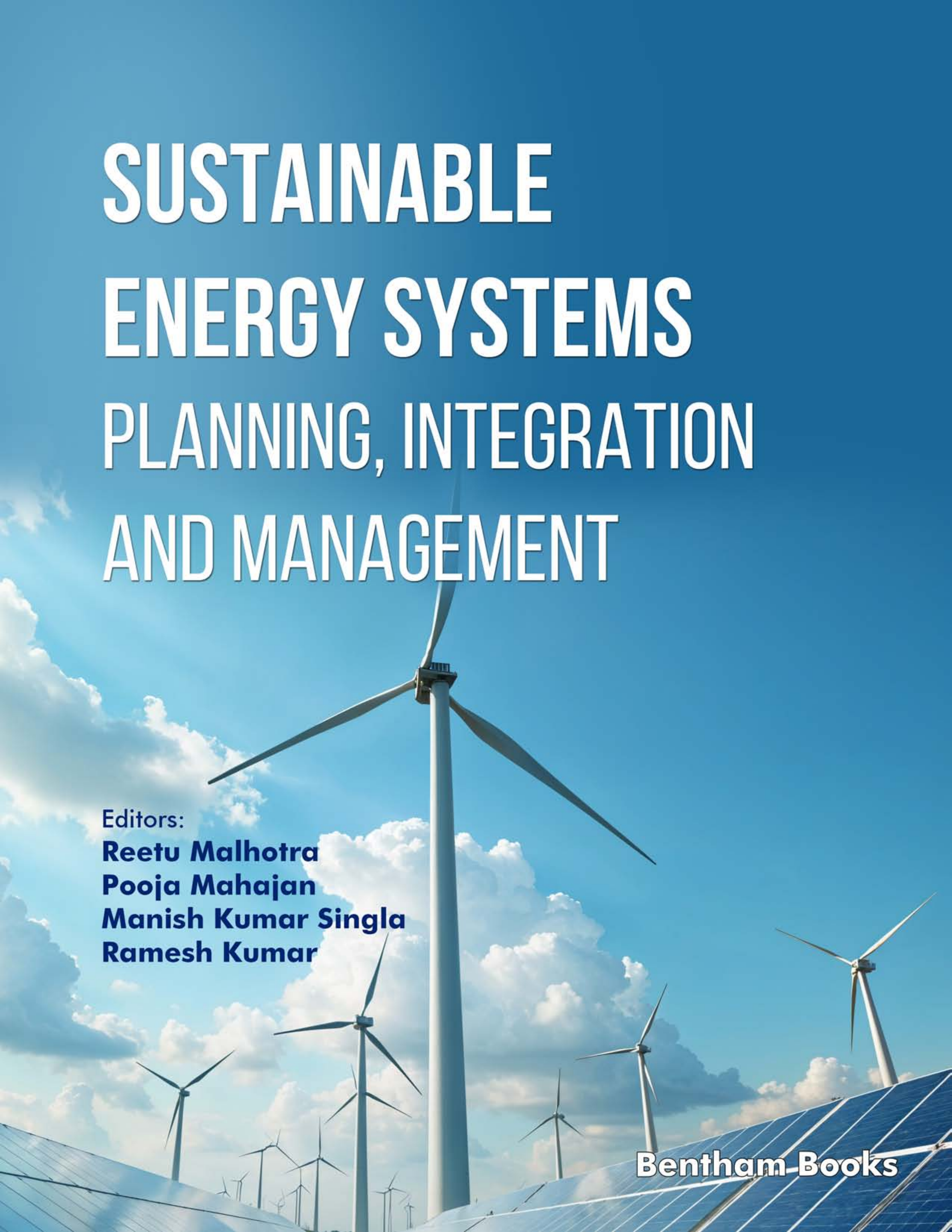

SUSTAINABLE ENERGY SYSTEMS
PLANNING, INTEGRATION AND MANAGEMENT

Editors:
Reetu Malhotra
Pooja Mahajan
Manish Kumar Singla
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Sustainable Energy Systems Planning, Integration and Management

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Sustainable Energy Systems: Planning, Integration and Management

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FOREWORD

It is with great pleasure that I introduce the book, ‘Sustainable Energy Systems: Planning, Integration, and Management.’ This revolutionary work explores the transformative potential of sustainable energy in revolutionizing various sectors. Sustainable energy systems have emerged as a cornerstone in addressing global challenges, reshaping conventional paradigms, and unlocking new possibilities. From the inception of energy solutions to their evolution into advanced, integrated systems; this book provides a comprehensive exploration of the field's development.

The authors adeptly lay a strong foundation, ensuring accessibility for readers with diverse backgrounds as they delve into the fundamental principles and design methodologies underlying sustainable energy systems. Furthermore, the book explores advanced simulation techniques and tools that have become indispensable in modeling and forecasting energy system behavior. These cutting-edge methods enable researchers and engineers to unravel the complexities of sustainable energy systems, transcending the limitations of traditional experimental approaches.

This insightful narrative highlights the pivotal role of simulation and integration in optimizing sustainable energy system performance, unlocking their full potential for global impact. As you embark on this enlightening journey, absorb the wealth of knowledge and expertise encapsulated within these pages. Whether you are a seasoned practitioner, an aspiring innovator, or simply curious about the future of sustainable energy; this book promises to broaden your horizons and empower you to contribute to the advancement of this vital field.

Ashok K. Chitkara
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PREFACE

The field of engineering has always been driven by innovation and the ability to translate ideas into perceptible solutions. In recent years, one of the most transformative forces driving this innovation has been the advancement of energy. This book, Sustainable Energy Systems Planning, Integration and Management, delves into this exciting intersection, exploring how cutting-edge imaging techniques are revolutionizing diverse sectors. Sustainable Energy Systems in engineering have transcended their role in the energy sector. They now offer powerful tools for non-destructive testing, material characterization, process creation, and design optimization. This book provides a comprehensive overview of these advancements, highlighting their impact on various energy sectors. By fostering communication and knowledge exchange between specialists and engineers, we can unlock the full potential of these technologies and accelerate innovation across diverse fields. Throughout the book, we explore the fundamental principles of Sustainable Energy Systems, delve into their practical example in different sectors, and discuss emerging trends that promise to revolutionize the field further.

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CHAPTER 1

AI-Enabled Approaches for Optimizing the Smart Grid System

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Abstract: A smart grid represents a huge leap forward from conventional grids and uses advanced technologies to make the power grid more efficient, reliable, and sustainable. One of its main features is two-way communications, which helps in self-healing, active consumer participation in managing energy, and resilience against both physical and cyber threats. A very important dimension of this transition is the integration of different sources of energy, including renewable energy, which plays a crucial role in reducing dependence on fossil fuels and maintaining an environmental-friendly energy path. The chapter examines key areas where AI can make significant contributions, including demand response management, energy forecasting, asset management, and fault detection. Predictions in the energy domain benefit from AI's processing power for huge volumes of data and continue to improve because of better accuracy, which will lead to grid stability. AI-powered fault detection systems can quickly identify and resolve issues, minimizing downtime and improving overall grid reliability. However, integrating AI into smart grids introduces new challenges, especially concerning cybersecurity and the increasing reliance on digital infrastructure. It offers the ability to optimize grid efficiency, integrate renewable energy more smoothly, and enhance resilience. This chapter contributes to the understanding of the potential benefits and challenges related to AI integration in smart grid systems, highlighting key approaches for future research and development in this rapidly evolving field.

Keywords: AI integration, Demand Side Management, Grid resilience, Renewable energy integration, Smart metering.

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Reetu Malhotra, Pooja Mahajan, Manish Singla & Ramesh Kumar (Eds.)

INTRODUCTION

With an increase in global population, the demand for electricity is rising. The world's electricity consumption has doubled over the past 30 years, reaching an estimated 28-thousand-Terawatt hours in 2021; however, the population is estimated to have increased by 8 billion [1] [2]. Electricity plays a crucial role in our everyday lives, especially in developed nations. The average household in the United States uses approximately 10,715 kilowatt-hours of electricity each year [3]. As developing countries rapidly industrialize, their energy needs are exploding.

Electric grids have traditionally served as the blueprints for power distribution systems in the past decades [4]. These grids are the coordinated structures engineered to deliver electric power from the generating facilities to electricity consumers. The backbone component consists of power generation facilities, high-voltage transmission lines, and distribution networks [5]. Electricity is produced at a power generation facility, then transmitted through high-voltage wires to central load areas. After that, the voltage is reduced before being distributed to individual consumers.

The conventional grid operates through one-way communication as electricity generated at power plants is transmitted to consumers with minimal interaction or feedback from end-users [6]. Some cons are inadequate power distribution, extremely high operational costs, significant problems in deploying renewable energy sources, and, very importantly, the high failure rate. Conventional grids are also prone to outages, lacking real-time monitoring and self-healing properties [7].

A smart grid is a modern electricity distribution network that utilizes computers and other electronic tools to collect information, including power consumption data, send it across the entire system, and then act on this interactivity between suppliers and users in real-time. The represents a significant improvement over the traditional, one-way delivery of electricity favored by power plants to consumers, enabling two-way communication and active control features [8].

CHARACTERISTICS OF SMART GRIDS

Smart grids are featured by various characteristics, as listed in Fig. (**1**). For instance, in self-healing, these grids can identify and respond to faults on their own, thus being dependable and reducing their downtimes. This also encourages active customer participation in the management of energy usage, generally through demand response programs. Moreover, grids can resist both physical and cyber attacks. Moreover, smart grids have the capacity to recover from such attacks and guarantee a stable power supply [9].

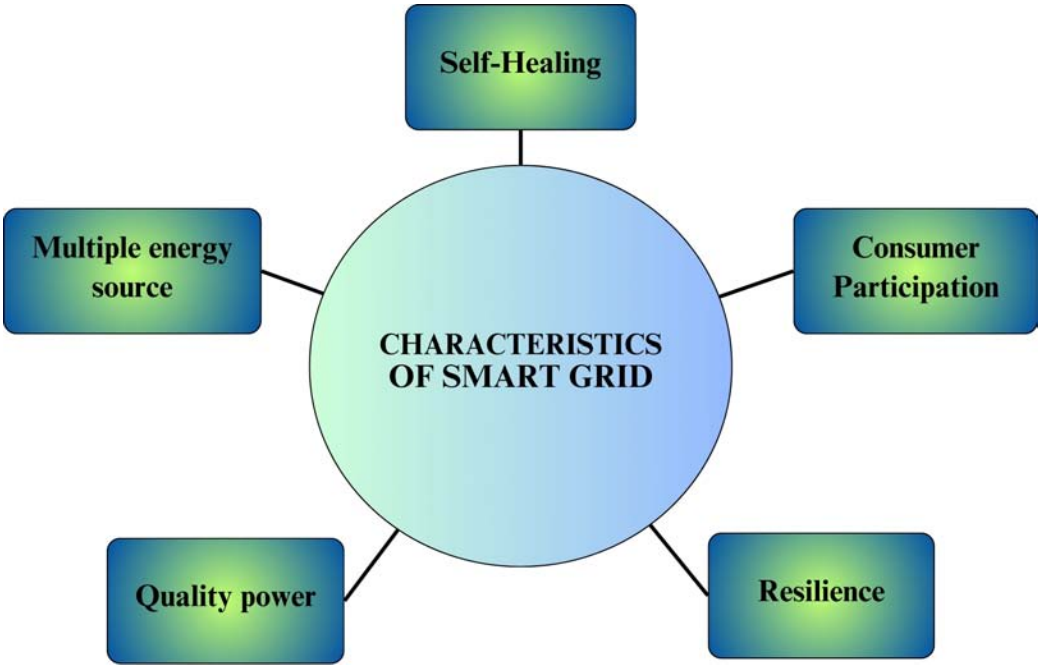

Fig. (1). Key characteristics of smart grid systems.

Also, smart grids are appropriate for modern users, as these grids provide high-quality power, minimizing issues like voltage sags and surges. Additionally, smart grids can interconnect, enable, and manage multiple generation options, including renewable resources or distributed generators, as shown in Fig. (**2**).

The core of a smart grid is the integration of green power sources, such as solar panels on our roof, with conventional grid systems [10]. These renewable energy sources are complementary to conventional power generation and help reduce the carbon footprint [11]. Plug-in hybrid electric vehicles, as shown in Fig. (**2**), also become part of this smart grid system. Most of these vehicles are capable of consuming electricity from the grid and also returning power back during times when the system's demand is high [12]. Also, smart thermostats, appliances, and in-home control devices can utilize the power of this system. The real-time pricing signals allow consumers to track and manage their energy usage (energy efficiency) in order to make cost savings [13].

CHAPTER 2

Renewable Energy Innovations: A Path to Sustainability

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Abstract: This chapter offers an in-depth exploration of different renewable energy sources that play a crucial role in advancing sustainable global energy systems. It thoroughly explores five primary renewable technologies: solar energy, wind energy, geothermal energy, hydro energy, and biomass energy, delving into the fundamental principles underlying each technology and detailing how they convert natural resources into usable energy. The analysis evaluates the strengths and weaknesses of each technology, focusing on their efficiency, environmental impacts, and economic viability. Furthermore, the chapter reviews the current advancements and successful implementations of these technologies across different regions, showcasing practical examples of their deployment. It also anticipates future applications by examining emerging trends, technological innovations, and potential advancements that can further solidify their role in meeting sustainable energy targets. This chapter provides a detailed overview and offers readers a comprehensive analysis of how renewable energy technologies are essential in addressing the global energy crisis and promoting a sustainable future. It underscores the critical need for continued innovation and strategic planning to optimize the integration and management of these technologies, ultimately highlighting their potential to revolutionize the energy sector and support a cleaner, more resilient world.

Keywords: Energy efficiency, Environmental impact, Renewable energy technologies, Sustainable energy systems, Technological innovation.

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Reetu Malhotra, Pooja Mahajan, Manish Singla & Ramesh Kumar (Eds.)

INTRODUCTION

Importance of Renewable Energy in Sustainable Systems

The global energy sector is experiencing a significant shift, propelled by the urgent need to transition from fossil fuels to more sustainable and environmentally friendly energy alternatives [1 - 5].Traditional energy systems, largely based on coal, oil, and natural gas, have been instrumental in fuelling industrialization and economic growth.However, the environmental consequences of these fossil fuel-based systems, particularly their contribution to climate change, air pollution, and ecosystem degradation, have become increasingly evident. As the world faces the combined problem of fulfilling expanding energy demand while reducing environmental effects, renewable energy has emerged as a critical alternative [6, 7]. Renewable energy is defined as energy generated from naturally occurring processes that are continuously replenished. These energy sources, such as sunlight, wind, water, biomass, and geothermal heat, offer a limitless and eco-friendly substitute for fossil fuels. Unlike limited fossil fuel resources, renewable energy sources are naturally regenerative and produce negligible to no greenhouse gases during operation, making them critical elements of sustainable systems. Renewable energy is important not just for the environment [8, 9]. It plays a key role in promoting energy security, reducing dependence on imported fuels, and promoting economic development [10]. As renewable technologies advance, their incorporation into energy systems may lead to more robust, decentralized power grids and the development of new industries and jobs. Furthermore, renewable energy technologies can overcome energy access issues, especially in isolated or underserved locations, through off-grid or distributed energy solutions [11].

In the current context of climate change, the move to renewable energy is no longer a choice, but an imperative. The Paris Agreement and numerous national commitments underscore the need to limit global warming to well below 2°C above pre-industrial levels, with efforts to keep it at 1.5°C. Achieving these targets will require a massive scale-up of renewable energy technologies, coupled with energy efficiency measures, to decarbonize power generation, transportation, and industry.

Overview of Key Renewable Technologies

This chapter explores five key renewable energy technologies, as shown in Fig. (**1**), that are transforming the global energy landscape: solar energy, wind energy, geothermal energy, hydro energy, and biomass energy [12, 13]. Each of these technologies leverages different natural resources to generate power, resulting in a more diverse and robust energy mix.

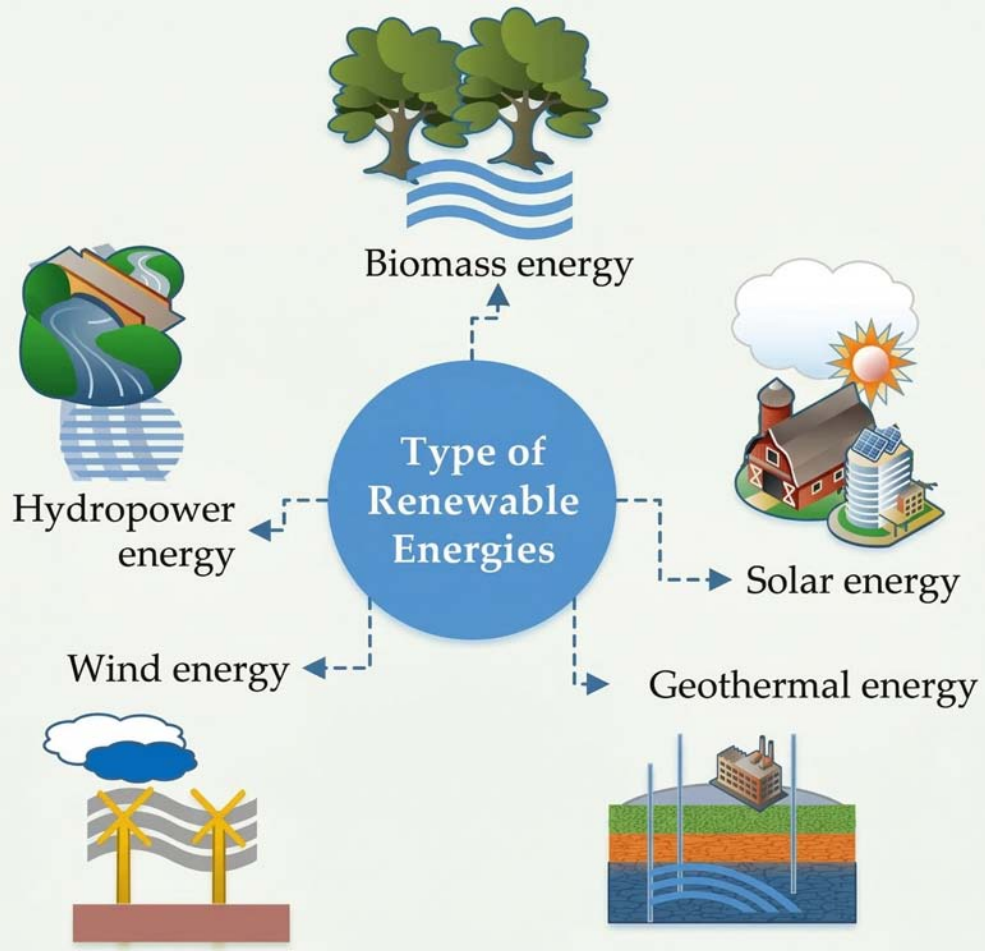

Fig. (1). Different types of renewable energy technologies [14].

Solar Energy: Solar power uses Photovoltaic (PV) cells or solar thermal systems to collect the sun's radiant energy. It is one of the most abundant and commonly used renewable energy sources. Solar technology has many applications, ranging from modest residential systems to large-scale utility installations.

Wind Energy: Wind turbines absorb and transform the kinetic energy of the wind into electricity. Wind power, being one of the fastest-growing energy sources, has enormous potential for large-scale generation, particularly in areas with high wind speeds.

CHAPTER 3

Hydrogen Production from Biomass: Advancing Renewable Energy Technology

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Abstract: H_2 production from biomass substrates offers a sustainable solution and carbon-neutral path to conventional hydrogen production methods. This chapter examines the potential role of thermochemical, biochemical, and biocatalytic processes for converting biomass into bio-hydrogen, evaluating their efficiency, scalability, and impact on the global clean energy transition challenges such as feedstock variability, process optimization, and economic feasibility are addressed to overcome such barriers. The chapter concludes with insights into future research, innovation, and policy support needed to advance biomass-based hydrogen production as a key renewable energy technology.

Keywords: Biomass energy, Hydrogen production, Renewable energy, Thermochemical processes.

INTRODUCTION

Hydrogen is a futuristic and clean energy solution for addressing global energy security and environmental concerns with potential applications across the sectors, including electricity generation and transportation due to its suitability for transportation, long-term storage, and minimal environmental impact [1 - 3]. Among various contemporary fuels preferred for observed significant parameters (GF, EIF, and HCF), hydrogen gas has emerged as a primary clean and sustainable fuel (Table **1**). Major contemporary hydrogen production processes (about 95%) are fossil fuel-based and energy-intensive, including hydrocarbon reforming (Fig. **1**) [4]. Unlike most of the non biomass based contemporary H_2 production techniques, the biomass-based hydrogen production is considered carbon-neutral because it releases only CO_2 that was recently captured from the atmosphere during biomass growth, maintaining a balanced carbon cycle that

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distinguishes it from fossil-based hydrogen production, which introduces new carbon into the atmosphere and contributes to climate change *via* greenhouse gas emissions [5 - 7]. The current chapter explores recent advancements and challenges in the production domain of biomass-derived hydrogen production. Goren *et al.* highlighted the environmental and economic impacts of hydrogen production from contemporary sources, positioning biomass as a key player in sustainable hydrogen generation [8, 9]. On the global scenario, the hydrogen economy has been advancing into various methodologies for hydrogen generation, focusing on their performance and sustainability through innovation [10, 11].

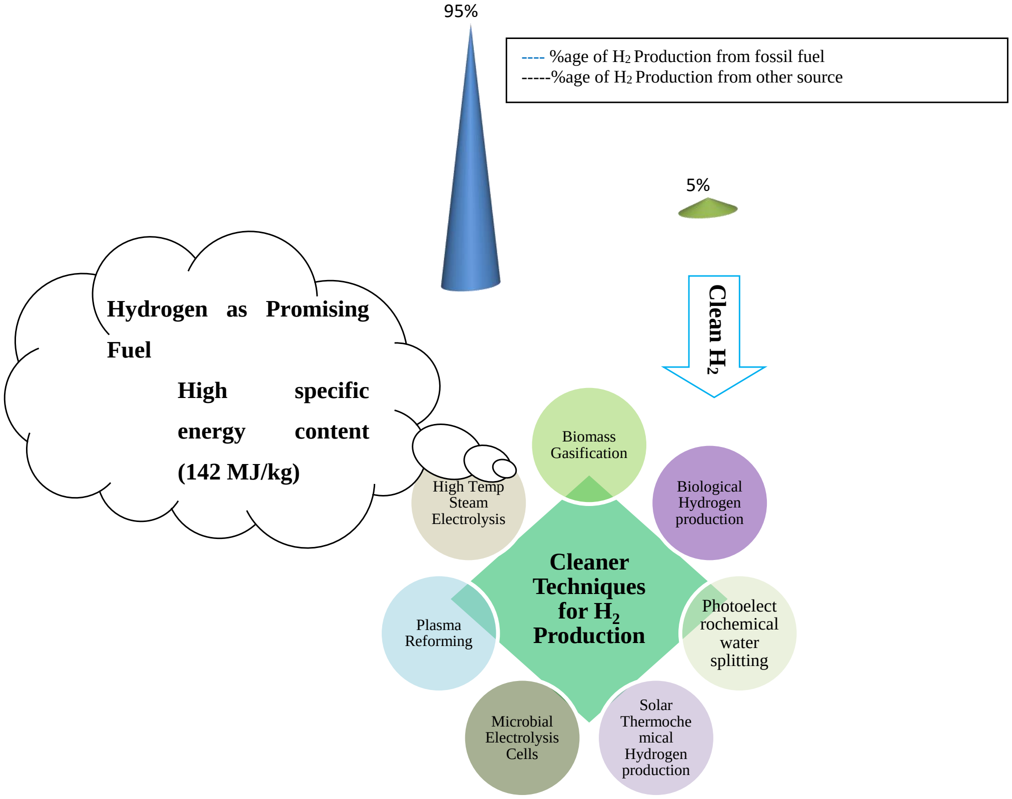

Fig. (1). Current status and pattern of H2 production in the global hydrogen economy based upon their sources.

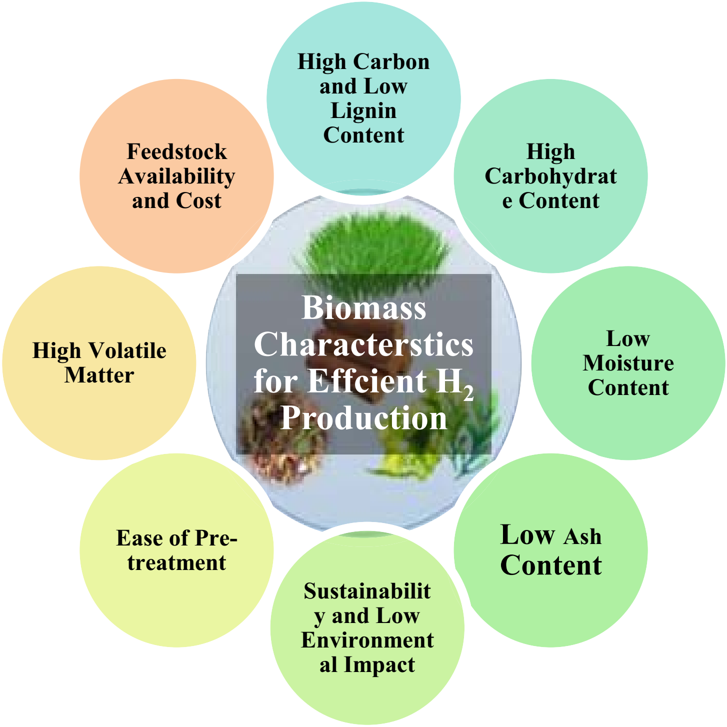

Fig. (2). Characteristics of biomass well-suited for biohydrogen production.

Table 1. Comparison of contemporary energy fuels in terms of GF, EIF, and HCF.

Fuel Type	GF (Greenization factor)	EIF (Environmental impact factor)	HCF (Hydrogen content factor)
Hydrogen	0.9	0.2	1.0
Coal	0.2	0.8	0.1
Oil	0.3	0.7	0.2
Natural Gas	0.4	0.6	0.3

Biomass is an organic resource that includes agricultural residues, forest residues, dedicated energy crops, organic municipal waste, and animal wastes, and can be explored as a sustainable solution for various applications [12, 13]. These organic matters can be explored to produce hydrogen and other byproducts through various methods, including gasification [14]. Variability in the characteristics of bio-feedstock is vital for yield and effective conversion into hydrogen production from the respective source (Fig. **2**). The following characteristics of biomass have an impact on efficient conversion and yields of H_2:

CHAPTER 4

Exploring Biomass: Opportunities and Innovations in Renewable Energy

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Abstract: Biomass energy is an important approach for sustainable future development. This abstract explores the various biomass methods used for energy generation, emphasizing their environment values, technological improvements, and economic potential. A biomass energy system converts the organic waste, forestry byproducts, and agricultural wastes into usable energy. This process helps reduce environmental pollution and assists in waste management. Biomass energy sources include diverse types of wood waste, and byproducts from wood processing. In addition to that, there are some other biomass sources, including sugarcane molasses and residues from paper pulp processing. By incorporating these practices into our daily life and policy frameworks, societies can significantly reduce energy consumption and promote a cleaner and sustainable future. The widespread adoption of biomass energy is crucial for achieving long-term environmental and economic benefits, which ensure a robust and sustainable energy source. It sets alternative energy sources with conventional ones to focus on fossil fuel-related challenges, such as greenhouse gas emissions and global warming. This research examines various aspects of biomass energy, including its sources, conversion process, environmental impacts, and economic viability. This paper highlights the renewable energy technologies used to produce electricity and yield heat from naturally replenishing resources. The advancement in technology and policy support has made renewable energy more competitive with fossil fuels, upgrading energy security and promoting rural development in terms of cost and reliability.

Keywords: Biomass energy, Energy sources, Environment impact, Renewable energy.

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Reetu Malhotra, Pooja Mahajan, Manish Singla & Ramesh Kumar (Eds.)

INTRODUCTION

Biomass energy is an important component of all kinds of renewable and sustainable energy sources, which are obtained from the burning of organic materials derived from living things. Lignocellulosic biomass, which is obtained from plants or plant-based materials and is not used for food or feed, proposes a flexible and promising alternative [1]. Its wide range of sources and advanced conversion technologies contribute to reducing dependence on fossil fuels and addressing climate change. The biomass energy flow chart is depicted in Fig. (1).

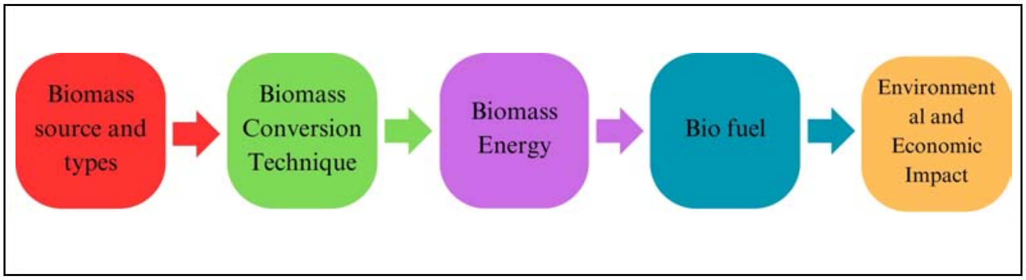

Fig. (1). Biomass Energy Flow Chart.

Bioenergy refers to energy harnessed from biomass materials and is currently the most extensively utilized renewable energy source globally [2]. Biomass resources are abundant and diverse, encompassing livestock manure, industrial and municipal waste streams (such as paper, plastics, and food waste), poultry byproducts, and sewage sludge. Bioenergy serves as an effective method for waste management, mitigating environmental pollution while contributing to economic stability [3]. This chapter explores the various forms of biomass, innovative technologies driving its development, and the opportunities and challenges associated with its use.

TYPES OF BIOMASS AND THEIR SOURCES

Biomass can be categorized into different types based on its origin, composition, and characteristics [4]. Below are some key types of biomass, along with their respective sources, as shown in Fig. (**2**):

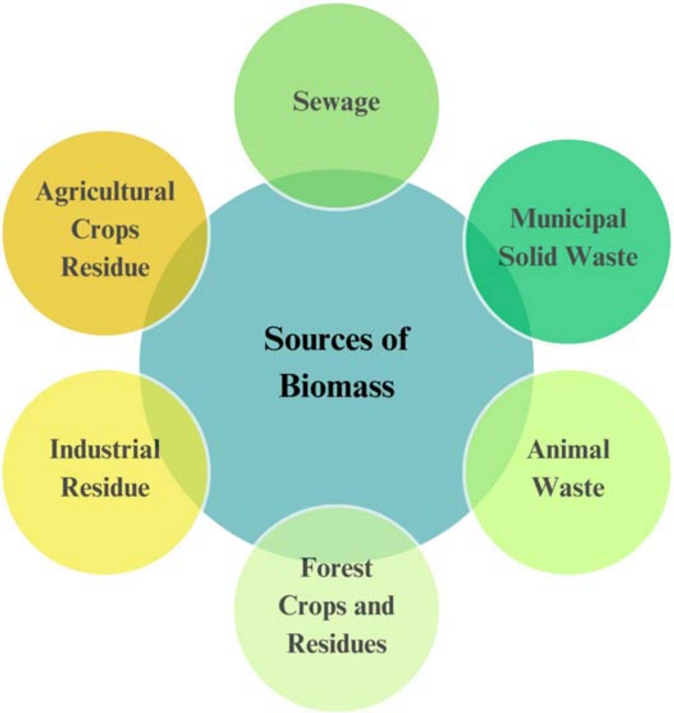

Fig. (2). Types of Biomass and their Sources [4].

- **Wood Biomass**

  Wood biomass originates from sources such as forest residues, wood chips, sawdust, and wood pellets. As one of the most traditional and extensively utilized forms of biomass, it can be directly combusted or processed into fuels. Using wood biomass can help reduce fossil fuel consumption, minimize greenhouse gas emissions, prevent deforestation, and support environmentally and economically sustainable practices [5].

- **Agricultural Residues**

Agricultural residues, including rice and wheat straw, bark, branches, corn husks, and fruit waste, are by-products of crop cultivation. These materials can be utilized directly as feedstock or converted into biomass products. Converting agricultural waste into biomass not only helps manage waste but also provides a range of sustainable alternatives for energy and material needs. The use of agricultural residues effectively enhances crop yields, improves soil fertility, provides additional income for farmers, and contributes to sustainability by recycling nutrients and organic matter [6].

CHAPTER 5

Renewable Energy Forecasting using Advanced Machine Learning Techniques

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Abstract: The integration of renewable energy sources into the power grid presents significant challenges due to their recurrent and variable nature. Accurate forecasting of renewable energy generation is crucial for grid stability, efficient energy management, and the optimisation of energy resources. This chapter explores the application of advanced machine learning techniques in renewable energy forecasting, which focuses on solar and wind energy. It begins with an introduction to the importance of renewable energy forecasting and the role of machine learning in addressing forecasting challenges. The fundamentals of renewable energy forecasting are discussed, highlighting the key challenges and the necessity for accurate predictions. The chapter delves into various machine learning techniques, including regression, classification, clustering, deep learning, ensemble methods, and hybrid models. A comprehensive comparison between traditional and advanced machine learning techniques is provided. Hybrid models and ensemble methods are explored for their potential to enhance forecasting accuracy. Real-time forecasting and optimisation techniques are also covered, emphasising their applications in smart grids and microgrids. The chapter includes real-world case studies and applications, showcasing successful implementations of machine learning in renewable energy forecasting. The ethical and social implications of using AI and ML in this domain are discussed, along with policy and regulatory considerations. This chapter aims to provide a comprehensive overview of the state-of-the-art in renewable energy forecasting using advanced machine learning techniques, offering valuable insights for researchers, practitioners, and policymakers.

Keywords: Autoregressive Integrated Moving Average (ARIMA), Cloud Motion Vectors (CMV), Data privacy, Emerging technologies, Numerical Weather Prediction (NWP), Renewable Energy Sources (RES), Security concern.

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INTRODUCTION

As demand for renewable energy increases, it is imperative to invest in research and development of renewable energy sources [1, 2]. Renewable energy is essential for reducing greenhouse gas emissions and mitigating severe climate change [3 - 5]. There are many advantages of renewable energy sources, such as reduced dependence on foreign energy, increased employment, and potential cost savings [1, 6]. Renewable energies include those that come directly from the sun, such as thermal, photochemical, and photoelectric energy, or indirectly, like wave energy, wind power, and the biomass energy stored in organic matter [7]. Renewable energy sources are continuously replenished by nature on a daily basis [7].

Types of Renewable Energy Sources

Energy plays a vital role in driving a nation's economic growth and overall development, serving as a fundamental input for industrial, agricultural, and technological progress. Renewable natural resources are the primary source of energy. Renewable energy sources are energy sources derived from the environment that are sustainable. Renewable energy is a never-ending source of clean energy and a vast source to replace the increasing need for fossil fuels. The major advantage of renewable energy over non-renewable energy is that they are readily available, can be renewed easily, and has a long lifespan. Nuclear power, biomass, geothermal, wind, solar, tidal, and wave energy are a few of them. If utilized efficiently, each of these energy sources has the potential to provide reliable and compatible energy while minimizing the burden on the environment. Renewable energy, derived from natural resources that replenish themselves over regular cycles, offers a sustainable and eco-friendly alternative to conventional fossil fuels. (Fig. **1**) illustrates the diagrammatic representation of various types of renewable energy sources.

- **Solar energy:** It is derived directly from sunlight and is the most abundant and frequently utilized energy source. Solar power is converted into thermal or electrical energy using mirrors and photovoltaic panels. It is the most widely available and cleanest renewable energy. Although sunlight availability varies by location and weather conditions, solar energy remains one of the most convenient and beneficial energy solutions for both domestic and industrial applications.
- **Wind energy:** Wind energy is energy derived from moving air. Large onshore and offshore turbines are used to harness the kinetic energy of moving air to generate electricity. Recent technological advancements, such as the development of larger rotor diameters and taller turbines, have significantly

improved power output and efficiency. Despite the intermittent nature of wind, many regions around the world possess substantial potential to develop wind energy as a reliable renewable source.

- **Hydro energy:** Hydroelectricity is generated using the energy of water currents. This is generated using the movement between differences in elevation, such as when water descends *via* reservoirs or rivers. Besides providing electric energy, hydropower reserves also provide navigation services and irrigation, as well as drinking and agricultural supplies. Currently, the most widespread form of renewable electricity is generated through hydropower. A common approach that is based on the regular patterns of rainfall could be affected by droughts when other techniques, including ecosystem changes, come into play.
- **Biomass:** Bioenergy is produced from biomass, which includes organic materials such as wood, charcoal, manure, and crops. It is common in rural areas of developing countries for heating, lighting, and cooking. Finally, some examples of current biomass sources include crops dedicated to bioenergy (second generation), agricultural and forestry residues, and organic waste. However, the exploitation of energy can lead to significant land-use changes, including desertification consequences due to deforestation. Therefore, their usage should be limited as much as necessary.
- **Geothermal energy:** Geothermal power is generated when heat is available from the Earth's interior through techniques like drilling or other methods. The surface geothermal fluids have the potential to generate power. Hydrothermal reservoir electricity generation is one of the oldest, most reliable technologies in energy production for more than 100 years.
- **Nuclear power:** Nuclear power is the production of electricity using heat produced from nuclear fission in a reactor. A nuclear power plant operates similarly to a large coal-fired power plant, with the key difference being the heat source: the nuclear reactor replaces the boiler. Aside from that, it uses the same essential components—pumps, valves, turbines, generators, steam generators, condensers, and other necessary instruments.

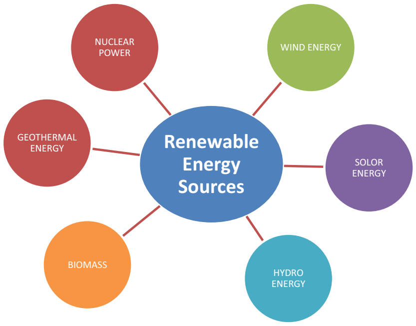

Fig. (1). Types of Renewable Energy Sources.

CHAPTER 6

Energy Planning and Management: A Holistic Approach

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Abstract: This chapter explores the fundamentals of energy planning and management, emphasizing the significance of sustainable practices in today's industrial environment. By introducing the innovative framework, the chapter, “Harmony of Creation: Integrating the 14 Ratnas of Samudra Manthan with the Technological Tapestry of Industry 4.0,” explains how traditional values might guide current energy policies by bridging old wisdom with contemporary technology.

The 14 Ratnas of Samudra Manthan serve as metaphors for key elements of energy planning and management. Each Ratna is linked to a principle or technology within Industry 4.0, offering new insights into sustainable practices. For instance, Amrita symbolizes the circular economy, emphasizing strategies focused on resource optimization and waste reduction, which are essential for increasing effectiveness and reducing energy usage. Similarly, Kamadhenu represents resource efficiency, highlighting conservation methodologies that coincide with energy-saving goals.

The chapter explores how to optimize energy management procedures by integrating Machine Learning (ML) and Artificial Intelligence (AI). It provides forecast models for energy use, operational effectiveness, and resource usage using resources such as Monte Carlo simulations. This approach underscores the importance of ethical governance and innovation in developing responsible energy strategies.

By weaving together the ancient wisdom of Samudra Manthan with Industry 4.0 advancements, this chapter provides useful advice for scholars, industry leaders, and policymakers. It highlights the potential for traditional principles to guide the ethical and sustainable use of advanced technologies, contributing to a balanced and responsible future in industrial energy management.

Keywords: Artificial intelligence, Energy management, Industry 4.0, Machine learning, Ratnas of Samudra Manthan.

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OVERVIEW OF ENERGY PLANNING AND MANAGEMENT

"Energy that is not utilized is energy that is conserved." The vivid phrase outlines a basic premise: improving the level of energy management can be achieved through limiting the evident wasting of energy, which leads to more sustainable energy consumption [1]. For instance, rising energy production does not always equate to more efficient energy use. It is a matter of making better use of the assets that we already possess. In the present day and age, wherein many industries are witnessing a radical change, energy planning and management [2] have assumed great significance as they affect the efficiency of the processes [3], sustainability factors, and the level of competition.

Definition and Importance of Energy Planning in Modern Industries

Energy planning is a methodical process that determines the best ways to produce, distribute, and use energy in order to meet present and future demands with the least amount of expense and environmental harm [4]. Another way to think about energy planning is as a collection of procedures for managing energy demand, resolving political and administrative obstacles to the development of energy, and other energy-related activities. This type of labor encompasses a broad range of tasks, including forecasting future energy consumption, managing supply, ensuring energy security for the advancement of the economy and society, and utilizing renewable energy sources.

Energy [5] is the pulse to all industry activities as it aids in the process of production and is essential in the application of technology and services in industries. Proper energy planning allows enterprises to operate without interruption for extended periods while protecting the environment. Effective energy management [6, 7] helps businesses become more environmentally conscious by lowering expenses and reducing carbon emissions. Energy planning [8] is vital for attaining energy efficiency, cutting waste, and guaranteeing long-term profitability as enterprises transition to sustainable practices [9]. One significant challenge in modern energy management is the need to balance traditional energy sources (such as fossil fuels) with renewable energy sources (such as wind, solar, and hydroelectric power) [10]. The effective integration of both types is essential for achieving sustainability goals [11]. Without strategic planning, industries face the risk of energy shortages, rising costs, and greater environmental impact, as shown in Fig. (**1**).

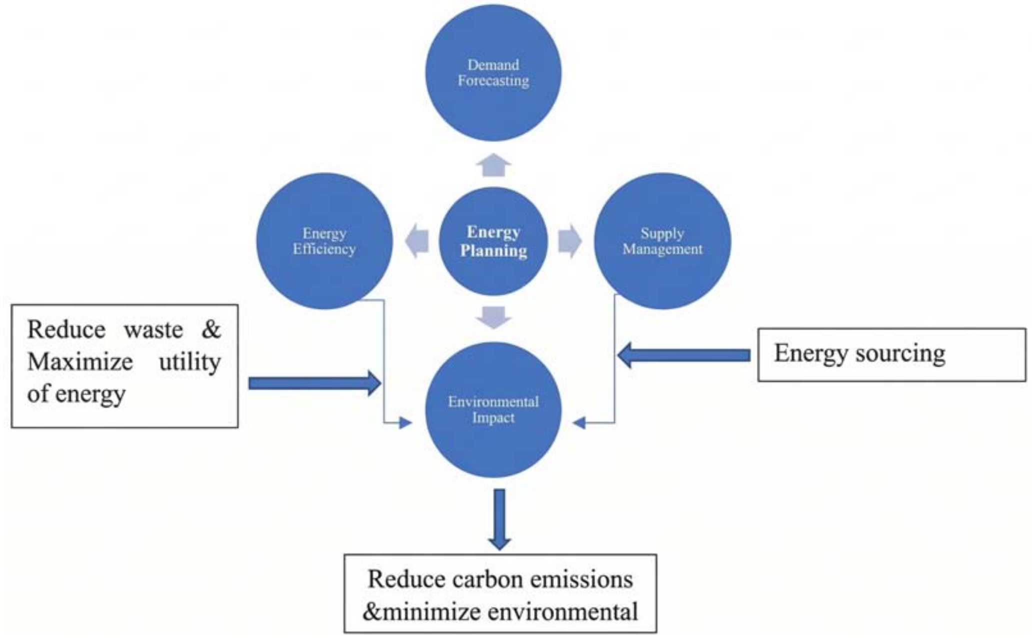

Fig. (1). Energy Planning.

Energy planning is at the core of the ecosystem, representing the following aspects.

Demand Forecasting: Predicts future energy needs based on historical data, market trends, and industrial growth.

Supply Management: Involves sourcing energy through a mix of traditional and renewable sources [12].

Energy Efficiency: Focuses on implementing technologies and practices to reduce waste and maximize energy utility [13].

Impact on the Environment: Tries to minimize environmental deterioration and cut down on carbon emissions.

Arrows in the Fig. (**1**) show the relationships and interactions between these components:

Demand Forecasting impacts Supply Management (ensuring that supply meets forecasted demand).

CHAPTER 7

Improved Opportunities in Energy Efficiency by using Supply Chain Management

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Abstract: Implementing energy efficiency into Supply Chain Management (SCM) is crucial for tackling the issues presented by the global energy deficits. As energy efficiency becomes increasingly essential for economic and social progress, it emphasizes the role of sustainable supply chains in enhancing business competitiveness, profitability, and overall performance. The discussion focuses on the complexities and risks inherent in global supply chains, identifying strategies to improve energy efficiency, particularly for Small and Medium-sized Enterprises (SMEs), which often face barriers such as limited access to capital and a lack of awareness. A comprehensive review of current literature highlights the need for a shift from single-firm energy efficiency to a broader, supply chain-wide approach. By reinforcing key stages of SCM and implementing sustainable practices, companies can achieve strategic goals, reduce costs, mitigate risks, and optimize processes. These offer a valuable framework for the energy sector and other industries, demonstrating how improved supply chain management can significantly enhance energy efficiency and contribute to the sustainability of global operations.

Keywords: Energy efficiency, SMEs, Supply chain management, Sustainability operations.

INTRODUCTION

In the contemporary world, severe energy crises have taken over due to high industrialization [1 - 4], urbanization, population, and the effects of climate change. The energy demand increases in conjunction with environmental problems worldwide; therefore, the situation is complex, and timely action is necessary for sustainable development.

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It is estimated that global energy demand will grow by about 25% by 2040, primarily due to emerging economies such as China and India, as well as other high-growth markets. Industrial usage accounts for approximately 42% of the total global energy consumption. China alone consumes nearly 30 percent of industrial energy. In other parts of the world, in Southeast Asia, Sub-Saharan Africa, and Latin America, there is economic growth, which increases energy use in industries, transport, and households, increasing pressure on global energy resources.

It complicates the energy crisis because of the further rapid expansion of urbanization and population growth. In 2022, the world had a population of 8 billion people, and it is estimated that by 2050, the world population will increase to 9.7 billion, with most of this growth in urban regions. Urban regions account for 75% of the world's energy consumption, thereby placing greater pressure on energy supplies. An increasingly large share of the world's energy demand, primarily in cities, is fueled by fossil fuels, which conflicts with efforts to mitigate climate change.

The largest emitter of greenhouse gases globally remains the source of energy production, which accounts for 72% of all emissions. According to the Intergovernmental Panel on Climate Change, the combustion of fossil fuels and resource forms such as oil, gas, and coal drives a cocktail of toxic pollutants into the air, causing serious damage to the environment and dimming the world's ability to reach the International Climate Change Goals set by the Paris Agreement. Examples include rising world temperature to less than 1.5 degrees Celsius above pre-industrial levels.

IRENA believes that enhancing energy efficiency might reduce global energy consumption by up to 40% by 2050, making it a very effective strategy for addressing the issue. Ultimately, the implementation of energy-efficient technology in industrial, transportation, and domestic applications reduces operational expenses and fosters environmental sustainability.

Improving energy efficiency is a significant part of managing any supply chain. It would lead to optimization in the logistics, transportation, and even production processes. This can be achieved by a reduction in fuel consumption: smart logistics can save up to 15% of fuel usage. Big multinational companies like Walmart, Apple, and Unilever have been adopting green practices in their supply chains while trying to reduce their carbon footprint. Transition toward renewable energy models and circular economy models is necessary to enhance energy efficiency and achieve environmental goals.

Energy efficiency is the key to sustainable development, as it encompasses the causes of environmental, economic, and social concerns. According to the United Nations Environment Programme, "sustainable development means that meeting the needs of the present without compromising the ability of future generations to meet their own needs." All the aspects that come under this concept include energy efficiency, reduced consumption, as well as resource conservation and minimizing their negative impacts, which in turn help to stimulate growth.

Energy efficiency is good not only for the environment but also in relation to a highly critical element of sustainable development, namely energy security. Improved energy use can reduce the high consumption of imported fossil fuels. This can be conceived such that a 1% increase in global energy efficiency could lead to a 2% decrease in demand for imported energy. Such reduced utilization further enhances the national energy security, stabilizes energy prices, and boosts the economies, especially in places with critical infrastructures.

Energy efficiency is now becoming a crucial change inducer for renewable energy sources and sustainable development. Overall, this demand can be met by the smaller share from renewable sources such as solar, wind, and hydro power sources. According to the agency, by combining energy efficiency with renewable energy technologies, carbon reductions will account for more than 90% of the required decrease to attain the global climate goal by 2050.

Energy efficiency creates an innovation culture with high productivity and competitiveness of the firms. Therefore, organizations embracing energy efficiency have fewer operating costs than their counterparts. They can, hence, use the saved resources for innovations in research and development [5]. The report by the World Economic Forum concludes that industries implement energy efficiency practices to support supply chains and build their competitive capacity. However, these energy-efficient technologies have also introduced new markets, ranging from retrofitting and developing new concepts, and thereby providing new employment and sustainable economic growth.

It is a crucial element in solving the international energy crisis and delivering the agenda of sustainable development. Energy efficiency cuts across both greenhouse gas emissions and energy security, as well as the opportunity to shift to renewables, integrating many aspects into supply chains and other critical sectors of the global economy. This approach helps mitigate the challenges posed by the international energy crisis and ensures long-term prosperity.

CHAPTER 8

Case Studies and Examples

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Abstract: The chapter "Case Studies and Examples" provides a compelling exploration of successful sustainable energy projects, offering in-depth analyses of pivotal case studies and exemplary initiatives. Through meticulous examination, this chapter illuminates the intricate tapestry of sustainable energy deployment, shedding light on the technologies, challenges, and triumphs that characterize these transformative endeavors. Two types of case studies have been discussed - "Type 1: Renewable Energy Integration in Urban Settings" and "Type 2: Community-Based Microgrid Development". Type 1 study thoroughly discusses the installation of energy-saving solutions such as solar photovoltaic systems and wind turbines to meet the growing energy demands of buzzing megacities. It explains the importance of implementing regulatory frameworks, considering urban planning solutions, and engaging stakeholders in decision-making, offering valuable insights into the successful amalgamation of sustainable energy technologies within majorly populated cities. Type 2 study deals with brainstorming the intricacies, executing innovative technology into functioning, and strategizing ways to maximize community engagement that lay the foundation for successful development of the microgrid. It details the hardships faced, including technical difficulties and monetary constraints, and enlists the successful steps undertaken that led to the fruition of different projects. These case studies exemplify the impact of sustainable energy solutions that are playing a key role in meeting the upcoming energy demands. This chapter provides the readers with a deeper understanding of the challenges and triumphs associated with realizing sustainable energy projects, showcasing to them the importance of informed decision-making and innovation.

INTRODUCTION

Our planet is facing challenges such as climate change, global warming, pollution, and the depletion of fossil fuels, due to which the requirement for sustainable energy solutions has become more prominent today thanever before. According to the Intergovernmental Panel on Climate Change (IPCC), unless greenhouse gas missions are substantially minimized, the global temperatures would rise by

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more than 1.5 degrees Celsius above pre-industrial levels by the year 2030, which would have severe consequences [1]. This will affect the urban areas where more than half of the world's population resides and consumes approximately 70% of the global energy.

Renewable energy sources, including solar energy, wind energy, hydroelectric energy, geothermal energy, and biomass, present a solution to eradicate the growing menace of climate change and depletion of fossil fuels. These technologies, if incorporated into the energy grid, not only ensure energy security but also facilitate a transition toward a low-carbon footprint by reducing greenhouse gas emissions. Recent developments in Photovoltaic (PV) efficiency, wind turbine design, and energy storage systems strengthen the potential for these renewable sources of energy to sustainably tackle current energy demands. Furthermore, interdisciplinary research into smart grid technologies and decentralized energy systems demonstrates the ease of optimizing energy distribution and its consumption, thereby addressing the challenges of sporadicness and lack of flexibility, which are inherent to renewable sources. With the growing energy demand among the masses and ambitious targets set forth by the international climate agreements, a continuous investment in research and development is crucial to unlock the full potential of renewable energy sources to ensure a resilient and sustainable future.

Renewable energy sources offer huge economic benefits not only in terms of financial metrics but also in terms of profound societal influence. Transitioning to renewable sources of energy creates more jobs, ranging from manufacturing of the equipment to their installation and further research, thereby helping local communities to grow and reducing unemployment. Such jobs will create a more skilled workforce as more training programs will be launched to enhance the skills of the workforce to match the growing demands. Furthermore, this will reduce the reliance on fossil fuels, ensuring energy independence, improving trade balance, and also safeguarding the economy from vulnerable and sporadic global energy prices. Deploying renewable energy technologies reduces the carbon footprint, and the operational costs involved also reduce with time. Once the renewable energy sources become fully functional, the cost of energy generation reduces considerably over time because the stocks of solar energy, wind energy, *etc.*, are immense. With research and development, we can further refine our technology to reap maximum benefits. This results in significant savings both for the consumers and the government or businesses, enabling the stakeholders to budget expenses in other areas of the economy. One cannot ignore the major environmental benefits that can be harvested, such as improved air quality and reduced healthcare costs. Thus, renewable technology not only fosters sustainable economic growth but also an improved quality of life.

The core of any developing or developed community lies in its urban areas. This is the reason that incorporating renewable energy sources and community microgrids within urban settings has the potential to reap maximum benefits. This involves transitioning from centralized fossil-fuel-dependent systems to decentralized sustainable systems to harness energy [2]. Community-based microgrids empower local communities to manage their energy requirements sustainably with reduced reliance on conventional grids, which are often susceptible to price rises and outages [3].

This renewable energy-based sustainable approach has multiple benefits - (**i**) there is a significant reduction in carbon emission and environmental degradation, (**ii**) energy costs are greatly reduced, (**iii**) employment opportunities arise for the local population, (**iv**) energy independence is ensured, (**v**) social security and satisfaction is ensured, (**vi**) affordable energy is available for underserved communities, and (**vii**) there is always a scope for improvement in the technology being used with extensive research and development. Community-based microgrids offer a more localized nature of the microgrids, which can be consistently improved for efficiency and reliability. Overall, the introduction of both renewable sources of energy and community-based microgrids in urban environments presents not just an option but an imperative solution to tackle the persistent threats posed by global warming and drastic climate change and to ensure a safe, secure, and sustainable future for the upcoming generations.

This chapter delves deeper into studying the intricacies involved in the successful installation and functioning of sustainable energy-based projects through a number of compelling case studies and initiatives. The chapter discusses the technology employed, obstacles faced, and factors responsible for the success of the projects discussed so far. The focus of this chapter lies in two significant areas: **(i)** integration of renewable sources of energy and **(ii)** community-based microgrids in urban settings. The case studies discussed hold special importance because the projects represent examples that align harmoniously well with the United Nations Sustainable Development Goals (UN SDGs), as shown in Fig. (**1**).

SUBJECT INDEX

Reetu Malhotra

Dr. Reetu Malhotra is currently working as a Professor at Chitkara University, Punjab, India. She is UGC-NET qualified with an All-India Rank of 48 and has over 22 years of extensive teaching and research experience. She has successfully guided two PhD scholars, and five doctoral candidates are presently pursuing research under her supervision.

Dr. Malhotra has made significant contributions to research, evidenced by 32 publications in high-tier international journals and 16 papers in reputed international conference proceedings. She is the author of three books and six book chapters in the domain of Engineering and Mathematics. An active innovator, she has filed 60 design and utility patents, out of which 38 patents (34 design and 4 utility) have been granted, and four utility patents have been published. She has also received three project grants under the NEWGEN IEDC scheme at Chitkara University, Punjab.

She has been invited as a resource person for more than 30 national and international FDPs, SDPs, workshops, and expert talks. Dr. Malhotra is associated with multiple academic bodies and serves as an Editor, Associate Editor, and Reviewer for several reputed international journals in Mathematics and Engineering. She has organized numerous national and international conferences, seminars, and workshops, and has actively participated in over 54 academic events.

Her research interests include Reliability Modeling, Queuing Theory, Numerical Analysis, and Optimization Techniques. She has been acknowledged with several appreciation letters for her excellence in teaching, outstanding academic results, and overall academic contributions.

Pooja Mahajan

Dr. Pooja Mahajan is working as an Associate Professor at Department of Applied Sciences, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India. With a remarkable career spanning over 18 years, she has distinguished herself as a versatile expert in Research, Development, Training, and Academics. Dr. Mahajan's ground breaking research is at the forefront of environmental science, focusing on transformative areas such as Phytoremediation of contaminated sites, waste water treatment, drinking water purification, dye removal, heavy metal removal, and sustainable energy techniques. Her innovative contributions have garnered international acclaim and recognition. Dr. Mahajan's scholarly impact is reflected in the publication of approximately 40 articles in high-tier and internationally reputed journals and 12 articles in international reputed conference proceedings. She has also authored two books "Fiber Crop-Based Phytoremediation: Socioeconomic and Environmental Sustainability," and “Designer cropping systems for polluted land” published by Elsevier. Her exceptional dedication to research has led to the credit of an impressive 15 patents, a testament to her ingenuity and commitment to advancing sustainable solutions for the global challenges of pollution and environmental degradation.

Manish Kumar Singla

Dr. Manish Kumar Singla is presently Assistant Professor in the Department of Electrical Engineering, Baba Farid College of Engineering and Technology, Bathinda India. He did his PhD in the Electrical and Instrumentation Engineering Department at Thapar Institute of Engineering and Technology, India. He received his B.E. and M.E. degrees in Electrical Engineering from the Punjab Technical University and Thapar Institute of Engineering and Technology, in India, respectively. He has published more than 40 manuscripts in good journals and granted more than 7 patents. He is serving as an academic editor in some well-known journals. His current fields of interest include Power Systems, Artificial intelligence, Machine Learning, Renewable Energy and Fuel Cell.

Ramesh Kumar

Dr. Ramesh Kumar was born in Nayan Village, Rajasthan, India in 1986. He received the B.E. In Electronics Instrumentation & control engineering from the University of Rajasthan, Jaipur in 2007 and the M.Tech. Degrees in Instrumentation & Control from Dr. B R Ambedkar National Institute of Technology Jalandhar, in 2009. And Ph.D. degree in Instrumentation from Dr. B R Ambedkar National Institute of Technology Jalandhar, in 2019. From 2014 to 2019 he was a Research Scholar with the Dr. B R Ambedkar National Institute of Technology Jalandhar under the Signal Processing Laboratory. Since 2009-14 and 2019-present, he has been an Assistant Professor with the Electronics Department, Different Indian Collages. He is the author of two books, more than 45 in SCI/Scopus/ conferences articles. He has received two MHRD CRS grant R&D projects from Govt. of India (Mint). His research interests include Biomedical Instrumentation, Tomography application in medical as well as Industrial. Currently working on many applications like cube set, fuel cell technology, renewable Energy sector etc. And holds 5 patents.