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OVERVIEW ON FUTURE TECHNICAL SKILLS AND SUSTAINABLE/RENEWABLE ENERGY

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Abstract

Curricula in sustainable and renewable energy need to be constantly updated and requires more integration of advanced technologies into higher education programs. These technologies offer innovative ways to engage students in the field of sustainable and renewable energy, providing practical skills and knowledge essential for addressing current and future energy challenges. When we talk about renewable energy, it is essential to consider the interactions between the different renewable resources. By combining these sources in a smart and integrated way, we can significantly enhance both energy reliability and overall sustainability. This holistic approach demonstrates how synergy among solar, wind, and other renewable energies can create a more stable and resilient energy system for the future.

Keywords

Renewable energy, Sustainability, Optimization, Storage, Artificial Intelligence

1. Introduction

The importance of renewable energy in creating a cleaner and more resilient future has been highlighted by the global emphasis on sustainability and climate change mitigation in recent decades [1-4]. An eco-friendly substitute for fossil fuels, renewable energy sources including solar, wind, hydro, and biomass help ensure a steady supply of energy in the future by lowering greenhouse gas emissions [5-7]. At the same time, the integration of artificial intelligence (AI) into energy systems has opened new opportunities for optimizing performance, predicting energy demands, and enabling smarter grid management. The combined advances in renewable energy technologies and AI have not only transformed the energy landscape but have also greatly impacted research, education, and innovation within universities worldwide. The fact that sustainable energy and renewable energy are closely related ideas should be kept in mind when defining sustainable energy. Sustainable energy refers to our responsibility to ensure energy access for future generations while minimizing environmental impact. In contrast, renewable energy involves generating enerIy from inexhaustible natural resources. By combining these two concepts, we can move toward a future where energy is both clean and equitably accessible. The evolution of renewable energy has been marked by a remarkable surge in research, technological advancement, and innovation, mostly motivated by the pressing need to improve global energy security and slow down climate change. As societies increasingly recognize the environmental and economic risks associated with fossil fuels, there has been a strong push toward developing clean and sustainable alternatives [8-12]. Energy conversion efficiency has advanced significantly as a result of this change, also storage solutions, and smart grid integration. The evolution of education systems in the field of energy has undergone significant transformation over the past two decades. There was a noticeable increase in research in the late 2000s and innovation in renewable energy technologies, largely driven by increasing global concerns over climate change mitigation and the need for enhanced energy security. Starting from 2015, the trajectory of energy education within higher education institutions experienced further advancement with the integration of artificial intelligence (AI). This integration has enabled universities and research centers to develop smarter, data-driven approaches to energy systems, improve modeling and simulation capabilities, and support the design of more efficient renewable energy solutions. AI has also played a key role in modernizing curricula, providing students with advanced analytical tools and fostering interdisciplinary skills necessary for addressing complex energy challenges [13-15]. Together, these developments have significantly strengthened the role of higher education in preparing future experts and leaders for the energy transition (Fig. 1).

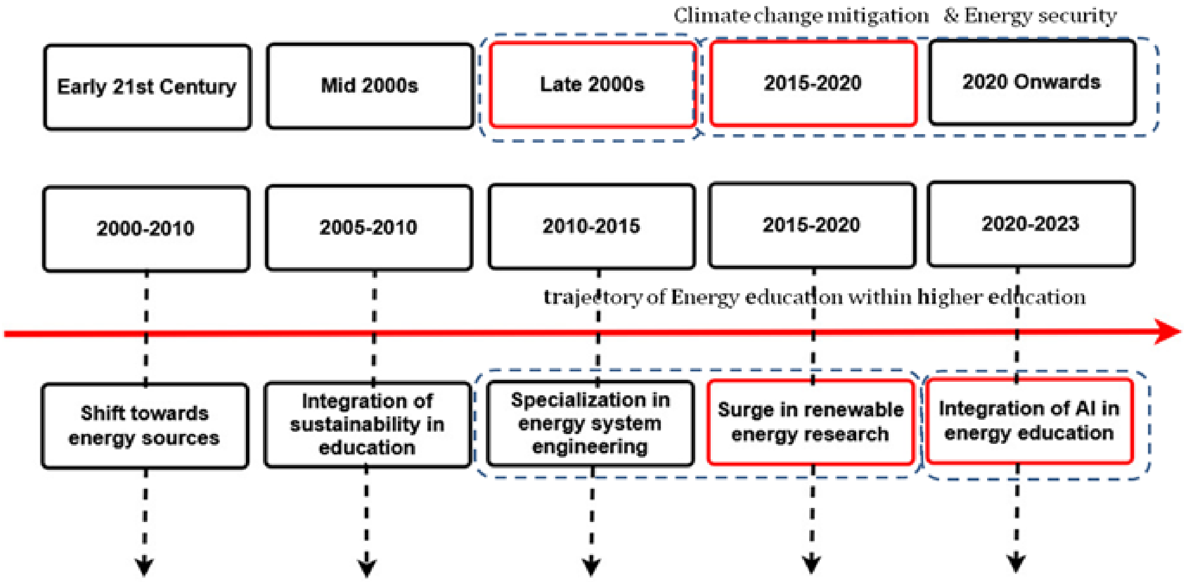

Fig.1. Evolution of education in the context of energy (2000-2023)

2. Integrating advanced technologies in sustainable and renewable energy

Integrating advanced sustainable and renewable energy technologies into higher education programs is essential for preparing the next generation of engineers, scientists, and policymakers to lead the global energy transition. By incorporating cutting-edge topics such as smart grids, energy storage, and artificial intelligence-driven energy management, universities can equip students with the technical skills and interdisciplinary knowledge needed to address complex energy and environmental challenges. This approach not only fosters innovation and critical thinking but it also gives graduates the tools they need to help create a more sustainable and resilient energy future. Advanced technologies play a crucial role in educating students about sustainable energy systems and preparing them for future careers in the renewable energy sector. The main advanced technologies that require the integration of artificial intelligence (AI) are summarized in Fig.2.

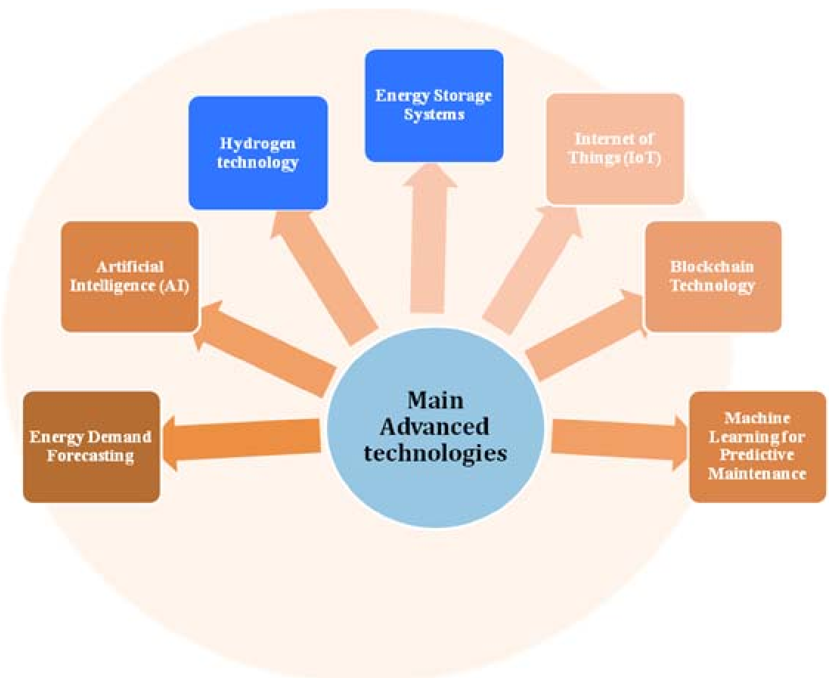

Fig 2. The main advanced technologies

For example, energy demand forecasting is essential for optimizing the generation, distribution, and consumption of renewable energy, using data analytics and predictive modeling to accurately forecast energy needs. AI-based education involves employing smart algorithms optimizing renewable energy production and consumption, thereby maximizing the system efficiency. Education on hydrogen technologies focuses on understanding the production, storage, and use of hydrogen as a clean energy carrier. Similarly, training on energy storage systems covers various technologies such as batteries and supercapacitors, which are critical for storing renewable energy for later use and ensuring energy availability during fluctuations. IoT device integration greatly improves the performance and efficiency of renewable energy systems by enabling real-time monitoring and control. Finally, renewable energy systems' maintenance requirements are predicted using machine learning methods, improving their operational reliability and extending system lifespan. Through these advanced approaches, students gain the technical expertise and innovative mindset necessary to contribute effectively to the evolving energy landscape.

2.1. Hydrogen Technology

Hydrogen technology involves understanding the production, storage, and application of hydrogen as a clean energy carrier. Indeed, hydrogen is considered a promising candidate for decarbonizing several energy sectors and supporting the energy transition. Like electricity, hydrogen is primarily an energy carrier rather than an energy source itself, as it must be produced through chemical reactions from primary resources. The main resources used for producing hydrogen are water (via electrolysis) and hydrocarbons such as coal, oil, or natural gas.

The "color" of hydrogen is crucial since it will be a major component in accelerating the energy transition. (Fig.3). For example, brown hydrogen (made from lignite or brown coal) and black hydrogen (made from black coal) are created via gasification, whereas grey hydrogen is made from natural gas. However, in order to lower emissions, blue hydrogen is also made from natural gas using a steam reforming technique in conjunction with carbon capture and storage devices.Water electrolysis produces green, yellow, and pink hydrogen. Nuclear power reactors provide the electricity needed for the electrolysis of pink hydrogen. Electricity from the local grid, which may originate from nuclear, renewable, or fossil fuels, is used to create yellow hydrogen. Geological hydrogen that occurs naturally in subterranean reservoirs is referred to as "white hydrogen". Meanwhile, green hydrogen is produced using renewable electricity sources such as solar, wind, or hydropower. Lastly, a unique type of hydrogen made from biomass is known as "dark green" hydrogen. In this instance, home, agribusiness, forestry, and agricultural waste can all be fermented or gasified to produce hydrogen.

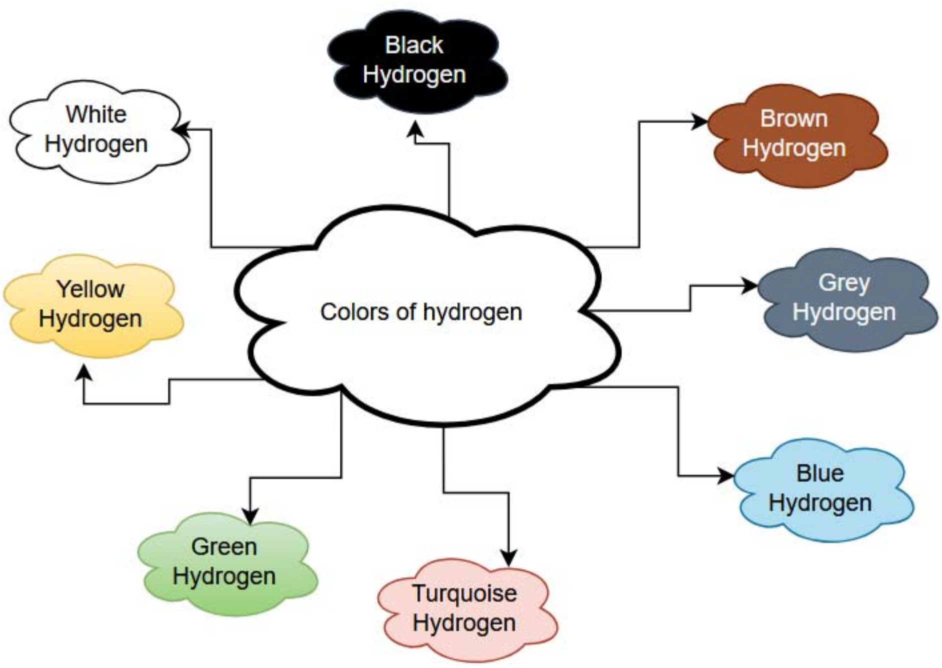

Fig 3. Hydrogen color coding

Production, storage, transportation, and terminal applications are all included in the extensive industry chain that makes up the hydrogen energy sector (Fig. 4).

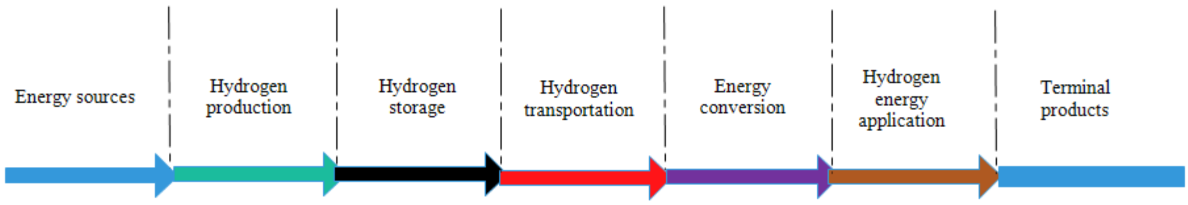

Fig 4. Schematic diagram of the hydrogen industry chain

For instance, using the extra energy generated by the RES, green hydrogen is created by electrolyzing water. It can be utilized as fuel for vehicles or to create electricity for energy production. transportation, industry, storage, and environmental solutions, demonstrating its potential to decarbonize multiple sectors (Fig.5).

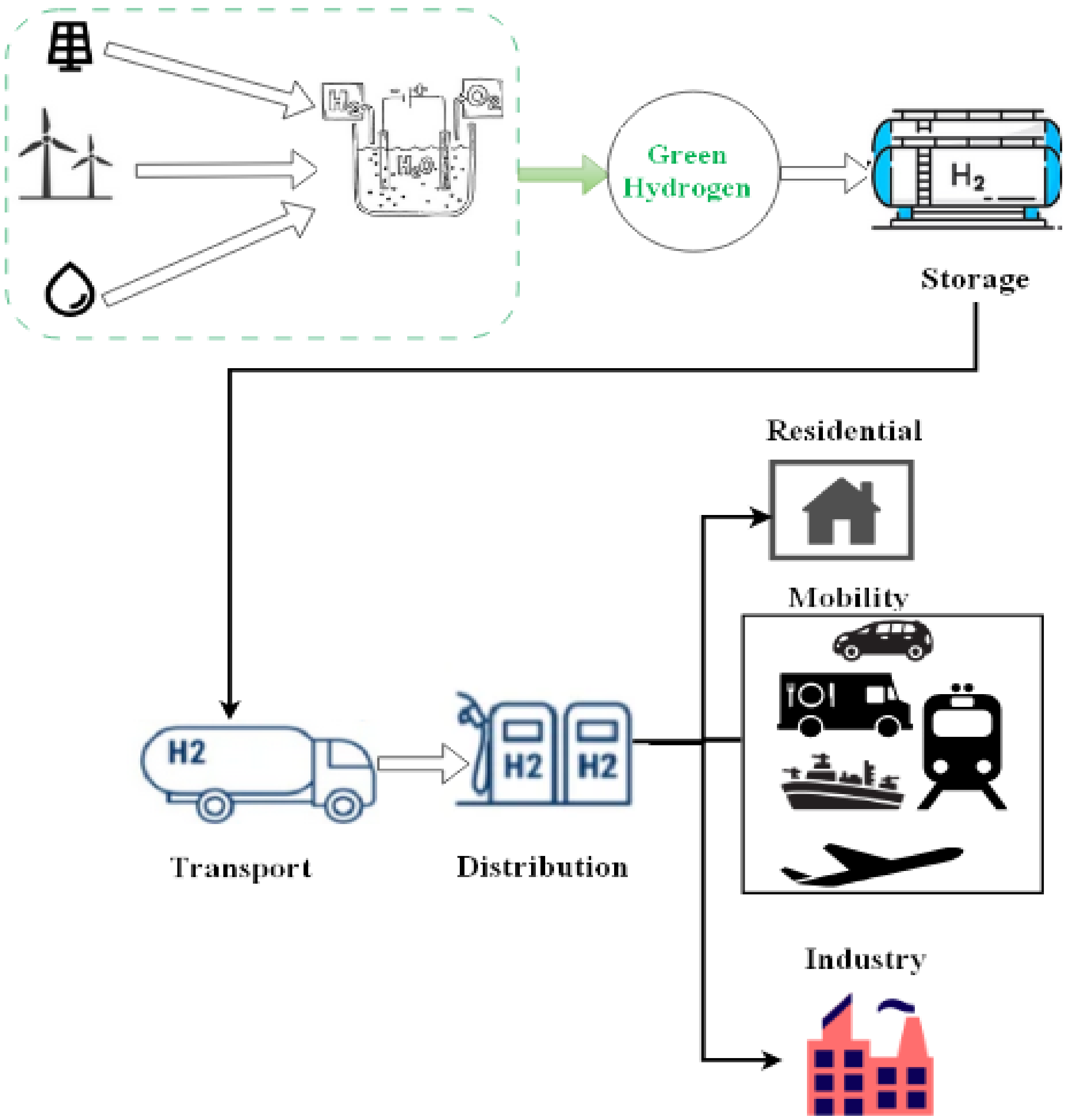

Fig 5. Green Hydrogen value chain

To make university programs on hydrogen more relevant and comprehensive, it is crucial to cover these various aspects which will allow students to develop a broad and deep understanding of hydrogen, while being prepared to address the technical, economic, and environmental challenges of this promising technology (Fig.6).

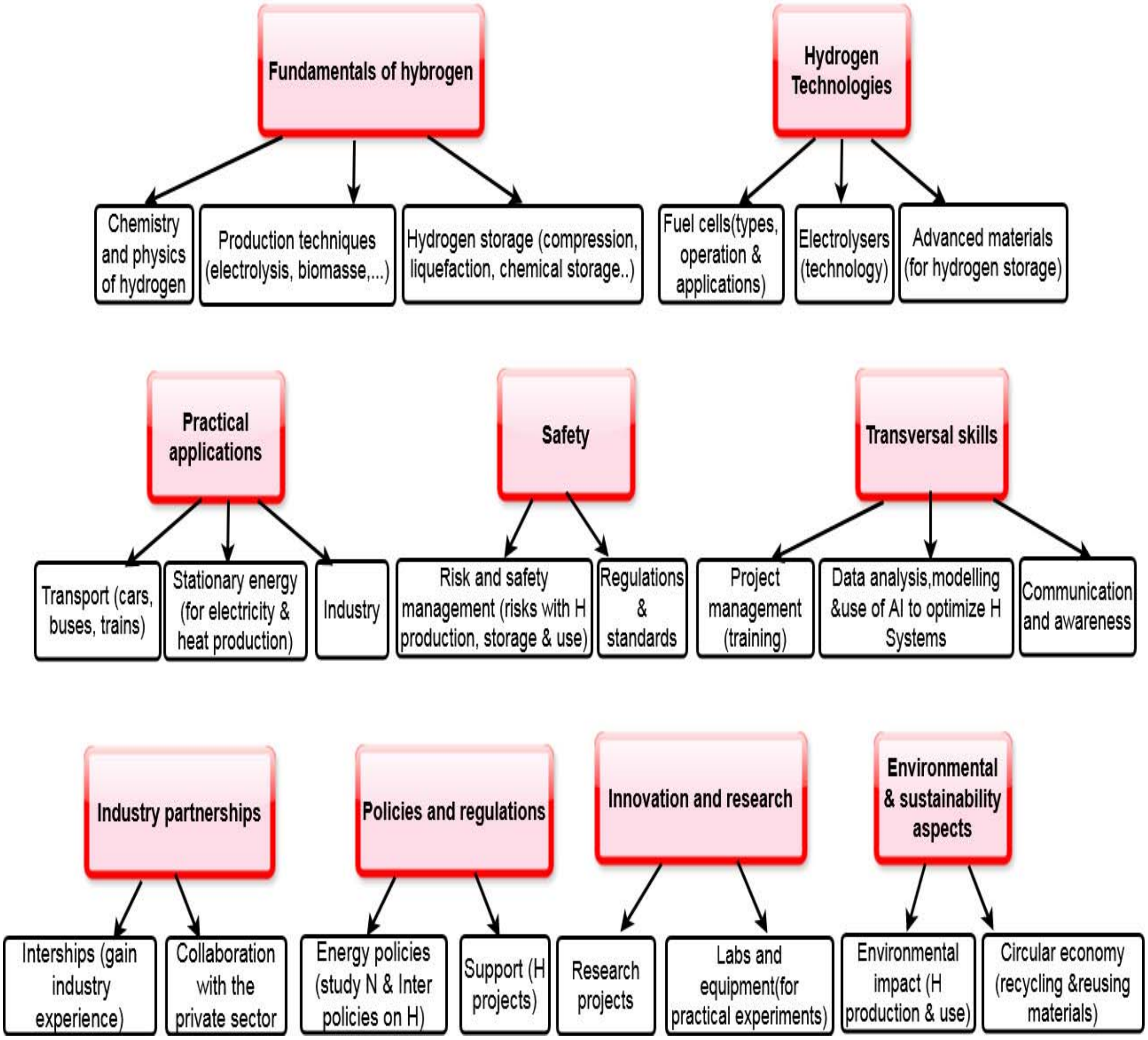

Fig 6. Various aspects allowing students to develop a broad and deep understanding of hydrogen

2.2 Artificial intelligence

Integrating artificial intelligence (AI) skills into renewable energy education is essential for preparing students to meet the evolving demands of the energy sector. Figure 7 illustrates the main research areas where AI is applied, highlighting its critical role in advancing and optimizing renewable energy systems**.**

The integration of artificial intelligence (AI) into renewable energy systems significantly enhances the optimization of energy production, storage, and supervision. Furthermore, combining AI with power electronics improves the efficiency, reliability, and intelligence of modern electrical systems.

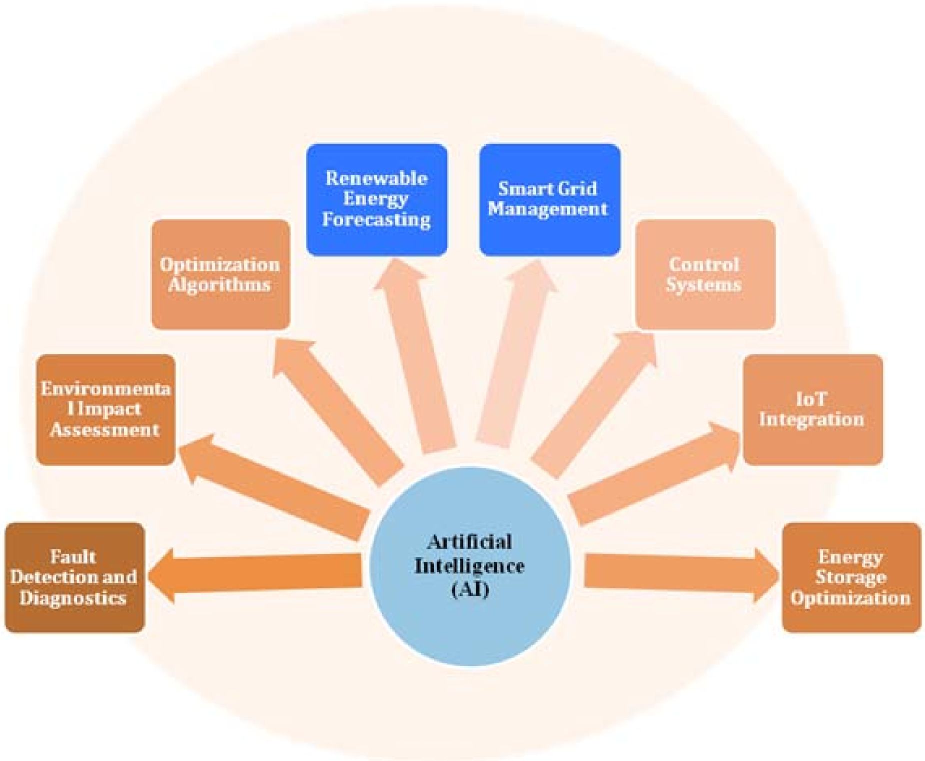

Fig 7. Main research axis where artificial intelligence is used

2.2.1 Optimization algorithms :

They are used to obtain the optimal orientation of photovoltaic (PV) panels and the best placement of wind turbines (WTs). In addition, they are essential in maximum power point tracking (MPPT) algorithms, such as PSO, ANN, FLC, AFLC, and GA, to maximize energy harvesting [17-24]. These algorithms are also employed in the design of hybrid renewable energy systems, where they help determine optimal design parameters and component sizing. Beyond these applications, optimization is widely used in electric vehicles (EVs), in the integration of energy systems, and in agriculture for enhancing renewable energy adoption [25-30].

2.2.2 Energy storage optimization:

It is equally crucial. In battery management systems (BMS), it supports state of charge (SoC) optimization and state of health (SoH) monitoring. In hybrid energy systems, optimization enables the effective combination of energy sources and storage to balance supply and demand. Within microgrids, energy storage is managed to efficiently coordinate local generation and consumption. Additionally, in vehicle-to-grid (V2G) applications, electric vehicles can serve as mobile storage units, further contributing to grid stability and flexibility [31-32].

2.2.3 Energy supervision

Energy supervision powered by AI is essential for real-time monitoring and control, including fault detection and energy flow management. For grid integration and management, AI-controlled power electronics provide services such as voltage and frequency regulation, enhancing grid stability. In demand response, AI algorithms enable power electronic devices to react to grid demands in real time [33-38]. Moreover, in energy storage management, AI improves BMS performance by optimizing charging and discharging cycles and predicting battery health, ultimately increasing system efficiency and reliability.

2.3 Energy storage

It is a critical element in RES, allowing for effective management and use of energy generated from intermittent sources like solar and wind (Fig.8).

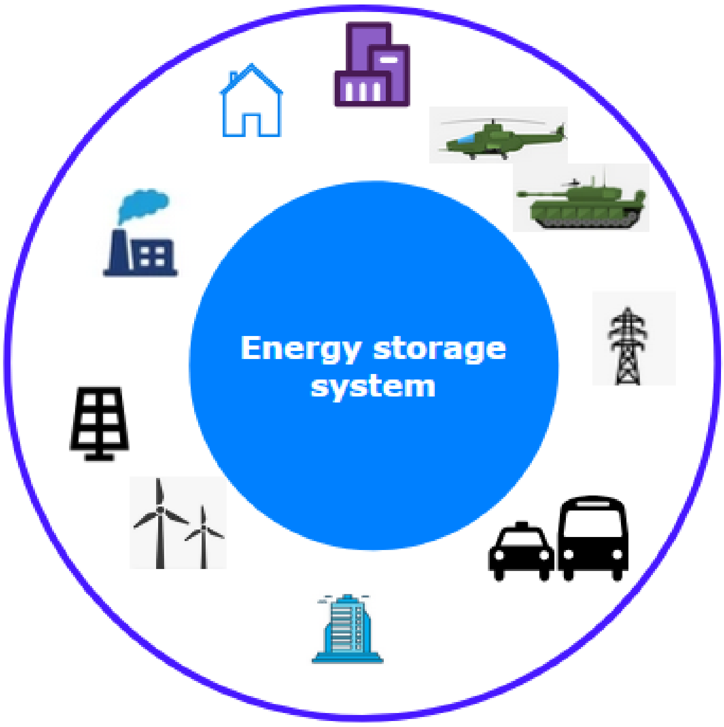

Fig 8. Main applications of energy storage system

To improve university programs concerning energy storage, it's essential to include several key aspects that cover the technical, practical, and theoretical dimensions of this technology (Fig.9).

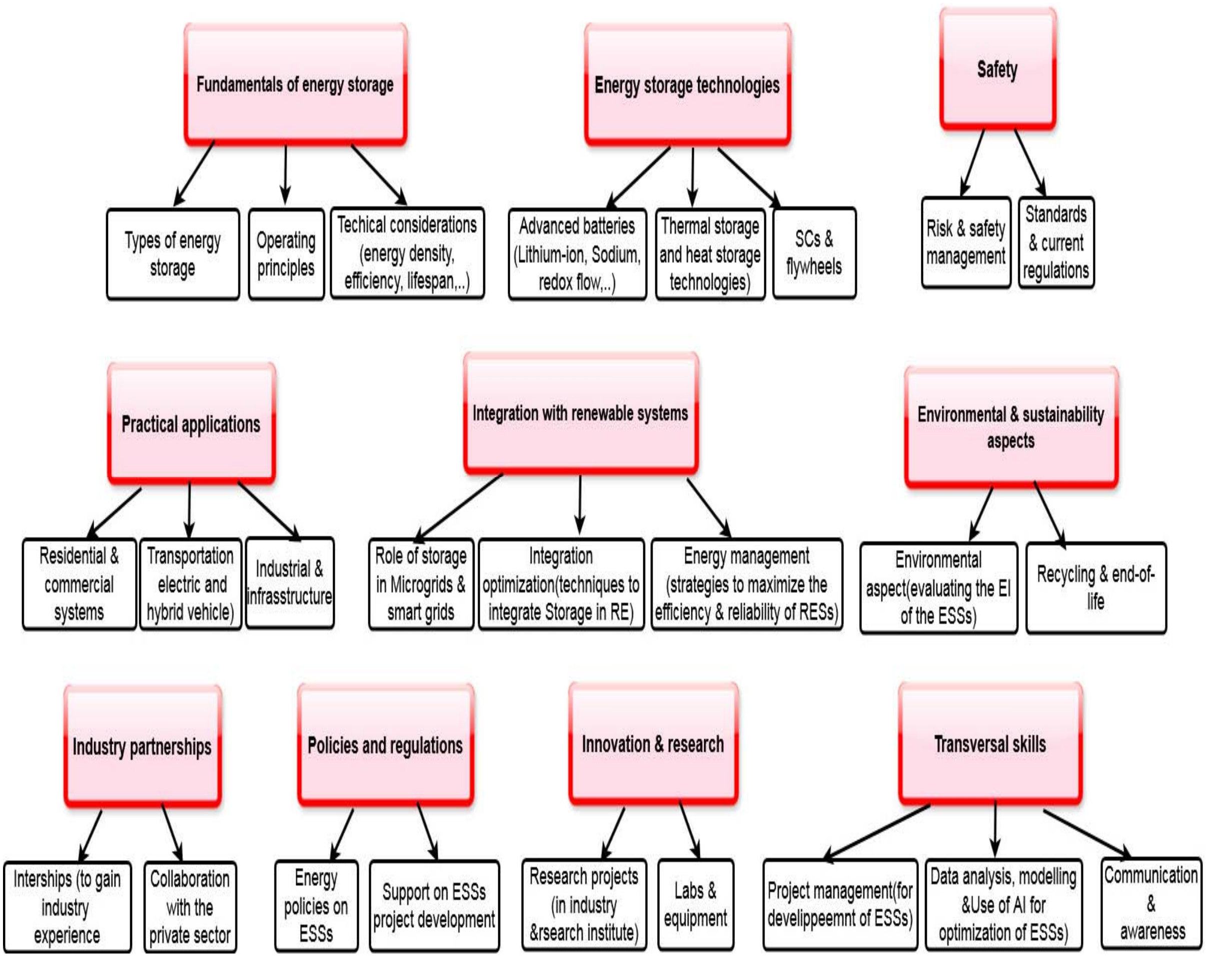

Fig 9 Various aspects allowing students to develop a broad and deep understanding of energy storage system

3. Curriculum development strategies

When developing curricula, teachers and researchers can use several strategies to anticipate and effectively adapt to changes in the renewable energy sector. First, in research and innovation, it is essential to regularly review the latest developments, technological trends, and policy changes in renewable energy. This helps ensure that course content remains up to date and aligned with current research priorities and industry needs. Second, by organizing internships and laboratory experiments, students can gain hands-on experience with real renewable energy projects and technologies. This practical exposure allows them to better understand system design, operation, and problem-solving in real-world contexts. Third, establishing partnerships and collaborations with industry and research institutions is crucial. Inviting industry experts to serve as guest speakers, advisors, or mentors provides students with valuable insights into current and emerging trends, technological innovations, and the skills most in demand in the job market. Additionally, encouraging students to participate in startups and entrepreneurial activities fosters innovation, creativity, and a proactive mindset toward developing new solutions for the energy transition. Finally, adopting an interdisciplinary approach that integrates engineering, environmental sciences, economics, politics, and social sciences helps students develop a comprehensive understanding of the renewable energy landscape. This broad perspective equips them to address complex energy challenges contributing to the sustainable energy systems development (Fig.10).

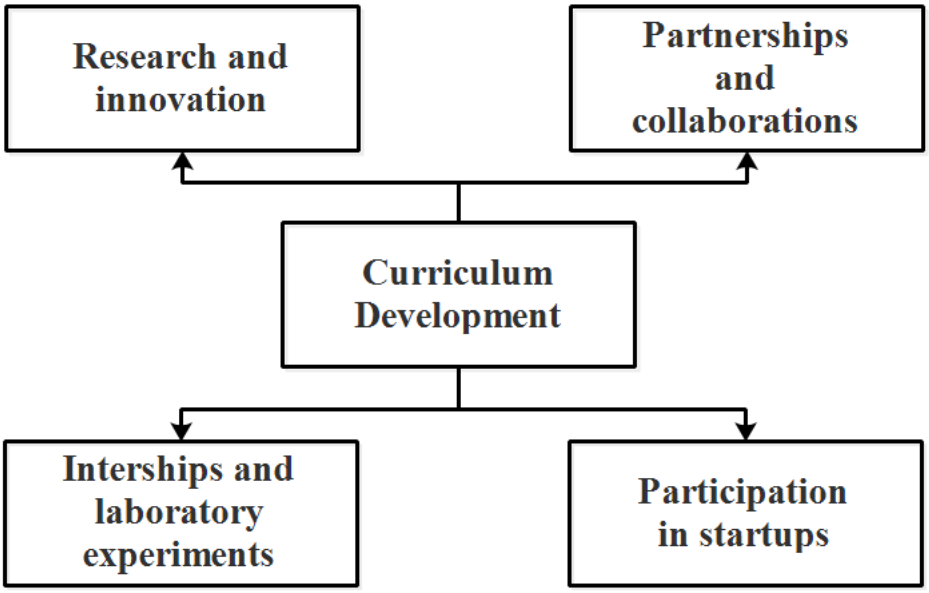

Fig 10. Strategies for Integrating Renewable Energy into Higher Education Curricula

4. Conclusion

In conclusion, integrating advanced technologies into sustainable and renewable energy curricula is essential for preparing students to meet the rapidly evolving demands of the global energy sector. By incorporating hands-on learning, artificial intelligence, energy storage solutions, and interdisciplinary approaches, higher education institutions can provide to students technical expertise and critical thinking skills used to drive the energy transition. Emphasizing the synergies between different renewable energy resources enables future engineers, researchers and students to design efficient and resilient energy systems. This modernized, holistic educational approach not only supports innovation but also empowers graduates to become leaders in developing sustainable solutions, contributing to a cleaner, more secure, and more equitable energy future.

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Biography

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