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Research article

Navigating the future by fuzzy AHP method: Enhancing global tech-sustainable governance, digital resilience, & cybersecurity via the SME 5.0, 7PS framework & the X.0 Wave/Age theory in the digital age

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Abstract: In the rapidly evolving landscape of the digital age, the call for intelligent governance has become paramount. This study offers a nuanced exploration of global sustainable governance, integrating the Seven Pillars of Sustainability (7PS) framework and innovation culture. Utilizing structural equation modeling and data from diverse government organizations, this research empirically established the 7PS framework's pivotal role in enhancing organizational sustainability, supported by a robust 95% confidence level. Notably, it unveiled the transformative influence of innovation culture in amplifying the 7PS's impact. The methodological innovation lies in strategically applying the fuzzy analytic hierarchy process (AHP), assigning priority weights to 7PS criteria, and identifying culture as the linchpin. This approach provided a robust framework for dissecting the complex interplay of emerging technologies, sustainable engineering, and cybersecurity. The study delves into the X.0 wave/age (X.0 = 5.0) theory, offering insights into the intricate dynamics of innovation, sustainability, and governance. Beyond academic discourse, this research informs practical strategies globally, particularly for small and medium-sized enterprises (SMEs) transitioning to SME 5.0/hybrid SMEs. Emphasizing inclusivity and diversity as catalysts for innovation, it scrutinizes contemporary challenges amid technological evolution and cybersecurity threats. Functioning as a visionary compass, the study elucidates the path to a 7PS sustainable future. It signifies a paradigm shift, transcending boundaries between knowledge domains. The fusion of the 7PS framework, X.0 wave theory, and fuzzy AHP navigates global governance, digital resilience, and cybersecurity, offering a transformative roadmap. This research contributes by substantiating the pivotal role of culture in emerging technologies, augmenting global tech-sustainable governance, fortifying digital resilience, and safeguarding cybersecurity.

Keywords: sustainable governance; digital resilience; X.0 wave/age theory; seven pillars of sustainability (7PS) model/framework; sustainable engineering; emerging technologies; digital age; sustainable future; fuzzy AHP method, SME 5.0

1. Introduction

In the relentless march of technological progress, digitalization has transformed not only the way we live but also the very essence of our existence. The pervasive influence of digitalization has reshaped the world and its people, rewriting the rules of engagement in nearly every aspect of life. From the way we connect and communicate to how we work, learn, and seek entertainment, digitalization has woven itself into the very fabric of our daily routines. As it permeates deeper into society, its impacts are felt not only on the individual level but also on the global stage. This digital age has ushered in an era of unprecedented connectivity, where borders blur and information flows freely, fostering both incredible opportunities and complex challenges. In this digitalized world, individuals find themselves at the nexus of innovation, where they must navigate the opportunities and dilemmas posed by the relentless march of technology, with implications that span from individual privacy to international geopolitics. The digitalization of the people and the world is an ongoing journey, one that continues to reshape human experience in profound and unpredictable ways. Mardani et al. [1] presented a hierarchical framework for evaluating energy-saving technologies in Iranian hotels, integrating fuzzy set theory and quantitative methods. They identified 17 key energy factors through a literature survey and ranked them using a fuzzy analytic hierarchy process (AHP). The study revealed that equipment efficiency, system efficiency, and active space cooling solutions rank highest.

Dobson's paper [2] delved into the necessity of behavioral changes for sustainable development. It discussed the significance of addressing attitudes for lasting behavioral shifts and compared fiscal incentives with the concept of "environmental citizenship" rooted in justice. The paper also explored the role of the high-school citizenship curriculum in promoting environmental citizenship.

Littig et al. [3] explored sustainability in the context of the Brundtland Report and Rio documents, emphasizing the integration of ecological, economic, social, and institutional dimensions. It briefly introduced sustainability models and discussed social sustainability through selected indicators. The paper suggested a sustainability concept rooted in needs, work, and their relationship with society and nature, advocating for social sustainability as both a normative and analytical concept.

Hopwood et al. [4] explored the diverse interpretations and responses surrounding the concept of sustainable development, which seeks to balance environmental and socioeconomic concerns. The paper offered a classification and mapping of various sustainable development approaches, their political and policy contexts, their perspectives on change, and the means of achieving it. It emphasized the importance of clarity in the meaning of sustainable development, focusing on sustainable livelihoods, well-being, and long-term environmental sustainability rooted in principles that connect social and environmental aspects with human equity.

Dobin [5] addressed the need for measuring innovation culture in organizations. The study introduced a seven-factor model for innovation culture derived from literature, interviews, and employee surveys in the financial services industry. This model can serve both descriptive and diagnostic purposes, aiding organizations in assessing and enhancing their innovation culture.

Eizenberg et al. [6] introduced a new conceptual framework for social sustainability, addressing a gap in theoretical and empirical studies. This framework acknowledges risk as a fundamental element in sustainability, particularly in the context of climate change-related uncertainties. Social sustainability aims to tackle these risks while addressing social concerns. The framework comprises four interrelated concepts: equity, safety, eco-prosumption, and urban forms. These concepts collectively contribute to reducing alienation, enhancing civility, fostering community, and promoting place attachment. This innovative framework provides a comprehensive perspective on social sustainability, emphasizing the importance of socially oriented practices in achieving sustainability.

Doost Mohammadian et al. [7] highlighted the importance of sustainable governance through innovation in the digital age. They employed structural equation modeling and data from government organizations to explore the impact of the Seven Pillars of Sustainability (7PS) and innovation culture on organizational sustainability. The study also emphasized the mediating role of innovation culture in this context. Furthermore, Fuzzy AHP was used to assign priority weight to the 7PS model criteria, with culture being the highest-rated criterion.

Goyal et al. [8] identified barriers to adopting sustainable production and consumption (SPC) in the Indian manufacturing industry, highlighting government, management, and finance-related obstacles. Using fuzzy AHP and TOPSIS methodologies, it ranked these barriers and proposed solutions to mitigate their impact. This study not only analyzed barriers but also provided solutions, aiding policymakers and industry stakeholders in promoting SPC and advancing sustainable practices.

Jamwal et al. [9] explored the nexus of Industry 4.0 adoption and sustainability challenges in emerging economy manufacturing SMEs. Focused on climate change and resource efficiency, the research revealed key hurdles, such as the lack of dedicated R&D teams and data security issues. The findings, derived from a comprehensive survey, offered empirical support for addressing sustainability concerns within Industry 4.0 and provided a practical framework for SME managers and policymakers to foster sustainability in the manufacturing sector of emerging economies.

Doost Mohammadian et al. [10] introduced the MODE IT project, focusing on curricular modernization using MOOCs (Massive Open Online Courses). The study highlights the importance of MOOCs in addressing complex labor market demands and the need for continuous learning. It aims to enhance Higher Educational Institution (HEIs) students' learning experiences, integrate innovative MOOCs-based instructional approaches into HEI curricula, and improve educators' skills. The paper discusses how the MODE IT project aligns with the X.0 wave/age (X.0 = 5.0) theory, emphasizing readiness for the educational future.

Doost Mohammadian et al. [11–13] discussed the impact of the COVID-19 pandemic on SMEs, highlighting the role of good governance for sustainability. They stressed the importance of education for fostering sustainability and introduced the concept of "hybrid SMEs/SME 5.0" through the X.0 wave/age (X.0 = 5.0) theory. This concept aims to shape the future of education and smart governance to address the challenges posed by the pandemic.

Doost Mohammadian et al. [14] examined the development of a readiness assessment framework for SMEs, specifically focusing on preparing them for adopting the educational components of the future Industry 4.0. They emphasized the growing importance of information technology and operational technology convergence and the need for SMEs to adapt to these changes for a sustainable future.

Doost Mohammadian et al. [15] introduced the DOOST SME ranking (DSRM) model, focusing on the development of educating SMEs in preparation for the future, specifically highlighting the impact of the fourth industrial revolution and emerging technologies such as the Internet of Things and artificial intelligence. This model categorizes SMEs based on various criteria, offering a ranking method that can help higher educational institutions (HEIs) and other educational stakeholders to foster educational excellence in the digital age, which they termed as "SMEs 5.0".

This study presents a roadmap for SMEs to integrate sustainability principles in decision making in the digital age. This is done by using the 7PS framework, an integrative approach that considers economic, social, and environmental aspects to sustain organizational performance, and X.0 wave, a theory offering insights into the intricate dynamics of innovation, sustainability and governance (Figures 1 and 2). The literature on the 7PS framework and X.0 wave theory is presented in the Section 2. A fuzzy AHP is used in Section 3 to ensure that 7PS criteria sustainability goals are prioritized effectively.

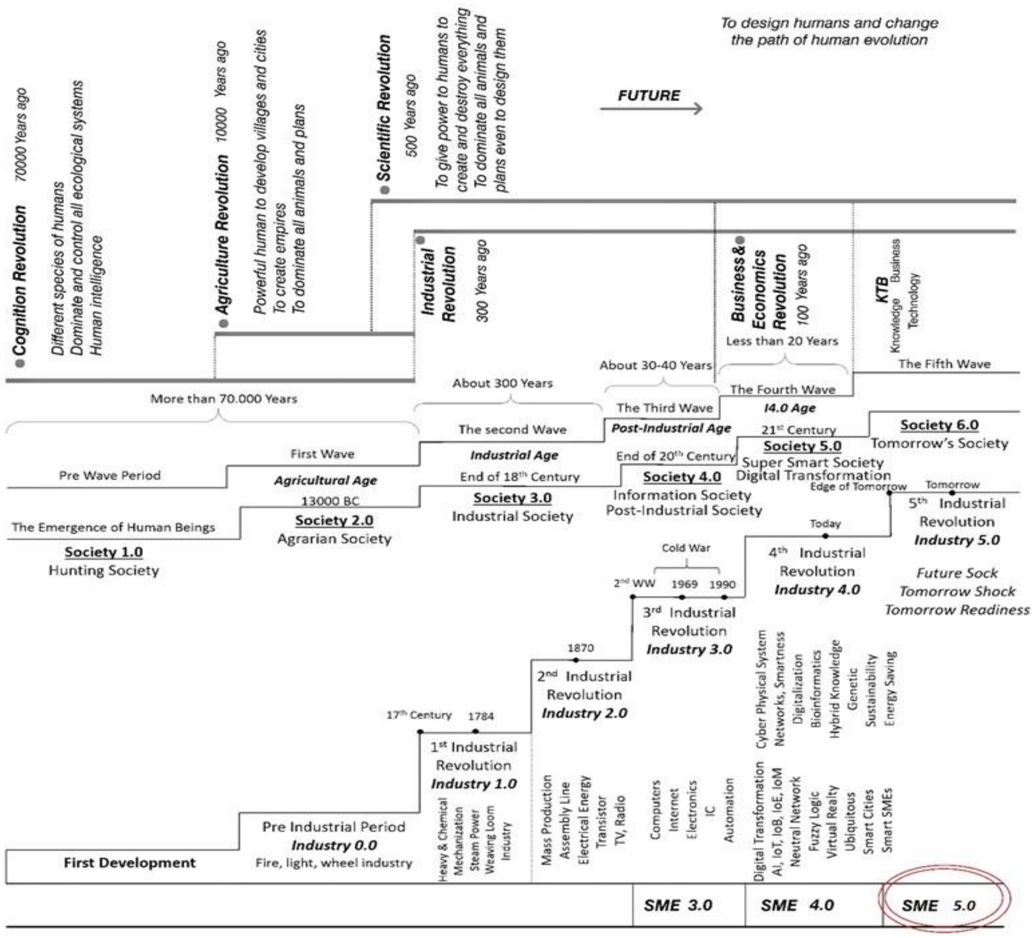

Figure 1. The X.0 wave/age (X.0 = 5.0) theory, ages, society, industries, technologies, and SMEs [7–17].

Spangenberg's paper [18] addressed the challenge of reconciling sustainability and economic growth within the framework of sustainable development. It underscored the importance of integrating economic, environmental, social, and institutional dimensions. The study introduced sustainability scenarios for Germany, highlighting the need for integrated policies to balance these objectives and identifying five core action zones for policy formulation. The criteria presented in the paper serve as tools for assessing policy proposals' impact on key sustainability objectives.

Oliver et al. [19] challenged EU innovation policies that prioritize R&D investment, instead emphasizing the significance of collaboration and regional context in SME innovation. It identified regional variations in SME innovation, with more innovative regions benefiting from a mix of R&D, collaboration, and non-R&D inputs, while less innovative regions rely more on external sources and collaboration. The study suggested the need for a place-sensitive and collaboration-based policy approach to enhance SME innovation across different European regional contexts.

Shi et al. [20] outlined the evolution of sustainable development (SD) theory, addressing misconceptions in its interpretation. They classified three periods in SD theory's development and advocated for strong sustainability as the accepted concept. The study also highlighted the significance of culture, good governance, and life-support systems in promoting SD.

Camilleri [21] focused on strategic attributions of corporate social responsibility (CSR) and environmental management in the context of the tourism industry. The research investigated stakeholders' perceptions of hospitality businesses' CSR and environmentally friendly practices, indicating that these practices can create value for companies, society, and the natural environment, improving growth prospects and long-term competitiveness.

Porter et al. [22] suggested that viewing the relationship between the environment and competitiveness as a fixed trade-off can be counterproductive. They argued that environmental regulations can lead to innovation and increased resource productivity, offsetting compliance costs and improving competitiveness. The authors proposed shifting the focus from pollution control to pollution prevention and emphasize the importance of resource productivity.

Tang et al. [23] investigated the relationship between green innovation and firm performance in the context of managerial concern for the environment. They found that green process innovation and green product innovation positively predict firm performance. However, the presence of managerial concern strengthens the positive effect of green process innovation but does not significantly impact green product innovation's effect on firm performance. These findings have implications for further research and business policy.

Dempsey et al. [24] focused on the social dimension of sustainable development, particularly in the context of urban sustainability. They emphasized that sustainable development encompasses economic, environmental, and social aspects. This paper aimed to provide a clearer definition of social sustainability within urban settings. It explored the connection between urban design and social sustainability, highlighting two key dimensions: equitable access and community sustainability.

Takalo et al. [25] conducted a systematic literature review on green innovation (GI) from 2007 to 2019. They analyzed 178 articles on GI, finding that topics related to the benefits of GI implementation were most common. Manufacturing industries had the largest share of articles, and mathematical modeling was the most frequently used research method. They identified leading journals and performed clustering of articles, citation analysis, and co-authoring network analysis. The study provided insights and research opportunities in the field of GI, valuable for universities, organizations, and companies involved in green innovation.

2. The concept of present work (background/literature review)

The X.0 wave/age theory, developed by Prof. Dr. Doost in 2010, is a theory on the evolution of civilizations based on technological advancements. The theory builds upon the earlier wave theories such as the industrial revolution and the information age and proposes that we are currently in the X.0 age, where X can be any number greater than 5 [5]. The theory proposes that throughout history, there have been distinct waves or ages of civilization, each characterized by a significant technological advancement that fundamentally changed the way people lived and interacted with each other and their environment. The X.0 wave theory provides a comprehensive framework for understanding the evolving relationship between human civilization, technology, and society. This theory identifies a series of distinct waves, each denoted by an X.0, representing pivotal stages in the development of our world. These waves signify profound shifts in various aspects of life, including technological innovation, economic paradigms, societal structures, and cultural norms. The X.0 wave theory is grounded in the concept of *waves of innovation*.

Each successive X.0 wave brings transformative changes, fundamentally altering the way we live, work, and interact with one another. These waves are closely linked to critical technological advancements that guide human societies toward new frontiers. The X.0 waves progressed as follows:

(1) X.1 = 1.0: the agricultural age. Marked by the domestication of plants and animals, leading to settled agriculture and permanent settlements.
(2) X.2 = 2.0: the industrial age. Characterized by the invention of steam engines and fossil fuel–powered machines, giving rise to mass production, urbanization, and modern capitalism.
(3) X.3 = 3.0: the information age (post-industrial age). Initiated by the rise of computers and the internet, revolutionizing global communication, fostering knowledge-based industries, and enabling the globalization of economies.
(4) X.4 = 4.0: the intelligence age (digitalization age). Defined by the extensive use of artificial intelligence, machine learning, and advanced technologies that reshape human life and work.
(5) X.5 = 5.0: the human age or the age of integration. An era where technology integrates with human biology, driving advancements in biotechnology, genetic engineering, and brain-machine interfaces, promising significant improvements in healthcare and human performance.
(6) X.6 = X.0: the transhuman age or the age of imagination. Representing the next phase of human evolution, where technology and biology merge, enabling humans to surpass their current limitations. This age holds the potential for groundbreaking changes, including the possibility of immortality and the exploration of new frontiers in space.

The X.0 in the theory name refers to an unknown future wave or age that will be characterized by a technological advancement that is currently beyond our imagination [5,13–16]

The theory suggests that the first wave, or 1.0, was the agricultural age, in which humans transitioned from hunter-gatherer societies to settled agricultural communities. The second wave, or 2.0, was the industrial age, in which humans developed steam power, mechanization, and mass production. The third wave, or 3.0, was the information age, in which the development of computers and the internet changed the way information is stored, processed, and communicated. The theory further posits that we are currently in the fourth wave, or 4.0, the age of artificial intelligence, which is marked by the development of machine learning, robotics, and automation. The X.0 wave theory is dynamic, envisioning a continuous evolution of human civilization as we adapt to rapidly advancing technologies and changing social and economic conditions.

In the context of the digital economy, the theory introduces the concept of Society X.0, where data becomes a primary driver of innovation and growth. However, it also raises concerns about privacy, as personal data is increasingly commodified and exploited by corporate entities.

Ultimately, the X.0 wave theory offers a valuable framework for comprehending the implications of our technological trajectory for innovation, markets, and privacy. It emphasizes that the current state of the digital economy is just one phase in a broader progression of technological and societal evolution. By taking a long-term perspective and considering potential future scenarios outlined by this theory, policymakers and industry leaders can develop more effective strategies to promote innovation, ensure competitiveness, and safeguard privacy in our rapidly evolving digital landscape.

The X.0 wave/age theory emphasizes the importance of innovation and technological progress in shaping the course of human history and argues that each wave of civilization builds upon the achievements of the previous one. However, it also acknowledges that each wave brings with it new challenges and risks, such as job displacement, environmental degradation, and social inequality, which must be addressed in order to ensure the continued progress and prosperity of humanity.

This theory has significant implications for businesses and applications. It suggests that businesses must be able to adapt to new technologies to survive in the changing landscape. For example, “SMEs X.0” refers to small and medium-sized enterprises that leverage digital technologies to innovate and compete. “Industry X.0” refers to the fourth industrial revolution, which is characterized by the integration of new technologies such as the internet of things, artificial intelligence, and big data analytics into the manufacturing process. “Society X.0” refers to the shift toward a more connected and data-driven society, where people can access and share information in real-time.

The X.0 wave/age theory is driven by technological advancements, and these technologies are expected to shape the future scenarios. Work X.0 refers to the changing nature of work, where automation and artificial intelligence will disrupt traditional jobs and create new ones. Entrepreneurship X.0 refers to the democratization of entrepreneurship, where technology has lowered the barriers to entry and enabled anyone with an idea to start a business. Job X.0 refers to the shift toward a more agile and flexible workforce, where people can work remotely and collaborate across borders. Edu X.0 refers to the transformation of education, where technology has made learning more accessible and personalized. Welfare X.0 refers to the potential for technology to solve some of the world’s most pressing challenges, such as climate change, poverty, and inequality.

The X.0 wave/age theory provides a useful framework for understanding the implications of this trend for innovation, markets, and privacy. The theory suggests that the current state of the digital economy is just one stage in a larger process of technological and social evolution, and that future waves or ages may bring about new challenges and opportunities. By adopting a long-term perspective and considering the potential future scenarios suggested by the X.0 wave/age theory, policymakers and industry leaders can develop more effective strategies for promoting innovation, ensuring competition, and protecting privacy in a rapidly changing digital landscape [1,5,11,12,17].

Table 1 describes how to measure sustainability based on the impact (i), probability (p) and ratio (r) of each pillar presented on Figure 2.

SME	Society	Industry	Waves/Ages	Revolutions			Year
	Hunting Society Society 1.0		Pre wave period	-)Cognition Revolution -)To Dominate and Control all ecological System -) Human Intelligence	The Emergence of Human Beings	-)First Development -)Different Spices of Human	70000 Years ago
	Society 2.0 Agrarian Society	-) Pre Industrial Period -) Industry 0.0 -) Fire, Light, Wheel Industry	-)The First Wave -)Agricultural Age	-)Agriculture Revolution -) Powerful Human to Develop Urban Areas -) To Create Emprises To Dominate All Animals, Plans and planets			13000 Years ago
				-) Scientific Revolution -)To Give Power to Humans to Create and Destroy Everything In the Planet -) Just one Human Specie			500 Years ago
	Society 3.0 Industrial Society	-)1^{st} Industrial Revolution -) Industry 1.0	The Second Wave Industrial Age	Industrial Revolution			17^{th} Centaury
		-) Heavy and Chemical Industry -) Mechanization -) Steam Power -) Wearing Loom					1784
		-)2^{nd} Industrial Revolution -) Industry 2.0 -)Mass Production -)Assembly Line -) Electrical Energy -) Transistor, TV, Radio					1870
SME 3.0	-) Society 4.0 -) Information Society -) Post Industrial Society	Industry 3.0 • Computers • Internet • Electronics • IC • Automation	-) The 3^{rd} Wave -) Post Industrial Age	-)Business and Economics Revolution1 Future	To Design Humans and Change the Path of Human Evolution	100 Years 40 Years The Cold War	2^{nd} WW 1969 1990 2000
SME 4.0 Smart SME	-)Society 5.0 -) Smart Citizen	The 4^{th} Industrial Wave • AI, IoT, IoB, IoE • IoM, Neutral Network • Fuzzy Logic • Ubiquitous • Networks	-) 4^{th} Industrial Wave -) Digitalization Age -) Digital Transformation -) Virtual Reality -) Cyber Physical Systems -) Smartness -) Digitalization	-)Business and Economic Revolution 2 -)Hybrid Organization -)Cloud HR -)Greenhouse Gases Reduction -)Energy Saving -) CSR	Bioinformatics Hybrid Knowledge Genetics Sustainability	10 Years	2006 2011 Today
SME 5.0 SMEs for Tomorrows' Shocks	Society 6.0	Industry 5.0	-) The 5^{th} Industrial Wave -) Tomorrow Age		KTM Model Future Shocks Tomorrow Shocks	Edge of Tomorrow	Tomorrow

Figure 2. Map of the X.0 wave/age (X.0 = 5.0) framework [7–17,26].

Table 1. Sustainability measurement [7–17,26].

Index	Description	Row
Si	Sustainability	1
Pi	Probability of each pillar	2
Ii	Impact of each pillar	3
ri Normal	Normalized ratio of each pillar	4
Si = ∑ (Pi * Ii * ri Normal)		

2.1. Sustainable future

Creating a sustainable future is a global challenge that requires collaboration between governments, businesses, and communities. In 2015, the Sustainable Development Goals (SDGs) established 17 goals for humanity as a comprehensive roadmap to achieve global sustainability; the hope for a sustainable world gained real traction among the next generation of businesses, governments, and investors. Technology, entrepreneurship, and smart policy-making have the potential of turning green ideas into a tangible reality. However, progress toward these goals is lacking.

A sustainable future requires managing natural resources sustainably across the globe, in order to protect and restore land, soil, forests, and ecosystems that are critical for life. Achieving sustainability in our daily lives requires a significant effort and is more efficiently achieved by looking at one issue at a time, such as reducing your carbon footprint or switching to sustainable energy sources (e.g., solar energy). Achieving this sustainable future is possible with both existing and expected technology, but only with major shifts in production patterns. Making these shifts will require overcoming substantial economic, social, and political challenges, being essential to work together to create a better future [10,11,17,18].

2.2. Global tech-sustainable governance

In the uncharted territory of this digital age, where innovation and transformation unfold at unprecedented speeds, a global tech-sustainable governance is imperative. Within the sweeping currents of technological advancements, we find ourselves at a pivotal juncture, seeking not only to harness the potential of digital innovation but also to navigate the seas of sustainability and governance. The tech giant TechWave Innovations Inc. is a notable example: In its quest for global expansion and technological innovation, the company faced a sustainability challenge, as its rapid growth demanded a colossal amount of energy and resources, underscoring the necessity for sustainable practices in the digital age. In this section, we explore the concept of global tech-sustainable governance, drawing inspiration from other real-world examples. We delve into the essence, relevance, and transformative role that global tech-sustainable governance plays in enhancing our capacity to face the digital age with resilience and cybersecurity at the forefront. This journey sets the stage for a comprehensive understanding of the intricate interplay between emerging technologies and the sustainable governance of our digital future.

2.3. Digital resilience

In this digital age, where innovation and disruption are the norm, the concept of digital resilience emerges as a guiding star. As we set sail, the first beacon we encounter is the formidable realm of cybersecurity measures. In this ever-evolving landscape, effective cybersecurity strategies serve as our protective armor. We deploy vigilant threat detection, impenetrable prevention measures, and swift incident response to guard our digital treasures and the sanctity of data. In the turbulent waters of digital disruptions, data redundancy and backup plans act as our steadfast anchors. These are our lifelines in the event of a tempest, ensuring that even when waves of uncertainty crash upon us, we remain resilient. Disaster recovery plans stand ready to salvage what is vital, offering reassurance in times of peril. In our quest for resilience, we harness the power of adaptive technologies. Machine learning and artificial intelligence become our navigational instruments, guiding us through treacherous waters by identifying and countering emerging threats in real-time. With these tools, we chart a course through the dynamic digital landscape. Acknowledging that even the most advanced vessels require skilled crews, we recognize the significance of human factors. Employee training, awareness, and the cultivation of a culture of security within our organization become the beating heart of our resilience. In the face of adversity, our crew remains steadfast and vigilant. As we sail forth, we are not blind to the challenges that lie ahead. The threat landscape, like tempestuous seas, constantly shifts and evolves. Resource allocation becomes a delicate balancing act, where we must weigh proactive resilience measures against the demands of day-to-day operations. The interconnectedness of our systems, while beneficial, also introduces vulnerabilities that require vigilant attention. In our unwavering pursuit of digital resilience, we steer our ship toward the shores of sustainable governance. Digital resilience is not just a safeguard; it is an enabler. It empowers organizations and governments to maintain essential services, protect sensitive data, and uphold trust in the digital realm. In our journey, the synergy between digital resilience and sustainable governance becomes our North Star, guiding our ship toward a brighter and more secure digital future. As we navigate the digital storm, digital resilience becomes our steadfast companion, ensuring that we not only survive but thrive in the ever-evolving landscape of the digital age.

2.4. Cybersecurity in the digital age

With the increasing reliance on digital technologies, data-driven systems, and interconnected networks, the protection of sensitive information and the integrity of critical infrastructure have become crucial imperatives.

The digital age has witnessed a rapid evolution of cyber threats, ranging from sophisticated cyberattacks to data breaches and identity theft. Cyber adversaries employ a wide array of tactics, techniques, and procedures to exploit vulnerabilities in digital ecosystems. Understanding the evolving threat landscape is essential for devising effective cybersecurity strategies. In an era where data has emerged as a valuable commodity, protecting the privacy of individuals and organizations is a pressing concern. Robust cybersecurity measures are essential to safeguard sensitive data from unauthorized access and breaches. Compliance with data protection regulations and standards is a pivotal aspect of ensuring data privacy. The resilience of digital systems and critical infrastructure against cyberattacks is a cornerstone of cybersecurity. Organizations and governments must adopt proactive measures to detect, mitigate, and recover from cyber incidents. Cyber resilience involves not only technological aspects but also strategic planning, incident response, and crisis management. Given the global nature of cyber threats, international cooperation plays a crucial role in combating cybercrime and ensuring cybersecurity. Collaborative efforts between nations, as well as public-private partnerships, are essential for sharing threat intelligence, best practices, and mitigating the cross-border impact of cyber incidents. As emerging technologies such as artificial intelligence, the Internet of Things, and 5G connectivity proliferate, new cybersecurity challenges emerge. The integration of these technologies into various sectors necessitates innovative approaches to cybersecurity, including threat modeling, risk assessment, and secure-by-design principles. Effective cybersecurity governance and policies are instrumental in shaping a secure digital environment. Governments and regulatory bodies must formulate and enforce cybersecurity regulations, standards, and guidelines to protect critical assets and promote best practices across industries. Building a culture of cybersecurity awareness and innovation is imperative in the digital age. It entails educating individuals and organizations about cyber risks, promoting a security-first mindset, and fostering innovation in cybersecurity technologies and strategies. In summary, cybersecurity is an integral component of navigating the future in the digital age. It enhances global tech-sustainable governance, digital resilience, and cybersecurity through frameworks and theories. Cybersecurity underpins the safeguarding of digital assets, the protection of privacy, and the resilience of societies in the face of evolving cyber threats. As the digital age progresses, understanding and addressing the multifaceted aspects of cybersecurity remain pivotal to charting a secure and resilient future.

2.5. The 7PS framework

In the dynamic landscape of the digital age, where technology permeates every facet of contemporary life, the quest for sustainable governance, digital resilience, and robust cybersecurity has taken center stage. Navigating this complex terrain requires not only technological prowess but also a comprehensive framework that transcends traditional boundaries and embraces the multidimensional challenges of the digital era.

The 7PS framework—a beacon of sustainability—illuminates the path toward a future where global governance, digital ecosystems, and cybersecurity are not just functional but thriving. Rooted in the philosophy that sustainability extends beyond environmental concerns, the 7PS framework expands its embrace to encompass economic prosperity, societal well-being, and the responsible stewardship of technological innovations. In the digital age, economic sustainability is intricately linked to technological advancements and global markets. Exploring the synergy between economic viability and digital innovation uncovers the essential role this pillar plays in securing sustainable governance and digital resilience. The interconnected digital world must prioritize social sustainability to ensure that the benefits of technology are accessible to all. Fostering inclusivity, diversity, and resilient communities is the essence of this pillar, aligning with the broader goal of equitable digital governance. The digital realm leaves environmental footprints, making environmental sustainability paramount for preserving the planet. This pillar explores responsible resource management and the mitigation of digital environmental impacts—a crucial aspect of the journey toward digital resilience and global governance. Cultural sustainability, as a bridge between heritage and innovation, gains significance in the digital age. This pillar, as shown in Figures 3 and 4, emphasizes the preservation of cultural identities and the fostering of creativity in our interconnected world. Technology is both a catalyst and an enabler in the quest for sustainable governance and digital resilience. This pillar sheds light on the responsible development and deployment of technologies that drive progress while safeguarding cybersecurity. Governance and policy sustainability lie at the core of the exploration. Effective governance structures, transparency, and adaptable policies are vital for steering the digital future toward sustainability and resilience. Collaboration is the linchpin of the digital age. This pillar emphasizes dialogue, partnerships, and shared responsibility as essential elements for navigating the complexities of global tech-sustainable governance, digital resilience, and cybersecurity. As we embark on this journey, the 7PS framework stands as a comprehensive guide, intertwining these pillars into a unified framework that addresses the multifaceted challenges of the digital age.

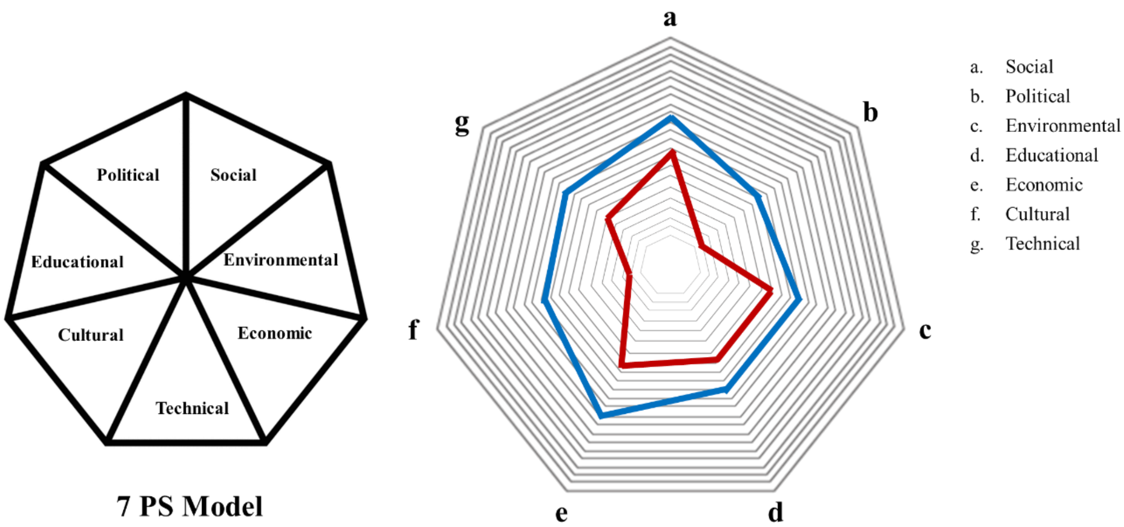

Figure 3. The seven pillars of sustainability (7PS) model [7–17,26].

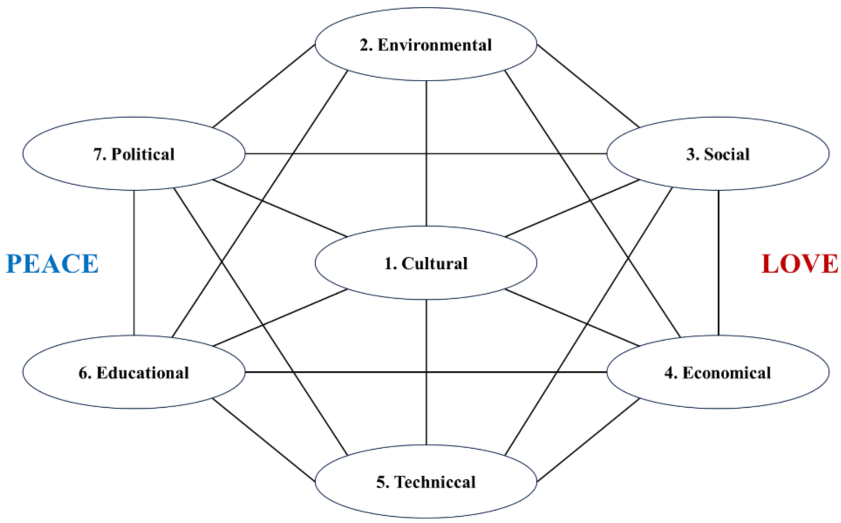

Figure 4. The seven pillars of sustainability (7PS) model, connections, priorities, and values (peace & love) [7–17,26].

The 7PS framework is a comprehensive approach to enhancing organizational sustainability. It encompasses seven key pillars, each playing a crucial role in fostering sustainability within organizations. These pillars are economic viability, social equity, ecological integrity, cultural vitality, community well-being and quality of life, inter/intragenerational equity and justice, and good governance. Economic viability is essential for an organization's financial stability and long-term growth. It emphasizes the need to balance profitability with sustainable practices. Social equity promotes inclusivity and diversity within organizations, ensuring fair treatment of employees and stakeholders. Ecological integrity addresses environmental responsibility, encouraging practices like reducing carbon emissions and adopting renewable energy sources. Cultural vitality focuses on preserving diverse cultural traditions while embracing innovation in an inclusive manner. Community well-being and quality of life aim to improve the lives of individuals living near organizational activities (Figures 5 and 6). Inter/intragenerational equity highlights the importance of fair decisions across generations, considering future implications. Good governance emphasizes transparent decision-making processes involving all stakeholders. Empirical evidence supports the pivotal role of these pillars in enhancing sustainability. Organizations that prioritize them tend to experience improved financial performance, increased stakeholder satisfaction, and reduced negative environmental impacts. Structural equation modeling using data from government organizations validates the positive relationship between implementing the 7PS framework and achieving sustainability goals. This demonstrates the framework's effectiveness in guiding decision-making toward sustainable practices. In conclusion, the 7PS framework offers a holistic approach to sustainability, addressing economic, social, environmental, cultural, and ethical dimensions. Its empirical substantiation underscores its significance as a tool for organizations striving to achieve sustainable development while considering various facets of sustainability.

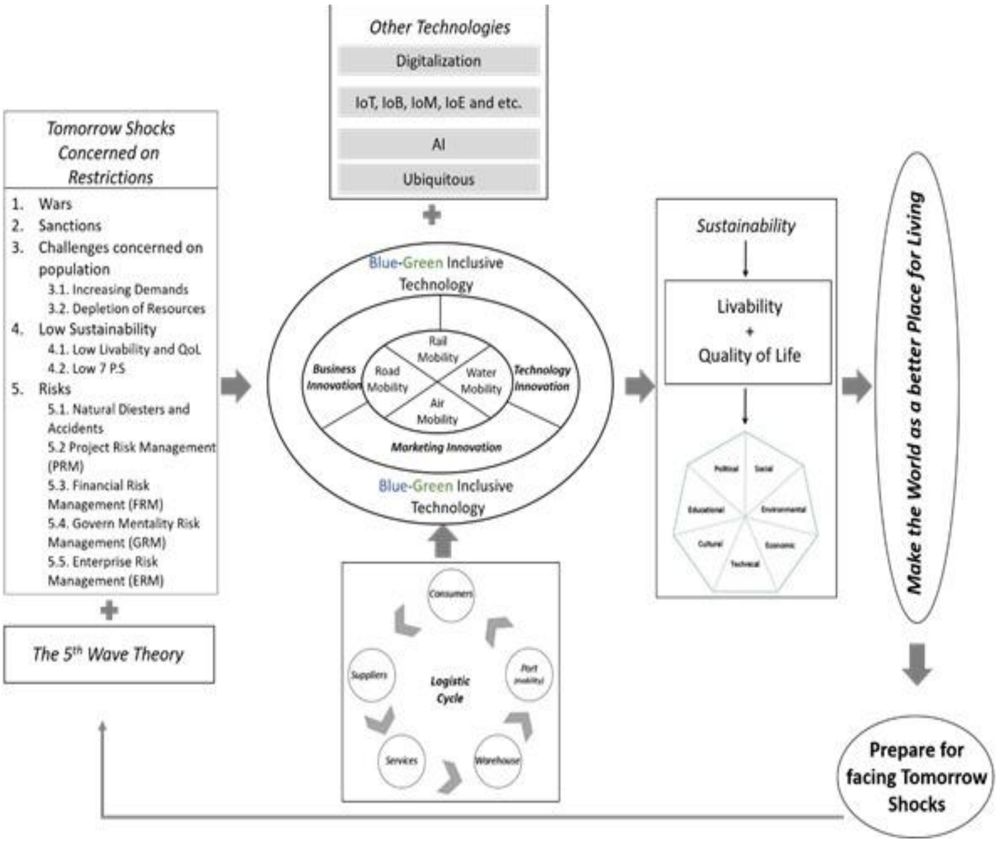

Figure 5. Technologies for making the world a better place for living [7–17,26].

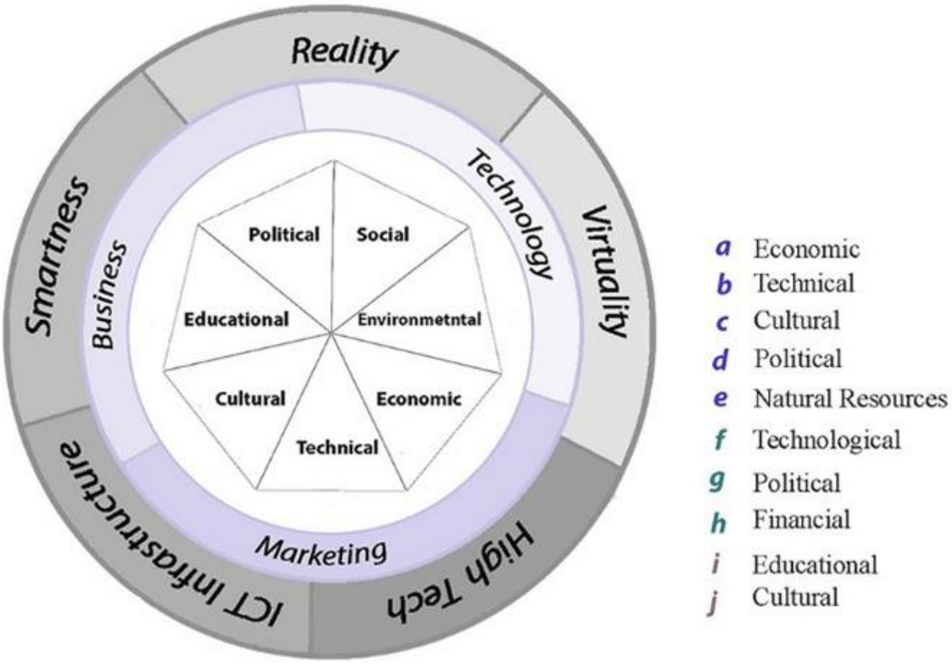

Figure 6. i-sustainability plus theory [7–17,26].

2.6. Culture of innovation

Amidst the ever-evolving digital landscape, nurturing an innovation-driven culture has become paramount for organizations aiming to attain sustainability and resilience. This section delves into the critical role that an innovation-centric culture plays in shaping the future of global tech-sustainable governance, enhancing digital resilience, and fortifying cybersecurity. Innovation culture is more than a buzzword; it represents the collective mindset, values, and practices within an organization that encourage and support the generation and implementation of novel ideas. Within the context of our study, understanding the dimensions of innovation culture is paramount. Innovation culture acts as a catalyst for sustainability, aligning with the principles of the 7PS framework. It empowers organizations to navigate disruptions and bolster their digital resilience strategies. Innovation also holds the key to cybersecurity in the digital age. Innovative approaches can fortify an organization's cybersecurity posture, addressing the complexities of modern threats and vulnerabilities. Fostering an innovation culture is pivotal for SMEs seeking to thrive in the digital landscape. SME 5.0, an emerging concept in the digital transformation of SMEs, hinges on embracing innovation as a core strategy. Inclusivity and diversity within an organization can fuel innovation. An inclusive workplace culture, diverse perspectives, and innovation outcomes are interconnected. In conclusion, the cultivation of a culture of innovation is a cornerstone for achieving global tech-sustainable governance, enhancing digital resilience, and safeguarding cybersecurity in the digital age. It serves as the connective tissue that binds these themes together, offering organizations a transformative pathway toward a resilient and sustainable future.

Innovation culture is a critical factor that greatly influences the effectiveness of the 7PS framework in enhancing organizational sustainability. Organizations that cultivate a strong culture of innovation are more likely to actively seek out sustainable solutions and embrace technological advancements that align with their sustainability objectives. Research conducted on innovation culture within organizations has consistently shown that companies that nurture an innovative mindset tend to engage more effectively with the 7PS framework and are more successful in implementing sustainable practices. This underscores the importance of fostering an organizational culture that encourages creativity, risk-taking, and collaboration, particularly in the context of sustainable innovation. By promoting creativity, collaboration, and a commitment to continuous improvement within an organization's culture, employees are encouraged to develop innovative solutions that not only address societal challenges but also align with sustainable principles. This emphasis on innovation culture plays a transformative role in enhancing the impact of the 7PS framework on organizational sustainability. Prominent organizations like Google and Apple have thrived by prioritizing innovation culture, allowing them to adapt to new challenges while maintaining their focus on achieving sustainable outcomes. These companies have effectively harnessed the power of innovation to develop groundbreaking technologies and sustainable practices simultaneously. Empirical evidence strongly supports the link between innovation culture and various measures of organizational sustainability, such as improved energy efficiency, waste reduction, and social responsibility initiatives. Research findings have demonstrated a robust positive correlation between the presence of an innovation culture and these sustainability metrics, further highlighting the transformative influence of innovation culture on organizational sustainability. In summary, innovation culture is a linchpin in augmenting the impact of the 7PS framework on organizational sustainability. Methods like the fuzzy AHP assign priority weights to criteria based on their relative importance, and innovation culture plays a pivotal role in this process. By fostering an environment that promotes innovative thinking and encourages collaboration across all levels of an organization's hierarchy, organizations can unlock significant potential for creating sustainable solutions that benefit both their operations and the broader society.

2.7. Theory of future mapping of comprehensive everything (or the X.0 wave/age theory)

In the context of navigating the future in the digital age, the X.0 wave theory holds significant promise. This theory encapsulates the idea that technological innovations and transformations occur in waves, ushering in distinct eras of human progress, such as Industry 4.0 and Society 5.0. At its core, the X.0 wave theory is guided by key principles. It recognizes innovation as the propeller of these waves, where groundbreaking technologies drive societal and organizational advancements. Moreover, it underscores the interconnected dynamics of technology, sustainability, and governance. Changes in one domain ripple across others, necessitating a holistic approach. The theory also emphasizes the need for adaptive governance structures that can keep pace with the rapid evolution of technology. Traditional governance models often struggle to adapt swiftly, requiring more agile approaches. Incorporating the X.0 wave theory into discussions of tech-sustainable governance is crucial. It illuminates the path toward governance models that integrate technological advancements while upholding sustainability principles across environmental, economic, and societal dimensions. Practically, the X.0 wave theory serves as a strategic compass for organizations and policymakers. By recognizing the transformative potential of these waves, stakeholders can proactively shape strategies that leverage innovation, sustainability, and effective governance. As the X.0 wave theory continues to evolve alongside technology and society, it remains vital in charting a course toward a future characterized by tech-sustainable governance, digital resilience, and fortified cybersecurity.

2.8. The role of SMEs in the digital transformation (SME 5.0/hybrid SME or tomorrow's SME concept)

The emergence of SME 5.0 represents a pivotal shift in the role of SMEs in shaping the digital future. SME 5.0, as a dynamic paradigm, encompasses advanced technologies, data-driven decision-making, and enhanced connectivity, all geared toward achieving sustainable growth and governance. This transformation is driven by various factors, including the pursuit of competitiveness, operational efficiency, and market relevance by SMEs. Government policies and incentives play a pivotal role in facilitating SME 5.0 adoption, providing essential support and resources to these enterprises as they navigate the digital landscape.

However, the path to SME 5.0 is not without its challenges. SMEs often encounter obstacles such as resource constraints and digital literacy gaps. Overcoming these challenges requires strategic planning and innovative solutions, drawing inspiration from successful case studies that highlight best practices and lessons learned. One of the defining characteristics of SME 5.0 is its alignment with the principles of global tech-sustainable governance. This paradigm promotes responsible and ethical digital practices, fostering transparency, accountability, and societal well-being. SME 5.0, therefore, assumes a transformative role in enhancing governance practices, contributing to a more sustainable and resilient digital ecosystem. Real-world experiences provide concrete evidence of the benefits of SME 5.0 adoption. Numerous SMEs have successfully transitioned to SME 5.0 models, achieving tangible outcomes and contributing to their respective industries. These case studies offer valuable insights and lessons that can be applied across diverse SME contexts, inspiring others to embark on their own transformative journeys. As we look to the future, SME 5.0 continues to evolve in response to emerging trends and technologies. Its role in shaping digital resilience and fortifying cybersecurity measures is increasingly significant. SME 5.0 acts as a catalyst for innovation, sustainability, and governance, offering a transformative roadmap for SMEs and the broader digital ecosystem. In essence, SME 5.0 represents more than just a technological shift; it embodies a holistic approach to navigating the complexities of the digital age. Its integration of advanced technologies, data-driven decision-making, and ethical governance practices positions SMEs as influential actors in achieving global tech-sustainable governance, enhancing digital resilience, and safeguarding cybersecurity in our ever-evolving digital society.

2.9. Inclusivity and diversity in innovation

Within the dynamic ecosystem of innovation, inclusivity and diversity play pivotal roles. Inclusivity ensures that a diverse array of voices is heard, contributing to the enhancement of global tech-sustainable governance through innovative solutions. Diversity in innovation breaks down traditional barriers and encourages the participation of individuals from various backgrounds. This fosters the cross-pollination of ideas, ultimately strengthening digital resilience in an interconnected world. Inclusivity and diversity are ethical imperatives and pragmatic drivers of innovation. They lead to the development of more representative and effective cybersecurity measures, aligning with the objectives of the digital age. Real-world case studies exemplify the transformative power of inclusive and diverse innovation initiatives. These examples underscore how embracing diversity leads to innovative practices in line with the principles of the 7PS framework and the X.0 wave theory. In the context of digital governance, inclusivity is paramount. It ensures equitable access and ethical use of technology, aligning with the broader goals of navigating the digital age securely and responsibly. As the digital landscape continues to evolve, inclusivity and diversity in innovation will be even more critical. Proactive efforts to foster inclusivity will help shape a more secure, resilient, and sustainable digital future, in harmony with the themes of your research.

3. Methodology and results

In the exploration of our research theme, which revolves around the commodification of personal data and its extensive ramifications, we can establish a connection with the challenge of aligning sequences delineated in the provided text. While our research does not directly pertain to sequence alignment, we can employ the concepts presented to tackle the issues arising from the commodification of personal data in the digital realm. Imagine the task of aligning sequences A and B; in our scenario, this equates to aligning diverse facets of the digital economy, such as data sources and market trends, integral to the commodification of personal data. Although we are not aligning nucleotides, we are aligning various elements within the digital landscape. Our objective is to determine the optimal alignment, akin to the highest-scoring alignment in sequence alignment, signifying the identification of the most efficient and ethical methods for managing personal data in the digital economy. To attain this goal, we can adapt the scoring system outlined in the text, replacing nucleotide evaluations with scores for different aspects of data usage, privacy safeguarding, and market impact. For example, positive scores may be assigned for ethical data practices, negative scores for privacy violations, and zero scores for neutral actions. Our research strives to discern the most effective strategies for aligning and coordinating the diverse components of the digital economy concerning personal data, employing similar recurrence relations to iteratively refine our approach as new data, technologies, and ethical considerations emerge. Ultimately, parallel to sequence alignment, our aim is to maximize the score—in our case, the overall societal benefit—by making locally optimal decisions contributing to global welfare in a digital economy characterized by data commodification.

$$S(i, j) = \max \begin{cases} S(i-1, j-1) + mat & \text{if } i > 0, j > 0 \text{ and } a_i = b_j \\ S(i-1, j-1) + mis & \text{if } i > 0, j > 0 \text{ and } a_i \neq b_j \\ S(i, j-1) + ind & \text{if } j > 0 \\ S(i-1, j) + ind & \text{if } i > 0. \end{cases}$$

The fuzzy AHP methodology is a powerful tool for assigning priority weights to the criteria within the 7PS framework, enabling a more nuanced assessment of complex decision-making processes in the context of sustainability governance. It allows for priority weights to be assigned based on evaluations made by experts or stakeholders involved in the decision-making process. Culture stands out as a linchpin criterion within this methodology due to its profound influence on the other pillars within the 7PS framework. By prioritizing cultural values within decision-making processes, organizations can ensure alignment between their sustainability goals and the broader cultural context in which they operate. In the context of assigning priority weights within the 7PS framework using the fuzzy AHP methodology, culture's significance becomes evident. It sets the tone for how employees perceive and engage with sustainability initiatives. A strong culture that values sustainability can drive transformative change, resulting in long-term positive outcomes for both the organization and society. The application of the fuzzy AHP extends beyond the 7PS framework, particularly in complex domains like global tech-sustainable governance. This methodology allows decision-makers to evaluate and prioritize factors affecting sustainable governance, taking into account uncertainties and vagueness inherent in emerging technologies such as artificial intelligence, the Internet of Things, sustainable engineering practices, and cybersecurity in the digital age. By using fuzzy AHP, organizations can effectively manage risks associated with these technologies while striving for a sustainable future. In summary, the fuzzy AHP methodology enhances decision-making within the 7PS framework and other complex domains by considering uncertainties and the influence of culture. This approach empowers organizations to make informed decisions that prioritize sustainability and align with their broader objectives and cultural context. In the context of our research, which revolves around the intricate dynamics of the digital economy and the pervasive implications of personal data commodification, we can draw a parallel with the concept of aligning sequences. While our research is not inherently about sequence alignment, we can adapt these analogous concepts to confront the multifaceted challenges posed by the commodification of personal data. Think of the challenge as aligning sequences A and B, akin to aligning various elements of the digital landscape, including data sources and market trends, pivotal in the process of personal data commodification. It is not about nucleotides, but rather about aligning the diverse facets of the digital world. Our overarching objective mirrors that of finding the optimal alignment, similar to seeking the "highest-scoring alignment" in sequence alignment. In our unique context, this quest translates to identifying the most effective and ethically sound approaches to manage personal data within the digital economy.

To accomplish this, we adapt the scoring system mentioned earlier. Instead of scoring nucleotide matches and mismatches, we assign scores to different facets of data usage, privacy protection, and market impact. Ethical data practices receive positive scores, privacy violations negative scores, and neutral actions are scored as zero. Our research's core purpose is to unveil the optimal strategies for aligning and harmonizing the intricate components of the digital economy concerning personal data. We employ similar iterative methods to fine-tune our approach, ensuring it adapts to evolving data, emerging technologies, and evolving ethical considerations.

Much like sequence alignment seeks to maximize scores, our ultimate aim is to maximize the overall societal benefit. We do this by making locally optimal decisions that contribute to global welfare in a digital economy marked by the commodification of personal data. In the ever-evolving landscape of the digital age, the commodification of personal data presents a multifaceted challenge with far-reaching implications for innovation, markets, and privacy. Within this context, our research objective is to employ a strategic decision-making approach, akin to a "greedy algorithm", to navigate the complexities of personal data commodification in the digital economy. Just as a greedy algorithm seeks to make locally optimal choices to find the best solution in various domains, our study aims to identify and implement data commodification strategies that optimize innovation, market dynamics, and privacy protection within the digital realm. Through this approach, we aspire to shed light on the intricate interplay between data-driven innovation and ethical considerations, ultimately contributing to a more comprehensive understanding of the digital economy's landscape.

In the context of our research concerning the commodification of personal data within the digital economy, we propose applying a modified version of the greedy algorithm to streamline decision-making processes and data analysis. While the traditional application of the greedy algorithm is often found in bioinformatics, IT, and other digital domains, it can be adapted to address specific challenges in the context of data usage, sharing, and privacy. Instead of aligning sequences, the modified greedy algorithm in our research aims to prioritize the most pertinent data sources. By employing a data-driven approach, this involves iteratively selecting and ranking data sources based on their relevance to the study of personal data commodification in the digital economy. The goal is to uncover sources that offer valuable insights into this complex domain.

The adapted greedy algorithm concept extends to privacy risk assessment within our research. It involves conducting a preliminary assessment of privacy risks associated with different data sources and then iteratively refining this assessment. Factors considered include data sensitivity, user consent, and potential privacy implications. The application of the modified greedy algorithm provides a systematic approach to formulate effective data sharing strategies. These strategies prioritize data sharing agreements that strike a balance between data utility, innovation, and the protection of privacy. Each decision regarding data sharing is made in a locally optimal manner, collectively contributing to the overarching research objectives.

In line with the adapted greedy algorithm, the research involves the development of adaptive privacy policies and consent mechanisms. These policies are designed to evolve continuously, responding to shifts in market dynamics and emerging privacy concerns. By doing so, we aim to ensure that privacy measures remain robust and up to date.

The modified greedy algorithm framework extends to the creation of user-centric data control mechanisms. These mechanisms empower users to customize their data sharing preferences, taking into account their comfort levels and the specific contexts in which their data is utilized. An application of the modified greedy algorithm in our research involves a comprehensive analysis of the digital economy and market trends. By selecting key indicators and factors that reflect personal data commodification, we prioritize data points and market trends with the most profound implications for innovation, market dynamics, and privacy within this domain. The research findings are presented using methods that ensure clarity and interpretability. Throughout the process, the decisions made are based on locally optimal choices, aligning with the overarching research goals within the broader framework of the study. This adapted greedy algorithm approach provides a structured and systematic method for addressing the challenges posed by personal data commodification in the digital economy. While the application of greedy algorithms is traditionally associated with bioinformatics and IT, our adaptation seeks to efficiently address the complexities of this research domain. Careful design and analysis of the algorithm within this context are essential to ensure its suitability and effectiveness. The incorporation of a greedy algorithm in this research, which focuses on the intricate exploration of personal data commodification in the digital economy and its multifaceted implications, may initially seem unorthodox. Greedy algorithms are traditionally associated with optimization problems where sequences of choices lead to specific objectives, often based on immediate, locally optimal decisions. However, this research delves into the complexities of sociotechnical and ethical dimensions intertwined with data privacy and the digital economy. Nonetheless, algorithmic thinking can be adapted to gain deeper insights into particular facets of this study. In this context, various applications illustrate how algorithmic concepts can enhance this research methodology.

One fundamental application involves data selection and sampling. Given the extensive datasets related to personal data and the digital economy that this research often entails, a greedy approach to data selection can be beneficial. This approach involves the careful curation of a representative subset of data, prioritizing elements most pertinent to the research inquiries, or those with significant computational influence. Feature selection is another critical aspect. When constructing predictive models or conducting statistical analyses, it is imperative to identify the most informative features while preserving the predictive power of the model. Here, a greedy algorithm can be instrumental in iteratively selecting these features. Additionally, in the context of privacy-preserving data sharing, a greedy approach is advantageous. It facilitates the dissemination of only essential information and involves data anonymization and aggregation, thereby revealing trends and insights without compromising individual privacy. Ethical considerations are paramount, given its focus on data privacy. Algorithmic fairness is crucial, and greedy algorithms can be utilized to inform decisions surrounding data usage and sharing, prioritizing fairness while minimizing biases. In the realm of market analysis, the study of the digital economy and its trends may benefit from a greedy approach, which involves selecting specific data points, metrics, or market segments that best encapsulate the commodification of personal data, offering valuable insights.

Furthermore, privacy impact assessments play a pivotal role. Developing a greedy algorithm for conducting these assessments helps pinpoint critical privacy risks and devise effective mitigation strategies in various data processing scenarios. User consent optimization is another dimension where algorithmic concepts can be applied. By employing a greedy algorithm, consent processes are designed that maximize user comprehension and control while upholding legal requirements. Also, the analysis of privacy policies of digital platforms and services can benefit from a greedy algorithm. This approach helps highlight essential terms and conditions that have implications for users' data privacy. It is crucial to emphasize that, while algorithmic concepts find their place in various aspects of research, ethical and legal considerations must remain at the forefront, particularly when dealing with personal data. Greedy algorithms represent just one facet of the computational approaches employed in specific dimensions of this research. The broader context, shaped by ethical standards, regulatory frameworks, and societal impact, ultimately guides this methodology and analysis. In our methodology, we integrate a greedy algorithm and fuzzy logic to address the multifaceted challenges associated with the commodification of personal data in the digital economy. This approach strikes a delicate balance between systematic data analysis and ethical considerations.

We begin with the application of the greedy algorithm for data selection and sampling. This algorithm intelligently selects a representative subset of personal data for analysis, prioritizing the most relevant data points. By doing so, we reduce computational overhead and focus on essential information crucial to our study. Next, we leverage fuzzy logic to assess the relevance of various data points within the selected dataset. Utilizing membership functions, we quantify the degrees of importance based on criteria such as data source, type, or context. This nuanced assessment allows us to make more informed decisions. Moving forward, we employ the greedy algorithm for privacy impact assessment. Starting with a baseline evaluation, our approach iteratively optimizes decision-making processes to minimize privacy risks while preserving data utility and fostering innovation. fuzzy logic comes into play for risk assessment, providing a comprehensive model to quantify the uncertainty and imprecision surrounding privacy risks. Our fuzzy rules consider various factors contributing to privacy risk, given the intricate nature of personal data. When it comes to decision-making on data sharing, the greedy algorithm guides us to balance data value, privacy preservation, and market dynamics. This approach allows us to optimize data sharing strategies for maximal benefit. For ethical assessment, we integrate fuzzy logic, evaluating the ethical dimensions of data utilization scenarios. Fuzzy rules gauge the degree of ethical alignment in each data usage case, grounded in principles like consent, transparency, and fairness. Our methodology also includes dynamic privacy policies adapted using the greedy algorithm to stay attuned to evolving digital economy practices. Continuous evaluation ensures that our policies optimize privacy, innovation, and market responsiveness. To put the control back in the hands of users, we employ fuzzy logic to design user-centric privacy controls and consent mechanisms. Users can customize their data-sharing preferences based on their comfort levels, allowing for a more personalized approach. In analyzing the digital economy and market trends, the greedy algorithm is employed to identify key indicators or variables exemplifying the commodification of personal data. We focus on factors that exert the most substantial influence on innovation, markets, and privacy. Finally, fuzzy logic is used to interpret and visualize research findings, providing a clear depiction of fuzzy degrees related to data relevance, privacy risk, ethical alignment, and market impact. This integrated approach empowers our research to tackle the intricate confluence of data commodification, ethics, and digital markets. By combining computational precision with ethical considerations, we strive to make well-informed decisions that resonate with local optimization (greedy) while embracing the nuances of uncertainty (fuzzy logic). Throughout our analytical and decision-making processes, our unwavering commitment remains focused on ethical considerations and the human dimension of data privacy. In the quantitative phase of our study, we aimed to validate the insights obtained through qualitative analysis, utilizing the fuzzy Delphi method. This method served as a robust tool to corroborate and further explore the antecedents and consequences of personal data commoditization within the digital economy. It allowed us to pinpoint the pivotal factors and outcomes associated with the commoditization of personal data. The fuzzy Delphi method is a collaborative process that hinges on the synergy between the researcher and a panel of subject matter experts. Expert opinions are systematically gathered through a meticulously designed questionnaire. In our research, we crafted a fuzzy Delphi questionnaire and distributed it to a select group of academic and organizational experts. This questionnaire was meticulously structured to capture the nuanced insights of these experts. Our study encompassed a diverse pool of expertise. In the qualitative phase, we engaged with 14 seasoned professionals specializing in business and university sustainability. For the quantitative phase, we expanded our reach to 23 experts from both academia and the corporate sector. The selection of these experts was meticulously carried out using a targeted sampling method, ensuring a well-rounded perspective. Throughout the qualitative phase, we conducted in-depth interviews with our selected experts. These interviews revolved around comprehensive inquiries related to the factors, antecedents, and consequences tied to the commoditization of personal data in the digital economy. This data collection process extended until we reached the point of theoretical saturation.

Building upon the insights gathered during the qualitative phase and leveraging the expertise of our panel, we developed a specialized fuzzy Delphi questionnaire. This questionnaire was thoughtfully crafted to elicit the informed opinions of experts in the field of personal data commoditization, particularly regarding its antecedents and consequences. The ensuing quantitative phase aimed to quantitatively validate and expand upon the rich qualitative findings. In the qualitative phase of our research, we set out to uncover the intricate antecedents and consequences of personal data commoditization within the digital economy. To achieve this, we employed a multifaceted research approach that combined textual analysis with semi-structured interviews, aiming to gain a comprehensive understanding of this complex phenomenon. We initiated our investigation by conducting a thorough analysis of texts pertinent to personal data commoditization. This textual scrutiny served as the foundational element for crafting insightful interview questions, meticulously designed to delve into the nuances of the subject matter. Subsequently, we executed a meticulous interview process, ensuring comprehensive coverage of key aspects and engaging with relevant stakeholders. The transcripts of these interviews were then subjected to a rigorous analysis. To conduct this analysis, we harnessed the power of the theme analysis method and leveraged the advanced capabilities of NVivo 12 software. Through this process, essential themes emerged, providing deep insights into the core elements of personal data commoditization. The key findings from our qualitative analysis have culminated in the identification of a comprehensive set of antecedents and consequences related to personal data commoditization. These findings are summarized in a detailed table, shedding light on the intricate web of factors contributing to the commoditization of personal data, alongside the diverse range of both positive and negative impacts associated with this phenomenon. The insights gleaned from this comprehensive analysis form the cornerstone of our research, offering a profound understanding of the digital landscape and the multifaceted challenges posed by the commoditization of personal data in the digital age.

In the qualitative phase of our research, we embarked on a comprehensive exploration of the intricate antecedents and consequences surrounding the commoditization of personal data within the digital economy. Our research methodology adopted a multifaceted approach, combining textual analysis with in-depth semi-structured interviews to establish a thorough understanding of this complex issue. This textual analysis served as the foundational step, enabling us to formulate probing interview questions that delved into the nuances of personal data commoditization. Subsequently, our semi-structured interviews were meticulously conducted, ensuring a comprehensive coverage of crucial aspects. The transcripts from these interviews were subjected to rigorous analysis, employing the robust thematic analysis method and making effective use of NVivo 12 software. Through this methodical process, crucial themes emerged, providing deep insights into the core elements of personal data commoditization.

The culmination of the qualitative phase unveiled an extensive array of antecedents and consequences associated with personal data commoditization. These findings are summarized in a structured format, highlighting 22 key factors that contribute to personal data commoditization and 11 positive and negative outcomes stemming from this phenomenon. These antecedents represent the intricate web of factors that play a role in the commoditization of personal data in the digital economy, while the consequences shed light on both the advantageous and adverse effects of this phenomenon. These detailed insights, as expounded in the subsequent sections of our paper, provide a profound understanding of the digital landscape and the multifaceted challenges presented by the commoditization of personal data.

Moving into the quantitative phase, we sought to establish a robust consensus among experts regarding the antecedents and consequences identified during the qualitative stage. This quantitative approach was pivotal in solidifying our understanding of the intricate topic at hand. In the second stage survey, mirroring the first stage, we collected responses to key topics and calculated fuzzy averages. Upon the conclusion of the second stage survey, our focus shifted to analyzing the differences in the de-fuzzified average of antecedents and consequences related to personal data commoditization. Our criteria for consensus were that if the difference was less than 0.1, experts had reached a consensus. The results present the different values of the de-fuzzified average. Based on the results, it is evident that the difference in de-fuzzified averages between the first and second stages was less than 0.1, signifying those experts had indeed reached a consensus regarding the antecedents and consequences of personal data commoditization. At this juncture, our survey was concluded, and we had successfully navigated both the qualitative and quantitative phases of our research, shedding light on the complex dynamics of personal data commoditization within the digital economy.

4. Discussion

The rapid evolution of technology in the digital age presents a dual challenge of both opportunities and risks, particularly in the context of sustainable engineering and cybersecurity. Advancements in technology offer innovative solutions that can contribute significantly to sustainability goals. However, they also introduce new cybersecurity threats that organizations must grapple with. Striking the right balance between adopting emerging technologies to advance sustainability without compromising data security or contributing to environmental degradation is a complex task. To address these contemporary challenges, organizations must integrate cybersecurity measures into all aspects of their operations. This entails ensuring that robust cybersecurity infrastructure and best practices are in place to protect critical data and systems from cyber threats as technology dependence continues to grow. The rapid pace of technological evolution also places demand on governance structures worldwide. Organizations need to continuously adapt to stay ahead of technological advancements while addressing the potential risks associated with cybersecurity threats. Collaboration between governments, organizations, and individuals is crucial in developing regulations, guidelines, and security measures to safeguard digital infrastructure from cyberattacks. Public-private partnerships are particularly important, as they combine resources from both sectors to effectively tackle these complex issues. Furthermore, the interplay between emerging technologies, sustainable engineering, and cybersecurity is essential in navigating global tech-sustainable governance. As new technologies continue to emerge, it is imperative to ensure that they are developed and deployed in ways that align with sustainable development goals. Sustainable engineering practices play a critical role in addressing environmental concerns associated with emerging technologies. Engineers can do so by adopting eco-design principles and considering life cycle analysis during product development to minimize resource consumption and maximize efficiency. In the face of increasing reliance on digital infrastructure, cybersecurity takes on paramount importance. The interconnectedness of systems makes them vulnerable to cyber threats, which can have profound consequences on both organizational operations and sustainability efforts. Ensuring the security of digital assets is integral to sustaining progress and protecting critical data. Moreover, inclusivity and diversity are recognized as catalysts for pioneering innovations within engineering education and the professional landscape amidst rapid technological evolution and cybersecurity threats. Embracing diverse perspectives fosters creativity and drives breakthrough solutions to address the complex challenges of the digitally connected world. Engineering education should promote inclusivity by encouraging underrepresented groups to pursue STEM fields and integrate ethical considerations related to cybersecurity into educational curricula. In summary, the challenges posed by rapid technological evolution and cybersecurity threats are multifaceted. Navigating these challenges requires organizations to strike a balance between innovation and security, adapt to technological advancements, and collaborate on cybersecurity measures. Sustainable engineering practices and a commitment to inclusivity and diversity are integral components of addressing these challenges and fostering innovation in a digitally connected world.

The X.0 wave theory is a valuable framework that sheds light on how to navigate the complexities of innovation-driven ecosystems while promoting sustainable governance practices across various sectors. It offers tools and insights into understanding how different waves of technological advancements unfold over time and how they impact an organization's ability to implement sustainable practices. Central to this theory is the recognition of the need for continuous adaptation and agility in the digital age. One of the key principles of the X.0 wave theory is that innovation, sustainability, and governance are intricately interconnected and should not be treated as separate domains. Instead, organizations should approach them holistically, recognizing that they influence and complement each other. This approach emphasizes the importance of adopting flexible strategies that can adapt to rapidly evolving technological landscapes while simultaneously ensuring sustainability and resilience. In today's digital age, the X.0 wave theory provides a valuable framework for understanding the dynamics between innovation, sustainability, and governance. It underscores the significance of embracing emerging technologies such as artificial intelligence, blockchain, and the Internet of Things as catalysts for sustainable development. By strategically leveraging these technologies, organizations can not only enhance their resilience in the face of rapid technological advancements but also promote sustainable practices. Furthermore, the theory delves into the interplay between innovation, sustainability, and governance at different stages of technological advancement, considering trends across various industrial revolutions, such as Industry 4.0. It suggests that organizations that embrace disruptive innovations while remaining committed to their sustainability goals can achieve long-term success in the digital age. By adapting their governance structures and policies according to the principles of X.0 wave theory, organizations can effectively navigate technological disruptions while fostering sustainable development. In essence, the X.0 wave theory offers a comprehensive framework for understanding the intricate dynamics of innovation, sustainability, and governance in the digital age. It posits that each wave of technological progress brings about transformative changes that reshape industries and societies. Decision-makers who harness the power of this theory gain valuable insights into how to address contemporary challenges through holistic solutions that integrate technological advancements with sustainable governance practices. By embracing the X.0 wave theory, organizations can develop strategies that not only drive innovation-led growth but also ensure the long-term sustainability of their operations and contribute to the betterment of society as a whole.

The findings from the studies discussed in this context have significant implications for SMEs that are undergoing transitions toward concepts like SME 5.0, hybrid SMEs, or tomorrow's SMEs. These emerging concepts place a strong emphasis on inclusivity, diversity, and collaboration as catalysts for pioneering innovations within engineering education and business practices. By incorporating the principles of global tech-sustainable governance into their operations, SMEs can position themselves as leaders in sustainable engineering practices. This involves leveraging emerging technologies strategically to drive growth while minimizing negative environmental impacts. It also means adopting intelligent governance practices guided by frameworks like the 7PS model, which can help SMEs navigate the complexities of sustainability effectively. These implications are particularly relevant for SMEs that are navigating transformative shifts toward SME 5.0 or hybrid SMEs concepts. Such shifts involve integrating advanced technologies into their business processes while prioritizing sustainable practices. By doing so, SMEs can not only enhance their competitiveness but also contribute to building a sustainable future. In addition to technology and sustainability, inclusivity and diversity are highlighted as crucial factors in pioneering innovations within engineering education for SMEs. Promoting inclusivity enables organizations to tap into a diverse talent pool, bringing fresh perspectives and ideas to the table. This fosters innovation and sustainable growth, aligning with the principles of the 7PS framework and the broader goals of global tech-sustainable governance. In summary, SMEs stand to benefit significantly from these research findings by embracing concepts such as SME 5.0 or hybrid SMEs. These concepts emphasize inclusivity, diversity, agility, and resilience within their operations. By fostering a culture of innovation, promoting sustainability initiatives, and leveraging emerging technologies, SMEs can position themselves as pioneers in driving technological innovations within engineering education and the broader business landscape. Moreover, the implications of this research extend beyond SMEs, offering practical strategies for organizations of all sizes as they address contemporary challenges arising from rapid technological evolution. These challenges encompass the potential of technologies like artificial intelligence, Internet of Things, blockchain, and cloud computing to revolutionize industries and create new opportunities, while also posing risks related to data privacy, security, and ethics. Furthermore, in the digital age, cybersecurity threats are a significant concern, requiring organizations to proactively implement robust cybersecurity measures to safeguard their digital infrastructure from breaches and attacks. Ultimately, the research findings provide valuable insights and strategies that can guide organizations in navigating the ever-changing landscape of technology, sustainability, and governance.

5. Conclusions

In conclusion, the journey toward a sustainable future in the digital age is a complex and multifaceted endeavor that requires a holistic approach, embracing insights from various disciplines and domains. Frameworks like the 7PS provide an integrative approach that considers economic, social, environmental, and other aspects to sustain organizational performance. The role of innovation culture is pivotal in bolstering organizational sustainability, fostering creativity, and adaptability within organizations. The fuzzy AHP methodology aids in assigning priority weights to the criteria within the 7PS framework, ensuring that sustainability goals are prioritized effectively. Meanwhile, X.0 wave theory offers valuable guidance in navigating the challenges posed by the digital age. SMEs can leverage these findings to transition into sustainable engineering practices and become pioneers in driving innovations for a better future. It is crucial for organizations to seamlessly integrate emerging technologies while ensuring robust cybersecurity measures to protect against contemporary threats. Inclusivity and diversity serve as catalysts for innovations within engineering education and professional landscapes. By promoting inclusivity, organizations tap into diverse talent pools, fostering creativity, and developing solutions with a broader societal context. Nevertheless, significant challenges such as rapid technological evolution and cybersecurity threats demand the attention of all stakeholders involved in global tech-sustainable governance. Comprehensive strategies that leverage frameworks like the 7PS model/framework alongside X.0 wave theory principles, guided by the fuzzy AHP method, enable organizations to enhance global tech-sustainable governance, digital resilience, and cybersecurity. In conclusion, achieving a sustainable future in the digital age requires the integration of sustainability principles into every aspect of decision-making. It demands intelligent governance that embraces innovation, inclusivity, and diversity, paving the way for a sustainable future for generations to come. This study offers a transformative roadmap for this journey, combining the power of various frameworks, methodologies, and cultural aspects to address the complex challenges and seize the opportunities presented by our increasingly interconnected world.

Author contributions

Hamid Doost Mohammadian: Conceptualization; Methodology; Validation; Resources; Omid Alijani: Project administration; Supervision; Data curation; Mohammad Rahimi Moghadam: Formal

Analysis; Investigation; Visualization; Writing; Behnam Ameri: Data curation; Resources; Writing – original draft.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

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