliability, and security [21].

Testing and Implementation:

- Quality Assurance: Sinha, R. (2018), Rigorous testing is necessary to ensure that robotic systems meet performance requirements and operate reliably in real-world conditions [22].
- Deployment: Sinha, R. (2019), Implementation involves deploying robotic systems and integrating them with existing infrastructure [23].

System Maintenance:

- Ongoing Support: Sinha, R. (2019), System maintenance is essential for ensuring the long-term operation and reliability of robotic systems, including software updates, hardware repairs, and performance monitoring[23].

Client-Server Architecture:

- Distributed Systems: Sinha, R. (2018), Client-server architecture is commonly used in robotic systems to distribute tasks between central servers and remote devices, such as robots and sensors [24].

Traditional vs. Digital Marketing:

- Promotion and Awareness: Sinha, R. (2018), Both traditional and digital marketing can be used to promote the benefits of robotics in solar and biomass energy and to reach target audiences [25].
- Data-Driven Marketing: Digital marketing, in particular, can leverage data analytics to personalize campaigns and measure effectiveness.

Cybercrime and Robotics:

- Cybercrime: Sinha, R. (2020), Robotic systems, like any connected device, are vulnerable to cyberattacks, such as hacking and malware infections [26].
- Social Impact: Sinha, R. (2018), Cyberattacks on robotic systems can have serious consequences, including disruptions to energy production, data breaches, and safety risks [27].
- Preventive Measures: Sinha, R. (2018), To mitigate cybercrime risks, it is essential to implement robust cybersecurity measures, including network security, access controls, malware detection and regular software updates [28].

By effectively leveraging these technologies and addressing cybersecurity concerns, robotic systems can play a significant role in advancing sustainable energy solutions.

7. CHALLENGES IN ROBOTICS FOR SOLAR AND BIOMASS ENERGY

Machine learning (ML) algorithms can play a crucial role in addressing many of the challenges faced in robotics for solar and biomass energy. Here's how some of the common algorithms can be applied:

Supervised Learning:

- **SVM:** Sinha, R. (2013), Can be used for tasks like classifying different types of solar panels or identifying defects in biomass materials [29].
- **Decision Trees:** Sinha, R. (2014), Can be used to make decisions about robotic actions based on sensor data, such as determining the optimal angle for solar panel positioning or deciding when to harvest biomass [30].
- **Random Forest:** Sinha, R. (2016), Can be used to improve the accuracy of predictions made by decision trees, especially in complex environments [31].

Unsupervised Learning:

- **K-Means Clustering:** Sinha, R. (2015), Can be used to group similar solar panels or biomass samples, which can be helpful for maintenance and quality control [32].
- **Naive Bayes:** Sinha, R. (2017), Can be used for tasks like predicting the energy output of a solar panel based on weather conditions or estimating the biomass yield of a particular crop [33].

K-Nearest Neighbors:

- Sinha, R. (2018), Can be used for tasks like predicting the failure rate of a solar panel based on its age and operating condition [34].

Hybrid Ensemble Technique:

- Sinha, R. (2023), Hybrid ensemble techniques, while promising for improving prediction accuracy, face several challenges in robotics for solar and biomass energy applications. These challenges include data quality issues, model complexity and overfitting, computational cost, heterogeneity and integration difficulties, interpretability concerns, and the need to adapt to dynamic environments. Addressing these challenges requires careful consideration of data preprocessing, model selection, hyperparameter tuning, and computational resources to ensure the effective application of hybrid ensembles in these domains[35].

Addressing Specific Challenges:

- **Data Quality and Quantity:** ML algorithms can be used to clean and preprocess data, and to generate synthetic data to augment existing datasets.
- **Algorithm Complexity:** Deep learning techniques, such as convolutional neural networks and recurrent neural networks, can be used to handle complex tasks like image recognition and time series analysis.
- **Hardware Limitations:** Edge computing and specialized hardware can be used to reduce the computational burden on robots.
- **Safety and Ethics:** ML algorithms can be trained on large datasets to ensure that they are robust and ethical, and to minimize the risk of unintended consequences.

By leveraging ML algorithms, robotics can become more autonomous, efficient, and reliable in the solar and biomass energy sectors, helping to address the challenges of sustainable energy production.

8. CONCLUSION

The application of robotics in the solar and biomass sectors heralds a shift toward more efficient, cost-effective, and sustainable renewable energy systems. In Bihar, where Bihar still struggles with power deficiency, ill-reliable access to electricity, and poverty, robotics in the solar sector is expected to address the problems mentioned, thereby improving access to electricity with greater efficiency. The combination of robotic use will make economically viable solar and biomass energy projects because it will automate labor-intensive jobs in such processes, optimize energy production, and reduce costs associated with operations. These will take the form of short-term direct benefits to the residents in the following ways: savings on cost and increases in the output of energy, and, in the longer term, job opportunity creation and the development of local skills. Similar to robotics, the economic benefits of cost reduction, increased productivity, and improved energy yields go side by side with a broad social impact. Robotic technologies introduced will have an impact on local economies, creating job opportunities of very high quality while bringing renewable energy nearer to people, especially those underserved and residing in rural settings. Renewable energy systems with efficient scalable functionality also contribute to decreased fossil fuel dependence, promoting environmental sustainability and carbon emissions reductions. For Bihar, with enormous potential for both solar and biomass energy, robotics holds more than a glimmer of hope to enhance the energy security of the state while offering a pathway to more inclusive and equitable economic development. Robotics can help build resilient infrastructures of energy that meet the increasing demand for energy in the state but ensure social benefits to the people and minimize environmental costs. Through robotics, interactions among government, the private sector, and local communities can mobilize opportunities in those directions. Robotics can be combined with renewable energy to provide opportunities for sustainable development in Bihar and other regions facing similar problems. The prospects of further research in this area, and deployment strategies in solar and biomass energy, will play key roles in bridging the gap in energy demand and supply and take areas like Bihar to a cleaner, greener, more prosperous future.

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CONFLICT OF INTEREST

The authors declare no conflict of interest between them.

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