



Short Commentary

Developing A Green and Sustainable Future: Advancements and Integration of Renewable Energy Resources

K. H Poorvashree¹, V Kalaivi², S. Dharshan³, Faizullah², Kusuma Kumari², H. M Anagha², Naveen Kumar¹, Soumya V. Menon^{2*}

¹Department of Forensic Science, School of Sciences, Jain (Deemed-to-be) University, Bangalore, India

²Department of Chemistry and Biochemistry, School of Sciences, Jain (Deemed-to-be) University, Bangalore, India

³Department of Data Science, School of Sciences, Jain (Deemed-to-be) University, Bangalore, India

*Correspondence to: Soumya V. Menon, PhD, Professor, Department of Chemistry and Biochemistry, School of Sciences Jain (Deemed-to-be) University, JC Road, Bangalore, Karnataka, 560027, India; Email: sweetsou_02@yahoo.com

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Abstract

The global energy sector is now undergoing a major transformation towards sustainability. Despite efforts to reduce reliance on fossil fuels and promote renewable energy (RE), fossil fuels remained dominant in 2022 and 2023. In 2022, fossil fuels accounted for approximately 63.5% of global power generation, while renewable sources, including hydropower, made up around 29%. By 2023, the share of fossil fuels slightly decreased to 62%, with renewables increasing to 30%. The broad use of RE sources such as solar, wind, hydro, geothermal, and other technologies underscore this transition. Sunlight, a steady energy source, is critical to satisfying the world's ever-increasing energy needs. This thorough analysis investigates the technical breakthroughs in these RE sources as well as their critical significance as environmentally beneficial alternatives to traditional energy sources. It also dives into the symbiotic link between smart technology and RE, demonstrating how innovation is altering energy generation, distribution, and consumption. Aside from technology, the article assesses the far-reaching socioeconomic consequences, such as major job creation, economic growth, and equal energy access. In conclusion, this study provides vital insights into the diverse road towards a sustainable energy future, emphasizing its importance in reducing climate change and building a cleaner, more sustainable energy environment.

Keywords: global power generation, economic growth, fossil fuels, innovation, renewable energy sources

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1 INTRODUCTION

The story of our energy world is a remarkable journey spanning decades of change and innovation. It chronicles

our transition from heavy reliance on fossil fuels, which powered industrialization and modernization, to the brink of an energy revolution driven by environmental concerns.

In the past, the environmental consequences of our energy choices were an afterthought. We burned coal, oil, and gas without considering the long-term impact. However, our planet soon began sending distress signals: acid rain, smog-filled cities, and oil crises highlighted the detrimental effects of fossil fuel dependence on the environment and our quality of life. This realization prompted us to explore renewable energy (RE) sources. As we moved into the late 20th century, the urgency of addressing climate change accelerated our shift towards sustainability. The Intergovernmental Panel on Climate Change raised alarms about the disastrous effects of greenhouse gas emissions. This call to action spurred investments in research and development, leading to a surge in technological advancements across the RE spectrum. Today, the transition to sustainable energy is not merely a choice but a necessity. We are in the midst of a sustainable energy revolution that aligns with our urgent goal of combating climate change and reimagining energy production and consumption. As nations worldwide commit to ambitious sustainability goals, understanding the advancements and integration of RE sources becomes crucial for informed decision-making^[1].

In this exploration, we delve into the intricacies of the grid integration challenges posed by RE sources, particularly their intermittency. We navigate the complexities of integrating RE into existing power grids, addressing issues such as intermittent supply, the pursuit of viable energy storage solutions, and effective grid management strategies. Concurrently, we focus on the transformative realm of smart technologies that have reshaped the energy sector. We examine how these innovations optimize the deployment of RE, encompassing real-time monitoring, efficient demand response mechanisms, and intelligent grid management. These advancements play a pivotal role in enhancing grid stability and bolstering the adaptability and resilience of our energy system. Moreover, we broaden our perspective to evaluate the socio-economic impacts of this transition to sustainable energy practices. Beyond technology, we assess how these changes affect individuals and society at large, including their potential to generate employment opportunities, stimulate economic growth, and expand energy access, particularly in underserved regions. Together, these insights illustrate how embracing sustainable energy practices paves the way for a brighter and more equitable future for all. By addressing these objectives, this review paper aims to contribute valuable insights into the ongoing sustainable energy revolution, fostering a deeper understanding of the intricate interplay between technological advancements, grid integration challenges, smart technologies, and socio-economic considerations.

2 SOLAR ENERGY

2.1 Photovoltaic (PV) Systems

PV systems are a widely adopted technology for converting sunlight directly into electricity. They consist

of solar panels made of semiconductor materials, such as silicon, that generate direct current (DC) when exposed to sunlight. The generated DC is then converted into alternating current using inverters for use in homes, businesses, and utilities.

Aspects of PV Systems Include:

- Types of PV Cells: Different types of PV cells exist, including monocrystalline, polycrystalline, and thin-film cells, each with varying efficiencies and costs.
- Efficiency Improvement: Research focuses on increasing the efficiency of PV cells through material innovation, anti-reflective coatings, and multi-junction cells.
- Bifacial Panels: These panels capture sunlight on both sides, increasing energy yield by reflecting light from surrounding surfaces.
- Building-Integrated PV: Integrating PV panels into building materials like roofs and facades enhances aesthetics and efficiency^[2].
- Emerging Technologies: Perovskite solar cells and organic PV cells show promise due to their potential for low-cost, efficient energy conversion.

PV systems have seen significant advancements in recent years, driven by research and development efforts to enhance efficiency and reduce costs. Monocrystalline and polycrystalline silicon-based PV cells remain predominant due to their established performance and reliability. However, thin-film technologies, such as amorphous silicon, cadmium telluride, and copper indium gallium selenide, have gained attention for their potential to reduce manufacturing costs and enable flexible applications^[3].

Recent Research Development:

Perovskite solar cells have shown remarkable progress in efficiency, with laboratory cells surpassing 25%. Perovskite materials are inexpensive to produce and can be solution-processed, allowing for low-cost manufacturing. Tandem solar cells, which stack multiple layers of different materials, have demonstrated efficiency records above 29%. This approach enables more efficient use of the solar spectrum. PV systems are considered a young green technology compared to conventional power generation sources, such as coal-fired and fuel-fired power plants. Nevertheless, the cutting-edge PV system has provided a solution to the world's sustainable development problems, and the PV installation has contributed to reducing the global greenhouse gas emissions from the power sector. The campaign to expand the PV system business has received support from several nations. The United States has set a target to reach carbon-free electricity by 2035. Malaysia is committed to reducing its carbon footprint and achieving a 20% RE target by 2025 in the national installed capacity mix. Sweden has added more money to the policy to promote incentives for the installation of PV systems in homes and businesses. The Italian government increased the tax benefit for installing PV

systems from 50% to 110%, allowing households to do so at no cost. The Italian government has allowed homeowners to install PV at no cost by increasing the tax break from 50% to 110% for PV system installation^[4].

Challenges:

- **Stability and Durability:** Perovskite solar cells face challenges with stability under prolonged exposure to sunlight and moisture, limiting their commercialization.
- **Materials Supply:** The PV industry's growth relies on the availability of critical materials such as silver, indium, and tellurium.
- **Energy Payback Time:** Despite improvements, the energy payback time for PV systems, particularly high-efficiency ones, remains a concern.

Potential Applications:

- **Building-Integrated PV:** PV panels integrated into building materials enable sustainable architecture while generating electricity.
- **Off-Grid Solutions:** PV systems can provide power to remote areas without reliable access to the grid.
- **Solar Farms:** Large-scale solar installations contribute to grid power and reduce dependence on fossil fuels^[5].

Impact: PV systems have become a cornerstone of global RE adoption, with capacity installations growing rapidly. Their environmental benefits, reduced costs, and potential for decentralized power generation contribute to a cleaner and more sustainable energy mix^[6].

2.2 Concentrated Solar Power (CSP)

CSP systems use mirrors or lenses to concentrate sunlight onto a small area, which generates heat that is then used to produce electricity. CSP systems are often used in large-scale power plants and offer advantages in energy storage and continuous power generation^[7].

Aspects of CSP Systems Include:

- **Parabolic Troughs:** Curved mirrors focus sunlight onto a central receiver, heating a fluid to produce steam for turbines.
- **Solar Power Towers:** Heliostats reflect sunlight to a central tower, where it heats a fluid or molten salt to generate steam.
- **Dish-Stirling Systems:** A parabolic dish concentrates light onto a Stirling engine, which converts heat to mechanical motion and then electricity.
- **Thermal Energy Storage:** Molten salt or other materials can store heat for nighttime or cloudy periods, enabling continuous power generation.
- **CSP systems have made strides in improving efficiency and energy storage, making them more competitive with other RE sources.**

Recent Research Developments:

CSP technologies have focused on enhancing thermal

energy storage systems to extend power generation into the evening or cloudy periods. Advanced receiver designs, such as supercritical carbon dioxide turbines, offer higher efficiencies and better heat transfer.

The roadmap for the CSP concludes as follows based on the most current IEA report: it is anticipated that by 2050, with the right level of governmental assistance, the CSP may produce 11.3% of the world's power consumption, with 9.6% coming from solar energy and 1.7% coming from backup fossil or biomass fuels. Furthermore, because of its high solar irradiation, which makes up for the higher cost of the additional transmission lines, Northern Africa has a significant potential to export power to Europe. The CSP might be used in various hightemperature water desalination applications in world; as detailed in this report, there are more than 143 projects globally, of which 114 are functioning, 20 are currently nonoperational or decommissioned, and 9 are under development and will start operating in 2022 and 2023^[8].

The top three nations building and running CSP plants are Spain, the United States, and China. With 51 projects established around the nation and more than 2.3 GW of installed capacity, Spain has the most. These projects are all in use. Despite just 1.5 GW of capacity being in operation, the US has implemented more than 26 projects around the nation since the start of CSP. China now has 596 MW of installed capacity, and several projects are still being built. compares the installed capacity for every nation on earth, taking into account all active power plants. Based on their thermodynamic cycle and cycle efficiency, CSP plants are categorized into three generations.

The Rankine cycle, which has a, is utilized by the first generation of CSP facilities, design cycle efficiency of 28-38% and a peak cycle temperature of 240-440°C, and the PTC, Solar Tower, and LFR are often employed. The majority of first-generation CSP plants lacked thermal storage, which meant that they could only function when it was sunny all day. The majority of deployed CSP capacity is still made up mostly of first-generation CSPs, with PTC systems now making up 64% of all projects. The majority of second-generation CSP facilities consist of PTC, SPT, and LFR, with maximum cycle temperatures of 565°C and Rankine cycle efficiencies ranging from 38 to 45%. The majority of newly constructed second-generation CSP facilities use thermal energy storage systems. Due to their high cycle efficiency, these second-generation CSP facilities might achieve an annual solar-electric efficiency of around 10-20%, as opposed to 9-16% for first-generation CSP systems. With the use of more advanced materials for heat transfer, thermal storage, and working fluid in the thermal cycle, the third generation of CSP facilities aims to raise the maximum cycle temperature. However, none of the third-generation CSP technologies have any commercial uses yet; they are all still in the demonstration stage. Third-generation

CSP's main objective is to reduce the LCOE by boosting solar electric efficiency when operating temperatures exceed 600°C.

Challenges:

- Land and Water Use: CSP systems require significant land area and water for cooling, which can be challenging in arid regions.
- High initial costs: CSP plant infrastructure, including as mirrors, towers, and heat storage, can be pricey.

Potential Applications:

- Grid Stability: CSP with thermal storage provides dispatchable power, enhancing grid stability by supplying electricity when needed.
- Industrial Processes: High-temperature CSP can provide heat for industrial processes like desalination and chemical production.
- Hybrid Systems: Integrating CSP with fossil fuel plants can reduce emissions and improve overall efficiency.

Impact: CSP technology is well-suited for regions with abundant sunlight and the need for both electricity and thermal energy. As energy storage technologies improve, CSP's ability to provide continuous and on-demand power becomes increasingly valuable^[9].

2.3 Advances in Solar Energy Conversion Technologies

Recent advancements in solar energy conversion technologies hold promise for further increasing efficiency and expanding applications. Advances in solar energy conversion technologies encompass a range of innovations aimed at improving efficiency, reducing costs, and expanding the application of solar energy.

Advances Include:

- Perovskite Solar Cells: These emerging cells have shown rapid efficiency improvements, offering potential for low-cost and flexible solar panels.
- Tandem Solar Cells: Multiple layers of different materials absorb different parts of the solar spectrum, enhancing efficiency.
- Nanotechnology: Nanomaterials and nanostructures are being used to enhance light absorption and electron transport in PV cells.
- Photon Upconversion: This technology converts low-energy photons into high-energy ones, increasing the efficiency of solar cells.

Recent Research Findings:

Tandem Cells: Tandem solar cells, which combine different materials to capture a broader spectrum of light, have achieved record efficiencies by optimizing light absorption and minimizing energy loss. **Perovskite Solar Cells:** Despite challenges, perovskite solar cells continue to improve in efficiency and stability, making them a potential

disruptor in the PV market. **Nanotechnology:** Researchers are exploring nanomaterials to enhance light absorption and electron transport in solar cells, potentially boosting efficiency. The ECOWAS (Economic Community of West African States) sub-region has diverse RE sources that can be harnessed to generate sustainable energy, increase energy access, and switch to a low-carbon future. Over the past seven years, the ECOWAS sub-region has developed both a plan for RE policy and an energy efficiency (EE) strategy. These plans aim to boost RE generation to 2425 MW in 2020 and 7606 MW in the decade after 2020, with 10-19% being produced from non-hydro sources, correspondingly. The EE program intends to decrease energy demand by 2000 MW, reduce distribution losses to 10%, achieve a 100% utilization rate of efficient bulbs, and improve EE in public buildings until 2030. The RE and EE required shares in the European Union have shown that linking the global action plan is essential to achieve the goals established at the suggested trajectory point. The purpose of the EE Program is to design and implement policies to increase the spread of RE in the region. The first objective is to achieve universalization by 2030 by using reliable, timely, sufficient, and cost-competitive sources of RE for all streams of energy supplies and services. To achieve the working document's objective of expanding access to contemporary cooking services in 2020, the second factor is access to modern cooking solutions. Grid-connected RE use, distributed and stand-alone RE use, and domestic RE use are included in the third category of EE program goals^[10].

Challenges:

- Commercialization Hurdles: Transitioning from laboratory-scale successes to large-scale manufacturing and deployment remains a challenge for emerging technologies.
- Durability and Longevity: Ensuring the long-term stability and durability of new materials is crucial for their practical viability.

Potential Applications:

- Flexible and Portable Devices: Perovskite and organic solar cells can be incorporated into flexible and lightweight devices, expanding their application in wearable technology and consumer electronics.
- Urban Integration: High-efficiency, aesthetically pleasing solar panels can be integrated into urban infrastructure, such as windows, facades, and public spaces.

Impact: Advancements in solar energy conversion technologies contribute to the ongoing reduction of RE costs, making clean energy more accessible and accelerating the transition away from fossil fuels.

2.4 Integration and Storage Solutions

Integrating solar energy into existing grids and systems requires effective storage solutions to manage fluctuations in solar output.

It Includes:

- **Battery Storage:** Lithium-ion and other advanced batteries store excess solar energy for use during peak demand or low sunlight periods.
- **Grid Integration:** Smart grid technologies enable seamless integration of solar energy into existing power grids.
- **Hybrid Systems:** Combining solar with other renewable sources like wind or hydroelectric power ensures more consistent energy generation.
- **Demand Response:** Adjusting energy consumption patterns based on solar availability helps optimize energy use.
- Effective integration and storage solutions are essential for maximizing the potential of solar energy within existing energy systems^[11].

Recent Research Findings:

- **Battery Innovations:** Research into new battery chemistries and materials, such as solid-state batteries, aims to improve energy density, safety, and charging capabilities.
- **Smart Grid Technologies:** Advanced grid management tools and demand-response systems enable better integration of intermittent RE sources like solar.
- Currently, the energy grid is changing to meet the growing energy demand, and also to support the rapid spread of RE sources.

As a result, energy storage technologies developed to increase the total utilization of the available green energy^[12]. These technologies enhance buffer capacity and support household and commercial consumption. Although various research projects have been conducted in the field, including PV and wind applications, the study on the suitability identification of different storage devices for various stationary application types is still a gap that needs further study and verification. By examining the present state and applicability of energy storage devices and determining the best sorts of storage technologies for grid support applications, the review filled these gaps. To identify their qualities and potentials, different technical, economic, and environmental impact evaluation factors are also taken into account. The thorough analysis demonstrates that the lithium-ion battery is suitable for low and medium-sized applications with high power and energy density requirements in the electrochemical storage category.

Among the electrical storage classes recognized as suitable for high-power applications are capacitors, supercapacitors, and superconducting magnetic energy storage devices. Additionally, thermal energy storage is recognized as useful in areas of bulk and seasonal energy application. It has been determined that the usage of hybrid solutions, which combine different storage devices, is a workable option in the industry with adequate identification of the application's needs and based on examinations of the techno-economic, environmental, and impact impacts of energy storage

devices^[13].

Challenges:

- **Intermittency:** The variable nature of solar energy requires robust energy storage systems to ensure a consistent power supply.
- **System Compatibility:** Integrating RE sources into existing energy grids can be challenging due to technical and regulatory factors.

Potential Applications:

- **Microgrids:** Solar panels combined with energy storage and smart controls can create localized microgrids that improve energy resilience and reduce reliance on the main grid.
- **Electric Vehicle Charging:** Solar panels can power electric vehicle charging stations, reducing the carbon footprint of transportation^[14].

Impact: Integration and storage solutions are crucial for transitioning to a more renewable energy-centric grid. By effectively managing solar energy fluctuations, these solutions contribute to a more reliable and resilient energy infrastructure.

3 WIND ENERGY

3.1 Onshore and Offshore Wind Farms

Onshore wind farms have historically dominated the wind energy landscape due to their economic feasibility and accessibility. However, recent research emphasizes the need for better utilization of land and consideration of community concerns. Offshore wind farms, while more expensive to install, have garnered attention for their potential to tap into stronger and more consistent winds, particularly in deeper waters. Ongoing studies explore cost reductions in offshore installations and improved environmental assessments to mitigate any unintended impacts^[12].

3.2 Turbine Technology and Efficiency Improvements

Wind turbine technology has undergone substantial evolution, with larger rotors and taller towers emerging as key trends. Recent studies focus on optimizing rotor design and improving materials for enhanced aerodynamics and structural integrity. Advanced control algorithms, machine learning, and sensor technologies are being integrated to optimize turbine performance in real-time responding to dynamic wind conditions. Moreover, direct-drive generator technology is gaining momentum due to its potential for higher efficiency and reduced maintenance^[13].

3.3 Grid Integration Challenges and Solutions

As wind energy's contribution to power grids grows, grid integration challenges become more apparent. Research centers on developing more accurate wind energy forecasting models that incorporate meteorological data and machine learning techniques. Innovative energy

storage solutions, including next-generation batteries and power-to-gas systems, aim to balance supply and demand. Additionally, smart grid advancements are being pursued to enhance grid flexibility and accommodate intermittent energy sources.

3.4 Environmental Impacts and Mitigation Strategies

Environmental concerns in wind energy expansion remain pertinent. The research investigates the interactions between wind farms and local ecosystems, highlighting the need for proactive mitigation strategies. Recent studies explore novel bird and bat monitoring techniques, including radar and acoustic technologies, to reduce collisions. Additionally, research delves into community engagement methods to minimize noise concerns and enhance public acceptance.

Recent Research and Challenges: Recent research in wind energy has focused on enhancing the efficiency of wind turbine components, improving grid integration with advanced energy storage solutions, and conducting more comprehensive environmental impact assessments. Challenges include optimizing offshore wind energy installations for cost-effectiveness and addressing the potential impacts on marine ecosystems. Additionally, achieving a harmonious balance between RE expansion and biodiversity conservation remains a crucial challenge.

Environmental Impacts and Mitigation Strategies: The environmental impacts of wind energy deployment are being studied extensively to develop effective mitigation strategies. Researchers are investigating the use of deterrent technologies, such as ultraviolet lighting, to minimize bird and bat collisions with turbine blades. Noise pollution concerns are being addressed through better turbine design and placement, along with an increased focus on community engagement. Continuous post-construction monitoring and adaptive management are essential to assess actual impacts and implement necessary adjustments.

4 BIOMASS ENERGY

4.1 Conversion of Biomass into Energy

Converting biomass into energy was typically done through processes like combustion, anaerobic digestion, or biochemical conversion. This method released stored energy from organic materials like wood, agricultural residues, and waste. The energy was used as heat, electricity, or even biofuels^[14].

Four types of conversion technologies result in specific energy and potential renewable products: Thermal conversion was use of heat, with or without the presence of oxygen, to convert biomass into other forms of energy and products. These include direct combustion, pyrolysis, and torrefaction. Combustion process done by burning of biomass in the presence of oxygen. The waste heat is utilized to heat or run a steam turbine that generates electricity used by a waste

heat boiler and waste heat. Biomass feedstocks are converted into gas and oil through pyrolysis at a regulated temperature and in the absence of oxygen. A generator is been powered by gases and oil, and certain technologies allowed for the production of chemicals and fuel from the gases. Torrefaction was comparable to pyrolysis, although it operated at lower temperatures.

Gasification was a popular name for thermochemical conversion. This technique creates producer gas and charcoal by controlled partial combustion at high temperatures, followed by chemical reduction. Agriculture waste used in gas turbines is one of the main applications for biomass. Production of jet fuel, chemicals, and diesel was the examples of advanced usages.

Biochemical conversion, which includes anaerobic digestion and fermentation, used enzymes, bacteria, or other microorganisms to convert biomass into liquid and gaseous feedstocks. These raw materials transformed into renewable chemicals, electricity, and transportation fuels. Chemical conversion was the process of turning biomass into liquid fuels, primarily biodiesel, by using chemical agents^[15].

Impacts: (1) Combustion caused Air Pollution, Greenhouse Gas, Ash Disposal, Pyrolysis was Complex Process & impacted on Bio-Oil Quality. (2) Thermochemical Conversion impact on High Energy Input, & Scale-Up Challenges; Biochemical Conversion impact Feedstock Variability & Fermentation Challenges; Chemical Conversion impact Complex Chemistry & Catalyst Dependency.

Challenge: EE: Some conversion methods, such as thermochemical processes, had lower EE due to the high energy inputs required to achieve optimal conditions. Technical Complexity: Many biomass conversion processes involved complex chemical and biological reactions that required for precise control of temperature, pressure, and other conditions. Transportation, storage, infrastructure^[16].

Recent Research:

Recently, innovations and technological advancements had came from the biomass industry. Advancements within the industry was primarily focused on the areas of harvesting and collection, storage, pretreatment, and conversion of biomass into bio-based products. When treated, biomass resources was been converted into energy used a variety of processes to generate electricity, fuel vehicles, residential and commercial heating, as well as provided process heat for industrial facilities^[16].

The research technology of catalytic chemical transformation and equipment for the transformation of biomass energy as well as fluidized gasification techniques was focused Combustion was well-proven from 1kW to 100MW it was relatively inefficient when linked with power

generation. conversion technologies had great potential, there are currently no global industry standards or consumer testing, allowed plant developers to choose which specific plant to buy. There are typically regional differences in the biomass feedstocks utilized, which must be taken into consideration when deciding plant design, handling, and storage facilities, decisions are sometimes made entirely on the hearsay of experienced operators of other comparable plants.

4.2 Biofuels and Biogas Product

Biofuels are energies deduced from renewable natural sources, similar to crops, algae, and waste accouterments. They used as a volition to traditional fossil energies. The product of biofuels involved processes like turmoil, distillation, and transesterification, depending on the type of biofuel being produced. Types of biofuels that include ethanol, biodiesel, and biogas^[15].

Challenges: Land Use and Competition-Biofuel products was contend with food crops for agrarian Land, potentially leading to advanced food prices and deforestation. When natural territories are converted into agrarian land^[17]. Resource Intensity Growing crops for biofuels requires water, diseases, and other coffers, which was strain original ecosystems and water inventories. Food Security Used by crops for biofuel products reduce the vacuity of food coffers, impacted global food security, especially in regions where coffers are formerly limited. Biodiversity Loss Large-scale monoculture husbandry for biofuel crops that affected the loss of biodiversity and disrupt original ecosystems.

Greenhouse Gas Emigrations -While biofuels was frequently touted as a cleaner volition to fossil energies, the product process itself was induced greenhouse gas emigrations, depending on factors like land use changes and energy sources^[18].

Impacts: Environmental impacts reduced greenhouse gas emigrations compared to reactionary Energy, Agrarian sector biofuels product stimulated pastoral husbandry bycreated jobs and request for agrarian product, Water quality, Climate change migration Global trade and frugality.

Recent Exploration: Biomass had a lower “energy viscosity” than fossil energies. As much as 50 of biomass was water, which was lost in the energy conversion process. The cost of produced biofuels from crops was far exceeds the current price of diesel or petrol, indeed if grown on set-aside land. A recent report showed that targeted revision in central carbon metabolism, similar to overexpression of isocitrate dehydrogenase and emission of glutamate synthase, can effectively enhance ethylene product in *E. coli*. civilization of biofuel-producing microalgae demands favorable environmental conditions, similar to suitable light, temperature, nutrients, saltiness, and pH. Although applying environmental stress can increase the product of biofuel, it generally at the

expenditure of dropped biomass yield^[19].

Biogas Product: Biogas production was the process of generating biogas through anaerobic digestion. Anaerobic digestion was a natural process which microorganisms break down organic matter in the absence of oxygen. This process resulted in the product of biogas, which was an admixture of primarily methane and carbon dioxide, along with trace quantities of other feasts^[20].

Biogas production worked by Feedstock Selection Organic accouterments similar to agrarian waste, beast ordure, sewage sludge, food waste, and energy crops that were used as feedstocks for biogas products (Digestion Process) The feedstock is placed in an enclosed vessel called a digester. In the digester, microorganisms (substantially bacteria) break down of the organic material through a series of natural responses, performed in the product of biogas. Biogas Composition The primary element of biogas was methane, which was a precious energy source. Carbon dioxide was also produced, along with lower quantities of Feast like hydrogen, nitrogen, and trace composites. Collections and storage of biogas was produced and accumulated in the digester. It was collected and stored in a gas storehouse system, which needs to be watertight to help the escape of methane. Challenges of biogas products Include feedstock vacuity, digester effectiveness, nonsupervisory and policy support, and icing the sustainable operation of biogas systems.

Recent Exploration: Exploration involved in the anaerobic digestion process, which aimed to understand their composition, function, and how to manipulate them to ameliorate biogas products also, studies had developed into colorful use for the generated biogas, similar to electricity generation, heat product, and vehicle energy. In recent times there was been a growing emphasis on sustainable practices, indirect frugality principles, and the integration of biogas products into waste operation strategies. This aligns with the global trend towards RE sources and environmentally friendly waste disposal styles. The most recent exploration trends included a focus on optimizing biogas products in lower-scale systems, similar to ménage or community digesters. also, there is growing interest in exercising biogas in decentralized energy systems and explored innovative uses beyond energy, similar to nutrient recovery and bio-based chemicals^[20].

4.3 Sustainability of Biomass Sourcing

The sustainability of biomass source was a pivotal consideration which used organic accouterments for colorful purposes, including biofuel products, biogas products, and other operations. Sustainable biomass source involved ensured that the product and use of biomass had minimum negative impacts on the terrain, society, and frugality.

Crucial Factors: Feedstock Selection Choose feedstocks that had low environmental and social impacts, avoided used land that had high biodiversity value, that was designated for conservation, or had important artistic or social significance, Ecosystem estimated the impact of biomass civilization on original ecosystems, soil quality, water coffer, and wildlife territories. Water Uses Assessed the water conditions of biomass crops and ensured that civilization practices don't deplete or pollute water coffer. Lifecycle Analysis to estimate the overall environmental impact of biomass products, transportation, and conversion processes^[21].

Challenges: Competition with Food Production Using land for biomass civilization can contend with food products, potentially led to advanced food prices and enterprises about food security. Environmental Impact Unsustainable civilization practices, similar to the inordinate use of diseases or fungicides, lead to soil declination, water pollution, and dislocation of original ecosystems. Land Use Change Converting natural ecosystems or timbers into biomass colonies^[22].

Impacts: Environmental conservation of biodiversity protected biomass source, reduced carbon emigrations sustainable biomass source can replace fossil energies, reduced carbon emigrations and mollifying climate change. Waste Reduction Biomass source used agrarian and forestry remainders, reduced waste and promoting resource effectiveness. Climate Change Mitigation Biomass was been used for carbon prisoners and storehouses contributing to climate change mitigation sweats^[11].

Research: Research on sustainable biomass source had the impact of biomass civilization on land use, biodiversity, and ecosystem services. Studies had assessed the felicity of different types of land for biomass products, the implicit competition with food crops, and the goods of land-use change on original communities and natural territories. Experimenters had also explored agroforestry systems that integrate biomass products with food crops, aiming to achieve sustainable land use and diversified agrarian practices. Biomass can be converted into bioenergy through thermochemical and biochemical processes. Thermochemical processes involve breaking down organic substances, converting chemical energy into heat energy. They include pyrolysis, gasification, liquefaction, hydrothermal carbonization, and supercritical fluid extraction. Biochemical processes use alcoholic fermentation, anaerobic digestion, photobiological hydrogen production, and microbial and microalgal fuel cells. Thermochemical processes have lower response times and purification costs.

The most biomass sources for biofuel products was overcome ramified obstacles in the dependable force of biomass feedstock. Developed a biomass portfolio, that can generally ameliorate the sustainability of not used biofuel systems. Bioethanol is a seductive biofuel that had the

eventuality to enhance energy security and environmental safety over fossil energies.

Challenges: Food Security Allocated land for non-food purposes, similar to biomass energy crops, can potentially impact food products and vacuity. Climate Change Relations Land use changes can interact with climate change impacts, aggravating vulnerabilities or mollifying pitfalls in changeable ways. Habitat Loss and Biodiversity Land conversion for energy or other purposes affected niche loss, hanging factory and beast species, and reducing biodiversity. Land declination ferocious land use practices can lead to soil corrosion, reduced fertility, and declination, impacting long-term land productivity. The "food vs energy" debate centers around the competition between used crops for food products and used them for biofuel or biomass energy products.

Arguments for Biomass Energy: RE Source Biomass energy provided a volition to fossil energies, reduced house gas emigrations and contributing to energy security. Diversification Used biomass for energy diversifies the energy blend, dwindling dependence on finite reactionary energies. Rural Development Biomass energy systems produced jobs and stimulate profitable growth in pastoral areas.

Recent Exploration: By analyzed geographical and technical potential of energy crops for the years 2050–2100 for land-use categories: abandoned agricultural land, low-productivity land, and 'rest land', i.e. remaining no-productive land^[23]. The goal was to create high-quality, land use/land cover maps for agricultural and wastelands in India. With acceptable level of accuracy assessment, it also determined the surplus biomass resources in wastelands and municipal solid waste distributed in Indian states. states was selected due to high level of agriculture production and high agro-biomass potential due to presence of large industrial agglomerations, and the high interest in bioenergy development in these states^[24].

5 EMERGING TECHNOLOGIRS

5.1 Tidal and Wave Energy

Waves and tides are both sources of energy in the ocean that we can harness to generate electricity. Waves are created by the wind and make the water move in circular patterns, while tides are caused by the gravitational pull of the Moon and Sun, resulting in long-wavelength waves and strong currents in coastal areas. The technology for generating power from waves and tides is similar to hydroelectric dams or wind farms, involving spinning turbines to create electricity. However, waves and tidal power differ in their locations and the specific mechanisms they use for power generation.

5.1.1 Recent Research

In recent, drone-based technology is also used to measure

tidal range and sea depth. Data mining and data analysis are also used to predict or forecast tidal energy resources and measure the future load demand for tidal energy.

The performance of tidal energy or ocean energy system is enhanced with the use of some advanced technology such as machine learning. Such type of advanced technology is used for prediction, and modeling and also created the relationship between the different parameters of ocean energy systems through the different types of data mining approaches. It also described the feasibility analysis of the wave energy system.

Advanced digital hardware, like satellites, drones, and sensors, along with sophisticated analytics such as machine learning and computer vision, are essential for real-time ocean governance. This combination enables us to gather data from various sources and analyse it efficiently. Artificial intelligence plays a significant role in optimizing ocean energy applications by using techniques like machine learning to enhance decision-making processes. While numerical modeling has traditionally been the go-to method for problem-solving in ocean engineering, artificial neural networks are proved to be a promising alternative, especially for complex and non-linear problems, as they often delivered better results.

5.1.2 Challenges

Global Shield: That offers significantly increased corrosion protection for longer component field life at a lower cost than stainless steel. The Parker Tracking System: It is a tagging and tracking solution to store, access and monitor critical asset information. Real-time access to this data enabled a process known as reliability-centered maintained by scanning metrics that indicated a potential future issue and enabled technicians to perform and maintained on a piece of equipment before it fails.

5.1.3 Impact

Tidal power can effect the marine life and it leads to the deaths of living creatures in the sea. The noise from the rotation of the turbines may impact fish habitation, quality of water and sedimentation process.

5.2 Ocean Thermal Energy Conversion (OTEC)

OTEC produced energy from temperature differences in ocean waters. OTEC is technology which produced energy by controlling temperature differences (thermal gradients) in between ocean surface waters and deep ocean waters. Energy from the sun heats the surface water of the ocean, especially in tropical areas, it makes the surface water warmer than the deep water. It can be used to create electricity and to turn saltwater into freshwater. OTEC systems works by using this temperature contrast. This process can also be used to produce fresh water from seawater as a by product. They have a setup where warm surface water is turned into vapour,

which then spins a turbine to generate electricity. After that, the vapour cools down and becomes liquid again when it's in contact with colder water from deeper in the ocean.

5.2.1 Research

Based on these advantages, several modes had been proposed for utilization of OTEC, such as OTEC-based power generation, OTEC refrigeration and desalination. In carbon neutralization benefits, there existed certain proposals for OTEC power generation that produced considerable amounts of electricity. The idea dates back to the 1930s when Georges Claude built the first OTEC plant in Cuba, using warm surface seawater to generate steam and drive a turbine for electricity production. Despite advancements since then, challenges like high costs, low efficiency, and corrosive environments hinder widespread adoption of OTEC for power generation. However, ongoing theoretical and pilot studies continue to explore its feasibility and potential benefits, particularly in terms of carbon neutrality.

5.2.2 Challenges

The main challenge with OTEC technology is its low energy conversion efficiency. This is because the temperature difference between warm surface seawater and cold deep seawater, which OTEC relies on, is relatively small, typically around 20°C even in tropical regions. For instance, one type of OTEC system called the Uehara cycle has a thermal efficiency of only about 4.97%. To address this issue, it's crucial to focus on improving the thermal efficiency of OTEC technology. One way to do this is by combining ocean thermal energy with other sources of low-grade heat, like solar energy and industrial waste heat. By using these additional heat sources to warm up the surface seawater, we can increase the overall temperature and improve the efficiency of the OTEC system^[25].

5.2.3 Impact

OTEC facilities utilize the temperature difference between warm surface water and cold deep water to generate electricity. Mixing of these waters causes harm to the marine life. For instance, nutrient upwelling from the deep could impact fish populations or trigger algae blooms. On a larger scale, widespread OTEC facilities could even affect overall ocean temperature, influencing weather patterns, climate, and ocean currents.

5.3 Solar-to-fuel Technologies

Solar fuels are man-made fuels created using solar energy. They can be produced through various methods, such as photochemical reactions (where chemical reactions are triggered by photons), photo biological processes (similar to Artificial photosynthesis (APS)), and electrochemical reactions. These fuels are similar in composition to fossil fuels but are produced using RE sources. One of the significant advantages of solar fuels is that they can seamlessly integrate

into the existing global fuel infrastructure without the need for modifications to engines, refineries, fuel distribution systems, or filling stations.

5.3.1 Research

Although solar energy technology research has primarily focused on the electricity sector, electricity accounts for only about one-third of the total primary energy consumption. Solar energy can also be converted into fuels, which continue to dominate U.S. energy consumption. Thus, solar-to-fuel conversion will be important in creating storable, transportable alternatives to high-energy-density fossil fuels.

There are several ways researchers are working on creating solar fuel systems. One method involved in recreating the molecular components of natural photosynthesis, like chlorophyll, through chemical synthesis. This aims to construct a functional photosynthetic system without the need for living organisms like plants or algae.

Another approach uses inorganic molecules, such as transition metal complexes, instead of chlorophyll. These molecules act as light absorbers and are coupled with either biological catalysts or inorganic catalysts like metal colloids or particles to generate solar fuels. A different method involved in bonding metal dyes to titania films to absorb light. These dyes are then chemically linked to transition metal catalysts to produce solar fuels. Lastly, inorganic semiconductors, similar to those used in solar panels, can be employed. They can either indirectly generate electricity in combination with catalysts for solar fuel production or act as photo electrodes to directly produce fuels from sunlight^[3].

5.3.2 Challenges

India lacks sufficient research, modern facilities, and manufacturing infrastructure to produce all the solar panels, equipment, and inverters needed to meet demand. This leads to increased imports from countries like China and Germany, driving up costs.

Solar systems require large upfront investments and take a long time to pay back. This capital burden can limit investments in other energy sectors and increase debt levels. The high initial costs discourage adoption of solar energy.

There is a general lack of awareness and education about solar energy, especially in rural areas. People don't understand the benefits, advantages, and accessibility of solar power. More active education and outreach is needed to teach people about solar, particularly in rural communities. Overall, the main challenges slowing India's adoption of solar energy are insufficient domestic production capacity, high upfront costs and long payback periods, and a lack of public awareness and education around the benefits of solar power. Overcoming these challenges will require investments

in R&D and manufacturing, financing mechanisms to reduce costs, and expanded outreach and training programs.

5.4 APS for RE Storage

APS mimics the natural process of photosynthesis found in plants and other organisms, it captures and stores solar energy as fuel instead of producing glucose. By using semiconductors, APS devices absorb sunlight and convert it into chemical energy, which can be stored and used later. This stored energy is cost-effective and efficient compared to traditional battery storage methods. Additionally, APS has the benefit of being carbon-negative, meaning it removes excess carbon dioxide from the environment and produces oxygen, making it a more environmentally friendly when compared to solar panels. Overall, APS has the potential to revolutionize solar power by offering a sustainable and efficient way to capture and store solar energy while mitigating carbon emissions.

5.4.1 Recent Research

Capturing Light Energy: Plants and some bacteria have special structures that capture sunlight and turn it into energy, kind of like solar panels. This energy is used to split H_2O into O_2 & H_2 .

Moving Electrons and Protons: Once sunlight is captured, it's used to move tiny particles called electrons and protons around. This movement creates a kind of electrical charge separation, which is important for making energy. **Making Oxygen and Hydrogen:** The electrons and protons move through a chain of special molecules, kind of like a conveyor belt, and help turn water into oxygen and hydrogen. Scientists are using advanced techniques like nanotechnology to mimic this process in artificial systems.

To make APS work better, scientists are tinkering with different materials and structures at the tiny molecular level. They added things called impurities to materials to change how they work, and they organized molecules in clever ways to make the process more efficient. This could help us make energy in a cleaner, more sustainable way, kind of like how plants do it.

5.4.2 Challenges

Splitting water to obtain hydrogen and oxygen involves using systems that capture light energy and then converts it into chemical energy through catalytic processes. However, the materials used for this process need improvement in terms of their stability and efficiency. Similarly, converting carbon dioxide into useful products like carbon monoxide, methane, or ethylene requires optimized catalysts that can balance activity, selectivity, and stability. One approach to improve catalyst performance is through techniques like Nano structuring and using bimetallic catalysts such as Au-Cu systems. Efficiently connecting the photosynthetic device with other catalytic fields is crucial for converting

renewable hydrogen into various chemical products. Essentially, it's about enhancing materials and catalysts to make these processes more efficient and sustainable^[26].

5.4.3 Impact

APS device involved semiconductor that absorbed solar energy and stored, by converting in the form of chemical energy. Regular photosynthesis, which produced carbohydrates from carbon dioxide and water, APS produced ethanol, methane, etc.

6 CHALLENGES AND FUTURE OUTLOOK

6.1 Economic Viability and Cost Reduction

The widespread adoption of emerging renewable technologies faces challenges due to substantial initial investment and operational costs. Ongoing research and development aim to alleviate these barriers by enhancing materials, refining manufacturing techniques, and simplifying installation processes. Additionally, government incentives, subsidies, and policies contribute to lowering costs and improving the economic feasibility of these technologies^[27].

6.2 Scaling Up and Global Deployment Challenges

As renewable technologies advance, the forefront challenges shift towards scaling up production and deployment. Concerns like conflicts over land use, environmental impact assessments, and the complexities of integrating with existing grids underscore the need for interdisciplinary collaboration among researchers, policymakers, and industry stakeholders. Efficient deployment strategies and international cooperation are crucial for making a substantial global impact^[28].

6.3 Addressing Intermittency and Grid Stability

The intermittent nature of RE sources such as solar and wind poses challenges for maintaining a stable and dependable power grid. To address this, energy storage solutions like advanced batteries, pumped hydro storage, and emerging technologies such as compressed air energy storage are essential for managing intermittency effectively. Moreover, there is a growing exploration of smart grid technologies and demand-side management to better balance supply and demand.

6.4 Role of RE in Achieving Climate Goals

RE technologies are pivotal in reaching climate mitigation objectives and shifting towards a low-carbon energy framework. Recent studies underscore the considerable potential of renewables to cut greenhouse gas emissions and diminish dependence on fossil fuels. Both policymakers and industry stakeholders are increasingly acknowledging the vital role of renewables in attaining enduring sustainability and tackling climate change.

7 CONCLUSION

In this inclusive review paper, we've covered the different

geography of RE sources, exploring their significance, advancements, challenges, and implicit benefactions to a sustainable future. The preface underscores the urgency of transitioning to renewables for mollifying climate change, setting the stage for a comprehensive analysis. Solar energy, epitomizing the eventuality of PV systems, CSP, and slice edge conversion technologies, emerges as a vital contender for global energy metamorphosis. Advantages of solar energy include reduce electricity bills, low operational costs, low environmental impact. Disadvantage include high initial installation cost, require large space for panels. complexity involves installation of solar panel, inverters and possibly storage system. Applications used in residential, commercial and industrial power generation. Wind energy, through onshore and offshore wind granges, showcases continual progress in turbine technology and addresses grid integration complications, though environmental considerations loiter. Advantages includes renewable and abundant in windy areas, low operational costs, can be installed on existing farms. Disadvantages includes intermittent energy production, noise and aesthetic concern, impact on local wildlife, Complexity requires installation of turbines and supporting infrastructure. Application-remote and rural power supply, utility scale power generation. Biomass energy's versatility is stressed, encompassing biomass-to-energy conversion. Advantages includes utilizing waste materials, which reduce greenhouse gas emissions compared to fossil fuels, which can be produced continuously. Disadvantage this method required a constant supply of biomass. Complexity involves collection, processing and conversion of biomass. Application includes heat and electricity generation, combined heat and power system, biofuel production. Advantage of biofuel production, it replaced conventional fuels, reduced dependence on oil, reduced greenhouse gas emissions. Disadvantage includes competition with food production, land and water use concerns, Complexity involves cultivation, harvesting and processing of biofuel crops. Application includes transportation and power generation. and biogas production, Advantages which converted waste into energy which reduced landfills waste and methane emissions and used for cooking, heating and electricity. Disadvantage this method requires continuous feedstock supply and biogas production have odor issues. Complexity involve anaerobic digestion process. Application helps in supply energy to rural and urban areas & waste management. Accompanied by a careful examination of sustainability and land-use counteraccusations. Arising technologies, encompassing tidal and surge energy. Advantages of tidal & wave energy includes minimal visual impacts, low operational costs once installed. Disadvantages includes potential environmental impacts on marine life & installed in limited locations. Complexity involves installation of underwater or surface devices. OTEC, Advantages includes constant energy supply & utilizes vast ocean thermal resources. Disadvantage includes high technological and maintenance challenges,

environmental impacts. Complexity required complex system to convert thermal energy to electricity. Application large scale power generation in tropical regions. solar-to-energy inventions, and APS, illuminate promising avenues for energy revolution.

The recognition of challenges, similar to profitable viability, scalability, intermittency mitigation, and the central part of renewables in achieving climate pretensions, forms the bedrock for a sustainable energy outlook. This review, gauging solar, wind, biomass, and arising technologies, underscores the intricate trip towards sustainability, emphasizing the cooperative sweat needed across disciplines, diligence, and global communities to embrace and appear the transformative eventuality of RE sources.

In conclusion, this review paper comprises of a comprehensive overview of colorful RE technologies, examining their current state, advancements, challenges, and unborn prospects. By addressing solar, wind, biomass, and arising technologies, the review underscores the multifaceted trip toward a sustainable energy future. As the world navigates the transition, a combined trouble from experimenters, policymakers, diligence, and society at large is imperative. To harness the eventuality of RE sources and steer humanity toward a greener and more prosperous future. This holistic understanding of renewable energy's different geography paves the way for informed opinion ns and cooperative conduct that will shape the line of global energy sustainability.

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Conflicts of Interest

The authors declared no conflict of interest.

Author Contribution

Dharshan S worked on the abstract, introduction, and the outline of the research paper. Poorvashree KH worked on the solar energy topic and figures in solar energy and wind energy. Faizullah. worked on the wind energy topic and recent research finding. Kalaivi v worked on biomass topic, investigation, Resources, Writing Review & Editing. Naveen Kumar worked on the challenges and future outlook. P. Kusuma Kumari worked on the emerging technologies section. Soumya V Menon did the final reviewing, editing and revising of the manuscript.

Abbreviation List

APS, Artificial photosynthesis
CSP, Concentrated Solar Power
DC, Direct current
ECOWAS, Economic Community of West African States

EE, Energy efficiency
OTEC, Ocean thermal energy conversion
RE, Renewable energy

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