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RESEARCH ARTICLE OPEN ACCESS

ENHANCING RENEWABLE ENERGY RELIABILITY: A STUDY ON HYBRID SOLAR-WIND SYSTEMS FOR EFFICIENT POWER GENERATION

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ABSTRACT

Hybrid solar–wind plants offer an effective resolution of the real problem of intermittency, ensuring steady electricity supply and minimizing the need for technology of storage. Although they cost more upfront, they provide savings over time, aid the environment and advance decarbonization targets. HOMER simulation for Basra also showed the predominance of solar power where the total annual capacity was 10.54 kWh/m², while wind provided 1.21 kWh, confirming the efficiency of hybrid system integration for Basra as a typical example. Worldwide experience, including Germany, China and the U.S., have also shown that systems such as hybrids are more reliable and cost effective than single platforms. These results emphasize how important the phasing control will be in the upcoming energy transitions, and the importance of advances in storage technologies, AI-based control, and the role of legislation in making these precedents.

I. INTRODUCTION

Amid the global concern regarding climate change and the dissipation of fossil fuel supplies, the need for sustainable, and renewable sources of energy has never been so pressing. Traditional, fossil fuel-based energy systems cause the release of greenhouse gases and pollution, and drive a spiraling global disaster 1. In this field, renewable energies, among these the solar, wind and hydro power sources, are increasingly the focus of interest in order to obtain clean, yet abundant and sustainable electricity. Among these, solar and wind energy are two of the most promising and widely-used technologies for the massive energy generation [3]. However, both energy sources suffer from intermittency, low efficiency and reliability, which makes it difficult to satisfy the whole global energy need when vertically used [4]. The solar energy, which is obtain through photovoltaic (PV) cells, entirely relies upon sunlight that varies greatly according to weather conditions, time frame and geographical locations [5].

Likewise, wind energy produced by wind turbines varies as a result of change in wind speed and it is affected by seasonal variations and local weather condition. However, these natural intermittencies are causing problems with maintaining a consistent and dependable electricity supply, at least in places where the grid has high dependence on renewable sources[6]. To counter these challenges, hybrid energy systems involving solar and wind power have emerged as an attractive alternative to mitigate intermittency challenges while enhancing the overall reliability and efficiency of renewable energy generation [7]. A combination of wind and solar in a single system can use the complementary characteristics on these two sources. Solar power works best during the day, while wind energy can be more prevalent at night or when it is not enough light [8]. The collaboration between both systems can help make sure that the power supply is more dependable and stable all day throughout the year.

This renders hybrid systems an excellent option for producing electricity in a way that is good for the environment [9]. Hybrid energy systems had several important advantages over traditional energy generation systems that operate on its own. First, they have a greater capacity factor, which is a ratio of actual energy produced to the greatest possible energy output. It's due to their ability of making power from both solar and wind sources [3]. So, the system works better overall and doesn't need as many backup power sources, such fossil fuel-based power plants, which are employed when renewable energy supply is low [10]. Combining wind and solar electricity can also lower the cost of storing and sending power because it means you don't need massive storage facilities to handle times when one of the sources is making a lot of power [11]. The creation and use of hybrid energy systems also fits with the global goal of moving to a low-carbon economy. A lot of countries are now establishing high goals for cutting greenhouse gas emissions and raising the amount of renewable energy in their energy mix [12]. Hybrid systems can help fulfil these goals by offering a more steady and reliable source of renewable energy that can help integrate renewables into the grid as a whole [13].

In this context, renewable energy sources such as solar, wind, and hydropower have gained significant attention due to their potential to provide clean, abundant, and sustainable electricity. Figure (1) shows how the quantity of renewable energy capacity added will change between 2019 and 2024. It also shows that wind energy will grow faster than solar energy. Wind energy won by a long shot in 2019, with 119.1 GW, while solar energy only added 59.4 GW. This pattern continued in 2020, when wind power rose to 153.2 GW and solar power grew to 107.8 GW. In the next few years, wind energy increased a lot faster. It grew to 232 GW in 2022 and then to 426.3 GW in 2023, which was faster than the constant rise of solar energy. Solar energy started getting better, but it was still slower than other kinds of energy, especially between 2021 and 2022. By 2024, wind energy had risen to an incredible 553 GW, but solar energy had only expanded to 120 GW. Because of new technology like offshore wind farms and cheaper costs, this research suggests that wind energy will become the dominant source of renewable energy capacity. Solar energy, on the other hand, has been accepted more slowly. This is partly because it doesn't always work, it costs more to install at initially, and there are issues with how to use the land. Both of these sources of energy are still very vital for the global endeavor to make the future low-carbon. Wind energy is becoming the main focus of big renewable energy projects, while solar energy is still a big part in locations with a lot of sun [14].

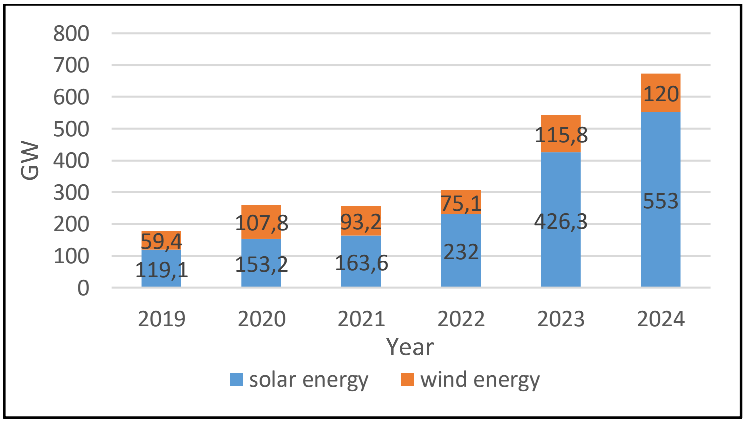

Figure 1: Renewable Energy Capacity Additions by Technology (2019-2024): Solar vs. Wind.
Source: Authors, (2026).

II. HYBRID SOLAR-WIND SYSTEMS:

Hybrid energy systems use both solar and wind power to make it easier and more dependable to get electricity from renewable sources. Figure (2) shows that these systems try to solve the problems of intermittency and variability that each source has when used alone by combining both technologies [15].

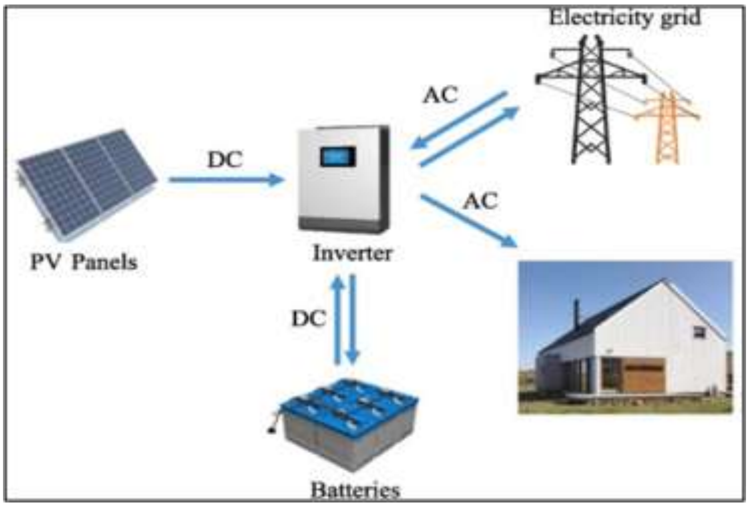

Figure 2: Hybrid Energy System.
Source: Authors, (2026).

II.1 KEY FEATURES OF SOLAR-WIND HYBRID SYSTEMS:

- Complementary Generation:

Solar and wind power operate well together. During the day, when there is sunlight, solar energy is usually abundant. Wind energy, on the other hand, is generally more useful at night or on overcast days when solar energy is low. [16].

- Improved Efficiency and Reliability:

Combining both sources makes energy generation more reliable resulting in fewer occasions when energy isn't available and a more stable power supply overall. This is especially helpful in areas where the weather changes a lot or the sun shines differently. [17].

- Reduced Need for Energy Storage:

The integration of solar and wind energy reduces the requirement for large-scale energy storage systems. The hybrid system can alleviate periods of underperformance from a single source, reducing dependence on storage devices and lowering costs.[18].

- Geographical Versatility:

These systems can be deployed in regions where either solar or wind alone might not be sufficient. Areas with both wind and solar potential can benefit greatly from hybrid systems, providing a more balanced and consistent energy output [19].

II.2 ADVANTAGES OF SOLAR-WIND HYBRID SYSTEMS

- Increased capacity factor: The system generates electricity more reliably, even during periods when one source is not performing.
- Lower dependence on backup generation: Reduces reliance on fossil-fuel-based power plants or expensive storage systems [20].
- Environmental benefits: Decreases greenhouse gas emissions and supports a sustainable energy transition.
- Scalability: Hybrid systems can be expanded or adjusted according to the energy demands and geographical conditions [21].

III COMPARISON BETWEEN STANDALONE AND HYBRID SYSTEMS:

Standalone systems are renewable energy systems that only use one source of electricity, such solar or wind power. These systems can be helpful in some situations, but they often have problems with variability and intermittency. Based on a lot of different things, Table 1 shows how solar-wind hybrid systems compare to standalone systems [22][23][24]:

Table 1: Comparison of Solar-Wind Hybrid Systems vs. Standalone Renewable Energy Systems.

Feature	Solar-Wind Hybrid Systems	Standalone Systems (Solar or Wind Alone)
Energy Generation Reliability	High reliability due to complementary nature of solar and wind; stable power output across the day and seasons	Lower reliability; dependent on the availability on one source, leading to gaps in generation
Intermittency	Reduced intermittency, as wind can generate power when solar is not available and vice versa	High intermittency; solar energy is unavailable at night and on cloudy day; wind energy depends on wind conditions
Efficiency	Higher overall efficiency, both sources contribute to consistent power generation	Lower efficiency; relies solely on on ernergy source, leading to periods od low generation
Cost of Installation	Higher initial costs du to the complexity of integrating both systems	Lower initial costs for installation compared to hybrid systems, as only one energy source is used
Energy Storage Needs	Reduced need for large scale energy storage systems; excess energy generation can be stored in batteries or used in real-tine	Higher energy storage requirments, especially during periods of low generation, requiring expansive battries or backup systems
Space Requirements	Requires more space for both solar panels and wind turbines, but offers better land utilization when integrated	Less space required compared to hybrid systems but still needs significant space for either solar panels or wind turbine
Operational Complexity	More complex to manage and operate; requires advanced control systems to optimize energy production and integration	Simple operation but may require backup or grid connection to maintain reliability
Scalability	Scalable; can be easily expand by adding more solar panels or wind turbines as demand increases	Limited scalability as each system relies on a single source of energy. Expanding capacity requires increasing the size of the same source
Geographical Suitability	Suitable for areas with variable weather conditions and diverse climates where both solar and wind potential exists	Best suited for areas where either solar or wind is highly predictable and abundant

Source: Authors, (2026).

IV. PERFORMANCE AND ENVIRONMENTAL/ECONOMIC ASPECTS:

Sunlight, wind, temperature, and seasons substantially affect hybrid systems. Where you reside affects solar and wind resource availability, which affects energy generating reliability and efficiency. Figure (3) shows that hybrid energy systems using solar and wind energy function differently depending on location.

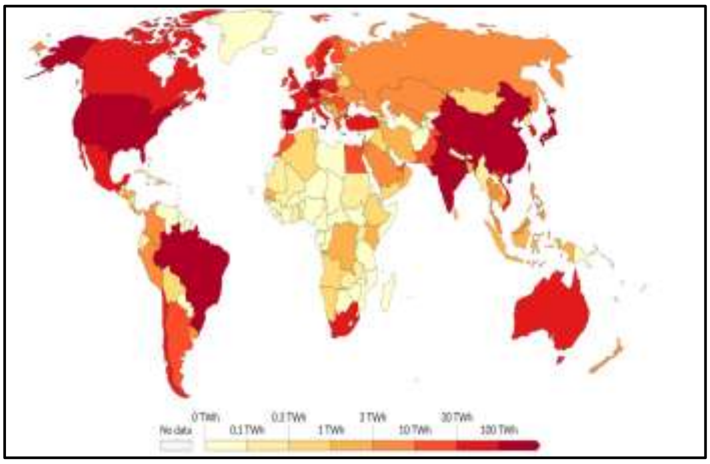

Figure 3: Solar and wind power generation, 2024.
Source: [25].

In deserts with a lot of sunshine and little wind, solar panels function more effectively than wind turbines. Wind turbines produce more electricity as the wind is steady, like on the coast or in mountainous areas, solar backups is used. Hybrid systems work better in these areas because they use the light during the day and the wind at night or on cloudy days. It makes the energy supply more stable [26]. Some island nations and remote areas have both solar and wind potential, and hybrid systems can be very useful there. They make sure that energy is always available and that you do not have to rely on outside grids. Hybrid systems may not work as well or cost as much in places where one source is more common. The performance and productivity of hybrid systems depend on environmental factors. In places with a lot of both wind and solar energy, like the coast or the desert [27], hybrid systems work better than solar or wind systems on their own. In desert areas, for instance, a solar-wind hybrid system mostly uses solar power. Wind turbines, on the other hand, make most of the power in places with a lot of wind along the coast [28]. Hybrid systems make sure that the amount of energy produced stays the same by making up for low performance from one source with the other. Hybrid systems make things more reliable in places where the seasons change a lot by using wind energy when the sun is not shining as much [29].

IV.1 SEVERAL WEATHER AND CLIMATE FACTORS PLAY A CRUCIAL ROLE IN DETERMINING THE PERFORMANCE OF HYBRID ENERGY SYSTEMS. THESE INCLUDE:

- Solar Radiation and Sunshine Hours:

The amount and length of sunlight hours are very important for solar power generation. These change with the seasons and latitude. For example, areas near the equator have longer days all year, which means they get more solar energy. Conversely, areas at higher latitudes, like those near the poles, have shorter days in the winter, which can make solar panels less effective [29].

- Wind Speed and Patterns:

The strength and steadiness of the winds determine how much wind energy can be made. The area's geography, its height, and how close it is to the coast or mountains are some of these things. Wind turbines work better on the coast and in the mountains because the winds are stronger and more steady there. The wind also changes with the seasons, and in some places, these changes can change how much power turbines make. [30].

- Temperature and Humidity:

The efficiency of both solar panels and wind turbines depends a lot on the temperature. In general, solar panels work better when it is cooler outside. This is because extreme heat can make the cells less efficient by making them more resistant. Wind turbines, on the other hand, are affected by the density of the air, which goes down as the temperature goes up. This makes them less efficient at making energy. Humidity is also important because high levels of moisture in the air can block solar radiation, which makes solar panels work less well. [31].

- Cloud Cover and Precipitation:

Cloud cover and rain can block sunlight from reaching solar panels, especially in places where the sky is often cloudy [32]. Rain or snow can also make wind turbines work less well by making ice build up or changing the speed of the wind. Hybrid systems, on the other hand, are better at handling these changes because wind turbines can keep working even when solar generation drops. [33].

- Environmental Obstacles:

The shape of the land and the presence of natural barriers like mountains, forests, or buildings can change the direction of the wind, creating wind shadows or turbulence that can make wind turbines less efficient. The orientation of the panels, shade from nearby objects, and local microclimates can all affect how well solar systems work. [34].

IV.2 ENVIRONMENTAL AND ECONOMIC CHALLENGES OF HYBRID ENERGY SYSTEMS:

Hybrid energy systems, like solar-wind combinations, have many benefits, such as reducing our dependence on fossil fuels and lowering greenhouse gas emissions. However, they also have some environmental problems [35]. Some of the main environmental issues that come up with renewable energy systems are:

- Land Use and Habitat Disruption:

Large space is needed for Large-scale hybrid system for Bothe solar panals and wind turbine. This can hurt habitats, especially in places where the environment is very sensitive. For example, wind farms can change the routes that birds take when they migrate, and big solar farms may have to cut down trees and other plants. But you can lessen these effects by picking the right place and doing environmental impact assessments. [36].

- Resource Extraction for Manufacturing:

To make solar panels and wind turbines, you need to get raw materials like copper, silicon, and rare earth metals. When these materials are mined, they can harm the environment, pollute water, and release more carbon into the air. To lessen the bad effects of these materials, it is very important to recycle them and use sustainable mining methods to lower their environmental impact. [37].

- End-of-Life Disposal and Recycling:

Another environmental problem is getting rid of old solar panels and wind turbine blades. Solar panels usually last 25 to 30 years [38], and wind turbines usually last 20 to 30 years [39]. When these parts reach the end of their useful life, they need to be recycled or thrown away in a safe way. If not done right, this can be expensive and bad for the environment.

- Noise Pollution and Aesthetic Impact:

People often complain about how noisy and ugly wind turbines are [40]. The noise from the turbines can bother animals and people who live nearby, and big wind farms can change the way rural or coastal areas look. These problems can be lessened by putting the turbines in the right places and making them quieter and more visually appealing[41].

IV.3 ECONOMIC FEASIBILITY ANALYSIS:

Initial Costs, Long-Term Benefits, and the Cost of Energy Generated Hybrid energy systems have high initial costs and long-term economic benefits, which is a problem from an economic point of view. The cost of installing, maintaining, and running these systems is one of the things that affects how economically feasible they are.

- Initial Costs:

Setting up a hybrid power system typically costs more upfront than implementing in a solar or wind system alone. The installation may also need improvements to the grid and energy storage systems, which will make the initial costs even higher. [42].

- Long-Term Benefits:

Over time, hybrid systems can save a lot of money compared to traditional systems that use fossil fuels. The only ongoing costs for hybrid systems are maintenance, since they do not use any fuel. Also, they can make electricity for 20 to 30 years or more, which means that after the initial investment, they provide a stable and predictable power supply at a lower cost. [44].

- Cost of Energy Production:

The Levelized Cost of Energy (LCOE) is a common way to compare the costs of making electricity from different types of energy. Because of the cost of installation, hybrid systems usually have a higher LCOE in the first few years. But the cost usually goes down over time because the system makes energy more efficiently and the need for outside power sources goes down [45]. The LCOE for hybrid systems is usually higher than that of traditional fossil fuel-based generation. However, when you look at long-term savings, environmental benefits, and lower carbon footprints, it is competitive with or even lower than many other renewable energy systems. [46].

V. GOVERNMENT POLICIES AND GLOBAL TRENDS

Policies made by the government are very important for the growth and development of hybrid energy systems. By using different incentives, rules, and programs [47], policymakers can change how renewable energy technologies are used and how they grow. There are many ways that governments can help hybrid systems, such as:

- Money: Governments often give people money to help them pay for the costs of putting in renewable energy systems. This could be in the form of grants, tax breaks, or government money. These incentives can help homeowners and businesses buy hybrid energy systems [48].

- Support for Research and Development (R&D): Governments can pay for R&D projects that make hybrid energy systems work better and more efficiently, especially when it comes to cutting costs, storing energy, and connecting to the grid. Governments can help lower the overall cost of renewable energy and make hybrid systems more likely to be used by a lot of people by encouraging new ideas [49].
- Regulatory Support and Grid Access: Governments can make it easier for hybrid systems to connect to the grid by making rules. These could be rules about who can use the grid, rules about net metering, and rewards for utilities that use clean energy sources. Governments can also make long-term plans for energy that put clean energy and renewable integration at the top of the list. This will help keep the market for hybrid systems stable [50].
- Public Awareness and Education: Governments can also help by teaching people about the benefits of renewable energy and hybrid systems in general. People are more likely to accept and use new ideas if they learn about them in public and are given reasons to get involved in the private sector [51]. The table (2) below compares important countries and emerging markets based on their government policies, economic viability, and success in developing renewable energy, with a focus on solar-wind hybrid systems. The comparison shows how different factors affect the use and growth of hybrid energy systems in different areas. It looks at things like how far we have come in combining different types of renewable energy, how well the rules work, and how much money they make.

Table 2: Comparison of Government Policies and Renewable Energy Development in Key Countries and Emerging Markets for Hybrid Systems.

Country	Government Support	Renewable Energy Capacity	Economic Feasibility	Challenges	Notable Developments	Ref.
Germany	Strong financial incentives, grid integration policies, and ambitious renewable energy targets	One of the largest solar and wind markets in Europe.	High initial costs, but strong long-term returns.	Land use conflicts, grid integration challenges.	Leading in energy transition (Energiewende), a robust market for hybrid systems.	[52] [53]
United States	Federal tax incentives, state-level renewable energy programs, and R&D funding.	Significant growth in wind and solar, with some hybrid projects.	Moderate upfront costs, but substantial long-term savings.	Varies by state; inconsistent policies.	Increased hybrid system adoption in rural and remote areas.	[54]
China	Strong government subsidies, investments in R&D, and national renewable energy targets.	World's largest producer of solar energy, fast-growing wind energy market.	Lower LCOE due to government support and scale of production.	Environmental impacts of large-scale wind and solar farms.	Leading global player in solar and wind, with growing interest in hybrid systems.	[55]
India	Financial incentives for renewable projects, state-level solar and wind policies.	Rapid growth in solar and wind energy sectors, potential for hybrid systems.	High initial costs but government support for financing.	Grid reliability issues and infrastructure gaps.	Hybrid solar-wind projects in rural areas and remote locations.	[56]
Brazil	Government incentives for wind and solar, favorable policies for hybrid systems.	Expanding wind and solar capacity, especially in the Northeast.	Competitive costs due to abundant natural resources.	Regulatory hurdles and land use concerns.	Emerging market for hybrid systems, particularly in remote areas.	[57]
South Africa	Feed-in tariffs, tax incentives for renewable energy projects.	Significant potential for both wind and solar energy.	High upfront costs but government programs to support financing.	Grid integration and high capital costs.	Increasing investment in renewable energy and hybrid systems.	[58]

Source: Authors, (2026).

The world needs more energy, that’s why many countries are looking into other, more sustainable ways to get it. Figure(4) shows that looking at energy use trends from 2015 to 2024 can tell us a lot about how hybrid energy systems are used, especially in countries where energy needs are growing quickly.By2024, China's energy use is expected to reach its highest level, which is almost 1,800 TWh.This is because the number of people and businesses is growing. In order to cut down on its reliance on fossil fuels, China will need to use more types of energy, like solar-wind hybrid systems. The U.S. rises more slowly, reaching about 800 TWh by 2024. This is because energy efficiency has gotten better. But hybrid systems are still good for the environment and the economy in the long run. Countries such as India, Germany, Brazil, and South Africa are experiencing moderate or sluggish growth. India's steady rise in energy use makes hybrid systems more useful.

The other countries, on the other hand, are growing more slowly, which shows that they need targeted and cost-effective renewable energy solutions Factories are using more and more energy, so China and the U.S. are ready to use hybrid systems on a large scale. Emerging markets might have trouble with the initial costs, but if their governments make good policies and offer financial incentives, they can adopt these technologies at their own pace. In countries where growth is slow,campaigns to raise public awareness and teach people can help them adopt even faster. Hybrid systems are the best way to keep energy prices stable over time, cut down on pollution, and make sure that energy will still be available in the future.New and rapidly growing markets need certain rules and incentives to make sure that they are widely used [59].

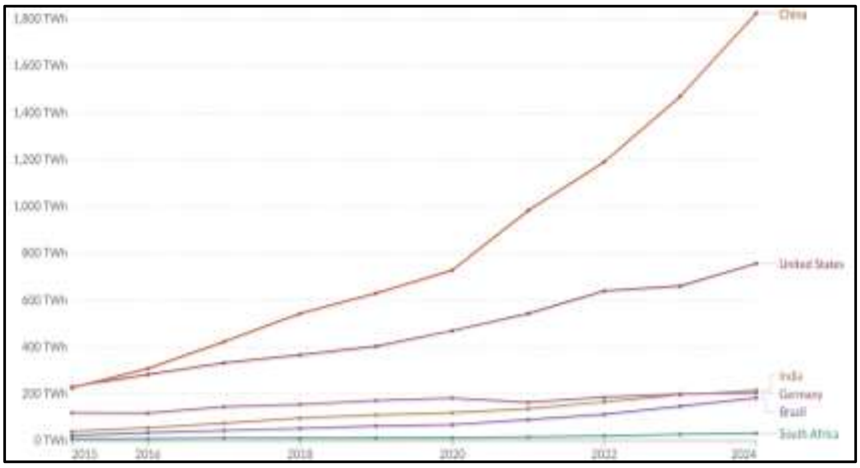

Figure 4: Energy Consumption Trends (2015-2024) for Major Economies.
Source: Authors, (2026).

VI. PRACTICAL APPLICATIONS AND FUTURE EXPANSION OF HYBRID SYSTEMS:

Solar-wind hybrid energy systems have been successful in both small villages and large power plants, generating electricity in areas where conventional energy infrastructure may be ineffective. It is too expensive to extend the regular electricity grid to these systems, which are useful in rural areas, islands, and remote communities [60]. These hybrid systems can give you a steady and reliable supply of electricity by using both solar and wind power. This can make life better and help the economy grow. In places where there is no grid access, hybrid systems can be used instead of expensive and bad for the environment diesel generators for backup power [61]. Hybrid solar-wind systems are better for the environment, last longer, and mean we do not have to buy fossil fuels from other countries as much. Energy storage systems make the system stronger by making sure that power is always there, even when it is dark or there is not much wind. Hybrid systems can save money over time, even in low-income areas, because they use less fuel and need less maintenance [62].

Hybrid systems give big power plants renewable energy that is more stable and flexible, which helps keep the grid stable. Hybrid systems make energy sources less volatile by using both solar and wind power. This is very important for getting more renewable energy into national systems because solar and wind power are not always reliable [63]. In large grids, hybrid systems can reduce the need for fossil-fuel power plants, which helps to create a more sustainable energy system. Hybrid systems also help electrical grids use more energy from sources that do not run out. Many countries are cutting their carbon footprints to meet international climate goals [64] as the demand for cleaner energy grows. It is easier and more reliable to add renewable energy to the grid when there are hybrid systems that use two sources of energy. This means that you can add more renewable energy to the grid without making the system less stable. If one power source stops working, the other can take over and keep the flow of energy going. This capacity makes it easier to handle at scale by reducing problems with intermittency [65]. This helps grids move toward more renewable energy.

Hybrid energy systems of the future will get a lot better, especially when it comes to how they store and control energy. We will need better ways to store renewable energy as we make more of it so that it can handle changes in energy sources. In hybrid systems, lithium-ion batteries store energy when it is at its highest and release it when it is at its lowest. More and more people need storage systems that work better, cost less, and last longer. People are looking into solid-state batteries, flow batteries, and compressed air energy storage (CAES) as ways to improve storage systems. These changes should make hybrid systems work better by making them last longer and store more energy [66]. Smart grid technology, better control systems, and better storage are the best ways to make hybrid energy systems better. To efficiently share power between solar, wind, and storage, hybrid systems need advanced power management [67]. AI and machine learning can improve control systems, which means that hybrid systems can see changes in how much energy is being made and used and change their behavior in real time.

These smart systems decide on their own how to store energy, feed it into the grid, and use it locally, which makes energy use and waste less of a problem [68]. In addition, demand-side management (DSM) systems that let people change how much electricity they use based on how much it costs and how much is available will be more important in hybrid energy systems. When you combine DSM with hybrid power systems, you can better match energy use with patterns of renewable generation. This makes the whole system work better. Solar wind hybrid energy systems are a new way to deal with the problems that come up when renewable energy is not always the same and changes [69]. These systems make electricity more reliably by using both solar and wind power. This is especially helpful in areas where neither is enough. Hybrid systems are more dependable because they can store energy, which means they can keep the power on even when generation is low. In remote areas and big power plants, hybrid systems are a long-lasting and cost-effective alternative to fossil fuels [70]. Hybrid systems use less fossil fuels and do less harm to the environment than traditional ways of making energy. Problems include using land, getting materials to make things, and getting rid of old parts. New designs, recycling, and managing resources in a way that does not hurt the environment can help make these big problems smaller [71]. It costs more to install hybrid systems, but they are a good investment because they save money on fuel, lower operating costs, and help the environment in the long run [72]. Even in poor countries, hybrid systems are becoming more affordable thanks to government subsidies, incentives, and research funding [73].

VII. CASE STUDY (IRAQ-BASRA): SIMULATION USING HOMER

The main focus of this study is the global trends, advantages, and issues associated with solar-wind hybrid systems. But HOMER software was used to run a localized simulation to show how these systems could work in the real world. We picked Basra, Iraq, as a good example because it gets a lot of sun and has a moderate amount of wind, which fits with what we talked about in the global context. This simulation does not narrow the study's focus; rather, it demonstrates the practicality, cost-effectiveness, and utility of hybrid systems in real-world contexts. A case study simulation was conducted using HOMER Pro software to validate the theoretical foundations and evaluate practical applicability, as detailed in the following section.

VII.1 ANALYSIS OF SOLAR GLOBAL HORIZONTAL IRRADIANCE (GHI) AND CLEANNESS INDEX DATA

This study analyzes the Monthly Average Solar Global Horizontal Irradiance (GHI) and Cleanness Index data, as shown in Figure (5), to understand the solar energy potential and atmospheric conditions impacting solar power generation. The following research provides information on monthly and annual solar radiation, trends in the cleanness index, and the potential for solar panels to generate power.

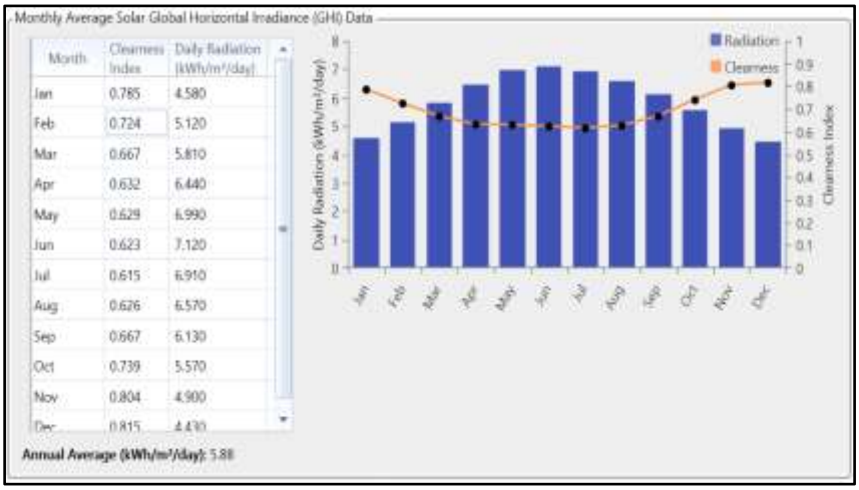

Figure 5: Monthly Distribution of Solar Irradiance and Clearness Index from HOMER Simulation (Basra, Iraq).
Source: Authors, (2026).

VII.1.1 Annual Average Solar Radiation

Over the course of the year, 5.88 kWh/m²/day is the average amount of solar energy received. The basis for assessing the potential for solar energy in various seasons is this figure.

VII.1.2 Monthly Breakdown of Solar Radiation

To illustrate how solar energy potential fluctuates throughout the year, Table 3 presents a monthly breakdown of solar radiation (in kWh/m²/day) and related energy output (in kWh). Understanding the monthly effectiveness of solar power generation requires an understanding of these figures.

Table 3: Monthly Breakdown of Solar Radiation and Energy Production.

Month	Solar Radiation (kWh/m²/day)	Energy Production (kWh)
January	0.687	0.687
February	0.768	0.768
March	0.8715	0.8715
April	0.966	0.966
May	1.0485	1.0485
June	1.068	1.068
July	1.0365	1.0365
August	0.9855	0.9855
September	0.8505	0.8505
October	0.8355	0.8355
November	0.756	0.756
December	0.6645	0.6645

Source: Authors, (2026).

VII.1.3 Cleanness Index

Clearer skies that are suitable for solar energy generation are indicated by values closer to 1 on the Cleanness Index, which measures sky purity.

• Highest Cleanness Index: With a Cleanness Index of 0.815, December has the clearest skies and the best solar-generating conditions.

• Lowest Cleanness Index: June has the lowest Cleanness Index (0.623) despite high solar radiation, indicating that air quality and cloud cover may have an impact on energy output.

VII.1.4 Seasonal Trends

• Spring to Summer: Solar radiation rises from January to June, reaching its maximum in June. In most locations, this cyclical pattern where summertime solar energy rises as the sun's angle becomes more direct—is common.
• Fall to Winter: Solar radiation levels decrease from June to December, with the lowest levels occurring in December. This decrease is due to reduced daylight hours and wintertime solar intensity.
• Cleanness Index Trends: During the summer, when there is usually more cloud cover, the Cleanness Index exhibits a similar seasonal tendency, peaking in December before declining.

VII.1.5 Energy Calculation

the annual energy production is calculated from a solar panel using the average daily solar radiation values for each month, assuming a panel area of 1 m² and an efficiency of 15%. The formula for calculating energy is as follows:
Esolar = Area × Radiation × Efficiency

Where:

• Area = 1 m² (for simplicity),
• Radiation = Monthly solar radiation values in kWh/m²/day,
• Efficiency = 0.15 (15%).
7.1.6. Solar Energy Calculation Results
Based on the provided monthly solar radiation values and assuming a 1 m² panel area with 15% efficiency, the monthly and total energy production is calculated as follows:
Monthly Energy Production (in kWh):
• January: 0.687 kWh
• February: 0.768 kWh
• March: 0.8715 kWh
• April: 0.966 kWh
• May: 1.0485 kWh
• June: 1.068 kWh
• July: 1.0365 kWh
• August: 0.9855 kWh
• September: 0.8505 kWh
• October: 0.8355 kWh
• November: 0.756 kWh
• December: 0.6645 kWh
Total Annual Energy Production: The total annual energy production from the solar panel is approximately 10.54 kWh.

VII.2 ANALYSIS OF MONTHLY AVERAGE WIND SPEED AND WIND ENERGY PRODUCTION

The Monthly Average Wind Speed data is analyzed in this study to assess the energy potential of a wind turbine in the area. The energy generated by a 3-meter-diameter wind turbine running at 35% efficiency, seasonal patterns, and wind speed breakdown are all included in the analysis. Figure (6) shows the data on wind speed and its seasonal fluctuations.

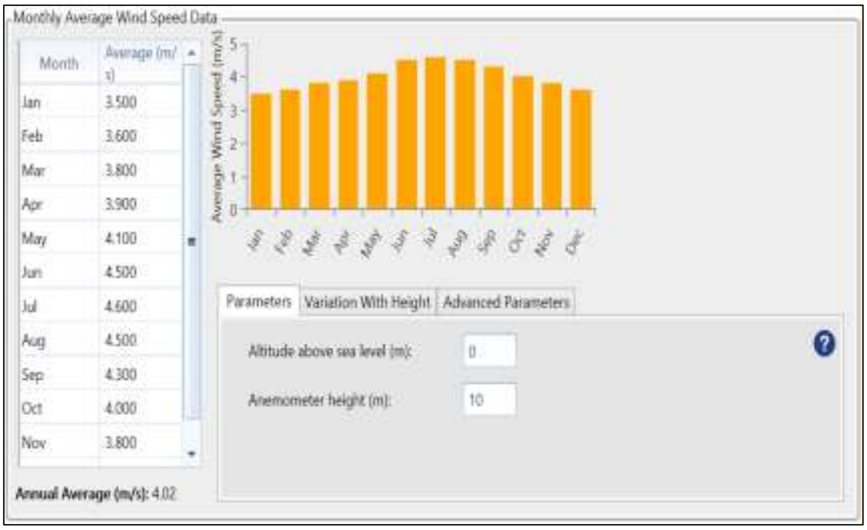

Figure 6: Analysis of Monthly Average Wind Speed Data.
Source: Authors, (2026).

VII.2.1 Annual Average Wind Speed

The annual average wind speed is 4.02 m/s, which indicates a moderate wind resource throughout the year.

VII.2.2 Monthly Breakdown of Wind Speed

As shown in Table 2, the monthly breakdown of wind speed (in m/s) and the corresponding energy production (in kWh) is presented. This data highlights the variation in wind speed and energy output throughout the year, indicating the periods of higher wind potential that can optimize energy generation.

Table 4: Monthly Breakdown of Wind Speed and Energy Production.

Month	Wind Speed (m/s)	Energy Production (kWh)
January	3.60	0.0707
February	3.60	0.0831
March	4.00	0.0899
April	4.10	0.1044
May	4.30	0.1381
June	4.40	0.1475
July	4.60	0.1381
August	4.30	0.1205
September	4.00	0.0970
October	3.80	0.0831
November	3.60	0.0707
December	3.60	0.0707

Source: Authors, (2026).

Seasonal Trends

• Spring and Summer (March to August): This season appears to be the most effective for generating wind energy because of the normally greater wind speeds, which peak in July at 4.60 m/s.
• Fall and Winter (September to February): During these colder months, wind speeds drop somewhat from 4.30 m/s to 3.60 m/s.
• Wind Energy Potential: The area has a moderate wind resource, with the greatest potential for wind energy generation occurring during the summer. As a result, wind turbines can operate effectively during these months.

Wind Energy Calculation

To calculate the energy production from a wind turbine, we use the following formula:
$E\_wind=0.5 \times \rho \times A \times V^3 \times \eta$

Where:

ρ= Air density (1.225 kg/m³)
A= Swept area of the turbine blades ($A=\pi \times (D/2)^2$)
V = Wind speed (m/s)
η = Efficiency (35%)

The monthly energy production is calculated using the wind speed values for each month.

Wind Energy Production Calculation Results. Based on the monthly average wind speeds and the 3-meter diameter wind turbine with 35% efficiency, the monthly and total energy production is calculated as follows:

Monthly Energy Production (in kWh):

• January: 0.0707 kWh
• February: 0.0831 kWh
• March: 0.0899 kWh
• April: 0.1044 kWh
• May: 0.1381 kWh
• June: 0.1475 kWh
• July: 0.1381 kWh
• August: 0.1205 kWh
• September: 0.0970 kWh
• October: 0.0831 kWh

• November: 0.0707 kWh
• December: 0.0707 kWh

Total Annual Energy Production: The total annual energy production from the wind turbine is approximately 1.21 kWh.

VIII. CONCLUSION

Future power generation can be dependable with a hybrid solar-wind system. The Basra simulation confirmed solar dominance with supporting wind input, so validating their complementarity under local conditions. Global experiences, especially in China, Germany, and the US, demonstrate that hybrid systems frequently outperform single-source setups in terms of cost-effectiveness and reliability. Further developments in storage technology, intelligent control, and supportive legal frameworks are anticipated to make these systems essential in accelerating the transition to low-carbon and sustainable energy.

IX. FUTURE WORKS

Based on your research on solar-wind hybrid systems, here are some potential future works that could further expand and refine the field:

1. Optimization of Hybrid System Configurations: Future research could focus on developing advanced optimization models to determine the optimal size, configuration, and placement of solar and wind components within hybrid systems, considering local climate, weather patterns, and energy demands.
2. Advanced Energy Storage Solutions: Investigating the integration of next-generation energy storage technologies (e.g., solid-state batteries, flow batteries, compressed air energy storage) to improve the efficiency and reliability of hybrid systems, particularly in off-grid applications.
3. Smart Grid Integration and AI: Further exploration of how artificial intelligence (AI) and machine learning can be integrated into hybrid systems for real-time optimization and predictive maintenance, allowing for better energy management and grid stability.
4. Impact of Climate Change on Performance: Assessing how the growing effects of climate change (e.g., temperature fluctuations, shifting wind patterns, and changing sunlight availability) might influence the long-term performance and reliability of solar-wind hybrid systems.
5. Hybrid Systems in Urban Areas: Exploring the application of solar-wind hybrid systems in urban areas where space constraints are a challenge. Research could focus on integrating these systems with urban infrastructure (e.g., rooftops, vertical farms) for improved land use.
6. Sustainability of Manufacturing and Disposal: Researching the sustainability of materials used in hybrid energy systems, focusing on recycling and the reduction of environmental impacts from manufacturing and end-of-life disposal, particularly for wind turbine blades and solar panels.

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