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Renewable Energy Technologies for Sustainable and Smart Communities



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Abstract

Accelerating climate change, urban expansion, and rising electricity demand have intensified the transition toward renewable-powered smart communities. Advanced renewable energy technologies, coupled with intelligent digital infrastructures, provide a transformative pathway for achieving carbon neutrality, grid resilience, and sustainable urban development. This chapter presents a comprehensive examination of next-generation renewable systems—including solar photovoltaics, wind energy, energy storage technologies, and green hydrogen production—integrated within smart grid architectures and digitally managed energy ecosystems. Emphasis was placed on artificial intelligence-driven optimization, blockchain-enabled peer-to-peer energy trading, sector coupling, and decentralized microgrid configurations that enhance operational flexibility and energy autonomy at the community scale. The study further analyzes resilience-oriented infrastructure planning, cyber-physical security frameworks, and policy-economic mechanisms that govern renewable deployment in urban environments. Sustainable urban design principles and renewable zoning strategies are evaluated to demonstrate how spatial planning and regulatory alignment accelerate low-carbon transitions. Comparative insights from renewable-driven smart cities highlight best practices, implementation challenges, and scalable models for integrated energy management. By synthesizing technological innovation, governance structures, digital transformation, and community-level implementation strategies, this chapter establishes a multidisciplinary framework for renewable integration within sustainable and smart communities. The findings contribute to the advancement of resilient, secure, and economically viable energy ecosystems aligned with global decarbonization objectives and next-generation urban sustainability paradigms.

Keywords: Renewable Energy Integration, Smart Grids, Green Hydrogen, Energy Storage Systems, Blockchain Energy Trading, Sustainable Urban Planning.

Introduction

Global energy systems are undergoing structural transformation driven by intensifying climate risks, accelerating urbanization, and sustained growth in electricity demand across residential, commercial, and industrial sectors [1]. Fossil-fuel-dependent infrastructures have historically supported economic development, yet carbon-intensive generation pathways contribute significantly to atmospheric greenhouse gas concentrations, environmental degradation, and

public health burdens [2]. Urban regions account for a dominant share of global energy consumption and emissions, positioning cities at the center of decarbonization strategies [3]. Transition toward renewable-powered smart communities has therefore emerged as a strategic imperative aligned with international climate commitments and sustainable development agendas [4]. Technological innovation in solar photovoltaics, wind turbines, bioenergy conversion, geothermal systems, and hydropower has expanded opportunities for large-scale clean energy deployment [5]. Cost reductions achieved through economies of scale and manufacturing advancements have improved competitiveness of renewable resources relative to conventional generation [6]. Integration of distributed energy assets into urban landscapes enables localized production and reduces reliance on centralized fossil-based power plants [7]. This transition represents not only an environmental necessity but also an economic opportunity capable of stimulating green investment, job creation, and technological leadership within emerging low-carbon markets [8].

Digital transformation has redefined the architecture of modern energy systems, facilitating convergence between renewable generation and intelligent management platforms [9]. Smart grid infrastructures incorporate advanced metering systems, sensor networks, automated substations, and high-speed communication technologies that enable real-time monitoring and adaptive control [10]. Bidirectional power flows support participation of prosumers equipped with rooftop solar panels, battery storage units, and electric vehicles [11]. Artificial intelligence and machine learning algorithms enhance forecasting accuracy, optimize dispatch strategies, and coordinate distributed resources across complex networks [12]. Cloud-based data analytics platforms process high-volume operational data to identify efficiency improvements and mitigate performance anomalies [13]. Integration of Internet of Things devices within buildings and distribution feeders enables granular energy tracking and responsive demand management [14]. This digital–physical synergy transforms conventional grids into dynamic, decentralized ecosystems capable of accommodating variable renewable resources while maintaining reliability and stability across interconnected urban infrastructures [15].