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Review

Natural Resource Optimization and Sustainability in Society 5.0: A Comprehensive Review

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Abstract: In this study, we examine Society 5.0, defined as a future framework where advanced technologies like artificial intelligence (AI), the Internet of Things (IoT), and other digital innovations are integrated into society for sustainable resource management. 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. Our methodology involves a detailed literature review, focusing on identifying and evaluating the roles of AI, IoT, and other emerging technologies in enhancing resource efficiency, particularly in the water and energy sectors, to minimize environmental impact. This approach allows us to present a comprehensive overview of current technological advancements and their potential applications in Society 5.0. Our study's added value lies in its synthesis of diverse technological strategies, emphasizing the synergy between circular economy practices and sustainable economic development. We highlight the necessity for resilience and adaptability to ecological challenges and advocate for a collaborative, data-informed decision-making framework. Our findings portray Society 5.0 as a holistic model for addressing contemporary global challenges in resource management and conservation, projecting a future where technology aligns with sustainable, equitable, and human-centered development.

Keywords: sustainable resource management; Society 5.0; human-centric development; collaborative solutions for ecological sustainability

Citation: Ramírez-Márquez, C.; Posadas-Paredes, T.; Raya-Tapia, A.Y.; Ponce-Ortega, J.M. Natural Resource Optimization and Sustainability in Society 5.0: A Comprehensive Review. *Resources* **2024**, *13*, 19. https://doi.org/10.3390/resources13020019

Academic Editor: Elena Rada

Received: 19 December 2023
Revised: 19 January 2024
Accepted: 22 January 2024
Published: 24 January 2024

1. Introduction

As we move forward in the early decades of the 21st century, we are experiencing astonishing changes in our world. These changes are remarkable, transforming the way we live, work, and interact with each other and our environment [1]. The latter part of the 2010s saw the rise of a concept in Japan that quickly garnered global attention: Society 5.0 [2]. This concept is not merely a sequel to the technological advancements of Industry 4.0 and Industry 5.0, which started reshaping our reality in the early 2010s [3]. Rather, it is a holistic vision that advocates for a society where advanced technology is intricately woven into the fabric of everyday life [4,5].

Society 5.0 represents a notable progression beyond the industrial orientations of Industry 4.0 and 5.0 [6]. It aims to harmonize state-of-the-art technologies, including automation and digitalization, with essential human requirements, especially in addressing environmental and resource management challenges [7–9]. This model blends technological advancements with a human-centered approach, striving to improve life quality and foster sustainable engagement with the environment. A crucial element of Society 5.0 involves optimizing resources while aligning with the United Nations' Sustainable Development Goals (SDGs) [10], detailed in documents [11–15], striving for a balance between economic development, ecological preservation, and social welfare. Our study primarily focuses on this integrative approach, linking technological progress with environmental and societal considerations.

The ethos of Society 5.0, in addressing these challenges, offers a revolutionary approach to technology utilization, one that transcends traditional paradigms. It advocates for the deployment of advanced technologies—from AI and IoT to renewable energy solutions—not merely as tools for economic advancement but as instruments for ecological balance and societal enrichment [16]. This approach entails developing and implementing inherently sustainable technologies, promoting circular economies, and enhancing resource efficiency.

Moreover, Society 5.0's vision emphasizes the need to rethink our relationship with natural resources. It propels us to move beyond the conventional 'take-make-dispose' model, urging a shift towards sustainable resource utilization that encompasses recycling, upcycling, and responsible consumption [17–19]. This paradigm shift is aimed at minimizing waste, reducing the depletion of non-renewable resources, and mitigating environmental impacts, thereby aligning technological advancements with the principles of sustainability.

In implementing these strategies, Society 5.0 is poised to address some of the most pressing issues identified in the SDGs, such as combating climate change, ensuring clean water and sanitation, promoting sustainable industrialization, and fostering responsible consumption and production patterns [20–22]. The integration of advanced technologies within Society 5.0 is envisaged to play a pivotal role in this process, offering innovative solutions for sustainable resource management. These solutions range from precision agriculture that optimizes water and fertilizer use to smart grids that enhance energy efficiency, and from waste-to-energy technologies to advanced materials that reduce environmental footprints [23].

In essence, the approach of Society 5.0 to technology and resource management marks a significant departure from traditional practices. It embodies a holistic, forward-thinking framework that is not only responsive to current environmental challenges but also proactive in anticipating future needs and opportunities. This comprehensive strategy, informed by the SDGs and empowered by technological innovation, holds the potential to transform our world, making the ambitious vision of a sustainable, efficient, and equitable society a tangible reality [24].

In this comprehensive review, we delve into the transformative impact of Society 5.0 on our perceptions of resource optimization and sustainability. Our primary aim is to explore the innovative ways in which this societal model employs technology not just for economic growth but also to foster a sustainable balance. This exploration includes insights into how businesses and industries are transitioning to a reality where sustainability is seamlessly integrated into their operational fabric, rather than being an optional addendum.

The purpose of this research is to uncover the intricate relationship between Society 5.0 and sustainable resource management, highlighting how this new societal framework can lead to significant positive changes in our world. In doing so, we pose several key research questions: How does Society 5.0 redefine our approach to resource optimization and sustainability? What are the tangible impacts of this societal model on environmental and resource management practices? How are technological advancements under Society 5.0 facilitating a shift towards more sustainable business and industrial practices?

2. Essential Resources for Advancing Society 5.0

In the era of Society 5.0, the sustainable management of natural resources becomes crucial for technological advancement and societal well-being. This section delves deeper into these resources (see Figure 1), exploring their future implications and necessity.

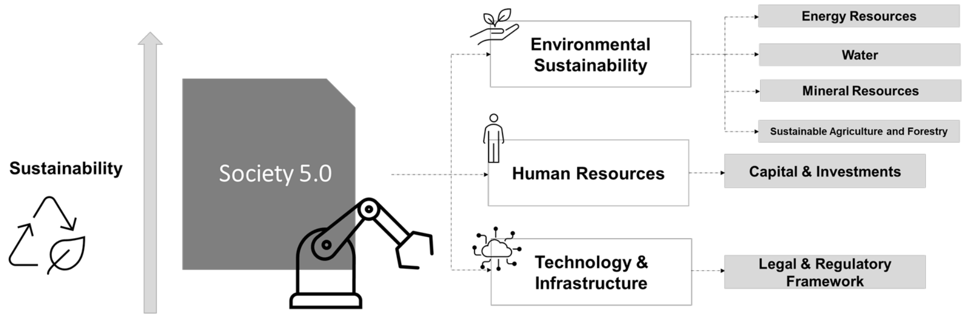

Figure 1. Towards Society 5.0: Envisioning the Integration of Resources for a Sustainable Future.

In Society 5.0, the connection between energy resources from different areas and the society's progress is key. In Section 2.1, it is shown how managing energy well is important for Society 5.0's overall plan. Section 2.2 talks about how various kinds of energy are needed to power the technology Society 5.0 uses. Section 2.3 connects mineral resources, which are important for making energy systems, to technological growth. Water, discussed in Section 2.4, is an essential energy resource and is necessary for both society and industry. In Section 2.5, the focus is on how energy-efficient methods are needed for sustainable agriculture and forestry, showing energy's role in keeping the environment healthy. Lastly, Section 2.6 highlights that human creativity and growth are supported by a good energy system. This structure was methodologically chosen to highlight the multifaceted nature of energy resources and their critical roles in various aspects of society and technology. It emphasizes the interconnectedness of energy systems, technology, and sustainable practices, underscoring the holistic approach required to build Society 5.0. Together, these sections show that using energy wisely and sustainably is central to building Society 5.0, where technology and the environment exist in balance.

In our methodology, we selected energy, minerals, water, sustainable agriculture and forestry, and human and intangible resources as focal points for Society 5.0, due to their interconnected roles in shaping a sustainable, technologically advanced society. Energy resources are crucial for powering innovation and maintaining a sustainable future; minerals form the backbone of technological infrastructure; water, as an indispensable resource, supports both societal needs and industrial processes; sustainable agriculture and forestry ensure a balance between human consumption and environmental health; and human and intangible resources, including knowledge and creativity, drive the evolution and adaptation of Society 5.0. This holistic approach to our methodology highlights the significance of these diverse yet interconnected resources in realizing the vision of a harmonious, forward-thinking society.

2.1. Society 5.0 and Sustainable Resource Management: A Combined Approach

The intersection of Society 5.0's defining characteristics with natural resource management represents a critical area of study and action. The integration of advanced technologies, a human-centric focus, sustainability, resilience, collaboration, data-driven decision-making, and the balance between the cyber and physical worlds—all these elements of Society 5.0 significantly impact how we approach the utilization and conservation of natural resources [25].

Within the framework of Society 5.0, the use of advanced technologies like AI and IoT becomes a vital tool for the efficient management of natural resources. These technologies enable more precise monitoring and better prediction in the use of resources such as water, energy, and materials, optimizing their use and reducing waste [26]. For instance, smart agriculture systems, which utilize sensors and data analysis, can enhance the efficiency of water and fertilizer use, contributing to the conservation of water resources and the reduction of environmental impacts [27].

The human-centric approach of Society 5.0 highlights the importance of considering human needs and well-being in natural resource management. This implies developing strategies that are not only technologically efficient but also sustainable and equitable from a social perspective [1].

Sustainability, as a fundamental pillar of Society 5.0, plays a pivotal role in shaping the development of resource management practices that are not only environmentally responsible but also economically viable over the long term. Emphasizing sustainable development, Society 5.0 encourages the creation of systems and practices that balance ecological health with economic prosperity. This includes the promotion of circular economies, a transformative concept that advocates for the reuse and recycling of resources, thereby significantly minimizing the extraction and consumption of non-renewable natural resources [28]. In these circular economies, waste materials are viewed not as trash but as valuable resources that can be continuously reintegrated into production cycles, leading to a substantial reduction in environmental impact. This shift towards circular economies under Society 5.0 represents a crucial step in achieving a more sustainable future where resource efficiency and environmental stewardship are paramount.

Resilience and adaptability, essential characteristics of Society 5.0, are also crucial in natural resource management. In a world where environmental challenges such as climate change and ecosystem degradation are increasingly prominent, the ability to adapt and respond effectively to these changes is key to ensuring the sustainability of resources [29]. Resilience and adaptability are not only about reacting to changes but also about proactively shaping resource management strategies that can withstand future environmental uncertainties.

Collaboration and data-driven decision-making are equally important. Cooperation across different sectors and the use of advanced data analytics can lead to more innovative and effective solutions in natural resource management [30]. This collaborative approach, which brings together stakeholders from various fields, including technology, ecology, and social sciences, ensures that the solutions developed are beneficial for both communities and the environment. Additionally, the integration of data analytics helps in accurately assessing resource needs and environmental impacts, fostering a more sustainable and efficient resource management paradigm. Lastly, the balance between the cyber and physical worlds in Society 5.0 allows for greater harmonization between technology and the natural environment. This opens up new possibilities for resource management, where technological solutions complement and enrich interactions with the natural world [31].

With these considerations in mind, the next section of the article will focus exclusively on natural resources within the context of Society 5.0. It will explore how the convergence of these characteristics can lead to more innovative and sustainable methods in the management and conservation of natural resources, a critical aspect for the future of our planet and society [32].

2.2. Energy Resources: Diverse Origins for a Sustainable Future

Solar Energy: At the heart of this energy mix is solar power, harnessed mainly through photovoltaic cells, which heavily depend on purified silicon derived from common quartz. The global market for solar panels is largely influenced by countries like China, the US, and Russia, which are major players in providing silicon. The IEA has projected that solar PV capacity could skyrocket, reaching around 930 GW by 2024, a clear sign of its growing footprint in our global energy landscape [33].

Wind Energy: Wind power, another key player in the renewable scene, relies on materials like steel (from iron ore) and concrete (from limestone) for building turbines and uses rare minerals like neodymium for the magnets. China stands out as a major supplier of these rare earth elements. GWECs reports show that global wind power capacity hit 743 GW in 2021, underscoring its rising star in renewable energy [34].

Fossil Fuels: Even as we pivot towards renewable sources, it is undeniable that fossil fuels—coal; oil; and natural gas—still have a significant footprint in our current global energy mix. The BP Statistical Review of World Energy 2022 indicates that over 80% of the world's energy consumption in 2021 was from fossil fuels. Yet, there is a noticeable shift to cleaner energy, especially in more developed countries [35].

Nuclear Energy: Then, there is nuclear power, a substantial low-carbon energy player. As of 2021, around 440 nuclear reactors were operational worldwide, supplying about 10% of global electricity, as reported by the World Nuclear Association [36]. Nuclear energy is pivotal in many countries' energy strategies, particularly for those aiming to cut down greenhouse gas emissions.

Biofuels: Lastly, biofuels—made from plants and animal waste—are becoming an increasingly vital part of the renewable energy sector. The IEA points out that biofuel production has been on a steady rise, expected to jump by 25% by 2024, largely driven by policies advocating for sustainable transport fuels [37].

Hydrogen: An emerging player in the energy landscape is hydrogen, often touted as the fuel of the future. With the global hydrogen market valued at approximately $150 billion in 2021 and projected to reach $2.5 trillion by 2050, hydrogen has the potential to revolutionize the energy sector [38]. Its ability to store and deliver energy in a usable form without direct emissions makes it a promising candidate for a clean energy future. Research and investment in hydrogen technologies are intensifying, as evidenced by the significant increase in green hydrogen projects worldwide, expected to reach a production capacity of 50 million tons per year [39]. This trend indicates its possible pivotal role in meeting the energy demands of Society 5.0, adapting to a variety of applications from transportation to industrial power generation.

Looking at the energy landscape of Society 5.0, it is marked by a diverse and evolving mix of sources. While renewables like solar and wind are climbing up the ladder, traditional energy forms like fossil fuels and nuclear power are still in play. Our future energy matrix is likely to be a tailored blend of these sources, catering to the specific needs and strengths of various regions, all converging towards the shared goal of sustainability and technological progress.

2.3. Mineral Resources: Essential for the Technological Infrastructure of Society 5.0

The evolution of technology in Society 5.0 hinges on a range of critical minerals, each playing a unique role in the development of high-tech infrastructure.

Lithium: Take lithium, for instance, a star player in the battery technology arena. Its story is intricately woven with the rise of electric vehicles and renewable energy storage systems. Global lithium reserves are estimated to be around 22 million metric tons. Alongside Australia, Chile and China emerged as the world's other leading lithium-producing countries, collectively spearheading the supply to meet the soaring global appetite for lithium [40]. This number is not just a statistic; it echoes the world's accelerating shift towards sustainable energy solutions.

Cobalt: Cobalt's tale, though, is tinged with complexity. Predominantly sourced from the Democratic Republic of Congo, which produced about 95,000 metric tons in 2021, cobalt's story is one of both abundance and ethical challenges [41]. This mineral is indispensable in crafting high-density batteries, but its procurement often raises concerns about responsible sourcing and the impact on local communities.

Rare earth elements: The narrative of rare earth elements is equally compelling. Dominated by China, which produced around 168,000 metric tons in 2021, these elements are the unsung heroes in various technologies, from smartphones to electric vehicles [42]. China's stronghold on rare earth elements not only underscores its global importance but also highlights the strategic need for diversified supply chains.

Copper: Copper's journey, known for its excellent conductivity, is essential in a myriad of applications, from electrical wiring to renewable energy systems. Chile, as the largest copper producer with a production of 5.7 million metric tons in 2020, plays a crucial role in this narrative [43]. Peru follows, adding its significant contribution to the global copper saga.

Aluminum: Aluminum, famed for its lightweight and corrosion-resistant properties, is vital in industries ranging from transportation to construction. In 2025, China solidified its leading position in the global aluminum production arena, producing an impressive 40 million metric tons [44]. This substantial figure not only emphasizes China's critical role in the aluminum market but also reflects the country's significant influence on the worldwide aluminum narrative.

Silicon: Silicon's tale is equally fascinating. As a cornerstone of the semiconductor industry, its production is crucial for the tech world. In 2022, the global production of industrial silicon reached 7.783 million tons, a figure that also indicates the amount of silicon-containing solid waste generated at each step of the production process [45]. This figure is not just about quantity; it is about the centrality of silicon in our digitally-driven era.

Each of these minerals (lithium, cobalt, rare earth elements, copper, aluminum, and silicon) is more than just an element on the periodic table. They are the keystones in the edifice of Society 5.0, playing pivotal roles in everything from energy storage to digital devices. Their stories, interwoven with global economics, sustainability, and technological progress, highlight the intricate tapestry of our modern world.

2.4. Water: The Lifeblood of Society and Industry

Water, in its multifaceted role, is not just indispensable for sustaining life but also a crucial resource for industrial applications. Freshwater, primarily sourced from aquifers and river basins, is under increasing pressure from factors like climate change and overconsumption. This scenario necessitates innovative solutions for water management. Desalination, a key technology particularly prevalent in the middle east, has seen a significant rise in adoption. Currently, there are about 21,123 desalination plants operational globally, serving the daily water needs of over 300 million people around the world [46].

The importance of water recycling cannot be overstated in addressing water scarcity. In countries like Israel, water recycling contributes to more than 85% of agricultural water use, showcasing its potential in sustainable water management [47]. Moreover, advanced irrigation techniques are gaining traction in agriculture, a sector responsible for approximately 70% of global freshwater withdrawals. Techniques like drip irrigation, which can increase water efficiency by up to 90%, and precision agriculture are becoming essential tools for sustainable agriculture [27]. In regions like California, the adoption of drip irrigation has led to a 20–50% reduction in water usage for certain crops [48].

As water scarcity becomes a more pressing issue, these technologies and methods are vital in ensuring the efficient and sustainable use of water resources. The integration of such techniques across various sectors is crucial for managing the world's freshwater supply effectively, especially considering the growing demands of an increasing global population.

Building further on these strategies, the integral role of water extends beyond agriculture into the realms of energy production and industrial processes. Water is a key element in generating hydroelectric power, a clean and renewable energy source. In industries, water is extensively used for cooling and processing, highlighting its indispensability in various manufacturing sectors. Moreover, the concept of water-smart cities is emerging as a crucial development. These cities integrate efficient water usage into their urban design and infrastructure, addressing the unique water challenges of urban environments.

This comprehensive approach to water management, which encompasses rural areas with their agricultural needs and urban settings with their distinct requirements, is vital for a sustainable water future. The strategy involves not just conserving water but also optimizing its use across different sectors. This includes adopting water-efficient technologies in homes and industries and promoting policies that support water conservation and sustainable usage.

As the global population continues to grow and the impacts of climate change become more pronounced, the need for effective water management strategies becomes more critical. It is not just about having enough water; it is about ensuring that water is used in the most efficient and sustainable way possible. This means balancing the water needs of communities, industries, and ecosystems in a way that supports the health of the planet and its inhabitants.

The integration and application of these varied water-related technologies and methodologies across different sectors is essential. It is about creating a cohesive system that manages the world's water resources in a way that is both effective and sustainable, meeting the needs of today without compromising the ability of future generations to meet their own needs.

2.5. Sustainable Agriculture and Forestry: The Balancing Act

The essence of sustainable agriculture deeply roots itself in nurturing topsoil and judiciously managing the land fit for farming. This crucial land is not uniformly spread across our planet. In countries like the United States, Brazil, and India, significant strides are being made in the fields of crop genetics and soil health. These innovations are pivotal, not just in boosting crop yields but also in fortifying the resilience of agriculture against the backdrop of a changing climate. Consider Brazil's progress in soybean production; in 2022, the nation achieved a remarkable output of 269 million metric tons, a testament to the effectiveness of these advancements [49].

In the same breath, let us consider forestry, which straddles the line between commercial exploitation and environmental conservation. The challenge here is to strike a delicate balance, especially in critical ecosystems like the Amazon Basin and the expansive boreal forests of Russia and Canada. These areas are not just forests; they are global assets in carbon sequestration and biodiversity preservation. The Amazon, with its sprawling 4.27 million square kilometers, is a prime example of nature's prowess in offsetting carbon emissions and harboring a rich tapestry of life [50].

It is clear that our approach to agriculture and forestry is more than a matter of policy or practice; it is a commitment to the health of our planet, aligning human development with the needs of the environment.

Moving deeper into our analysis, we connect the dots between sustainable agriculture, forestry, and the vision of Society 5.0. This concept of an advanced society puts a strong emphasis on balancing technological innovation with environmental care. Agroforestry, blending trees with crops or livestock, is an excellent example of this balance. It shows how we can use land in a way that is good for nature and still helps us grow food or raise animals, using technology to manage resources better. This matches Society 5.0's idea of mixing old ways with new tech to create healthier, more productive environments.

In forestry, keeping forests healthy for the future is crucial. This means managing them in a way that helps with climate change by storing carbon and keeping the forests for years to come. This kind of care for forests fits right into Society 5.0's goal of having economic growth without hurting the environment.

The link between farming, managing forests, and taking care of the environment in Society 5.0 shows a real commitment to our planet. It is about making systems and ways of doing things that help people and the planet. In Society 5.0, farming and forests are not just about making things or protecting nature; they are key to a future where we live sustainably, use technology wisely, and look after our environment.

2.6. Empowering Society 5.0: Human and Intangible Resources

The foundation of Society 5.0 lies in its Human Resources. The future demands a workforce skilled in AI, robotics, data analysis, and cybersecurity. Industry 5.0 highlights the collaboration between humans and machines, requiring a workforce that is technically skilled and adaptable to rapid technological changes [51]. Developing this talent is key to innovation and competitiveness in an advanced society.

Another crucial aspect is Technology and Infrastructure. Investing in high-speed networks, data centers, and IoT platforms supports the large data volumes and connectivity needed for modern industrial and social models [52]. These elements are vital for a digitally connected world, enabling efficient communication and the integration of technologies into daily life.

Environmental Sustainability is equally important. As technology impacts the environment, focusing on emission reduction, waste recycling, and sustainable agriculture is essential. These practices protect the environment and ensure the sustainability of technological advancements [53].

Capital and Investments also play a significant role. Funding for research, development, and implementation of advanced technologies is crucial for ongoing innovation [54]. A combination of public and private investments is necessary for sustainable and progressive technology development.

An effective Legal and Regulatory Framework is indispensable. Addressing issues like data privacy, cybersecurity, labor rights in automated environments, and AI ethics requires a strong legal structure [55]. This framework protects individual and societal rights and encourages technological innovation and adoption.

Realizing Society 5.0 needs a coordinated approach to managing diverse natural resources. Understanding the unique origins and roles of each resource highlights the complexity and interconnectedness of our global ecosystem. Strategic resource management, aligned with technological advancements, is essential for a sustainable, resilient, and equitable society.

3. Society 5.0 Resources: An In-Depth Review

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. In pursuit of this comprehensive exploration, we have meticulously curated a selection of numerous articles authored by esteemed experts and visionary thought leaders hailing from diverse domains. Each article delves rigorously into a distinct facet of Society 5.0, offering not only distinctive insights, empirical substantiation, and forward-thinking perspectives but also a strong emphasis on sustainability. Within Table 1, presented below, we provide an overarching view of these articles, laying the foundation for an exhaustive scrutiny of the multifaceted resources that not only drive but sustain the evolution of Society 5.0.

In Table 1, our analysis of Society 5.0-related literature encompasses seven distinct areas, reflecting the multifaceted nature of this concept. To ensure a comprehensive and nuanced understanding, we adopted a systematic and rigorous approach in our literature review. This involved meticulously searching through several academic databases, employing a combination of keywords that encapsulated the essence of Society 5.0 and its associated sectors.

For our analysis, we established specific selection criteria focused on the relevance of the articles to Society 5.0, their contribution to the field, and the novelty of the research. We prioritized studies that offered innovative insights or presented new angles on the application and impact of Society 5.0 concepts. The period from 2017 to the present was chosen strategically to capture the most recent advancements and discussions in the field, marking a significant phase in the evolution of Society 5.0.

The method of analysis involved a thorough reading and categorization of the selected articles. Each article was evaluated for its core content, thematic relevance, and the depth of its analysis regarding Society 5.0. We then synthesized the findings to draw out key themes and trends, which were categorized into the seven sections represented in Table 1. This structured approach allowed us to not only compile a diverse range of viewpoints but also critically assess the interconnections and differences within the literature, thereby providing a holistic overview of the current state and future prospects of Society 5.0.

Table 1. Society 5.0 Resources Articles Overview.

Society 5.0	Articles
Sustainable Energy and Resource Efficiency	Carayannis et al. [56], Nižetić et al. [26], Petrescu et al. [57].
Environmental Sustainability and Society 5.0	Kasinathan et al. [20], Mourtzis et al. [21], Turner et al. [58].
Smart Solutions for Ecological Challenges	Fukuda [59], Onu et al. [60], Wang et al. [61].
Society 5.0 and Human-Centric Approaches to Nature	Deguchi et al. [62], Narvaez Rojas et al. [63], Phuyal et al. [64].
Integrating Technology and Environmental Management	Calp & Bütüner [65], Maddikunta et al. [66], Villar et al. [67].
Technological Advancements in Industry 4.0 and 5.0	Ali et al. [68], Beier et al. [69], Javaid et al. [70], Liang et al. [71], Xu et al. [72].
Societal Impacts and Development in Society 5.0	Fukuyama [73],
	Gustiana et al. [74],
	Kusiak [75],
	Masoomi et al. [76],
	Nahavandi [77],
	Pascoal-Faria et al. [78],
	Pereira et al. [79],
	Potočan et al. [80],
	Ptak et al. [81],
	Roblek et al. [82],
	Serpa & Ferreira [83],
	Skobelev & Borovik [84],
	Smuts & Van der Merwe [85],
	Zengin et al. [86].

3.1. Sustainable Energy and Resource Efficiency

Carayannis et al. [56] 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. [26] 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. [57] 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.

3.2. Environmental Sustainability and Society 5.0

Kasinathan et al. [20] 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. [21] 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. [58] 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.

3.3. Smart Solutions for Ecological Challenges

Fukuda [59] 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. [60] 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. [61] 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.

3.4. Society 5.0 and Human-Centric Approaches to Nature

Deguchi et al. [62] 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. [63] 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. [64] 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.

3.5. Integrating Technology and Environmental Management

Calp & Bütüner [65] 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. [66] 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. [67] 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.

3.6. Technological Advancements in Industry 4.0 and 5.0

Ali et al. [68] 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. [69] 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. [70] 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. [71] 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. [72] 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.

3.7. Societal Impacts and Development in Society 5.0

In a rapidly evolving digital landscape, Fukuyama [73] 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. [74] 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 [75] 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. [76] 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 [77] 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. [78] 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. [79] 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. [80] 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. [81] 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. [82] 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 [83] 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 [84] 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 [85] 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. [86] 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.

3.8. 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 2). Central areas include green technology in businesses, urban planning for smart cities, and renewable energy production.

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. [87] 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. [88], 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.

Table 2. 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.

4. Perspectives on Society 5.0: Evaluating Key Resources

In Society 5.0, addressing the sustainable management of essential resources, including both rare and common minerals, is a pressing challenge. Rare minerals such as neodymium, dysprosium, and terbium are crucial for high-tech applications, while common minerals like copper, iron, and aluminum play a vital role in various industries. The demand for these minerals, driven by technological advancements and green initiatives, contrasts with environmental and geopolitical concerns. For instance, the global market for neodymium was valued at approximately $11.3 billion in 2019 and is expected to grow, reflecting its importance in technologies like wind turbines and electric vehicles [89].

Strategic diversification of supply sources is essential to mitigating supply risks. Exploring new mineral deposits in stable regions can alleviate dependencies while enhancing recycling and reuse can reduce mining reliance and environmental degradation. Material science innovations could significantly decrease the demand for scarcity-prone minerals, with research indicating potential alternative materials [90].

Efficient water management is another crucial aspect. Implementing smart irrigation and industrial recycling can considerably reduce water waste. Given the impact of climate change on water availability, such strategies are vital for a resilient water supply [91].

In the energy sector, the transition to renewable sources like solar and wind necessitates advancements in storage and efficiency. The renewable energy market is projected to reach $1.1 trillion by 2025, highlighting the growing need for innovative energy solutions [92].

Beyond tangible resources, human capital, technological innovation, and adaptability are indispensable in Society 5.0. Human capital, with its wealth of knowledge and creativity, becomes a pivotal asset. Continuous learning is essential, preparing individuals for advanced technologies and evolving environments. Skills development in critical thinking and problem-solving is crucial for fostering innovation [93].

Technological innovation, with the ongoing evolution of AI, IoT, and robotics, will increase efficiency across sectors and address complex challenges. This wave of innovation, if aligned with human-centric approaches, can significantly improve life quality. However, technology must be developed and applied to serve human interests sustainably [16].

Adaptability and continuous learning are vital in this era. The ability to quickly adapt extends beyond technologies to policies, regulations, and business strategies. In a constantly changing world, the capacity for continuous evolution will be a key differentiator [94].

Society 5.0 advocates for a blend of innovation, global cooperation, and sustainable resource management practices. This approach aims to create a balance where technology serves human needs without compromising environmental health. The envisioned future is one where technological progress and resource sustainability support a more equitable world, demonstrating that technological and ecological goals can be aligned [95].

5. Conclusions

In concluding our extensive review of resource optimization and sustainability within the framework of Society 5.0, we propose a conceptual model that encapsulates the intricate and interconnected dynamics of this transition. Society 5.0 represents a profound shift, moving beyond mere technological advancements to fundamentally alter how we perceive and interact with our resources and environment.

Our conceptual model situates Society 5.0 at the confluence of three critical domains: advanced technology, human-centric development, and sustainable resource management. The essence of this model lies in the synergy among these domains, where each element supports and enhances the others. Advanced technology, including AI and IoT, acts as the driving force for efficiency and innovation in resource management. However, this technological impetus is guided by a human-centric approach, ensuring that advancements align with societal needs and ethical considerations. The third domain, sustainable resource management, represents the ultimate objective, aiming to ensure that both technological and human-centric developments contribute to a healthier planet and society.

The role of minerals, both rare and common, is integrated into this model as one of the fundamental components of this technological evolution. The responsible sourcing, use, and recycling of these minerals creates a cycle that not only supports the technological infrastructure of Society 5.0 but also maintains environmental integrity.

Water and energy management are identified as pivotal elements within this model. Their sustainable management is essential to ensuring that these vital resources bolster the societal and technological advancements of Society 5.0. The model advocates for cutting-edge solutions in these areas, like smart grids and water conservation technologies, which are emblematic of the principles of Society 5.0.

Our literature review highlights a shared recognition among experts regarding the critical importance of harmonizing technological progress with sustainable resource management. This harmony is key to the success of Society 5.0 and vital for ensuring the long-term health and prosperity of our environment and society.

However, it is important to acknowledge the limitations of our study. The rapid evolution of technologies and societal structures means that our findings represent a snapshot of a continually changing landscape. Future research should focus on the ongoing development of these technologies and their societal implications, as well as the practical challenges of implementing the principles of Society 5.0 globally.

Society 5.0 envisions a future where technology and sustainability are intertwined, leading us toward a more efficient, equitable, and sustainable existence. This journey is fraught with challenges, but through collective efforts and a steadfast commitment to innovation and sustainability, these challenges can be transformed into opportunities for progress and development. This model not only theorizes the central concepts of Society 5.0 but also serves as a roadmap for future research, policy-making, and societal transformation.

Author Contributions: Conceptualization, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; methodology, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; formal analysis, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; investigation, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; resources, J.M.P.-O.; data curation, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; writing—original draft preparation, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; writing—review and editing, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; visualization, C.R.-M., T.P.-P., A.Y.R.-T. and J.M.P.-O.; supervision, J.M.P.-O.; project administration, J.M.P.-O.; funding acquisition, J.M.P.-O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing are not applicable to this article.

Acknowledgments: The authors acknowledge the financial support from CONAHCyT (Mexico) and CIC-UMSNH.

Conflicts of Interest: The authors declare no conflicts of interest.

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