Society 5.0 Resources

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Society 5.0 represents an evolution from the industrial focus of Industry 4.0, aiming for a harmonious balance between technological progress and human-centric values, consistent with the United Nations Sustainable Development Goals. In the endeavor to propel Society 5.0 forward, achieving a profound comprehension of its core resources takes center stage. These resources encompass a wide spectrum, ranging from the tangible and technological elements to the intangible facets deeply intertwined with human-centric considerations.

sustainable resource management Society 5.0 human-centric development

1. Sustainable Energy and Resource Efficiency

Carayannis et al. [1] highlight the significance of nuclear fusion energy in the context of Society 5.0, especially with the International Thermonuclear Experimental Reactor (ITER) project's advancement in 2020. They propose a 'Global Commission for Urgent Action on Fusion Energy' to foster international collaboration and accelerate the shift from fossil fuels to a fusion-based economy, aligning with Society 5.0's sustainable energy goals.

Nižetić et al. [2] discuss the vital role of smart technologies in addressing global warming and promoting balanced economic development, as highlighted at the SpliTech 2018 conference. Their review emphasizes interdisciplinary collaboration for efficient resource utilization and energy conversion, focusing on green buildings, solar energy, and smart cities. This aligns with Society 5.0's goals of sustainable and intelligent resource management.

Petrescu et al. [3] discuss the essence of Industry 5.0 in aligning with the sustainable goals of Society 5.0. They emphasize the reintegration of the human element into industrial processes, advocating for advanced technologies that not only support human endeavors but also cater to their needs and interests. Industry 5.0, according to them, is not just about technological advancement but also about fostering a sustainable industry, aiming for a "totally sustainable society". The paper also delves into the sustainability of the industrial sector, highlighting its dependence on the planet's energy resources. It stresses the multifaceted nature of the energy transition, which, while protecting the environment, also brings economic, social, and technical challenges. Addressing these challenges necessitates the collective effort of companies, consumers, investors, and educational institutions to foster a change in mentality and behavior toward sustainability.

2. Environmental Sustainability and Society 5.0

Kasinathan et al. [4] explore the role of disruptive technologies in achieving SDGs within the framework of Society 5.0 and Industry 5.0. They emphasize the heightened need for societal changes towards sustainability, a process where technology is key, especially in the wake of the pandemic. The study delves into how disruptive technologies influence SDGs through various domains like product development, healthcare, and smart cities. Particularly, it maps these technologies' impacts on SDGs 3, 8, 9, and 11. The research suggests that integrating Industry 5.0 and Society 5.0 to develop smart cities and villages enhances the prospects of attaining the SDGs due to the synergy of these integrated frameworks. The study also includes a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis to evaluate this integrated approach, providing valuable insights for industrialists, policymakers, and researchers in aligning technological advancements with the goals of environmental sustainability.

In their research, Mourtzis et al. [5] explore the evolution from Industry 4.0 to Society 5.0, emphasizing a shift towards human-centric and sustainable resource management. While Industry 4.0 focuses on digital efficiency in manufacturing, Industry 5.0 integrates human aspects into these technologies, aiming for a sustainable and resilient design. This approach is crucial in Society 5.0, where the emphasis is on harmonizing technological advancement with sustainable resource utilization and human well-being.

Turner et al. [6] discuss Industry 5.0's focus on integrating human decision-making into digital manufacturing, aligning with the environmental and social goals of Society 5.0. Their study highlights the importance of dynamic Life Cycle Assessment (LCA) facilitated by intelligent products, particularly in managing resources efficiently and achieving net-zero carbon goals. The paper emphasizes the critical role of human involvement in the sustainable reuse and disassembly of products, which is essential for resource conservation and addressing environmental concerns in the manufacturing process.

3. Smart Solutions for Ecological Challenges

Fukuda [7] examines Society 5.0, a concept initiated by Japan, envisioning a new human-centered society. The paper analyzes the transformation of Japan's Science, Technology, and Innovation (STI) ecosystem, comparing it with Germany and the United States. It identifies key socio-economic risks affecting Japan's STI ecosystem, such as labor, capital, and spatial challenges. To address these risks, the paper suggests transitioning from a push-based to a pull-based STI ecosystem, focusing on creating societal value. This approach is pivotal in enhancing system resilience, revitalizing productivity, and promoting growth in Society 5.0. Central to this transition is the efficient utilization and management of resources, ensuring that technological and innovative advancements contribute to ecological solutions and sustainable development within the framework of Society 5.0.

Onu et al. [8] delve into the implications of Industry 4.0 for optimizing renewable energy and material development, highlighting the potential for increased efficiency and sustainability. Their study emphasizes how Industry 4.0 technologies, such as IoT and AI, can enhance resource management, contributing to a more sustainable, low-carbon future. By addressing economic, regulatory, and technical challenges, the study underscores the crucial role of Industry 4.0 in advancing the efficient use and development of renewable resources. This research is

particularly relevant for those looking to implement strategies that align technological innovation with sustainable resource utilization.

Wang et al. [9] examine the role of artificial intelligence (AI) in advancing the construction industry within the Industry 4.0 framework, particularly in enhancing the sustainability and efficiency of construction materials. The study highlights AIs application in improving concrete, composites, and metals, focusing on durability, safety, and recyclability. They foresee a future where AI, integrated with big data, revolutionizes the design, manufacturing, and operation of construction materials, contributing significantly to resource efficiency and sustainable development in the construction sector.

4. Society 5.0 and Human-Centric Approaches to Nature

Deguchi et al. [10] explore the concept of Society 5.0, particularly focusing on its implications for future urban living and resource management. Their research, conducted under the H-UTokyo Lab, delves into how a technology-based, human-centered society, emerging from the fourth industrial revolution, can transform city life. The study emphasizes the importance of a data-driven, knowledge-intensive, and non-monetary approach to shaping urban environments. Central to their analysis is how Society 5.0 can lead to more efficient use of resources in urban settings, aligning technological advancements with sustainable, human-centric urban development. This research provides insights into the directionality of Japan's national vision for Society 5.0, highlighting its potential to foster sustainable resource management in future cities.

Narvaez Rojas et al. [11] discuss Japan's Society 5.0, focusing on utilizing technological advancements to address critical societal challenges and contribute to sustainable development. The study links Society 5.0's goals with the SDGs, emphasizing the importance of using modern technology sustainably to ensure efficient resource utilization and to create an inclusive society where technological benefits reach everyone.

Phuyal et al. [12] explore the concept of smart manufacturing, which leverages interconnected machines and tools enhanced by big data processing, artificial intelligence, and advanced robotics. Their paper examines the current state of smart manufacturing systems, identifying gaps between existing manufacturing systems and future smart manufacturing technologies. The study highlights how these technologies contribute to improving manufacturing performance, particularly in optimizing energy use and workforce efficiency. The paper also presents a survey of recent developments in smart manufacturing, analyzing its impacts, challenges, opportunities, and future directions. This research underscores the potential of smart manufacturing to revolutionize resource utilization and efficiency in the manufacturing sector.

5. Integrating Technology and Environmental Management

Calp & Bütüner [13] analyze the evolution of industrial revolutions, culminating in Society 5.0, which integrates technologies like AI, cyber-physical systems, and cloud computing from Industry 4.0. They emphasize Society 5.0's aim to enhance living conditions and foster social development through these technologies, focusing on

sustainable welfare and smart societal solutions. The chapter reviews the history of industrial revolutions, defines Society 5.0's goals, innovations, and synergy with AI, and discusses the challenges in implementing this latest revolution. The study highlights Society 5.0's role in improving resource management and environmental sustainability through effective technological integration.

Maddikunta et al. [14] present a survey-based tutorial on Industry 5.0, emphasizing its role in combining human creativity with intelligent machines for resource-efficient manufacturing. They introduce new concepts and definitions of Industry 5.0, discussing its potential applications in areas like intelligent healthcare, cloud manufacturing, and supply chain management. The paper also covers supporting technologies for Industry 5.0, including edge computing, digital twins, and blockchain. It concludes by identifying research challenges and open issues essential for realizing Industry 5.0, highlighting the importance of this evolution in achieving efficient resource management and sustainability in Society 5.0.

Villar et al. [15] investigate the impact of Industry 5.0 on supply chain management, introducing the concept of "Supply Chain 5.0". Their study, based on a systematic literature analysis of documents from 2016 to 2022, presents a framework for understanding the key technologies and trends in Supply Chain 5.0. They emphasize how Industry 5.0 can optimize supply chains, aiding companies in efficiently managing resources and maintaining competitiveness in a rapidly evolving industrial environment.

6. Technological Advancements in Industry 4.0 and 5.0

Ali et al. [16] discuss the use of graphene nanoparticles in Industry 4.0, highlighting their potential to enhance sensory capabilities in various industries. This advancement is significant for the transition to Society 5.0, where graphene's role in smart factories can contribute to greater digitalization and efficiency. The study focuses on integrating these materials with AI and blockchain, emphasizing their importance in evolving towards a more connected and technologically advanced society.

Beier et al. [17] analyze the incorporation of sustainability within Industry 4.0, focusing on its alignment with the SDGs. Their findings indicate a predominant focus on economic aspects, with limited evidence of Industry 4.0 advancing sustainable production. This gap underscores the necessity of integrating sustainability more profoundly into Industry 4.0, which is crucial for transitioning towards the more holistic, sustainability-focused goals of Society 5.0.

Javaid et al. [18] emphasize the importance of cyber-physical systems (CPS) in Industry 4.0 for enhancing real-time data analysis and manufacturing efficiency. The integration of CPS, along with IoT and Digital Twin technologies, is crucial for smart manufacturing and decision-making. This advancement in interconnected systems and automation is key to progressing toward Society 5.0, where digital and physical integration drive industrial efficiency and sustainability.

Liang et al. [19] explore the use of Landfill Gas (LFG) from municipal solid waste as a sustainable energy source for data centers in Xiamen, China, aligning with the circular economy concept. Their study assesses the environmental and economic impacts of this approach, utilizing LFG for energy while recovering waste heat. This method not only recycles waste effectively but also reduces primary energy use and CO_2 emissions. The reuse of waste heat enhances energy efficiency and provides socio-economic benefits. This innovative strategy of using LFG and waste heat for data centers supports resource recovery and energy efficiency, contributing to the sustainable development of urban cities. This approach resonates with the goals of Society 5.0, which aims to integrate technological advances with sustainable resource management for societal benefit.

Xu et al. [20] discuss the transition from the technology-driven Industry 4.0 to the value-driven Industry 5.0. They analyze key questions surrounding the coexistence of these two industrial revolutions, aiming to stimulate debate on their differentiation and integration. This discussion is crucial in understanding the shift towards Society 5.0, where the focus is on harmonizing technological advancements with human-centered values and sustainable resource management.

7. Societal Impacts and Development in Society 5.0

In a rapidly evolving digital landscape, Fukuyama [21] highlights the transformative role of ICT in shaping society and industry, particularly focusing on Society 5.0. This concept, as an integral part of Japan's industrial policy, aims to create new values and sustainable growth strategies, addressing global trends and challenges. Within this framework, Gustiana et al. [22] propose a novel digital platform design using a Sociotechnical System (STS) approach. Their work aims to address multifaceted poverty issues, contributing to Society 5.0's vision of a more inclusive technological world where no individual is excluded from advancements.

Kusiak [23] delves into the nuances of smart manufacturing, emphasizing digitization, sustainability, and resilience. These concepts are pivotal in the shift towards Society 5.0, where smart manufacturing becomes a cornerstone for sustainable and efficient industrial practices. In line with this, Masoomi et al. [24] explore the potential of Industry 5.0 to enhance sustainable practices in the renewable energy supply chain. Their study aligns with Society 5.0's goals, focusing on adaptability, human-centered orientation, and addressing social and environmental issues.

Nahavandi [25] introduces Industry 5.0, highlighting the synergy between human workers and robotics, a collaboration that promises increased productivity and job creation, resonating with the core values of Society 5.0. This human-robot collaboration underlines the shift towards a society that values both technological advancement and human input.

Pascoal-Faria et al. [26] discuss the transition from prototyping to rapid manufacturing within Industry 4.0, underscoring the importance of sustainable materials in manufacturing. Their focus on reducing carbon footprints and integrating digitalization into material science contributes to the environmental sustainability goals of Society 5.0. They emphasize the need for a unified approach to digitalizing material science, considering the diverse range

of materials and their unique properties. This approach is instrumental in developing digital twins for the entire manufacturing cycle, extending to future life cycle stages, including reuse and recycling.

Pereira et al. [27] examine the promises of Industry 4.0 in revolutionizing industrial production, emphasizing its role in enhancing life quality and productivity. The emergence of Society 5.0 from Industry 4.0, particularly in Japan, is driven by the aging population and the need to use Industry 4.0 tools and technologies for human benefit. Society 5.0, as envisioned, positions humans at the center of innovation, leveraging advanced technology for societal well-being.

Potočan et al. [28] report that addresses how Society 5.0 balances Industry 4.0 with responsible economic development and social problem resolution through Corporate Social Responsibility (CSR). Their findings advocate the integration of technology into CSR models tailored to address individual social problems regionally. This study provides practical guidance for improving CSR practices in organizations, aligning with the environmental and social circumstances of modern society.

Ptak et al. [29] investigate the potential of renaturalized lakes in Poland, a significant step towards increasing water resources and offering new ecosystem services. Their methodology complements water-management efforts aimed at increasing retention, presenting a less invasive and more economically justified approach compared to new investments in artificial hydro-technical infrastructure. This aligns with Society 5.0's focus on sustainable natural resource management.

Roblek et al. [30] analyze the technological developments in the internet and internet technologies, highlighting their significance for sustainable development and the emergence of Society 5.0. Their automated content analysis of scientific articles reveals themes central to the development and impact of internet technologies on sustainable development, contributing to the conceptualization of Society 5.0.

Serpa & Ferreira [31] reflect on the increasing presence of digital technology in contemporary societies, emphasizing its impact on human relationships and sustainability innovations within Society 5.0. Their document analysis underscores the importance of recognizing the non-neutrality of technological phenomena and mobilizing appropriate instruments to maximize the efficiency of sustainable digital innovations.

Skobelev & Borovik [32] discuss the current phase of Industry 4.0, characterized by the integration of the physical and virtual worlds, and the emerging paradigm of Industry 5.0. This new phase envisions the deep penetration of artificial intelligence in everyday life, enhancing human capacity, and positioning humans at the center of technological advancements. Their work outlines the convergence of modern technologies, from IoT to emergent intelligence, which will facilitate the transformation from Industry 4.0 to Industry 5.0.

Smuts & Van der Merwe [33] address the need for organizations to navigate Society 5.0, a knowledge-intensive society where sustainable balance is achieved through systems integrating cyberspace and physical space. Their research, using automated content analysis, identifies key knowledge management aspects related to

sustainability in Society 5.0, mapping them to the triple bottom line of environment, society, and economic performance.

Lastly, Zengin et al. [34] explore the concept of Society 5.0 and its effectiveness in Turkey, particularly concerning the SDGs. Their research, based on a survey among academicians, assesses the influence of SDGs on Industry 4.0 and Society 5.0, revealing that Turkey is still progressing by focusing on outdated processes rather than leading in the field of Society 5.0 and Industry 4.0.

Together, these studies provide a comprehensive view of the multifaceted impact of Society 5.0 on various aspects of life, emphasizing the integration of technological advancements with a focus on sustainable development and human-centered approaches.

8. Smart Solutions for Environmental Challenges

In addressing environmental challenges within the context of Society 5.0, smart solutions play a pivotal role, focusing on new technology to enhance energy efficiency, effectively manage resources, and support sustainability (**Table 1**). Central areas include green technology in businesses, urban planning for smart cities, and renewable energy production.

Table 1. Smart Solutions for Environmental Sustainability in Society 5.0.

Solution Category	Description	Impact
Smart Cities	Use of new technologies to efficiently manage resources like water and energy, reduce waste, and reduce pollution. Energy-efficient buildings use renewable energy sources like solar power.	Reduces resource consumption, lowers the carbon footprint, and promotes sustainable urban living.
Renewable Energy	Increased use of solar and wind power to combat global warming and promote balanced economic growth. Enhanced distribution and optimization of these energy sources through new technology.	Leads to sustainable and reliable energy solutions and helps reduce the effects of global warming.
Cultural and Behavioral Shifts	Fostering a change in how people, businesses, and governments think and act towards the environment. Promoting the adoption and effective use of sustainable technologies.	Encourages society-wide adoption of sustainable practices, mindful of ecological impact.

Smart cities are integral to this approach, utilizing innovative technologies for efficient resource management, such as water and energy while reducing waste and pollution. Energy-efficient buildings in these cities use renewable sources like solar power, aiding in environmental protection and resource conservation.

The shift towards renewable energy sources, such as solar and wind power, is critical in the energy sector. This transition combats global warming and fosters balanced economic growth, with advanced technologies optimizing the use and distribution of these resources, leading towards a sustainable and reliable energy future.

Moreover, these smart solutions signify more than technological advancements; they represent a paradigm shift in how we think and act toward the environment. This involves educating communities, businesses, and governments about these technologies and their applications, aiming to cultivate a society that is advanced, sustainable, and environmentally conscious.

In this context, the development of sustainable business models (SBMs) has gained momentum, driven by increased environmental awareness. As Karuppiah et al. [35] highlight, SBMs are becoming a significant topic in both industrial and academic realms. Their analysis using the PRISMA framework on 63 articles from the Scopus database reveals emerging areas in SBMs, including strategies, challenges, drivers, the role of innovation, and digital technologies' impact. This study provides a comprehensive view of SBMs, emphasizing their quantitative focus in the manufacturing industry and suggesting future research directions.

Furthermore, the concept of circular bioeconomy (CBE) practices, as explored by Karuppiah et al. [36], demonstrates its capability to improve sustainable industrial performance. Their systematic literature review assesses the impact of CBE practice on industry sustainability, identifying challenges such as limited understanding, technological and financial support, and the need for a well-established reverse supply chain network. This study contributes significantly by highlighting the challenges industries face in adopting CBE practices and the synergy between CBE practice and sustainability.

These insights into SBMs and CBE practices align with the principles of Society 5.0, where technological innovation is harmonized with ecological and social considerations. They underscore the need for continuous innovation and adaptability in various sectors, emphasizing the importance of sustainable practices in achieving a future that is not only technologically advanced but also ecologically responsible and equitable.

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