

Evolution in Energy Utilisation in the Era of Industry 5.0

Sourav Majumder*, Subhrodipto Basu Choudhury**, Niloy Kr. Pal***,
Soma Garani****, Arunima Hazra*****

Abstract

In the context of Industry 5.0, a shift towards human-centricity, sustainability, and resilience through the extensive assimilation of advanced technologies (i.e. Artificial Intelligence (AI), Internet of Things (IoT), robotics, and human-machine collaboration), this research examines the transformative trajectory of the energy utility industry. The primary output of this study is to present the trajectory of the evolution of energy utilities from traditional, centralized energy systems to decentralized, intelligent and adaptive systems and processes that adhere to Industry 5.0 principles. This study reveals major shifts such as smart grid adoption, prosumer participation, anticipatory maintenance using AI, and heightened green energy innovation.

The motivation for this study arises from a worldwide urgency to transition to sustainable energy systems that are efficient and resilient to socio-environmental disruptions. Industry 4.0 brought digital automation of processes to energy systems, whereas Industry 5.0 emphasizes incorporating human intelligence and values into the evolution of technology. This evolution presents opportunities and challenges for the energy utility sector, thereby contributing to the need for investigating the roles.

This study is a consolidated analysis of the role of Industry 5.0 in energy utility strategies that drive efficiency, sustainability, and consumer satisfaction, while also benefiting governments, utilities, and technology organizations who want to undergo Industry 5.0 to facilitate and deliver cleaner energy futures and energy utility systems.

Keywords: Industry 5.0, Energy Utility Transformation, Human-Centric Innovation, Smart Grid Technology, Sustainable Energy Systems, AI in Energy Management, Decentralized Energy Networks

Introduction

The scenario of energy is evolving significantly, propelled by the convergence of technology development, the importance of climate change, and social and economic factors. Central to the more impactful changes in energy markets is the evolution from traditional, centralized utility structures to smart, decentralized, and sustainable energy systems. Industry 4.0 set a rough stage with automation, digitization, technology and connectivity. The emerging Industry 5.0 framework is reorganizing a path forward by reinstating the intention of the human context and action to the technological context and action, and placing resilience, sustainability, and humans back in the central position of the Industrial paradigm (European Commission, 2021).

Industry 5.0 is not simply a growth in technological advancement; the advancement toward Industry 5.0 signals a profound transition that will associate its development in accordance with society and environmental interests. Industry 5.0 aims to achieve human and machine complementarity in advanced technological processes, using the latest technologies such as Artificial Intelligence (AI), Internet of Things (IoT), blockchain, and robotics in ways that advance human decision-making, enhance the adaptability and resilience of necessary systems, and at the same time uphold sustainable development goals. In this regard, the energy utility context, which normally offers rigid structures and high fossil fuel dependency, is also

* PhD Scholar, Department of Management, Rani Durgawati University, Jabalpur, Madhya Pradesh, India.

** Assistant Professor, School of Commerce and Management Studies (SCMS - PG), Dayananda Sagar University, Bengaluru, Karnataka, India. Email: subhrodiptobasuchoudhury@gmail.com

*** Assistant Professor, Department of Chemistry, MIT WPU, Kothrud, Pune, Maharashtra, India.

**** PhD Scholar, Department of Fishery Science, WBUAFS, Kolkata, West Bengal, India.

***** PhD Scholar, Department of HRM, Adamas University, Kolkata, West Bengal, India.

viewed as a key area for innovation; integration across multiple sectors, and there is a need for reconfiguration within the Industry 5.0 vision.

As per a report by the International Energy Agency (IEA, 2023), demand for energy across the globe is projected to increase at a rate of over 25% by 2040 as a result of factors such as urbanization, digital consumption and electrification of transportation systems. At the same time, the ability to decarbonize energy systems, in keeping with the United Nations Sustainable Development Goals (SDGs) and the Paris Climate Agreement, is simultaneously putting strings on investment in renewable technologies and smarter infrastructure. This has culminated in a condition that can be termed “game-changing” in that from now on the energy system must be completely rethought in terms of the ways it generates, manages, distributes and consumes energy.

The energy utility sector, in the era of Industry 5.0, is concerned with technological intelligence, human-centric design, and sustainably integrated development, comprised of three intertwined pillars. The historical tendency for energy utilities to lag behind in terms of adapting to transformative energy change is becoming existentially perilous, as changes must occur in the direction of becoming a digital, data-driven, and customer-responsive service. Whether it be intelligent integration of smart grid technology, demand-side management innovations, AI-enabled forecasts for energy consumption, and blockchain-enabled peer-to-peer energy trading, the future of energy utility is not science fiction, but actual deployment and implementation as is occurring in Germany, Japan and the Netherlands (IEA, 2022; World Economic Forum, 2021).

Along with technological capabilities, Industry 5.0 encourages the customization of energy experiences by assisting consumers as they transition into “prosumers” (i.e. producers and consumers of energy). With the democratization of energy enabled by rooftop solar, battery storage, and smart meters, which allow household energy monitoring and control in real-time. Household energy solutions are rarely as simple as tracking your own energy consumption; however, in Denmark, with the “SmartNet” initiative, they are integrating household energy systems with grid networks. Danish citizens can also feed surplus renewable energy into the grid,

improving access to renewable energy sources and a suite of AI algorithmic capabilities to properly load balance energy and mitigate energy waste (European Smart Grid Task Force, 2022).

Importantly, the human-centric approach of Industry 5.0 addresses long-standing issues of energy inequity and access more globally. Many emerging economies across Asia, Africa, and Latin America are now equipped with an opportunity to adopt decentralized microgrids and off-grid renewable energy solutions combined with smart monitoring systems to leapfrog these more stringent, legacy infrastructure and provide local communities with better energy access and include them within an energy transition from a sustainability lens, with economic inclusivity (IRENA, 2023).

Nevertheless, many challenges still exist. Privacy of data, cybersecurity, problems with regulators, and a lack of currency with skills are all considerable barriers to mainstreaming Industry 5.0 principles into energy utilities. Additionally, this transition necessitates capital investment, coordination with stakeholders, and changing the way organizations conceptualize their objectives of providing expanding energy; all of which are inherently complicated, especially in resource-challenged environments.

This study sets out to thoroughly assess how the energy utility sector can adapt to the principles and technologies of Industry 5.0. By exploring global trends, technological innovations, and real-world examples, the research aims to identify the key factors that contribute to success, the challenges faced, and policy recommendations that can assist governments, private utilities, and researchers in creating energy systems that prioritize human needs and environmental sustainability.

Through the use of secondary data derived from international energy reports, policy documents, and industry white papers, this study analyses how regions are making headway in the energy sector. The book traces the adoption trends, examines the dissemination of technology, and evaluates regulatory settings that either facilitate or hinder this transformation.’ The focus is not solely on the technical aspects of technology, but also on ‘how’, including governance models, processes, and human-centred designs to build robust energy utility systems in Industry 5.0.

This paper briefly discusses the evolution of energy utilities as a crucial aspect of Industry 5.0, emphasizing its significant impact on sustainability, technological advancement and empowerment of people. By combining theoretical concepts with practical implementations, it presents significant opportunities for collectively constructing our energy future while adhering to the fifth industrial revolution's principles.

Literature Review

The ongoing change of the global energy utility sector lies deeply in the development of industrial paradigms. While Industry 4.0 introduced automation, data exchange and interconnected systems, the industry is redefined and has implemented the ideological foundation of 5.0-human-focus, stability and flexibility. It is redefined again that energy systems are imagined and implemented (European Commission, 2021). This literature reviews have severely synthesized academic, policy and industry-based contributions, which have examined energy utilities and intersections of technical development with a focused lens on the capacity and performance of the industry 5.0 ambitions.

Theoretical Foundations: Industry 5.0 and Energy Utility

The concept of Industry 5.0 departs by reorganising human values in technological progress from its predecessor. As Dameer et al. (2021) Note, Industry wants to coordinate personal and permanent consequences between 5.0 cognitive computing and human intelligence. In terms of energy, it is not only to digitize energy operations, but also to do so in ways that prefer social needs, moral ideas and ecological balance (Nahavandi, 2019; Joo et al., 2021).

Under Industry 5.0, the theoretical grounding of energy system innovation is designed by the principles of cyber-physical systems (CPS), human-machine cooperation, and inclusive infrastructure design (Leeo et al., 2017). The transition reflects a systemic change from centralized energy supply chains towards decentralized, partnership and future energy ecosystems (Ciaramella et al., 2022).

Smart Grid and Digital Energy Infrastructure

Smart grid industries have evolved as a core technological foundation for 5.0-based energy utilities. These grids integrate digital communication, IoT, and machine learning to enable real-time monitoring, dynamic load balance and bidirectional energy flow (Home and Gafurian, 2011).

Study by Zhang et al. Alhacoon and U (2016) emphasize that future analytics in the smart grid enable active maintenance; their implementation is often limited by data silos and the infrastructure of heritage. Integration of Blockchain Technologies - Endoni et al. was mistrust in the work (2019) and Gai et al. (2021) - The genus was proposed as a solution for safe, transparent and decentralized energy transactions.

Artificial Intelligence in Energy Management

AI is certainly the most transformative promoter of Industry 5.0 in the energy sector. It enables real-time forecasting, discrepancy detection, consumer behaviour modelling and automatic grid operations (Mines & Zhang, 2021). Machine Learning algorithms are used to predict energy consumption patterns, optimize renewable energy use and detect defects before growing (Wang et al., 2020).

Banse et al. (2011) show how AI applications have reduced energy intensity in construction by 20%. In addition, the study of a recent case by Lee et al. (2023) shows that operational cost has validated environmental benefits when the AI-operated demand in Chinese urban areas has been deployed on the reaction system. Nevertheless, moral concerns about data privacy and algorithm bias are under-addressed (Passcuvatti, 2020).

Decentralization, Prosumerism, and Citizen Participation

The research of Parag et al. (2026) suggests that the democratization of energy production is another important aspect of this revolution. Citizens are rapidly becoming "prosecutors" who not only consume but also produce and share energy through microgrid and community solar

initiatives. Volsink (2020) shows that such participants have increased social acceptance of renewable energy projects.

Decentralized energy systems, as reviewed by Pudineh et al. (2020), are particularly impressive in developing economies where centralized grid expansion is economically unattainable. Smart metering and distributed laser technologies reviewed by Han et al. (2019), enabling transparent and equitable energy exchange among homes and small-scale producers.

Sustainability and Environmental Integration

Hirschhausen et al. (2018) has shown that sustainable energy systems should be built in regulatory and institutional reforms. In addition, the progress of energy storage technologies, as is investigated by Dun et al. (2011) and Taroa et al. (2016), is important in the race to manage. Recent successes in the lithium-sulphur and solid-state battery systems have the ability to address storage bottlenecks in decentralized grids (Goodeno & Park, 2013).

Human-Centric and Ethical Considerations

Industry separates 5.0 most fundamentally, its obvious human centenary orientation. This includes reaching access to reaches, strength and energy equity, especially in regions of marginalized areas (Sachs et al., 2022). Study by Sovakool et al. (2019) A lawyer for only energy infection, where the deployment of technology is aligned with social inclusion and local capacity building.

Literature also indicates moral risks. Utility operations can cause job displacement from highly automated jobs without adequate human monitoring or to create

dependence on proprietary AI systems (Brynjolphton & McAfi, 2014). For example, researchers such as Zuboff (2019) are cautious against “monitoring capitalism”, where utility becomes a tool for behavioural manipulation rather than data empowerment.

Policy and Regulatory Frameworks

In energy utilities, the successful implementation of Industry 5.0 requires a further policy framework. According to Ropeke (2022), governance structures should be developed to accommodate multidimensional energy flow, dynamic pricing models and cross-sector integration. The European Union Green Deal (European Commission, 2021) and India's Smart Cities Mission (NITI Aayog, 2022) offer templates for case study regulatory modernization and multi-interest coordination.

In addition, regulatory sandbox and public-private innovation laboratories have proved to be effective in testing and scaling of emerging energy technologies (Ofgem, 2020; Unido, 2021).

Research Methodology

The research is purely done on secondary data obtained from the Government of India website on MNRE (Ministry of Renewable Energy). The energy generation from renewable resources like hydro, solar and wind, along with non-renewable like thermal, has been studied for comparative analysis. The capacity generation (GW) from FY 2014-2025 has been analysed, and a projected generation has been calculated using the Moving Point Average Method (MPA).

In the latter part, correlation and regression analysis have been done for the following purpose:

Table 1: Justification for Data Analysis

Sr. No.	Method	Variables	Reason
1	Correlation	Energy types	Dependence strength of one energy on another
2	Regression	Share and total	The relation between share and total energy generation capacity
3	Moving Average	Energy type	Estimate the projected generation capacity (GW)

Data Analysis and Interpretation

Table 2: Generated Energy Capacity (GW) and Projected Generated Energy Capacity (GW)

<i>Installed Renewable Energy (GW) in INDIA (2014-2024)</i>								
<i>Year</i>	<i>Thermal</i>	<i>Nuclear</i>	<i>Hydro</i>	<i>RES</i>	<i>Total RE</i>	<i>Grand total</i>	<i>Growth (%)</i>	<i>Share of RE (%)</i>
2014-2015	188.9	5.78	41.27	39.95	81.22	275.9	10.62	29.44
2015-2016	210.68	5.78	42.78	47.09	89.87	306.33	11.03	29.34
2016-2017	218.33	6.78	44.48	58.56	103.04	328.15	7.12	31.40
2017-2018	222.91	6.78	45.49	70.65	116.14	345.83	5.39	33.58
2018-2019	226.28	6.78	45.4	79.41	124.81	357.87	3.48	34.88
2019-2020	230.6	6.78	45.7	88.26	133.96	371.34	3.76	36.07
2020-2021	234.73	6.78	46.21	95.8	142.01	383.52	3.28	37.03
2021-2022	236.11	6.78	46.72	109.89	156.61	399.5	4.17	39.20
2022-2023	237.27	6.78	46.85	125.16	172.01	416.06	4.15	41.34
2023-2024	243.22	8.18	46.93	143.64	190.57	441.97	6.23	43.12
Growth Rate	28.7559555	41.52249	13.71456	259.5494				
CAGR	2.55969783	3.533894	1.293507	13.65168				
2024-2025	205.97	6.113333	42.84333	48.53333				
2026-2027	217.306667	6.446667	44.25	58.76667				
2027-2028	222.506667	6.78	45.12333	69.54				
2028-2029	226.596667	6.78	45.53	79.44				
2029-2030	230.536667	6.78	45.77	87.82333				

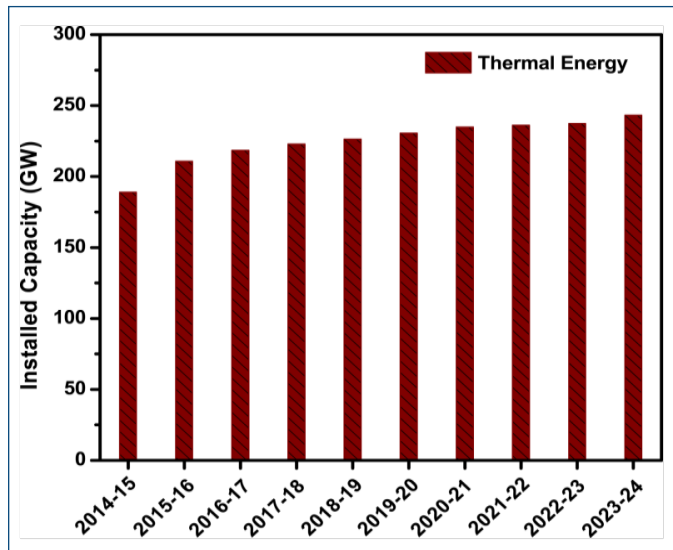


Fig. 1: Thermal Capacity (GW)

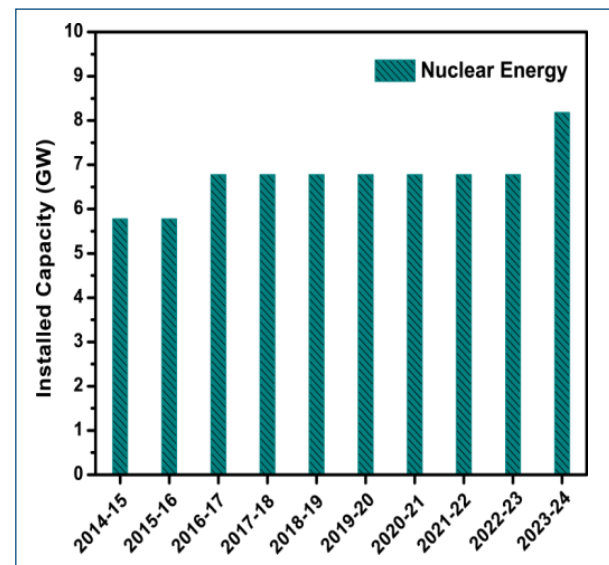


Fig. 2: RES Capacity (GW)

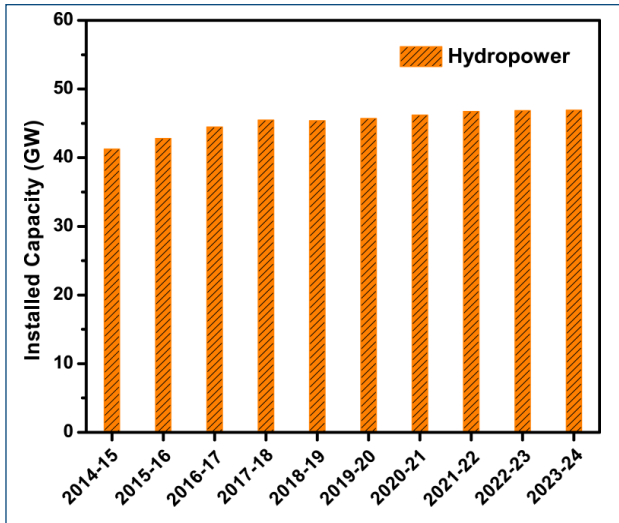


Fig. 3: Nuclear Energy Capacity (GW)

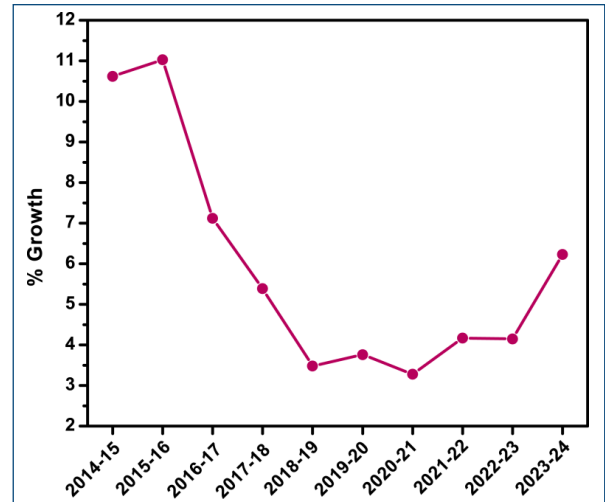


Fig. 5: Percentage (%) of Growth

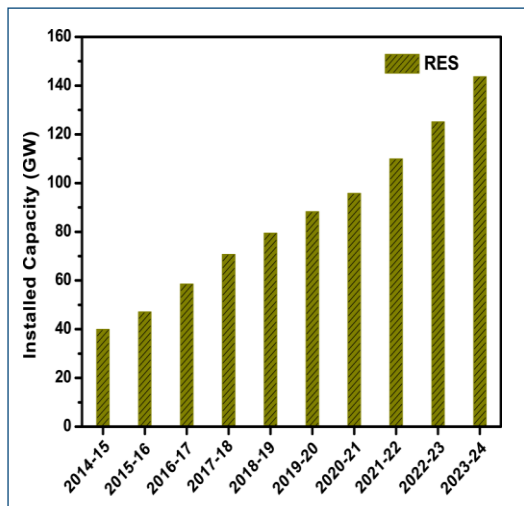


Fig. 4: Hydro-Power Capacity (GW)

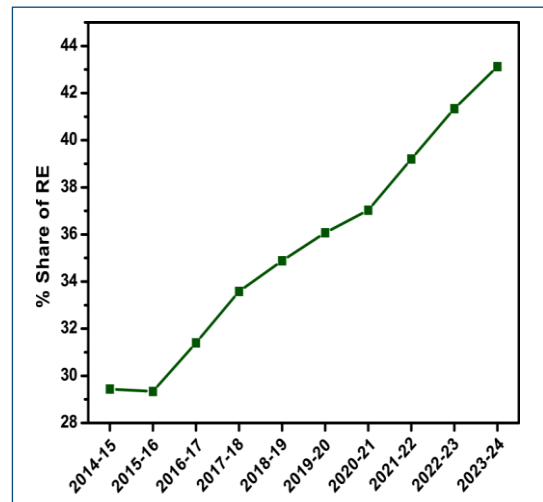


Fig. 6: Percentage (%) of share for RE

Table 3: Regression Statistics on Renewable Energy and Thermal Capacity Generation (GW)

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	1
Standard Error	1.27808*10 ⁻¹⁴
Observations	10

Table 4: ANOVA Statistics on Renewable Energy and Thermal Capacity Generation (GW)

Parameter	df	SS	MS	F	Significance F
Regression	4	11226.87564	2806.719	1.71823 * 10 ³¹	4.99621 10 ⁻⁷⁸
Residual	5	8.16748 *10 ⁻²⁸	1.63 10 ⁻²⁸		
Total	9	11226.87564			

Table 5: Regression Coefficient on Different Types of Energy Generation Capacity (GW)

<i>Parameter</i>	<i>Coefficients</i>	<i>Standard Error</i>	<i>t-Stat</i>	<i>P-value</i>
Intercept	-7.10543×10^{-14}	2.64431×10^{-14}	-0.26871	0.798890546
Thermal	2.67586×10^{-15}	1.41942×10^{-15}	1.885182	0.11808832
Nuclear	4.17489×10^{-15}	1.18325×10^{-14}	0.352833	0.738600839
Hydro	1	1.16617×10^{-14}	8.58×10^{13}	4.09359×10^{-69}
RES	1	3.14755×10^{-16}	3.18×10^{15}	5.86368×10^{-77}

Data Interpretation

Now, the above exhibits show the distribution pattern of a few sources of energy capacity generation (GW) in India

from 2014 to 2024. The table below has been presented as summarized format for better understanding of the above data as analysed:

Table 6: Statistical Tool with Justification

<i>Method</i>	<i>Statistical Tool</i>	<i>Software</i>	<i>Justification</i>
Graphical Plotting	Scatter Plot	MS Excel	Pictorial year-wise comparison
Projection	Moving Point Average (MPE)	MS Excel	Prediction helps in the preparation of a budget for resources
Inter-dependence	Regression	MS Excel	The dependence strength of one type of energy on another

Integration of Industry 5.0 and the Energy Transition Era

The emergence of Industry 5.0 with the global energy transition signifies a transformative leap in how modern societies approach the generation, distribution, and consumption of energy. This integration reflects a decisive evolution from merely automating and digitizing energy processes, as seen in Industry 4.0, toward systems that are human-centric, intelligent, adaptive, and sustainable. As nations across the globe grapple with the twin imperatives of decarbonization and energy equity, the principles of Industry 5.0 centered on human-machine collaboration, ethical innovation, and systemic resilience, offer a compelling framework for reimagining energy utilities. Rather than viewing energy as a commoditized product flowing unidirectionally from supplier to consumer, the Industry 5.0 paradigm recognizes energy systems as dynamic socio-technical ecosystems where humans play active, decision-making roles alongside machines, algorithms, and infrastructure.

Industry 5.0 technologies such as artificial intelligence, blockchain, Internet of Things (IoT), and cyber-physical systems are being tailored not just for performance efficiency, but for resilience, equity, and cognitive adaptability in energy utilities. These technologies support intelligent forecasting, real-time grid optimization, and

peer-to-peer energy trading, enabling communities to manage energy in decentralized, demand-responsive, and environmentally sensitive ways. Countries like Germany, Denmark, and Japan have pioneered such shifts through their national smart grid programs, but increasingly, emerging economies such as India are leveraging these technologies to leapfrog outdated centralized infrastructure. In Indian pilot projects, for instance, blockchain-based peer energy trading platforms are being combined with rooftop solar and smart metering systems to empower local prosumers—individuals and communities who not only consume but also generate and share energy. These innovations align seamlessly with India's broader energy transition goals under the National Hydrogen Mission, the Smart Cities Mission, and the Atmanirbhar Bharat framework.

From a business analytics and digital design perspective, the integration of Industry 5.0 allows for the optimization of user interfaces in energy management systems to reduce waste, improve decision-making, and prevent digital overconsumption. The excessive and unregulated use of digital devices often results in increased power consumption, server loads, and network stress, which has amplified concerns around internet addiction and its associated energy demands. Industry 5.0 responds to this challenge by embedding behavioral analytics, adaptive algorithms, and neuroadaptive interfaces into

energy dashboards, allowing users to engage with real-time consumption data in intuitive and energy-conscious ways. These systems, trained on user patterns and socio-cognitive inputs, provide feedback loops that not only optimize personal energy use but also contribute to overall grid stability. This human-in-the-loop model is essential for addressing not only technical performance but also social responsibility and digital well-being, particularly in an age where digital behavior significantly influences environmental outcomes.

The role of human-centric design in energy utilities is further reinforced by the decentralization of power generation and the emergence of localized microgrids. These systems, guided by AI-enabled predictive models, allow remote or underserved communities to participate in the energy transition through off-grid and hybrid renewable solutions. With smart sensors, low-latency communication, and autonomous demand-balancing mechanisms, these microgrids ensure continuity of supply, reduce transmission losses, and promote energy democracy. This is particularly relevant in regions like rural India, sub-Saharan Africa, and Southeast Asia, where access to centralized grids is either cost-prohibitive or structurally infeasible. Industry 5.0 thus creates pathways for inclusive innovation by aligning technological progress with local aspirations, environmental constraints, and economic diversification.

In tandem with decentralized production, the rise of green hydrogen, biogenic energy storage, and AI-enhanced electrolysis demonstrates how Industry 5.0 fosters convergence between biological and digital energy innovations. AI-driven hydrogen plants, for example, are being designed to optimize resource input, minimize environmental impacts, and forecast energy availability based on weather patterns and real-time grid needs. This reflects a departure from technocentric industrial logic to one grounded in biospheric consciousness, where energy systems are modeled not only for output maximization but also for planetary stewardship. Moreover, these advancements are being deployed with ethical considerations at the forefront, ensuring transparency, privacy, and social inclusion through regulatory sandboxes, multi-stakeholder co-design, and open-data protocols. Such ethical-by-design frameworks are vital to safeguard against the algorithmic bias, surveillance capitalism, and digital exclusion risks

that can arise from unregulated AI deployment in critical energy infrastructures.

Policy synchronization plays an equally crucial role in realizing the full potential of Industry 5.0 within the energy transition. Existing regulatory regimes, designed for centralized and monopolistic energy delivery, must be reconfigured to accommodate multidimensional flows, participatory markets, and cognitive technologies. This calls for institutional innovation, including agile regulatory environments, transdisciplinary taskforces, and integrative governance platforms that align utility operators, technology developers, consumers, and environmental stakeholders. International frameworks such as the European Commission's Industry 5.0 vision, the UN's SDG7 Energy Access targets, and India's climate missions demonstrate that the momentum for such transitions is already underway. However, the real breakthrough lies in harmonizing global standards with local experimentation, allowing countries to scale energy solutions that are not only technologically sound but also socially responsive and environmentally restorative.

Conclusion

Renewable energy, energy storage, electric vehicles, and technology advancement are all anticipated to play a part in India's energy future. It will need audacious policies, technical advancements, and greater international collaboration to combat climate change while guaranteeing energy availability for all citizens. Key challenges like infrastructure development, financing mobility to start-up culture, and long-term policy consistency should be overcome to accelerate progress. India's larger objectives of sustainability and economic progress are closely tied to its energy transition.

Future Direction

India's future direction in the energy sector is shaped by the country's rapidly growing energy demand in various sectors. India is moving towards green and sustainable energy resources to achieve net-zero carbon emissions. Significant enhancement in RE capacity installation is evidenced since the last five years and is expected to achieve 500 GW capacities by the end of 2030. The central part of India has greater exposure to sunlight that

supplies enormous potential for solar energy expansion, a large coastal area and a river-centric region that plays a crucial role in hydropower generation, and biomass derived from agricultural waste is expected to enhance bioenergy generation. India is also expanding its wind power capacity, particularly along the coastline, which has significant potential for offshore and onshore wind farms. Smart grids and advanced metering infrastructure will drive efficient energy distribution and storage capacity across the country. Govt. initiatives like the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme are pushing for a shift towards EVs. India is developing pollution-free nuclear reactors for the diversification of energy, which could be a key part of the energy mix in the future. As a part of renewable energy sources, India is also focusing on futuristic green hydrogen production, which could satisfy high energy requirements in heavy industries, as well as for long-distance transportation and storage. This initiative is fostered by governmental plans like the National Hydrogen Mission, which aims to make India as a global hub for green hydrogen production. Smart programs like the Perform, Achieve, and Trade (PAT) scheme and Energy Conservation Building Code (ECBC) are helping to reduce energy intensity in industries and buildings. To accelerate the sustainable growth and self-reliant energy production, the National Action Plan on Climate Change (NAPCC), State Action Plans, and Atmanirbhar Bharat Abhiyan are aligned, which could shape the country's future energy scenario. As India transitions away from coal, CCS technology could play a role in mitigating emissions from existing fossil fuel plants, particularly in the industrial sector. The future energy system in India will be increasingly digitalized with modern technologies like the Internet of Things (IoT), artificial intelligence (AI), and data analytics, improving energy management, grid optimization, and customer engagement. Other promising methodologies could be developed using blockchain and other decentralized technologies, particularly in the field of energy trading and peer-to-peer energy transactions. India will continue its clean energy expansion through various energy corridors with international support.

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Conflict of Interest

The authors of the manuscript do not have any conflicts of interest regarding the preparation of the manuscript.

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AI Disclosure

The authors confirm that no AI-based tools were utilized in conducting this research or writing the manuscript. All content is original and reflects the authors' own work.

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