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Hybrid Renewable Energy Systems: Efficiency and Sustainability in Power Plants

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Abstract— This study analyzes the efficiency of hybrid renewable energy systems combining solar, wind, biomass, and energy storage to improve power plant reliability and reduce carbon emissions. Simulations using HOMER Pro software reveal system efficiency reaching 55%, with cost reductions to $0.04/kWh. Hybrid systems demonstrate lower carbon emissions than fossil-based technologies, offering environmental and economic benefits. These findings highlight the necessity of advancing energy storage technologies and optimizing resource utilization for clean energy transitions.

Keywords: Renewable energy, power generation, energy efficiency, conversion technology, sustainability.

I. Introduction

While renewable energy technologies such as solar and wind power have advanced significantly, research on hybrid systems remains limited. This study uniquely evaluates hybrid configurations using real-time simulations and expert interviews to address energy variability challenges and improve system efficiency. The findings provide a comprehensive approach to optimizing renewable energy contributions to global energy grids.

Climate change and increasing global energy needs drive renewable energy development as an alternative environmentally friendly energy source. Based on data from the International Renewable Energy Agency (IRENA), the contribution of renewable energy to global electricity generation will increase to 30% by 2023. However, significant obstacles remain, such as energy intermittency and conversion efficiency, which still need to be overcome.

Previous studies have shown that solar panels and wind turbines significantly improve efficiency and cost. However, more research is needed on large-scale integration into the electricity grid. This article explores the latest approaches in renewable energy conversion technologies, identifies critical constraints, and provides strategic recommendations to increase renewable energy's contribution to electricity generation.

The energy crisis and climate change are global challenges that require sustainable solutions. Fossil-based energy sources have dominated electricity generation and are the main contributors to greenhouse gas emissions. Based on the Intergovernmental Panel on Climate Change (IPCC, 2023) report, the energy sector contributes more than 75% of global carbon emissions, with coal-based power plants being the primary cause. This demands a shift towards cleaner and renewable energy sources.

Renewable energy, such as solar, wind, biomass, hydro, and geothermal, offers excellent potential to replace fossil fuels. The International Energy Agency (IEA, 2022) reported that global renewable energy capacity reached 3,372 GW in 2022, an increase of 9% compared to the previous year. However, the development of technology and infrastructure remains a significant challenge to increasing the contribution of renewable energy to the national energy mix, especially in developing countries.

Energy has become a basic human need that supports economic development and quality of life. Energy demand continues to increase along with global population growth and rapid industrialization. According to the World Energy Outlook report (IEA, 2022), global energy consumption is projected to increase by 25% by 2050. Most of this demand still relies on fossil fuels, such as oil, coal, and natural gas, which account for around 80% of total global energy consumption in 2023.

However, dependence on fossil fuels has significant environmental impacts, including carbon dioxide (CO_2) emissions, air pollution, and climate change. A report from the United Nations Framework Convention on Climate Change (UNFCCC, 2022) emphasizes that if emissions are not drastically reduced, global temperatures could rise by more than two °C above pre-industrial levels by the end of this century. This will worsen natural disasters, create food crises, and increase public health risks.

In response, many countries have committed to a green energy transition through renewable energy development. The European Union, for example, has set a target to achieve carbon neutrality by 2050, with more than 50% of energy coming from renewable sources by 2030 (European Commission, 2023). Similarly, in Indonesia, through the National Energy General Plan (RUEN), the renewable energy contribution is targeted at 23% in the national energy mix by 2025 (Ministry of Energy and Mineral Resources, 2023).

In the last decade, renewable energy technology has made significant progress. New-generation photovoltaic panels have a conversion efficiency of up to 24% under optimal conditions (Green et al., 2021), while modern wind turbines can operate at lower wind speeds, increasing the capacity factor by up to 40% (Liu et al., 2020). Biomass, with its abundant potential in tropical regions, is an alternative solution for electricity generation based on organic waste (Yadav et al., 2022).

However, each technology has its advantages and disadvantages. For example, solar power relies heavily on solar radiation, making it less than optimal in cloudy or cold climates. Similarly, wind power faces the challenge of intermittency due to wind speed fluctuations (Zhao et al., 2020).

Integrating renewable energy into the electricity grid requires the development of intelligent infrastructure, such as smart grids, to manage supply variability. A study by De Carne et al. (2024) suggests that developing lithium-ion battery-based energy storage systems could address these challenges, although high initial costs remain a significant barrier.

Renewable energy encompasses a wide range of technologies, each with unique characteristics. Here is a summary of recent developments in key technologies:

1. Solar: Photovoltaic (PV) panels are one of the fastest-growing renewable energy technologies. With the discovery of perovskite materials and tandem cells, solar panel efficiencies have increased to over 28% under laboratory conditions (Green et al., 2021). Installation costs have also dropped dramatically, making solar power more competitive in the global energy market.
2. Wind Power: New generation wind turbines are designed to operate at lower wind speeds, allowing them to be used in more locations. Offshore turbines installed at sea also show great potential due to their higher capacity factors compared to onshore turbines (Liu et al., 2020).
3. Biomass: As an energy source derived from organic matter, biomass offers a solution for waste treatment and electricity generation. Developing more efficient gasification and combustion technologies has increased the economic viability of biomass as an energy source (Yadav et al., 2022).
4. Hydropower and Geothermal Energy: Hydroelectricity remains the most significant contributor to global renewable energy, with over 1,300 GW of installed capacity (IRENA, 2023). Meanwhile, geothermal energy is growing in countries such as Indonesia, which has the second-largest geothermal reserves in the world.

Despite significant technological advances, studies show several areas for improvement in implementing renewable energy. First, energy conversion efficiency must be improved to keep up with fossil-based technologies. For example, the average efficiency of solar-based power plants is still below 20% in real-world operating conditions (Mora-Herrera et al., 2021). Second, large-scale renewable energy integration faces technical and economic challenges, such as a more flexible and stable electricity grid.

In addition, few studies have explored hybrid approaches to optimize the potential of various renewable energy sources. This approach is considered to have great potential to increase efficiency and reduce the impact of intermittency (Rahman et al., 2022).

Although renewable energy technologies have made significant progress, several obstacles still need to be overcome:

1. Efficiency and Cost: Some technologies still have low efficiency when applied in real-world conditions. For example, wind turbine efficiency in tropical regions is often less than optimal in temperate regions (Zhao et al., 2020). Furthermore, even though technology costs continue to decline, initial investment in infrastructure remains a significant challenge, especially in developing countries.
2. Energy Variability and Storage: Renewable energy sources such as solar and wind are intermittent, depending on weather conditions. This causes instability in the energy supply. Developing reliable and affordable energy storage systems, such as lithium-ion batteries and hydrogen storage, is a current research focus (De Carne et al., 2023).
3. Grid Integration: Renewable energy generation systems often need to be designed to be directly connected to the conventional electricity grid. A smart grid infrastructure is needed to efficiently manage various sources of electricity flows (Rahman et al., 2022).

This study presents a comprehensive analysis of the development of hybrid technologies in renewable energy-based electricity generation. This approach combines the advantages of existing technologies, such as photovoltaics and wind turbines, with energy storage technologies to create more efficient and reliable solutions.

This article presents an innovative approach combining hybrid technologies. Combining the advantages of several energy sources, such as photovoltaics, wind turbines, and biomass, and utilizing energy storage technology is expected to create a more stable, efficient, and environmentally friendly electricity generation system.

The objectives of this research are to:

1. Evaluate the performance of current renewable energy conversion technologies.
2. Identify the main obstacles to integrating renewable energy into the electricity grid.
3. Provide recommendations for developing policies and technologies to increase the contribution of renewable energy to global electricity generation.

II. METHOD

This study uses a comprehensive approach involving various qualitative and quantitative methods to achieve the research objectives, which focus on the development of renewable energy conversion technology in power plants. This approach is designed to ensure data accuracy, analysis relevance, and the accuracy of recommendations.

A. Literature Study

The first stage of the research is to conduct an extensive literature study that includes:

1. Scientific Databases: Searches were conducted on platforms such as Scopus, Web of Science, and Google Scholar with the keywords “renewable energy conversion,” “hybrid power systems,” and “energy integration challenges.”
2. Selection Criteria: The selected articles are peer-reviewed journals published in the last 5 years (2018–2023) relevant to the research topic. Of the 300 articles found, 50 were selected based on their suitability to the research objectives.

This study aims to identify current technology trends, energy conversion efficiency, integration challenges, and solutions proposed in previous studies. This information will be used to build research arguments and determine the focus of further analysis.

B. Secondary Data Analysis

Secondary data is used to evaluate the performance of renewable energy technologies and their impact on the environment and power generation efficiency. Data sources include:

1. Institutional Reports: Data from international organizations such as the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA) and reports from Ministries of Energy in developing countries.
2. Global Statistics: Information related to installed renewable energy capacity, cost per kWh, carbon emissions, and capacity factors is taken from annual publications such as Renewable Energy Statistics (IRENA, 2023) and World Energy Outlook (IEA, 2023).

Data analysis was performed using Microsoft Excel and Python software for graphic visualization and statistical calculations. These results provide a quantitative picture of renewable energy technologies’ efficiency, cost, and impact.

C. Technology Simulation

Hybrid power plant simulations were performed using HOMER Pro software to evaluate the potential combination of renewable energy technologies to evaluate the potential combination of renewable energy technologies. This method includes:

1. System Configuration: The hybrid system includes photovoltaic panels, wind turbines, biomass generators, and battery-based energy storage systems.
2. Input Parameters: Input data include solar radiation, wind speed, installation cost, and daily electricity load patterns. These data are obtained from the HOMER Global Resources database.
3. Performance Indicators: Simulations evaluate energy efficiency, cost per kWh, carbon emission reduction rate, and electricity supply stability.

Simulations were performed using HOMER Pro, incorporating solar radiation, wind speed, and daily load patterns from HOMER Global Resources. The analysis measured efficiency, carbon emissions, and stability. Semi-structured expert interviews added qualitative insights to validate the findings and propose strategic recommendations. The simulation results compare the hybrid system’s performance with fossil fuel-based power plants and single renewable technologies.

D. Expert Interviews

A qualitative approach was conducted through semi-structured interviews with 10 experts in the field of renewable energy. The experts interviewed include:

1. Academics active in renewable energy research.
2. Practitioners from power generation companies.
3. Policymakers in the energy sector.

The interviews aimed to gain in-depth insights into:

1. Practical challenges in integrating renewable energy technologies.
2. Policies needed to support the development of renewable energy infrastructure.
3. Innovative solutions to improve the efficiency and stability of renewable energy-based power plants.

The data obtained were analyzed using thematic analysis methods, where key response patterns were manifested in thematic categories relevant to the study.

E. Data Validation and Analysis

To ensure the validity of the research results, several verification steps were carried out:

1. Data Triangulation: Comparing the results from literature studies, secondary data analysis, simulations, and expert interviews to ensure consistency.
2. Internal Peer Review: Two peers reviewed the draft analysis results to ensure the accuracy of the interpretation and recommendations.
3. Simulation Sensitivity: The simulation underwent a sensitivity analysis to evaluate the impact of changes in input parameters on the results.

The method applied in this study provides a holistic approach to evaluating renewable energy conversion technologies. The combination of literature studies, secondary data analysis, technology simulations, and expert interviews ensures that the research results are not only based on quantitative data but also strengthened by qualitative insights.

III. RESULTS AND DISCUSSIONS

A. Renewable Energy Technology Performance

This study evaluates the performance of three major renewable energy technologies—solar, wind, and biomass—and hybrid systems that combine them. The analysis is based on efficiency, capacity factor, and cost of energy production.

Solar power has been one of the fastest-growing renewable technologies over the past decade. With an average efficiency of photovoltaic (PV) modules reaching 19.5% in commercial installations, this technology can generate significant energy in areas with high solar radiation intensity. Simulations show that the capacity factor of solar panels ranges from 20% to 25%, depending on geographic location.

One of the main advantages of solar power is the decreasing cost of energy production. By 2023, the average cost of generating 1 kWh of electricity using solar power will reach $0.05, a decrease of more than 70% compared to the previous decade (IRENA, 2023). However, solar power has a significant challenge in that it depends on weather conditions, which can cause daily energy production fluctuations.

Wind power technologies, both onshore and offshore, offer a higher capacity factor than solar power, ranging from 35% to 40%. Modern wind turbines are designed to operate at low wind speeds, increasing reliability across a wide range of geographic locations.

Wind power's main advantages are high efficiency and low operating costs. The average energy production cost for wind power is $0.06/kWh, slightly higher than solar power but much more economical than fossil fuel-based technologies.

However, this technology also faces obstacles, including visual and acoustic impacts often controversial in residential areas. In addition, wind speed variability can affect the stability of energy supply, especially during seasons with inconsistent wind speeds.

Biomass utilizes organic waste to produce energy through combustion, gasification, or anaerobic fermentation. This technology offers the highest capacity factor among the three analyzed, ranging from 60–70%. Biomass also has the advantage of providing a stable energy supply independent of weather conditions.

However, the average biomass efficiency is only 30%, lower than solar and wind power. The production cost is also higher, averaging $0.08/kWh. In addition, the biomass combustion process can produce small carbon emissions (around 0.05 tons of CO_2/kWh), although it is still much lower than fossil fuels.

Hybrid systems combine several renewable energy technologies to maximize their respective advantages. This study simulated a combination of solar, wind, biomass, and battery-based energy storage. The results showed that this system achieved the highest efficiency of 45%, with a capacity factor of 50–60%.

One of the main advantages of a hybrid system is the ability to reduce the variability of energy production. The combination of different resources allows this system to continue producing electricity even if one of the energy sources is unavailable. The energy production cost for the hybrid system was also recorded as the lowest, at $0.04/kWh.

Based on the results of the analysis, solar and wind power offer low production costs but have challenges in the form of dependence on weather conditions. Biomass provides stability of supply but at a higher cost. Meanwhile, the hybrid system showed the best overall performance, combining high efficiency, low cost, and reliable energy supply stability.

The simulation results show significant differences in efficiency, capacity factor, and energy production costs between different renewable technologies. Based on the analyzed data, photovoltaic panels have an average efficiency of 19.5%, with a capacity factor of 20–25% in locations with high solar radiation. Meanwhile, wind turbines show a higher capacity factor of 35–40% in areas with constant wind speed. In terms of cost per kWh (see Table 1), solar has the lowest average cost of $0.05/kWh, followed by wind at $0.06/kWh and biomass at $0.08/kWh. Combining hybrid technologies reduces the cost to $0.04/kWh, mainly due to energy storage optimization.

Table 1. Comparison of Performance and Cost of Renewable Energy Technologies

Technology	Efficiency (%)	Capacity Factor (%)	Cost per kWh ($)
Solar Power	19	20–25	.05
Wind Power	35	35–40	.06
Biomass	30	60–70	.08
Hybrid Systems	45	50–60	.04

B. Carbon Emission Comparison

Carbon emissions are one key factor in assessing the sustainability and environmental impact of various power generation technologies. This study analyzes carbon emissions to compare renewable energy-based power plants (solar, wind, biomass, and hybrid systems) with fossil fuel-based power plants, such as coal and natural gas.

Fossil-based power plants, especially coal-based ones, significantly contribute to global carbon emissions. For example, coal-fired power plants emit around 0.9 tons of CO_2 per kWh, while natural gas-fired power plants emit around 0.4 tons of CO_2 per kWh (IEA, 2023). Both energy sources are significant contributors to global warming due to the carbon released into the atmosphere during the combustion of fossil fuels. In addition, the extraction and processing of fossil fuels also contribute to higher carbon emissions, thus worsening the environmental impact.

In contrast, renewable energy has the potential to reduce carbon emissions significantly. Solar and wind power, known as clean energy sources, produce almost no carbon emissions when operating. Energy generated from photovoltaic (PV) panels or wind turbines has very low emissions, approaching zero—around 0.01 tonnes of CO_2 per kWh. The main processes that contribute small emissions to this technology are the production, transportation, and installation of components such as PV panels and wind turbines, but this is much lower compared to emissions from fossil fuel power plants.

Meanwhile, biomass as a renewable energy source produces higher carbon emissions than solar and wind power but is still lower than fossil fuels. Carbon emissions from biomass are around 0.05 tonnes of CO_2 per kWh. This is due to the combustion process of biomass, which produces CO_2, although most of the carbon released comes from organic matter that previously absorbed carbon from the atmosphere during its growth phase. So, although biomass is not entirely free of emissions, it has a more minor impact than fossil fuel combustion.

Hybrid systems combining several renewable technologies show lower carbon emissions than biomass alone. Using energy storage systems (such as batteries) combined with solar and wind power reduces dependence on fossil fuel sources and ensures a more stable energy supply. Overall, the carbon emissions of the hybrid system are around 0.03 tonnes of CO_2 per kWh, which is lower than biomass but still reflects the impact of the components used in energy storage.

This analysis concludes that renewable energy technologies, especially solar and wind, are superior in reducing carbon emissions. Fossil-based power plants are still the main contributor to global emissions, while biomass and hybrid systems, although slightly higher, are still much more environmentally friendly than fossil fuel use.

The analysis results in Table 2 show that renewable energy systems significantly reduce carbon emissions compared to fossil fuel-based power plants. Coal-based power plants produce an average emission of 0.9 tonnes of CO_2/kWh, while solar and wind power have emissions close to zero. Hybrid systems using biomass produce around 0.05 tonnes of CO_2/kWh emissions.

Table 2. Carbon Emissions by Technology

Technology	Carbon Emissions (ton CO2/kWh)
Coal	.90
Natural Gas	.40
Biomass	.05
Solar Power	.01
Wind Power	.01
Hybrid Systems	.03

C. Hybrid System Efficiency

Hybrid systems, combining multiple renewable energy technologies such as solar, wind, biomass, and energy storage (batteries), offer higher efficiency than single renewable energy generation. This combination allows the integration of multiple resources to overcome fluctuations in energy production and improve the reliability of electricity supply. The study identified that hybrid systems have an average efficiency of around 45%, which is higher than the efficiency of each single technology, which ranges from 19.5% to 35%.

One of the main advantages of hybrid systems is their ability to reduce the variability of energy produced by individual renewable energy sources. Solar and wind power are often affected by varying weather conditions. For example, solar panels' energy production depends on sunlight's intensity, while wind turbines require constant wind speeds. By combining multiple energy sources, hybrid systems can ensure a more stable energy supply. If one renewable energy source is unavailable, another source can replace it, reducing dependence on fossil fuels.

Energy storage systems (such as batteries) in hybrid systems also play an essential role in improving efficiency. Batteries allow the storage of excess energy generated during high production periods and then use it when supply is low, such as at night for solar or when the wind is not blowing. This increases the system's capacity to provide continuous energy, even during weather instability.

Hybrid systems can also reduce operating costs by combining the advantages of each technology. Combining renewable systems with energy storage allows for long-term energy cost reductions, as there is less reliance on fossil fuel supplies and more efficient use of renewable energy.

Overall, hybrid systems are highly efficient for generating stable and sustainable renewable energy. Their ability to utilize renewable resources simultaneously makes them an excellent choice for increasing energy security and reducing reliance on fossil fuel sources.

The simulated hybrid systems (see Table 3) show significant advantages in energy efficiency and electricity supply stability. Their average efficiency is 45%, higher than that of single technologies. In addition, using energy storage batteries increases supply stability by up to 90% despite variability in the primary energy source.

Table 3: Comparison of Efficiency of Renewable and Hybrid Energy Systems

Energy System	Efficiency (%)	Capacity Factor (%)	System Components
Solar Power	19.5	20–25	Photovoltaic panels
Wind Power	35.0	35–40	Wind turbines
Biomass	30.0	60–70	Biomass (organic waste)
Hybrid System (Solar + Wind)	45.0	50–60	Photovoltaic panels + Wind turbines + Energy storage
Hybrid System (Solar + Biomass)	47.5	55–65	Photovoltaic panels + Biomass + Energy storage
Hybrid System (Wind + Biomass)	50.0	55–65	Wind turbines + Biomass + Energy storage
Hybrid System (Solar + Wind + Biomass)	55.0	60–70	Photovoltaic panels + Wind turbines + Biomass + Energy storage

Table 4. The Effect of Energy Storage Usage on Hybrid System Efficiency

Hybrid System Type	Efficiency (%)	Operating Cost ($/kWh)	Energy Storage Advantages
Solar + Wind without Storage	38.0	.05	No energy backup at night or during bad weather
Solar + Wind with Storage	45.0	.04	Energy storage increases reliability and efficiency
Solar + Biomass without Storage	40.0	.06	Biomass acts as a constant energy backup
Solar + Biomass with Storage	47.5	.05	Energy storage reduces dependence on biomass during peak demand
Wind + Biomass without Storage	42.0	.06	Dependence on wind speed and biomass
Wind + Biomass with Storage	50.0	.05	Energy storage allows for more stable operation
Solar + Wind + Biomass with Storage	55.0	.04	Optimization of all three sources increases system capacity and reduces operating costs

These tables provide a clearer picture of the efficiency and performance of renewable energy systems, both single and hybrid systems. Energy storage plays a significant role in improving the overall efficiency of hybrid systems. The available data also show that hybrid systems with multiple energy sources and energy storage have significantly higher efficiency and lower operating costs.

Table 4 shows that hybrid systems combining several renewable energy technologies, such as solar, wind, and biomass, offer significantly higher efficiency than single renewable technologies. These results align with the findings of several previous studies, which show that using hybrid systems can optimize the potential of each renewable technology, reduce dependence on fossil fuels, and increase the stability of the energy supply.

Research conducted by IRENA (2023), Ammari et al. (2022), Rehman et al. (2021), Waewsak et al. (2020), and Awan et al. (2019) shows that the efficiency of hybrid systems can reach a higher level compared to single renewable energy-based power plants. In this study, the simulation results show that a hybrid system combining solar and wind energy can achieve an efficiency of up to 45%. In contrast, with the addition of biomass and energy storage, the efficiency can increase to 55%. This supports the findings from Table 1, which illustrates that the hybrid system offers a higher capacity factor, which is between 50-60%, compared to single technologies with a capacity factor between 19.5% and 35%.

The hybrid system not only provides advantages in terms of efficiency but can also reduce operational costs. The results obtained from this study show that the energy production cost for the hybrid system is around \$0.04/kWh, which is much lower than the single biomass technology, which has a cost of around \$0.08/kWh. This aligns with the findings of Yuan et al. (2020) and Lian et al. (2019), who noted that the hybrid system can reduce long-term energy production costs by combining renewable energy sources that can reduce dependence on fossil fuels.

One of the main challenges in using renewable energy is the variability of energy supply, which is influenced by weather conditions such as sunlight intensity and wind speed. Solar power, for example, can only produce energy during the day, while wind power depends on constant wind speed. As a solution, a hybrid system that combines both energy sources can improve the reliability of energy supply, especially in locations with variations in wind intensity and solar radiation (Hassan et al., 2023).

One study by Chen et al. (2021) showed that a solar-wind hybrid system can reduce energy production fluctuations by 30% compared to a single system. By combining different energy sources with different production patterns, a hybrid system can reduce dependence on fossil fuel supply and improve overall energy security. This study shows that with battery-based energy storage, the hybrid system can maintain a stable energy supply outside the main production hours of solar and wind power. The results of the hybrid system section also show that energy storage is essential in improving overall efficiency. Energy storage allows energy generated during peak production to be stored and used when energy demand is high or renewable energy production decreases. For example, energy storage allows solar energy at night and optimizes wind energy production when wind speeds are low. This supports the findings published by Liu et al. (2022), who found that using energy storage in a hybrid system can improve the efficiency and stability of energy supply by 20-25%. In addition, the results from Table 2 show that the hybrid system with energy storage results in lower operating costs (\$0.04/kWh) and is more efficient than the system without energy storage, indicating that the presence of storage technology is crucial in improving the performance of the hybrid system.

While solar and wind power have advantages in terms of efficiency and low carbon emissions, biomass is still needed to provide a stable energy supply, especially during unstable supply from other renewable energy sources. Simulation results showing that a hybrid system combining biomass with solar or wind power can provide higher efficiency and better capacity factors than biomass alone support the view that biomass plays an essential role in reducing dependence on fossil fuels (Hossen et al., 2022; Al-Ghussain et al., 2021).

However, as Zhang et al. (2023) noted, its carbon emissions remain a concern despite biomass's high capacity and reliable supply. Biomass produces higher carbon emissions than solar and wind power, although lower than fossil fuels. Therefore, the use of biomass in hybrid systems must be done carefully, ensuring that biomass utilization is carried out sustainably and does not significantly increase carbon emissions. Overall, hybrid systems offer great potential to increase efficiency, reduce operating costs, and provide a stable and environmentally friendly energy supply. Systems combining solar, wind, and biomass with energy storage have proven more efficient, with efficiencies reaching up to 55% and lower production costs than single renewable energy technologies. Although biomass still has carbon emissions, integrated hybrid systems can provide a more sustainable and reliable solution to meet future energy demands.

IV. CONCLUSION

Renewable energy conversion technologies have great potential to improve energy efficiency and reduce environmental impacts. However, successful large-scale implementation requires collaboration between government, industry, and academia. Investment in energy storage technologies and developing smart grids is crucial to addressing these challenges.

This study shows that hybrid systems that combine renewable energy technologies such as solar, wind, and biomass, along with energy storage, have the potential to achieve higher efficiencies compared to single renewable energy systems. Hybrid system efficiencies can reach up to 55%, with lower operating costs and higher capacity factors than single energy technologies. In addition, energy storage is essential in improving supply stability and reducing dependence on fossil fuels. Although biomass still produces carbon emissions, its integration into hybrid systems can help provide a more stable and reliable energy supply without significantly sacrificing efficiency.

Enhanced Integration of Renewable Technologies: Further development of hybrid system integration with other renewable energy technologies, such as geothermal or hydroelectric, is recommended to improve overall system capacity and efficiency. **Development of More Efficient Energy Storage**: Investment in energy storage technologies, such as lithium-ion batteries or hydrogen-based energy storage, is essential to improve the reliability and stability of energy supply in hybrid systems. **Research on Sustainable Biomass**: To reduce the impact of carbon emissions, further research on the use of more environmentally friendly biomass, such as biomass from organic waste or agricultural by-products, is needed.

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