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Artificial Intelligence for Sustainable Energy Transition: Optimising Renewable Energy Integration and Management

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الذكاء الاصطناعي لتحول الطاقة المستدامة: تحسين تكامل وإدارة الطاقة المتجددة

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ABSTRACT

As climate change and long-term energy security drive the global energy sector towards renewable resources, powerful tools are required to optimise integration and management. A novel framework is proposed for effectively utilising Artificial Intelligence (AI) in the renewable energy landscape. AI algorithms can analyse weather patterns, historical generation data, and environmental factors to predict renewable energy output. Energy dispatch is optimised, grid integration is improved, and energy storage requirements are reduced. A system powered by artificial intelligence also significantly reduces downtime, optimises maintenance schedules, and minimises operational costs in wind turbines, solar panels, and other renewable infrastructure. AI can also optimise energy flows, reduce grid instability, and ensure efficient resource utilisation within the smart grid by dynamically managing renewable sources, energy storage systems, and demand profiles. Furthermore, AI-driven spatial analysis and resource mapping can identify optimal locations for renewable installations, considering factors like wind speed, solar irradiance, and environmental constraints. This paper presents two AI frameworks, one for solar energy and one for wind energy, to demonstrate possible applications. They both utilise comprehensive data acquisition, including real-time sensor data and external factors like weather forecasts and historical generation patterns. AI algorithms use these combined data to perform critical tasks such as predictive maintenance, minimising downtime, and maximising efficiency. Power output forecasting enables real-time adjustments based on weather, and optimal site selection maximises energy production. AI is used for proactive issue identification, accurate power output forecasting based on wind conditions, grid demand, storage capacity, dynamic load optimisation for maximum energy efficiency, and wind farm site selection. Integrating these tailored AI frameworks with solar and wind energy can achieve significant benefits such as increased efficiency, reduced operational costs, and seamless grid integration. In addition to analysing the challenges and opportunities associated with this AI integration, the paper explores infrastructure development, ethical considerations, and data acquisition. A second benefit of the research methodology is that it highlights how these tailored AI frameworks can optimise the integration of solar and wind renewable energy sources, providing valuable insights for researchers, practitioners, and policymakers who wish to use AI to create a more sustainable and efficient energy system.

Keyword: Artificial Intelligence, renewable energy, climate change.

الملخص.

وبما أن تغير المناخ وأمن الطاقة على المدى الطويل يدفعان قطاع الطاقة العالمي نحو الموارد المتجددة، فإن هناك حاجة إلى أدوات قوية لتحسين التكامل والإدارة. تم اقتراح إطار جديد للاستخدام الفعال للذكاء الاصطناعي (AI) في مشهد الطاقة المتجددة. يمكن لخوارزميات الذكاء الاصطناعي تحليل أنماط الطقس وبيانات التوليد التاريخية والعوامل البيئية للتنبؤ بإنتاج الطاقة المتجددة. تم تحسين توزيع الطاقة، وتحسين تكامل الشبكة، وتقليل متطلبات تخزين الطاقة. كما يعمل النظام المدعوم بالذكاء الاصطناعي على تقليل وقت التوقف عن العمل بشكل كبير، وتحسين جداول الصيانة، وتقليل تكاليف التشغيل في توربينات الرياح، والألواح الشمسية، وغيرها من البنية التحتية المتجددة. يمكن للذكاء الاصطناعي أيضًا تحسين تدفقات الطاقة، وتقليل عدم استقرار الشبكة، وضمان الاستخدام الفعال للموارد داخل الشبكة الذكية من خلال الإدارة الديناميكية للمصادر المتجددة، وأنظمة تخزين الطاقة، وملفات تعريف الطلب. علاوة على ذلك، يمكن للتحليل المكاني ورسم خرائط الموارد المعتمد على الذكاء الاصطناعي تحديد المواقع المثالية للمنشآت المتجددة، مع الأخذ في الاعتبار عوامل مثل سرعة الرياح، والإشعاع الشمسي، والقيود البيئية. تعرض هذه الورقة إطارين للذكاء الاصطناعي، أحدهما للطاقة الشمسية والآخر لطاقة الرياح، لإظهار التطبيقات الممكنة. كلاهما يستخدم الحصول على البيانات الشاملة، بما في ذلك بيانات الاستشعار في الوقت الحقيقي والعوامل الخارجية مثل التنبؤات الجوية وأنماط الجيل التاريخية. تستخدم خوارزميات الذكاء الاصطناعي هذه البيانات المجمعة لأداء المهام الهامة مثل الصيانة التنبؤية، وتقليل وقت التوقف عن العمل، وزيادة الكفاءة. يتيح التنبؤ بمخرجات الطاقة إجراء تعديلات في الوقت الفعلي بناءً على الطقس، كما يؤدي الاختيار الأمثل للموقع إلى زيادة إنتاج الطاقة إلى الحد الأقصى. يتم استخدام الذكاء الاصطناعي لتحديد المشكلات بشكل استباقي، والتنبؤ الدقيق لإنتاج الطاقة بناءً على ظروف الرياح، وطلب الشبكة، وسعة التخزين، وتحسين الحمل الديناميكي لتحقيق أقصى قدر من كفاءة الطاقة، واختيار موقع مزرعة الرياح. يمكن أن يؤدي دمج أطر الذكاء الاصطناعي المخصصة هذه مع الطاقة الشمسية وطاقة الرياح إلى تحقيق فوائد كبيرة مثل زيادة الكفاءة وتقليل تكاليف التشغيل والتكامل السلس للشبكة. بالإضافة إلى تحليل التحديات والفرص المرتبطة بتكامل الذكاء الاصطناعي، تستكشف الورقة تطوير البنية التحتية، والاعتبارات الأخلاقية، والحصول على البيانات. الميزة الثانية لمنهجية البحث هي أنها تسلط الضوء على كيف يمكن لأطر الذكاء الاصطناعي المصممة خصيصًا تحسين تكامل مصادر الطاقة المتجددة الشمسية وطاقة الرياح، مما يوفر رؤى قيمة للباحثين والممارسين وصانعي السياسات الذين يرغبون في استخدام الذكاء الاصطناعي لإنشاء بيئة أكثر استدامة وكفاءة لنظام الطاقة.

الكلمات الافتتاحية: الذكاء الاصطناعي، الطاقة المتجددة، تغير المناخ.

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1. Introduction

Technology innovation in the near to medium term is the focus of this paper. System operators, regional planners, and market participants will benefit from identifying and developing new tools and techniques. With these tools and techniques, a future power system can use more renewables and be more economical and reliable [1].

In this document, the MIT Energy Initiative (MITEI), an interdisciplinary program within the Massachusetts Institute of Technology focused on addressing global energy challenges, presents a plan to increase renewable energy integration. The future's electric power system will comprise many small, modular, and distributed energy sources. The system will likely depend heavily on renewable energy resources and efficient demand-side technologies, often owned and operated by customers[2]. This vision represents a significant departure from the current central station power system, which relies on large and expensive generating assets. Getting to this future state will take decades. Ensuring the system is reliable and cost-effective while guiding it towards a sustainable future is required. It will take technological advancements, policy changes, and innovative business models to make this happen [3]. The increasing use of intermittent renewable energy sources has prompted a quest for creative answers to how to incorporate renewables into power systems. The move to a future with no greenhouse gas emissions starts with sustainable energy systems[4]. Renewable energy has its challenges, but they can be overcome. Removing this obstacle means rethinking how power systems work, expand, and adhere to policy[5]. The global energy sector must switch to renewables to fight climate change and ensure long-term energy security. Since the mid-19th century, human activities, primarily burning fossil fuels, have been causing global climate change, according to the Intergovernmental Panel on Climate Change[6]. Sea levels are rising, extreme weather events are happening, and ecosystems are being disrupted by climate change. To limit global warming to 1.5°C, greenhouse gas emissions from the energy sector must be reduced rapidly and significantly (UN Environment Programme, 2021). Global energy is at a crossroads, and we need renewable energy. Several reasons make this transition critical[7].

1. Burning fossil fuels is the primary cause of climate change, causing rising temperatures, extreme weather events, and biodiversity loss. Transitioning to renewable energy sources is essential for climate change mitigation[8].

2. Solar, wind, and hydropower can help reduce reliance on imported fossil fuels, increase energy security, and stabilise prices[9].

3. Using renewable energy sources can reduce environmental degradation, meet the world's energy needs more sustainably, and ensure that future generations can access clean and reliable energy[10].

4. Renewable energy can create jobs, innovate technology, and lead to new investments in infrastructure.

As the world faces these challenges[11], governments, businesses, and individuals should work together to accelerate the transition to renewable energy. Getting from fossil fuels to renewables requires collaboration among all stakeholders. The government implements policies that support the transition to renewable energy, setting renewable energy targets and providing incentives for renewable energy investment. A business's responsibilities include investing in renewable technologies, implementing sustainable practices, and advocating for renewable energy policies.

Individuals can also make a difference by choosing electric vehicles, using solar panels, and reducing energy consumption[10]. Education and awareness will also support this transition.

Renewable energy is the only way to mitigate climate change[10]. Renewable energy sources must be improved and accessible through research and development[12]. In addition to environmental conservation, renewable energy will improve public health, reduce energy poverty, and foster a more resilient and sustainable global economy. If this transition is embraced with urgency and determination, there is a tremendous opportunity for positive change for our planet and future generations. In addition to accelerating the transition to renewable energy at the global level, countries and international organisations can also work together to achieve it. The paper will discuss how AI can integrate renewable energy systems in this paper. As a result of artificial intelligence technologies, renewable energy systems can be optimised for increased performance and efficiency, forecasting and grid management can be enhanced, and more intelligent decisions can be made concerning energy production and consumption. A more sustainable future can be achieved by harnessing the power of AI to accelerate the transition to renewable energy.

2. Sustainable Energy Transition Importance

Mitigating climate change depends on energy transition for several reasons. Global warming is mainly caused by high greenhouse gas emissions. Climate scientist Stephen Schneider defines global warming as increasing the earth's surface temperature. Masera and Rivero[13] say the sun's energy reaches the world as light, some of which is absorbed and some radiated as heat. Gale gases trap heat, warming the earth's surface[14]. Greenhouse gases are causing global warming because they are emitted at a higher rate. If greenhouse gas emissions aren't controlled by next year, it won't be possible to prevent a level of global warming that will create dramatic climate change. Our planet's future is at risk from catastrophic climate change unless greenhouse gases are actively and ambitiously reduced. It might be necessary to transition away from fossil fuels in favour of clean energy sources, such as renewable energy, which emits much less greenhouse gases. Despite emitting relatively few greenhouse gases, studies consistently show that nuclear energy isn't a long-term solution for today's energy and environmental challenges. Energy sustainability and combating climate change could be more accessible with artificial intelligence and research into improving renewable energy sources[15]. Our future can be brighter, greener, and more sustainable if we use AI technologies and direct scientific research towards using renewable energy more efficiently. Controlling greenhouse gases is key to stabilising the climate[16][17] With renewable energy, we can switch from fossil fuels to cleaner energy sources. Despite its low greenhouse gas emissions, it's considered unsustainable and not a viable solution for today's energy and environmental problems. The most effective way to make renewable energy more efficient and sustainable is to use artificial intelligence [18]. Table 1 illustrates how sustainable energy benefits everyone, including the environment, economic growth, social well-being, and resilience.

Table (1): Benefits of Sustainable Energy Transition

Category	Benefits	Ref.
Environmental	- Reduction in greenhouse gas emissions - Decreased air and water pollution - Preservation of ecosystems and biodiversity - Mitigation of climate change impacts	[6] [19] [20]
Economic	- Creation of green jobs and industries - Reduced fuel costs and energy efficiency lead to long-term cost savings - Enhanced energy security and reduced dependency on imported fuels - Stimulation of technological innovation and competitiveness	[20] [21] [22]
Social	- Cleaner air and water improve public health - Enhancing energy access and equity, especially in remote and underserved areas - Infrastructure and urban development that enhance quality of life - Through decentralised energy systems, communities can be empowered	[21] [20]

Resilience and Security	- Natural disasters and disruptions are less likely to disrupt energy systems - Through diversified energy sources, energy supply can be more stable and reliable - Conflicts over energy resources and geopolitical tensions are reduced	[23] [24] [25]
Global Leadership	- Taking action on climate change and sustainability - Implementation of international climate agreements and commitments - Developing clean energy p partnerships and collaborations internationally	 [26] [27]

3. Role of AI in Renewable Energy Integration

The inherent variability of renewable energy sources like solar and wind makes integrating them into the grid tricky. Artificial intelligence offers a robust set of tools for optimising this integration:

3.1. Renewable Energy Forecasting:

Using machine learning methods, where systems learn from their environment instead of being explicitly programmed, is promising to improve renewable energy generation forecasts[28]. Historical generation data, real-time weather conditions, and environmental factors can be analysed using AI algorithms like LSTMs, SVMs, and ANNs to identify complex patterns and relationships[29]. With more data and technological advancements, these learning systems keep getting better.

3.2. Benefits of Improved Grid Integration:

- **Enhanced Grid Stability:** By adjusting conventional power generation based on accurate forecasts, grid operators can reduce the risk of blackouts.

- **Reduced Reliance on Fossil Fuels:** Knowing how much renewable energy will be available minimises the need to keep fossil fuel plants on standby.

3.3. Improved Power Quality

Power supply fluctuations are reduced when renewable energy sources are integrated smoothly, so consumers benefit from better quality and reliability. Keeping fossil fuel plants on standby is also minimised.

3.4. Predictive Maintenance

Renewable infrastructure like wind turbines and solar panels can benefit from proactive maintenance powered by artificial intelligence. AI algorithms analyse sensor data and historical operational patterns to predict potential faults and detect anomalies [30]. This enables:

- **Reduced Downtime:** To maximise energy and revenue, find problems early so you won't have as much downtime.
- **Optimised Maintenance Schedules:**

  Maintenance interventions can be scheduled only when necessary using AI-driven insights, reducing operational costs.

3.5. Smart Grid Management:

The smart grid's complex interplay of renewable energy sources, energy storage systems, and demand profiles necessitate dynamic management. AI algorithms can analyse real-time data to:

- **Optimise Energy Flows:** AI can route energy efficiently within the grid, minimising losses and ensuring optimal resource utilisation.

- **Reduce Grid Instability:** AI can adjust system parameters to maintain grid stability by anticipating fluctuations in renewable energy output and demand.
- **Ensure Efficient Resource Utilisation:** AI optimises energy storage systems, ensuring sufficient reserves during peak demand periods while maximising the utilisation of renewable energy sources.

4. **Renewable Energy Resource Planning and Development:**

Resource mapping and AI-driven spatial analysis are essential to finding the best locations for renewable energy installations. The following factors may be analysed by an AI algorithm, including wind speed, solar irradiance, land availability, and environmental constraints [31]:

- **Maximise Energy Generation Potential:** Assess the feasibility of generating energy at various locations and determine which locations offer the greatest return on investment.
- **Minimise Environmental Impact:** Using artificial intelligence, renewable energy projects can consider protected areas and bird migration patterns.

Various artificial intelligence methods exist, from simple rules-based expert systems to more advanced ones like machine learning [30]. Expert systems can be used to develop a decision support system for renewable energy management and solve complex problems[31].

Renewable energy sources are tricky to integrate and manage because they're intermittent. Due to the system's temporal and spatial variability, traditional forecasting and dispatching methods don't work [32]. Artificial intelligence will help solve these challenges and pave the way to a more efficient, reliable, and sustainable renewable energy future as energy systems become more complex and decentralised[33].

5. High-performance optimisation of solar energy systems using a framework integrating AI applications

For high-performance optimisation of solar energy systems, a framework for integrating AI applications should include the following:

5.1. Data Acquisition and Preprocessing:

- **Sensor Network:** Integrate a comprehensive sensor network across the solar panels, including:
    - Solar radiation irradiance sensors
    - Sensors for monitoring panel temperatures
    - Tracking power output with voltage and current sensors
    - Additional environmental sensors (wind speed, humidity)
- **Data collection and storage:** Establish a robust data collection system that gathers real-time sensor data and securely stores it.
- **Preprocessing and Data Cleaning:** Correct any inconsistencies, outliers, and missing values in the collected data.

5.2. AI Model Selection and Training:

- **Identify Optimisation Goals:** Clearly define your optimisation goals, such as:
    - Producing as much energy as possible
    - Energy loss minimisation

  - Predicting equipment failures and preventing them
  - Integrating the grid and improving the quality of the power

- **Selecting Appropriate AI Techniques:** Choose appropriate AI algorithms based on the optimisation objectives. Examples include:
  - **Long Short-Term Memory Network (LSTM):** Uses historical data and weather conditions to forecast solar energy.
  - **SVMs (Support Vector Machines):** Used to detect anomalies and predict faults in solar panels.
  - **Reinforcement Learning:** Maximising resource utilisation and energy dispatch.

- **Training and Validation of AI Models:** AI models are trained using pre-processed data, then their performance is evaluated.

5.3. Applications powered by artificial intelligence:

- **Forecasting solar energy output with high accuracy:** Apply AI models to predict solar energy output, enabling accurately:
  - Grid integration and stabilisation.
  - Storage of energy in an optimal manner.
  - The efficient dispatch of conventional energy sources.
- **Maintenance Predictive:** Use AI-based anomaly detection and fault prediction algorithms to:
  - Maximise energy production and minimise downtime.

  - Reduce operational costs and optimise maintenance schedules.
  - Provide solar equipment with a longer life expectancy.

- **Smart Grid Integration:** Make use of artificial intelligence to manage dynamic grids, including:
  - Minimising grid losses by optimising energy flows.
  - Anticipating fluctuations in renewable energy output and demand.
  - Ensuring efficient utilisation of energy storage systems.

5.4. Continuous Monitoring and Improvement:

- **Real-time Monitoring:** Follow the performance of the AI models and the overall solar energy system constantly.
- **Data Feedback Loop:** The data from the system should be fed back to the AI models to help them learn and improve continuously.
- **Performance Evaluation:** AI-based optimisation strategies should be reviewed and adjusted.

Table 2 illustrates the solar energy integration framework, and Figure 1 summarises the solar AI framework.

Table (2): AI – Solar Energy Integration Framework

Stage	Description	Example
Data Acquisition and Preprocessing	Monitor the performance of solar panels in real-time (irradiance, temperature, voltage, current). Cleaning and preprocessing of data.	Measure solar irradiance with pyranometers, track power output with voltage/current sensors, and measure temperature with temperature sensors. Clean and organise the data for AI model training.
AI Model Selection and Training	Identify the optimisation objectives specific to solar energy (maximising energy production, minimising energy losses, and predicting panel failure). Select the appropriate artificial intelligence algorithms (LSTM for forecasting and SVM for anomaly detection) and validate and train the models.	The goal is to maximise solar energy production. The LSTM network forecasts solar energy based on historical generation data, weather conditions (wind speed, cloud cover), and panel temperature. Pre-processed sensor data trains the LSTM model.
AI-powered Optimisation Applications	Using AI models for Solar Energy Forecasting: Accurately predict solar energy production. An anomaly can be detected with predictive maintenance, and potential solar panel failures can be predicted. Effectively managing energy storage and optimising energy flows within the grid are key components of smart grid integration.	The use of LSTM network for forecasting solar energy, along with AI-powered predictive maintenance algorithms and smart grid integration, maximises energy production, reduces reliance on fossil fuels, optimises energy storage, minimises downtime, and reduces operational costs, resulting in a longer lifespan for solar panels and efficient utilisation of energy storage systems.
Continuous Monitoring and Improvement	Monitoring the performance of the AI models and the overall solar energy system continuously. Create a feedback loop where data from the system is fed back to the AI models to improve and learn continuously. Ensure that AI-powered optimisation strategies are regularly evaluated and adjusted as necessary.	Ensure that AI forecasts, energy production, and system performance are accurate. Adapt optimisation strategies (e.g., maintenance schedules) as necessary based on new data.

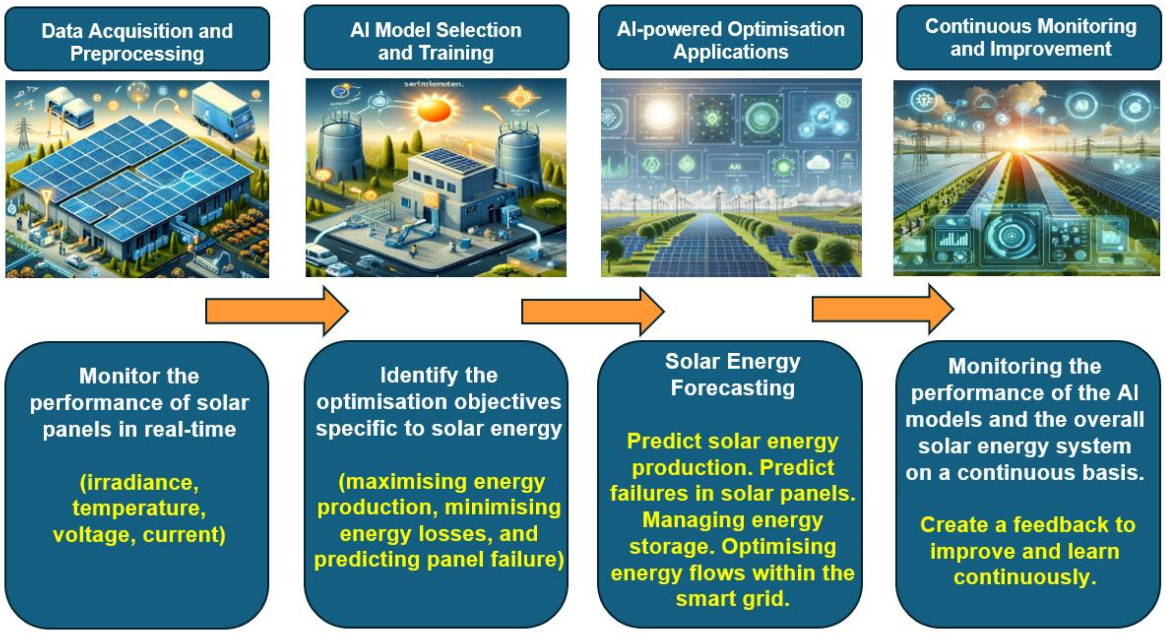

Figure (1): Summarised AI – solar frame work

6. A framework for integrating AI into wind energy optimisation

Integrating AI applications into wind energy systems offers significant potential for high-performance optimisation. Framework components are summarised in Table 3 and Figure 2.

Table (3): AI – Wind Energy Integration Framework

Stage	Description	Example
Data Acquisition and Preprocessing	**To collect real-time data, install a sensor network across the wind turbines:** *Anemometers for wind speed and direction Sensors on blades to measure pitch, vibration, and strain *Temperature sensors within the wind turbine *Environmental sensors (for example, humidity sensors)	Deploy anemometers on the turbine mast at various heights, vibration sensors on blades, and temperature sensors within key components. Clean and organise the data for AI model training.

AI Model Selection and Training	Determine the following optimization goals for wind energy: *Maximise energy production, Minimise downtime, *Optimize blade pitch to accommodate changing wind conditions. *Choose appropriate artificial intelligence algorithms: LSTM for wind speed and power forecasting, SVM for anomaly detection in sensor data, and reinforcement Learning for dynamic blade pitch control. Train and validate the models.	Goal: Minimise downtime while maximising energy production. With LSTM, you can forecast wind speed and power based on historical data, weather conditions, and real-time sensor readings. Use SVM to detect anomalies in sensor data and predict potential failures. Implement Reinforcement Learning for real-time blade pitch control. Preprocessed sensor data trains the models.
AI-powered Optimisation Applications	*Predict wind speed and power output with high accuracy using AI models. *Maintain wind turbine components by detecting anomalies and predicting failures. *Real-time blade pitch control optimises energy capture and reduces turbine stress.	AI forecasting predicts wind speed and power output, which means: - Smoother grid integration and less fossil fuel use. Dispatching conventional energy more efficiently. Management of energy storage efficiently. Optimise energy production and minimise downtime with predictive maintenance algorithms. Reduce operational costs and optimise maintenance schedules. Increase wind turbine component lifespan. Real-time blade pitch control powered by AI: - Maximises energy capture. Reduces mechanical stress on turbines.
Continuous Monitoring and Improvement	Continually monitor the performance of the AI models and the overall wind energy system. Implement a feedback loop in which system data is fed back to the AI models to improve and learn from them continuously. Analyse and adjust the AI-powered optimisation strategies regularly.	Check the accuracy of AI forecasts, energy production, and system performance. Based on new data, adjust optimisation strategies (e.g., maintenance schedules, blade pitch control parameters).

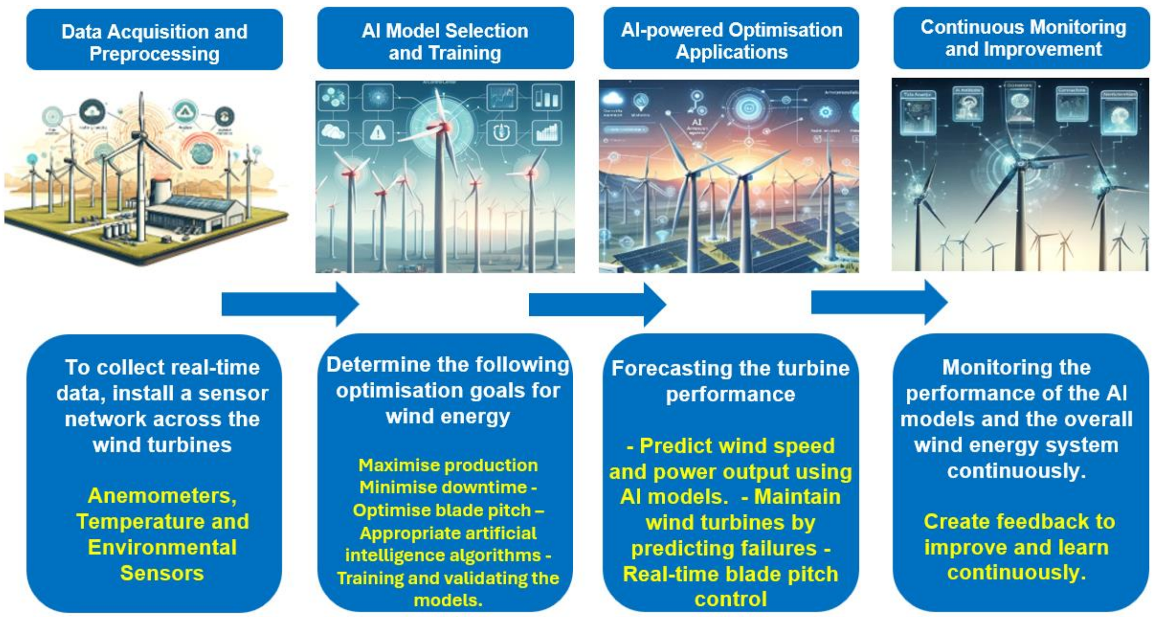

Figure (2): Summary of the wind energy integration framework

7. Challenges in Renewable Energy Management

A short-term challenge associated with renewable energy generation is the lack of predictability of some renewable sources, which can result in large fluctuations in supply within days or even hours. A lack of predictability affects the power grid's operation and poses significant challenges in achieving a stable energy supply. Since wind energy exhibits considerable variability, it is necessary to accumulate more significant operating reserves and to provide specialised regulation services to manage fluctuations effectively. The curtailment of renewable sources such as hydropower and biomass can also result in significant changes in renewable output, highlighting the need for improved management practices. Even though wind power is on its way to becoming cost-competitive, market forces are already making renewables a concern. Electricity generated from renewable energy sources may negatively impact the environment and climate change in the future [34]. Simulation results show greenhouse gas emissions will decline as states rely more on renewables. A part of the reduction can be attributed to using renewable energy resources, known for their low or zero emissions, and which displace conventional electricity generation methods that contribute to greenhouse gas emissions [35].

With environmental sustainability becoming increasingly important, renewable resources will be required to reduce emissions of pollutants and greenhouse gases. Demand for renewable energy will increase the need for infrastructure and efficient deployment of these resources within the electricity market[36]. Harnessing renewable energy and implementing stricter environmental policies can mitigate climate change. Consequently, the operation of the power system may be challenging. As wind power is highly variable, it requires large operating reserves and specialised regulation services[37]. Furthermore, significant changes in the output of renewable energy sources, such as hydropower and biomass, may result in their curtailment. As wind power becomes cost-competitive in many circumstances, market forces already affect renewable resources[38]. Using renewable energy sources for electricity generation can adversely affect the environment and climate change. The more renewable resources the state uses to generate electricity, the lower its greenhouse gas emissions will be [39]. Because renewable energy sources emit very little or no emissions, they are replacing the emissions associated with electricity generation. These resources will be required in the future to minimise pollution and greenhouse gas emissions. As a result, the electricity market will become increasingly dependent on renewable energy sources [40].

8. AI Solutions for Renewable Energy Optimisation

Since renewable energy is highly distributed, nondispatchable, and uncertain, current methods of integrating and optimising it are unsuitable. AI is being developed to optimise renewable energy plants, forecast their output so they can be scheduled and planned for grid systems, and assess their ability to serve as ancillary services for power systems. Power demand can be met by renewable resources, loads can be balanced by renewable resources, and the best mix of renewable resources can be determined using quality models and decision support systems. In addition, artificial intelligence can help with the decision-making process for renewable integration by providing insights into changing market structures, pricing and incentive programs, and various policy options. The development of advanced technologies like energy storage systems and smart grids. By balancing environmental, economic, and social equity objectives, artificial intelligence methods can be used to evaluate energy systems' sustainability. This will promote collaboration between researchers, policymakers, industry experts, and the public [41]. As a result of this collaboration, renewable energy integration will be successful globally and can mitigate the effects of climate change effectively. As a result of the power of artificial intelligence, we can seamlessly integrate renewable energy into our electricity grids, enabling us to provide reliable and clean electricity to communities worldwide.

9. Modern Solutions for Energy Optimisation

Various industries have embraced artificial intelligence (AI). Optimising the integration and management of renewable energy has received much attention. This burgeoning field will facilitate a more sustainable future by improving the efficiency and effectiveness of renewable energy sources[42]. Energy optimisation and seamless integration of renewable energy are explored in this section. In the future, renewable energy can be generated, distributed, and consumed more efficiently and effectively with these innovative approaches[41]. These systems optimise energy efficiency and reduce waste by automatically adjusting supply and demand. Reduces reliance on non-renewable energy sources [43]. By anticipating energy demand patterns, AI-enabled tools can enhance prediction and optimise production. Data analysis and predictive modelling can help optimise renewable energy generation to meet the needs of consumers, thereby reducing costs and increasing reliability[18]. Additionally, artificial intelligence has proven to help develop energy management systems that are sustainable and efficient. These advanced algorithms enable real-time energy management. AI-driven solutions can reduce energy waste, lower carbon emissions, and improve sustainability by optimising energy consumption patterns. AI is revolutionising how we harness and use renewable energy by optimising its integration and management[44]. Efficiency, environmental friendliness, and economic viability can be improved by artificial intelligence. By adopting these modern solutions, future generations will live on a greener, more sustainable planet.

10. AI Applications in Energy Storage Systems

Integrating renewable energy resources and developing intelligent distributed energy systems requires AI energy storage control and management systems. Sandia National Laboratories, for example, is developing an autonomous control system for wind-powered hydrogen fuel cells[45]. By utilising artificial intelligence, Japan's Electro Source No. is optimising advanced lead-acid battery energy storage systems. Japan Storage Battery Co. and Furukawa Battery Co. developed ES3 software, which enhances charging efficiency, estimates the state of charge of the system, and detects faults [46].

There are no fail-safe mechanisms in current energy systems for curtailing energy efficiently through various components, limiting the growth of renewable energy sources and preventing resource utilisation. Through artificial intelligence, these issues can be resolved by improving the tracking of storage inventory, optimising energy storage and conversion devices, and improving system monitoring and diagnosis to ensure excellent system reliability.

11. Ethical Considerations in AI-Enabled Energy Management

Assess the effectiveness, ability to implement, and impact of AI-enabled intelligent energy management in sustainable energy transitions. The trade-offs between energy, sustainability, environmental risk, and how AI can improve productivity and manage critical energy resources. Demonstrate how AI can be used to manage energy resources in a sustainable manner for future generations. Identify potential risks and unintended consequences of using AI in the energy management sector that may harm energy and the environment in the long run. Assess the sustainability impacts of AI-enabled energy management and provide recommendations for monitoring and guiding AI applications in the energy sector towards socially and environmentally desirable outcomes.

12. Conclusions

Artificial Intelligence (AI) can accelerate the transition to a sustainable energy future by integrating it into renewable energy systems. AI models, like Long Short-Term Memory (LSTM) networks, improve solar and wind power production forecasting by analysing historical data and weather conditions. As a result, energy output and efficiency are maximised. Furthermore, AI algorithms such as Support Vector Machines (SVMs) can detect anomalies and predict equipment failures before they occur, thus reducing downtime and maintenance costs while extending the life of renewable energy assets. Through real-time optimisation, AI enhances grid stability. Dynamic energy production and distribution adjustments use AI to ensure a balanced grid supply and demand. By optimising energy flows and storage, reinforcement learning algorithms prevent grid instability. Smart grids can also be made more efficient and reliable with AI. Smart grids adjust to energy supply and demand fluctuations, ensuring consistent and stable power. AI-driven renewable energy systems have substantial economic and environmental benefits. AI reduces the reliance on fossil fuels and saves a lot of money by optimising energy production and maintenance. Enhanced efficiency and stability of renewable energy systems contribute to substantial reductions in greenhouse gas emissions, reducing the effects of climate change and promoting a cleaner, more sustainable environment. Renewable energy systems become more efficient and reliable with AI-driven solutions. With AI's continuous learning and improvement capabilities, adapting to new technologies and environmental changes is easy. In addition to facilitating the transition to a sustainable energy future, these advancements in AI are pivotal in achieving global sustainability goals and mitigating climate change impacts.

List of Abbreviations

AI	Artificial Intelligence
ANN	**Artificial Neural Network**
LSTM	Long Short-Term Memory Network
MITEI	MIT Energy Initiative Company

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