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A RESEARCH ANALYSIS: THE IMPLEMENTATION OF INNOVATIVE ENERGY TECHNOLOGIES AND THEIR ALIGNMENT WITH SDG 12

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The object of the research is the alignment of innovative energy technologies with the Sustainable Development Goal (SDG) 12, which pertains to sustainable consumption and production. The problem to be solved – there is an ambiguity regarding how these technologies contribute to SDG 12. This study aims to conduct a strategic analysis of external factors influencing innovative energy technologies from the perspective of SDG 12. The results show that innovative energy technologies, like bioenergy, geothermal energy, solar energy, wind energy, hydropower, and ocean energy, enhance energy efficiency, cut emissions, and reduce waste and toxins. These technologies align with SDG 12 and are shaped by various legislations. They intersect with the shift from fossil fuels, requiring analysis in the context of other UN SDGs. Legal frameworks must adapt to innovative energy technologies. The findings highlight that innovative energy technologies support SDG 12 by ensuring energy efficiency and reducing emissions. These technologies address economic and environmental challenges, promote sustainable progress and economic growth, enhance business competitiveness, stabilize prices, diversify energy sources, ensure national energy security and reduce energy poverty. The scope and conditions for practical application of the results of this research provide valuable insights for the scientific community, energy companies, policymakers, and investors in the energy sector. They can be used to inform decisions and strategies aimed at aligning energy technologies with the objectives of SDG 12. However, the implementation and effectiveness of these technologies also depend on regulatory support, industry collaboration, and public acceptance of new energy solutions

Keywords: innovative energy technology, renewable energy, energy transition, sustainable consumption, sustainable production

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1. Introduction

The present patterns of production and consumption are not viable in terms of their impact on the economy, society, and environment, notwithstanding their historical association with economic expansion. According to scholarly research, the utilization of Earth's resources and the presence of pollution have gone beyond the planet's carrying capacity [1]. On a global scale, human beings consume resources at a rate that exceeds the capacity of ecosystems to regenerate by 50 %. The biocapacity of the world in 2021 is estimated at 1.5 global hectares per person [2]. Hence, based on the available data, it can be inferred that a minimum of 1.5 Earths would be required to adequately support the current ecological footprint [3].

The 2030 Agenda's Sustainable Development Goals (SDGs) offer a balanced framework for environmental, social, and economic sustainability. To sustain the way of life for both present and future generations, SDG 12 promotes sustainable consumption and production to tackle climate change, biodiversity loss, and pollution. The energy sector, vital for activities like healthcare, agriculture, and education, plays a crucial role in sustainability, poverty reduction, and national growth [4, 5]. Energy is a key driver of societal progress and its efficient use is essential for a country's growth, further underscoring the importance of the energy sector [5].

Prevailing energy production and consumption have notable environmental, social, and economic effects and are deemed unsustainable. Energy significantly influences the rate of progress as well as sustainable development of all nations [6], with current methods causing increased greenhouse gases and air pollutants, driving climate change. Energy sector emissions account for over 80 % of global emissions [7], with the primary challenges being overconsumption and reliance on fossil fuels [8]. Switching to low-carbon energy is crucial, but so is exploring all alternative sources and reducing consumption. Typical evidence of this is the fact that buildings, where people spend over 90 % of their time, are notably wasteful [9]. Modern lifestyles heavily rely on energy, with the residential sector accounting for nearly 30 % of the EU's 2020 energy consumption, highlighting the potential for GHG reduction [10]. Transitioning to renewable energy sources is essential for environmental preservation [11]. One of the primary climate change mitigation strategies connected to sustainable energy consumption is the increase of energy usage efficiency and the utilization of renewable energy sources in homes [12]. Global energy demand is set to rise by around 47–50 % over the next 30 years [13, 14] due to economic growth, population increase, urbanization, and technological advancements [14–17]. Economic growth is expected to average 2.8 % annually until 2050. The population could reach 9.7 billion, with 68 % residing in cities, leading to an 80 % rise in urban energy demand [16–19]. Presently, 80 % of energy comes from fossil fuels – coal, oil and natural gas [14, 20], which are finite [21–23], and significantly contribute to environmental degradation [21, 24–26]. These emissions result in climate issues like droughts, floods, deforestation, and even species extinctions [25]. If unchecked, pollution could quintuple [25], causing average global temperatures to rise by 1.5 °C [27]. This would harm every Earth region [27]. To ensure the well-being of the growing global population and meet sustainable development goals, a transition to cleaner, renewable energy sources is vital [16, 20, 28]. The current energy transition is a shift from one dominant energy resource or set of resources to another [23]. This shift involves adopting efficient, affordable, and low-carbon technologies, ensuring environmental protection, resource conservation, and a healthier planet [17, 25, 26]. Traditional energy sources are causing environmental harm and failing to meet global needs, with over 3 billion people lacking basic energy services [29]. Innovative energy technologies offer solutions, promoting technological growth, social inclusion, and poverty reduction [5]. They're essential for sustainability, diversifying energy structures, stabilizing fossil fuel prices, and enhancing national security [28]. As the world's population nears 9.7 billion, the demand for sustainable energy intensifies. Innovative energy technologies like advanced solar panels and green hydrogen can reshape the energy sector, reduce emissions, and democratize access. However, successful large-scale implementation and integration require thorough analysis and alignment with societal needs.

Sustainable consumption and production is a holistic approach to reducing the negative environmental impacts of production and consumption processes. In the field of energy, SCP takes on particular importance as energy plays a crucial role in every aspect of our lives and has a significant impact on the environment. Addressing the energy challenge through the prism of sustainable production and consumption practices involves both harnessing sustainable sources of energy and ensuring that energy consumption is used efficiently. Sustainable consumption and production patterns are essential for achieving Sustainable Development Goal 12 (SDG 12), which calls for the deployment of innovative energy technologies that decarbonize and support the transition from fossil fuels to renewable energy sources. However, the complex interplay between energy innovation, economic factors and political policies requires a comprehensive research analysis to understand how innovative energy technologies can be successfully implemented and aligned with the objectives of SDG 12. In this respect, there are compelling scientific reasons for exploring this topic.

2. Literature review and problem statement

In the last twenty years, a considerable body of research has demonstrated that both developed and developing nations heavily depend on fossil fuels as their primary energy source. This reliance on fossil fuels leads to substantial emissions of greenhouse gases, particularly carbon dioxide, thereby exacerbating the phenomenon of global warming. The utilization of fossil fuels at the stages of manufacturing, transportation, and consumption results in diverse levels of water and air contamination, encompassing irreversible pollution in certain geographical areas. Based on data from the International Energy Agency, there was a notable surge in worldwide primary energy supply, over 40 %, during the period spanning from 2000 to 2018. Consequently, this surge has resulted in an unparalleled escalation in the emission of greenhouse gases.

A significant amount of these emissions contributes to the phenomenon of global warming and the occurrence of extreme weather events, which provide a substantial risk to the well-being and continued existence of human beings. Research investigations exploring the detrimental impacts of air pollution on human health and overall welfare have established a correlation between exposure to air pollution and heightened susceptibility to asthma episodes, chronic bronchitis, limitations in physical activity, and elevated mortality rates attributed to lung cancer or cardiovascular disease. The paper [30] focused on evaluating the effects of transitioning to 100 % renewable energy on air pollution and its consequent health and economic implications. By mapping out the gradual changes in pollutant emissions and detailing each sector's impacts, the study [30] provided insights up to 2050. The article [30] presents the results of the study highlighting that air pollution from fossil fuel combustion and long-term exposure to particulate matter air pollution are associated with adverse health effects and premature mortality. Hence, as posited by the authors in their publication [30], their research demonstrates that the act of divesting from fossil fuels and transitioning towards renewable energy sources yields substantial decreases in air pollutants that have direct implications for human well-being. This transition also carries substantial advantages in terms of global health and economic gains, as it helps prevent premature deaths and reduces healthcare expenses. However, the study [30] did not delve into air pollution dispersion modeling, nor did it consider the meteorological and topographical nuances of each region. Additionally, the long-term health impacts of air pollution exposure beyond 2050 were not addressed. The omission of these areas was likely due to the complexities involved, the study's defined scope, potential data limitations, and the intent to pave the way for more specialized future research in these domains.

Numerous scholarly investigations examining the interplay between renewable energy utilization and carbon emissions have consistently demonstrated that the adoption of renewable energy sources leads to a discernible reduction in carbon dioxide emissions. The paper [31] studies the relationship between renewable energy consumption and CO_2 emissions, specifically revisiting the Environmental Kuznets Curve (EKC) hypothesis. The authors analyze the potential impact of renewable energy consumption on environmental quality and investigate whether the validity of the EKC hypothesis depends on the income level of individual countries. A study [31] examines the relationship between carbon dioxide (CO_2) emissions and the use of renewable energy sources in 17 OECD countries for the period 1977–2010. The study conducted by researchers in [31] showed that the utilization of renewable energy sources had a discernible impact in reducing carbon dioxide emissions. There exists a valid argument that the utilization of renewable energy sources can successfully help mitigate global warming. However, the authors did not explore the potential limitations or drawbacks of increasing renewable energy consumption, such as the economic costs or feasibility of implementing renewable energy policies due to the limited scope of the study and the focus on the relationship between renewable energy consumption and CO_2 emissions.

Renewable energy resources are inherently regarded as inexhaustible and thus serve as a significant substitute for fossil fuels in the context of long-term sustainability. The accelerated depletion of fossil resources renders it impractical to rely on them for meeting energy demands in the future, thereby necessitating immediate attention to the availability of non-renewable resources for both current and future generations. This paper [32] focuses on examining the short-run relationship among population, renewable energy usage, economic growth, energy consumption, and carbon dioxide emissions in the Southeast Asian countries (ASEAN). The study aims to contribute to the current literature and offer policy implications for the ASEAN countries and other emerging markets. The authors used an advanced econometrics approach, the panel vector autoregressive model, and the system generalized method of moments estimator to analyze the data. While previous studies have confirmed the importance of renewable energy in boosting long-term sustainability and sustainable economic growth, reducing CO_2 emissions, and supplementing an increasingly substantial demand for energy consumption, little attention has been paid to the ASEAN region. The authors aimed to fill this gap in the literature by examining the short-run relationship among the variables of interest. The research [32] finishes by finding a correlation between renewable energy and the fundamental principle of sustainability. However, the paper [32] does not explore the long-run relationship among the variables, which has been examined in previous studies in the ASEAN region. The authors state that they are interested in the short-run relationship among the variables and that their study is the first of its kind to employ an advanced econometrics approach for a sample of seven ASEAN countries. Therefore, the authors did not explore the long-run relationship among the variables in this study. The paper [33] delves into the intricate relationship between economic growth and energy consumption, particularly focusing on the pivotal role of energy in nations' socio-economic development of the 23 OECD countries in the period 1985–2016. The primary concerns raised revolve around the world's heavy reliance on fossil fuels, which exacerbate carbon emissions and global warming. Not only are these fossil fuels projected to deplete soon, but their uneven global distribution and price fluctuations also pose economic threats and vulnerabilities for many countries. Given these challenges, countries are increasingly gravitating towards renewable energy sources, which promise a reduced carbon footprint. The primary objective of the study [33] is to examine the impact of renewable energy on the energy security risk of 23 OECD countries from 1985 to 2016. The paper's significant contributions include being the first to investigate this relationship for OECD countries and providing separate analyses for individual renewable energy sources like wind, solar, hydropower, and biomass. According to the findings presented in the study [33], it is estimated that the depletion of oil, gas, and coal reserves will occur by the years 2052, 2060, and 2090, respectively. Hence, as posited by the authors of [33], the pursuit of sustainable growth necessitates the exploration of alternative energy sources as viable substitutes for fossil fuels, exemplified by renewable energy sources. However, the paper [33] did not explore the specific policy implications that can be drawn from the findings for promoting renewable energy adoption in 23 OECD countries between 1985 and 2016. The paper [22] analyzed fossil fuel energy consumption, fossil fuel depletion, and their relationship with other variables such as energy dependence and share of renewable energy in gross final energy consumption for 29 European countries. The progress made by individual European countries toward a low-carbon energy system was also analyzed, and projections for the future and their impacts were addressed. The calculation of indicators, merit figures, and mathematical and statistical analysis were used to clarify and emphasize the trends, problems, and provide condensed information that can be useful in the decision-making process. The significance of renewable energy in the shift towards a low-carbon energy system and the reduction of reliance on diminishing fossil fuels is emphasized in the study [22]. One could posit that the persistent utilization of fossil fuels lacks long-term sustainability, while renewable energy sources are inherently seen as both inexhaustible and sustainable in the long run. However, the paper [22] did not explore the specific policies or measures that European countries could implement to reduce their dependence on fossil fuels and transition to a low-carbon energy system. The reason for this is not explicitly stated in the paper.

Previous research has indicated that the utilization of renewable energy sources has the potential to alleviate the issue of energy poverty. The research [34] investigates the global implications of utilizing renewable energy sources in addressing the issue of energy poverty. It assesses the global energy poverty index, examines the potential of the renewable energy industry in reducing energy poverty, and delves into regional differences in this relationship. The findings of the study [34] demonstrate a statistically significant and beneficial association between the escalation in the utilization of renewable energy sources and the efficacy in mitigating energy poverty. However, the study acknowledges that its insights into the relationship between renewable energy and poverty alleviation are preliminary. While it introduces a benchmark regression model suitable for future studies on specific countries or regions, it also recognizes the need for exploring other potential mediating factors like energy transition and infrastructure in upcoming research. The study [35] provides evidence that supports the existence of a favorable relationship between the utilization of renewable energy sources and the mitigation of energy poverty on a worldwide scale. This implies that the development of renewable energy has the potential to make a significant contribution towards effectively addressing energy poverty on a global scale. The utilization of renewable energy indirectly contributes to the decrease of poverty through the promotion of energy efficiency. However, the authors noted that despite previous research on energy poverty and its influencing factors, there are still shortcomings in understanding the current circumstances of energy poverty. They did not explore these remaining gaps in the literature in the paper [35].

The research papers examined highlight that renewable energy has the potential to mitigate the problem of diminishing energy security by offering a more reliable and sustainable energy source that is less reliant on external variables. This is in addition to its capacity to decrease emissions and offset carbon dioxide emissions. As discussed above, the results presented in the study [33] demonstrate that the utilization of renewable energy sources has the potential to mitigate the vulnerabilities associated with energy security. The utilization of renewable energy sources yields numerous advantages, encompassing the facilitation of sustainable economic expansion, mitigation of environmental deterioration, and enhancement of energy security.

The implementation of innovative energy technology is considered a crucial factor by researchers in facilitating the utilization and advancement of renewable energy sources. In the scientific literature, non-renewable energy sources are generally seen as non-innovative and renewable energy sources as innovative [36]. According to the paper [4], innovative energy technologies encompass a range of technologies that harness renewable energy resources, enhance the efficacy of energy systems, and provide customers products and services that empower them to manage their energy consumption. The development of renewable energy sources is an ongoing process that involves the utilization of cutting-edge technology and materials. This enables the effective extraction of resources and the seamless integration of the generated energy into various economic activities. Renewable energy, as commonly cited in scientific literature, encompasses five primary domains of technical advancement: bioenergy (specifically biomass), direct solar energy (through solar panels), geothermal energy (via geothermal power generation), hydropower (utilizing hydropower plants), and wind energy (harnessing wind turbines) [4]. Furthermore, the article [37] notes that ocean energy is considered as the sixth pioneer area for renewable energy technologies. However, its widespread implementation is currently constrained by uncertainty and ongoing development efforts [37]. One may contend that there are shared attributes among all innovative energy technologies, namely their utilization of renewable energy sources, generation of renewable energy, and limited or negligible environmental consequences.

Acknowledging the pressing need to address the issue of climate change, the European Union has made a firm commitment to achieving carbon neutrality by 2050, thereby positioning itself as a pioneer in this endeavor. The European Green Deal places significant emphasis on the pivotal role that the transition to clean energy will play in achieving this ambitious goal. The Green Deal represents a novel approach to achieving sustainable and inclusive economic expansion. It places significant emphasis on the imperative to reassess the provision of clean energy across various sectors, including the entire economy, food production, agriculture, construction, manufacturing, consumption, large-scale infrastructure, and transportation. This strategy is closely aligned with the envisioned Sustainable Development Goals (SDGs) to be accomplished by the year 2030. The imperative for meeting the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda necessitates a worldwide shift towards sustainable energy systems.

The paper [25] addresses the escalating global issues of pollution, global warming, and climate change, emphasizing their harmful impacts on both abiotic and biotic resources, including humans, animals, and plants. These challenges have prompted intensified interest in developing eco-friendly technologies to counteract and alleviate the effects. The article [25] focuses on specific technologies that meet criteria such as effectiveness, carbon reduction, cost management, and alignment with Sustainable Development Goals (SDGs). Each technology is evaluated based on its working principle, ability to lower carbon footprints, cost-effectiveness, and potential for future applications. According to the findings of the work [25], the implementation of innovative energy technologies with low carbon emissions plays a significant role in fostering sustainable development. The paper underscores the need for collaborative efforts between researchers and environmentalists to refine, design, and implement these solutions more widely. However, the paper focused on technologies and doesn't deeply explore the root causes of the mentioned problems or the specific health hazards they pose. The utilization of renewable energy technology plays a crucial role in facilitating the transition towards a more environmentally sustainable future. Within this particular context, a significant portion of the research has been directed towards Sustainable Development Goal 7, which pertains to the attainment of sustainable and inexpensive energy sources. Nevertheless, it is important to note that the Sustainable Development Goals (SDG) are intricately connected, as evidenced by the fact that the attainment of SDG 7 is contingent upon the implementation of responsible, sustainable consumption and production, as outlined in SDG 12 [38].

Over the past two decades, the world's alarming reliance on fossil fuels has not only led to increased carbon emissions and environmental degradation but has also placed humanity's future at great peril. Research has comprehensively documented the myriad challenges this dependence poses – from the exacerbation of global warming to severe health implications for humans. While the switch to renewable energy sources offers promising solutions, there exists a significant lacuna in understanding the role of innovative energy technologies in promoting sustainable consumption and production patterns, specifically in achieving Sustainable Development Goal 12 (SDG 12). Traditional renewable energy sources like wind, solar, and hydropower have received considerable attention, the potential of innovative energy technologies in changing the paradigm of energy consumption remains underexplored. The promise lies in not just their potential to replace fossil fuels, but in their ability to redefine our production and consumption patterns, ultimately driving us closer to SDG 12. For instance, energy storage technologies, which allow excess energy generated during peak times to be stored and used during lean periods, could revolutionize the reliability of renewable energy. Similarly, the integration of smart system in energy management can lead to predictive analysis of consumption patterns, ensuring optimal energy use and reducing wastage. The transition from fossil fuels to renewable energy is a monumental task, requiring global cooperation, substantial investments, and innovative thinking. However, it is now imperative to redirect the discourse towards comprehending the transformative impact that innovative energy technologies can have on the global patterns of consumption and production. This study aims to address existing knowledge deficiencies and offer novel perspectives on the utilization of innovative energy technologies in rectifying unsustainable consumption and production practices. Ultimately, this research intends to help towards the realization of SDG 12. This research has the potential to fill the gaps in current knowledge and offer guidance to many stakeholders, including policymakers and companies. By doing so, it can contribute to the advancement of sustainable and equitable practices in the energy sector, aligning with the objectives outlined in SDG 12.

3. The aim and objectives of the study

The aim of this study is to conduct a strategic analysis of external factors influencing innovative energy technologies from the perspective of SDG 12. This will provide an opportunity to shape the trajectory of innovative energy technologies in the context of global sustainability goals. It offers a holistic view of the external environment, providing valuable insights to a wide range of stakeholders committed to driving change. And also, it contributes to further academic research and international collaboration, advancing the global sustainability agenda.

To achieve this aim, the following objectives are defined:

– to determine the characteristics of innovative energy technologies;

– to identify aspects for the implementation of innovative energy technologies;

– to set the core targets and indicators of SDG 12, which emphasizes sustainable consumption and production;

– to analyze areas of the impact of the energy transition from fossil energy to using innovative energy technologies;

– to analyze affected targets and indicators from SDG 12 to innovative energy technologies.

4. Materials and methods

The object of the research is the alignment of innovative energy technologies with the Sustainable Development Goal (SDG) 12, which pertains to sustainable consumption and production.

The hypothesis of the study is an assumption that the implementation and utilization of innovative energy technologies significantly contributes to promoting sustainable consumption and production patterns, facilitating the attainment of Sustainable Development Goal 12 (SDG 12). Innovative energy technologies, particularly those that harness renewable energy resources, enhance energy efficiency, reduce emissions, waste, and toxins, and therefore align with the objectives of SDG 12. Additionally, these technologies address wider economic and environmental challenges, support sustainable progress and growth, and provide various societal benefits, such as energy security and poverty reduction.

Assumptions adopted in the research:

– the implementation of innovative energy technologies inherently supports the ethos of sustainable consumption and production (SDG 12);

– the transition from conventional, high-carbon energy sources to innovative energy technologies is imperative for addressing climate change, ensuring economic progress, and promoting sustainable and environmentally friendly energy systems;

– the success and widespread adoption of innovative energy technologies is a multifaceted process, dependent on a harmonious alignment of technical elements, market dynamics, enterprise strategies, and environmental factors;

– the energy industry has a significant impact on global consumption and production patterns and therefore plays a pivotal role in achieving or impeding the targets and goals outlined in SDG 12;

– the transition to renewable energy is not just a technological or economic shift but also involves a complex interplay of political, social, environmental, and legal dynamics;

– the implementation of innovative energy technologies will inherently and directly lead to the achievement of Sustainable Development Goal 12 and its various targets and indicators.

The research methodology includes the PESTEL method, abstraction, a comprehensive review of the scientific literature on energy transition, renewable energy, sustainable development, sustainable consumption and production in the energy sector, energy technology innovation, including its implementation, characteristics, aspects and challenges.

The concept of that PESTEL method is to identify external factors or challenges that may have an impact on the transition from fossil fuels to innovative energy technologies while taking into account its political, economic, social, technical, environmental, and legal environment [39]. As a result, the difficulties that must be overcome for energy policies, energy planning, and renewable energy technologies promotion and implementation to be full and effective can be examined within five context-related categories: political, environmental, social, technical, economic, and legal. The abstraction aims to focus on the main, essential features of the phenomenon under consideration, revealing their essence and creating generalized concepts, theories, classifications, categories, principles, etc. [40]. The scientific literature analysis is the basis on which new knowledge related to the research being conducted is based [41]. The research leveraged a multi-faceted scientific literature analysis: energy transition (literature pertaining to the global shift from fossil-based to zero-carbon energy systems was examined); renewable energy (publications discussing the dynamics, advances, and potentials of various renewable energy sources were explored); sustainable development (articles and papers focusing on the broader scope of sustainable development, its goals, implications, and the role of energy within it were assessed); sustainable consumption and production in the energy sector (studies exploring the challenges and innovations in responsible energy consumption and production were scrutinized); energy technology innovation (this segment concentrated on the evolution, characteristics, practicalities, and challenges of innovative energy technologies). The collected literature was subjected to a thematic analysis to identify and categorize recurring patterns and themes. NVivo software was utilized to help in clustering related themes. By mapping the current state of knowledge against the desired objectives of SDG 12, gaps in alignment were identified. This provided insight into potential areas for technological improvement and innovation. Experts in the fields of renewable energy, sustainable development and energy technological innovation were consulted to ensure the accuracy and comprehensiveness of the literature review results. Their views helped to further refine and validate the study's findings.

5. Results of the study on research analysis on the implementation of innovative energy technologies and their alignment with SDG 12

5. 1. Determination of the characteristics of innovative energy technologies

When conducting an analysis of innovative energy technologies, scholarly investigations mostly concentrate on five distinct characteristics [28, 42], as shown in Fig. 1.

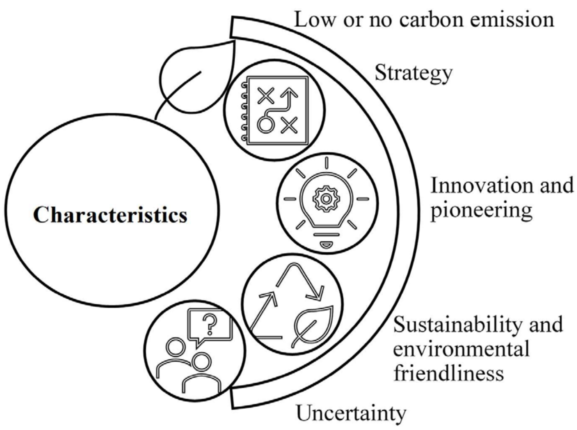

Fig. 1. Key characteristics of innovative energy technologies

Low or no carbon emission. Low-carbon or zero-carbon energy technologies refer to the use of alternative energy sources that result in minimal or negligible carbon dioxide emissions [42]. Conversely, high-carbon energy technologies rely primarily on fossil fuels such as oil and coal, resulting in significant carbon dioxide emissions and related pollutants [28]. Wind energy, biomass, solar energy, and tidal energy are examples of low-carbon and zero-carbon energy technologies [28]. The term "low-carbon energy" encompasses energy sources, including geothermal energy, that emit minimal to no carbon dioxide and related pollutants. These technologies serve as instrumental tools for both harnessing and transforming natural resources while mitigating greenhouse gas emissions [28], as carbon dioxide associated with energy production accounts for 85 % of global emissions and serves as a significant contributor to global warming [43].

Strategy. Due to resource limitations, it is becoming increasingly important to develop a strategy that ensures the sustainability of energy resources. The use of renewable resources such as solar energy can provide a continuous and sustainable stream of energy to support economic development [42]. The continuous growth of the industrial economy will deplete the renewable and limited resources of traditional fossil fuels such as oil and coal [28]. However, abundant reserves of renewable energy sources such as solar, wind, and ocean energy can ensure safe and sustainable energy use and promote economic development [28]. As the global population and energy demand continue to grow, there is an urgent need to improve and implement innovative energy technologies [44]. Moreover, the innovative energy technology sector has the potential to emerge as a key industry for future economic progress, with significant and lasting impacts on social and economic progress as well as national security. Enhancing the competitiveness of this sector is therefore a critical economic strategy [28].

Innovation and pioneering. Expanding the application of new energy sources alone is not enough to fully replace oil and gas resources. To meet this challenge, scientists must continue to conduct innovative research, improve technology performance, expand applications, and ensure market competitiveness [42]. Sources of innovative energy technologies such as wind, solar, and biomass are currently struggling to compete with traditional energy sources such as oil and coal [28]. Only through technological innovation can the performance of innovative energy technologies be improved and their scope of application be expanded, enabling them to compete effectively in the market [28]. The transition to a low-carbon system cannot be achieved by the spontaneous evolution of the system alone; it requires policy guidance and coordination across various sectors and policies [43]. The development of innovative energy technologies faces several challenges, including technical factors, cost barriers, an imperfect policy system, and an unfavorable market environment [28]. Overcoming these obstacles is crucial to the advancement of innovative energy technologies, since they serve as the primary means to promote the industrialization of low-carbon scientific and technological achievements and accelerate the achievement of carbon peak and carbon neutrality [45]. Supporting the research and development of these advanced innovative energy technologies is essential because they serve as the backbone of sustainable development [28].

Sustainability and environmental friendliness. Clean, renewable, and sustainable energy is a new form of energy that minimizes environmental damage, provides long-term usability without pollution, and promotes balanced development. For example, Iceland has one of the greenest and most sustainable environments in Europe, using both hydropower and geothermal energy [46]. By using hydropower and geothermal energy, Iceland can produce non-polluted products and open up new opportunities, including in bioscience and health technologies where purity and sustainability are important [46]. Innovative energy technologies such as wind, solar, and biomass play a critical role in achieving these goals. Advancing research, improving technology efficiency, and fostering market competitiveness are critical to realizing the full potential of clean and renewable energy [28, 42, 47]. Policy support and an enabling regulatory framework are also essential for widespread deployment [28, 47].

Uncertainty. Innovative energy technologies are characterized by their recent development and the presence of numerous uncertain factors [42]. These technologies represent new or emerging high-tech solutions with high risk, high profit potential, and significant uncertainty. The inherent uncertainty associated with innovative technologies poses challenges in terms of investment risk and income unpredictability, primarily due to the impact of uncertainty on technology advancement. Consequently, high uncertainty emerges as a key feature of innovative technologies, particularly concerning technology itself, human capital, and public policy [28].

In summary, the characteristics of innovative energy technologies highlighted are supported by scientific evidence and arguments. They address the key challenges of modern energy production and consumption in the context of global climate change, fossil fuel depletion, environmental degradation, the ever-changing technological environment and the need for economic and strategic foresight in the energy sector.

5. 2. Identifying aspects of innovative energy technology implementation

The advancement and deployment of innovative energy technologies represent a technological breakthrough and have emerged as a significant strategic decision for industrialized nations and certain developing nations. As extensively noted by numerous scholars, this phenomenon is primarily associated with four key factors [28], as shown in Fig. 2.

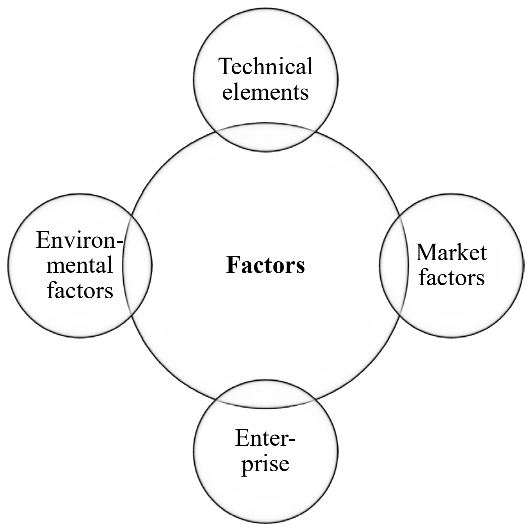

Fig. 2. Key factors of innovative energy technologies

Technical elements. The successful development of innovative energy technologies depends on several technical elements, including their functions, performance, and advantages [28]. In addition, the acquisition of sufficient commercial capital is crucial for their realization. In order to meet the market demand for advanced technology and new energy, it may be necessary to phase out technologies that lack outstanding features and potential. Green innovations not only create commercial opportunities, but also contribute to environmental improvement by preventing or mitigating negative impacts and increasing productivity [48]. The technical elements involved in the development of innovative energy technologies mainly revolve around the complexity of the technology itself and the stage of technical achievements [28]. For example, when transitioning to innovative technologies, it is essential to consider their integration with existing technologies [49]. The use of innovative energy technologies is a critical requirement for their commercialization, which includes technological advances, industry standards, and potential threats from alternative technologies [28].

Market factors. Entrepreneurs play a crucial role in bringing innovative technologies to the market, despite the inherent risks [49]. Market demand for innovative energy technology is a dynamic process of trial and error, involving the interplay of technology, supply, and business and consumer demand. As a result, the development of innovative energy technology faces significant uncertainties [28]. Furthermore, the ability of renewable energy producers to compete with conventional energy producers is influenced by market dynamics and customer satisfaction [50]. The importance of these barriers varies across technologies and markets, with their priority changing as the technology progresses towards commercialization [50]. To prevent the premature withdrawal of innovative energy technologies from the market, it is imperative to address the barriers that inhibit consumer adoption and lay the groundwork for further expansion of these technologies [28].

Enterprise. Adapting to changes in the external environment that affect a firm's strategic goals for technological development allows the firm to foster fundamental capabilities [28]. Previous research highlights the importance of managerial knowledge and skills and organizational culture as key components in fostering innovation [51]. Consequently, changes in a firm's strategic goals would influence the allocation of internal resources and ultimately affect the firm's capabilities [28]. In the complicated scientific landscape, the positioning and status of innovative energy technology serve as critical factors that influence a company's strategy and play a pivotal role in the development of its business capabilities [28]. Moreover, technological advancement has become an important measure for enterprises to improve overall efficiency and achieve more targeted economic growth by promoting technological progress [52].

Environmental factors. The development of technologies and the identification of potential environmental support providers involves a continuous and iterative process of trial and error [28]. Learning processes play a critical role in the development, adoption, and continuous improvement of new technologies [53]. In the field of innovation creation, the importance of new knowledge as a primary driver cannot be overlooked [49]. Continuous learning and feedback mechanisms facilitate the coordinated advancement of innovative energy technologies in tandem with the environment [28]. At the same time, a system is gradually emerging that prioritizes innovative energy technologies in competition with older energy technologies [28, 49]. The development of renewable energy technologies depends on a wide range of standards and regulations [54].

In summary, these four aspects are the most direct and influential factors affecting the successful and practical implementation of innovative energy technologies. This underlines the interconnectedness and multidimensionality of technological innovation, particularly in the energy field.

5. 3. Key targets and indicators for SDG 12, which highlights sustainable consumption and production

The energy industry should assume a large portion of the responsibility for helping to promote sustainable development. Furthermore, SDG 12, aims to focus on achieving energy and resource efficiency, developing sustainable infrastructure, and providing essential services and green jobs. Sustainable Development Goal (SDG) 12, which focuses on ensuring sustainable consumption and production patterns, comprises 11 targets (Table 1).

The goal aims to bring about a balance between human development and the planet's capacity to sustain such growth. Target 12.1 advocates for the implementation of the 10-Year Framework on Sustainable Consumption and Production. Developed countries are expected to be at the forefront of this, recognizing the limitations of developing countries in terms of resources and capability. By the year 2030, there's a target to efficiently manage and utilize natural resources in a sustainable way. This emphasizes conservation, responsible usage, and long-term viability (target 12.2). Target 12.3 aims to tackle the issue of food waste. By 2030, the goal is to cut in half the food waste per person at the retail and consumer level, and to reduce losses in the production and supply chains, which includes after harvesting. Target 12.4 is about handling chemicals and all forms of waste in an environmentally safe manner. The aim was to achieve this by 2020, in line with international standards, and to greatly reduce their discharge into the environment, mitigating their harmful effects on both humans and nature. By 2030, the intention is to majorly cut down on waste generation by focusing on prevention, reduction, recycling, and reusing materials (target 12.5). Target 12.6 encourages major corporations, including those operating at a global scale, to integrate sustainable practices and report on their sustainability measures. Target 12.7 calls for governments and institutions to consider sustainability when purchasing goods and services, in line with the nation's policies and priorities. By 2030, the aim is to ensure everyone globally has access to information and awareness about sustainable development and lifestyles that are in tune with nature (target 12.8). Target 12.a is about support, where developing countries are assisted in building their scientific and technological abilities to transition to more sustainable consumption and production patterns. A push towards sustainable tourism, target 12.b seeks the development and deployment of tools to monitor the impacts of sustainable tourism that offers employment opportunities and celebrates local culture and goods. Target 12.c deals with subsidies for fossil fuels, which often lead to wasteful consumption. The idea is to reevaluate these subsidies, possibly restructure them or even phase them out, especially if they are detrimental to the environment. However, it's crucial to approach this considering the particular challenges and conditions of developing nations to ensure the poor and affected communities are safeguarded. In essence, SDG 12 is about reshaping our consumption and production systems to become more sustainable, where we can achieve economic growth and development without exhausting our planet's resources or harming the environment.

Table 1

Sustainable Development Goal (SDG) 12 targets

SDG 12	SDG 12: Ensure sustainable consumption and production patterns
12.1	Implement the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries
12.2	By 2030, achieve the sustainable management and efficient use of natural resources
12.3	By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses
12.4	By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
12.5	By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse
12.6	Encourage companies, especially large and transnational ones, to adopt sustainable practices and integrate sustainability information into their reporting cycle
12.7	Promote public procurement practices that are sustainable, in accordance with national policies and priorities
12.8	By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
12.a	Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production
12.b	Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products
12.c	Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and affected communities

5. 4. Areas of the impact of the energy transition from fossil energy to using innovative energy technologies

The sustainability of renewable energy depends on factors such as climate change, energy demand, security and accessibility, and the creation of green jobs. It can be hampered by public opposition and low investment funding [55]. In order to meet the needs of current and future generations, energy transition policies need to take into account the various dimensions of sustainability: economic, technological, institutional, natural and social [56]. Energy policy should reflect the sustainability of the environmental, economic and social pillars, and it is important to take into account technical and political specificities.

To analyze the impact of the transition from fossil fuels to innovative energy technologies, a PESTEL method is used, which includes six key categories: political, environmental, technological, economic, social, and legal. This analytical framework allows for a comprehensive assessment of the various areas affected by this transition. By examining these dimensions, the multifaceted implications of the transition can be better understood and assessed. Table 2 shows the main aspects of the analysis. A more detailed analysis of each category is discussed below the Table 2.

Political. Not all countries currently have a renewable energy policy in place [57], and leading countries such as the US need to step up their commitment. While policies to integrate renewable energy into the energy mix are well developed in developed countries, they are new for developing countries [58]. The UN is a global organization with member states from the developed and developing world that presents global sustainability policies and goals, including the Sustainable Development Goals (SDGs), but there are barriers to the implementation of renewable policies in developing countries, such as: limited information, experience, institutional commitment, cooperation, priority for renewable energy, and other legal and regulatory issues [59]. Politically, issues related to innovative energy technologies must be considered primarily in terms of their political feasibility and the relevant target groups of the individual parties. In principle, it can be assumed that in the current situation there is a political consensus in favor of a fundamental expansion of innovative energy technologies. However, this consensus is no longer present in the same form due to Russia's war of aggression against Ukraine. Politically, high prices in the energy supply sector are particularly problematic. This needs to be closely monitored, especially when it comes to the expansion of innovative energies, as these are significantly more expensive than other energies to begin with. In addition, the situation is particularly difficult and challenging due to the difficulty of enforcing long construction periods that exceed the usual election periods. Similarly, the initial development of innovative energies is generally considered to be more expensive and less secure in terms of supply than remaining with existing fossil energy sources. The EU experience shows that research and innovation policies are important for achieving sustainable development goals, and therefore the promotion of innovative, renewable energy technologies should be underpinned by research and innovation law [60]. Difficulties in the transition phase need to be mitigated politically and communicated to citizens. Policies need to ensure a sustainable transition without threatening the livelihoods of local populations, which is why it is important to involve the participation of local communities [61]. It is also politically necessary to involve other nations through diplomatic relations and the linking of common energy networks. This kind of interconnected globalization of energy networks is inevitable for innovative energies due to technical constraints. It is the task of politics to get involved in international agreements as well as in the joint development of renewable energies and the necessary energy transmission system and to intervene in a regulating way.

Economical. In general, the use of renewable energy is economically viable. However, it is important to consider that renewable energy sources are significantly more expensive than existing energy sources, especially in the initial stages of implementation, and require significant initial investment. However, these higher initial costs are offset by minimal variable costs during operation, which favors renewable energy sources. It should be noted, however, that the integration of renewable energy sources within the current electricity market framework is subject to limitations in terms of economic and social acceptability, mainly due to their dependence on weather conditions and grid transmission. Despite the integration of systems such as merit order, which appropriately incorporate renewable energy through allocation based solely on variable costs, instances of non-simultaneous peaks in demand and supply can still lead to escalating prices. As a result, these costs are passed on to consumers, creating a complex interplay between economic, political, and social spheres. In addition, the existing financing models for renewable energy, particularly in Germany, are noteworthy, as the EEG levy has been suspended at times in recent years. In developed countries, financing for renewable energy is stable, but in developing countries, confidence in governments to maintain renewable energy targets fluctuates [58]. Although not all countries currently have a renewable energy policy, many countries have adopted measures to support renewable energy, such as financing and investment in infrastructure, fiscal incentives such as feed-in tariffs, tax incentives, taxes and loans, and market-based instruments such as green certificates and greenhouse gas emission allowances [57]. The most widely implemented policy to support renewable energy generation, the feed-in tariff, has been found to be effective [62]. However, when designing financial support for renewable energy, it is important that it does not only benefit large investors. Therefore, policy and legislation should avoid distorting the energy law towards specific flexibilities and technologies. From an economic perspective, the transition to renewable energy is a logical choice. In our economy, the promotion of innovation, the development of new systems and the reduction of energy costs are key drivers of long-term prosperity. In addition, environmental protection, which is inextricably linked to this transition, is an important economic goal and a critical factor for the future. It is important that policymakers choose effective energy planning tools to avoid negative economic impacts. In addition, renewable energy projects have a positive impact on economic growth in the medium term.

Social. As discussed in the section on economic feasibility and effectiveness, an appropriate design of the electricity market and a socially acceptable distribution of additional costs during the transition period are essential. It is worth noting that distributed innovative energy technologies, while dependent on weather conditions, are highly dependent on transmission networks. The absence of these networks leads to inequalities in both energy pricing and availability. Conversely, the ability to generate and sell individual energy using small decentralized production units can be seen as inherently advantageous. The creation of new green jobs is seen as an advantage of renewable energy, but this is not always the case as job creation varies from country to country and sector to sector. Each project has to be assessed individually, taking into account the labor market, technology and other factors [63]. In addition, there is often public opposition to the development of renewable energy [64]. In areas with high renewable energy potential, there is often an overlap with other uses of natural resources, including livelihoods and biodiversity, leading local communities to reject renewable energy in the face of competition and change. Policymakers need to take these challenges into account, including engaging and benefiting communities.

Technological. While renewable technologies in terms of equipment, methods and techniques are rapidly evolving and being optimized [65,66], technologically, innovative energy technologies remain an active area of research, but the basic and linear technology required for their implementation has already been developed and is commercially viable. However, the integration of renewable energy sources and generators is technologically much more complex than existing systems. To realize the potential of innovative energy systems, robust transmission capacity is needed, along with the construction of storage facilities to mitigate temporary power shortages. These storage facilities can act as a buffer to quickly compensate for fluctuations. The variability of energy production poses the greatest challenge to the technological implementation of innovative energy systems. Given the unpredictable and challenging nature of energy production, grid planning and the ability to respond quickly to grid fluctuations are becoming increasingly important. Consequently, there is a need to develop technological solutions for rapid grid stabilization and effective grid control.

Table 2

The main aspects of the PESTEL analysis

Political	– while developed countries have mature renewable energy policies, developing nations face barriers like limited information, experience, and regulatory issues; – the transition to innovative energies requires political support, international cooperation, and the involvement of local communities to ensure sustainable development without compromising local livelihoods
Econom-ical	– renewable energy requires a significant initial investment but offers minimal operational costs; however, its integration into the current electricity market can lead to price fluctuations due to non-simultaneous peaks in demand and supply; – effective policies like feed-in tariffs support renewable energy, but it's essential to ensure diverse beneficiaries and consider both economic and environmental goals in transitioning towards sustainable energy
Social	– the transition to renewable energy requires an equitable electricity market design and consideration of varying job creation across regions and sectors, while accounting for potential competition with other natural resource uses; – local communities sometimes resist renewable energy projects due to concerns about livelihoods and biodiversity, emphasizing the need for policymakers to involve and benefit these communities
Technolog-ical	– innovative energy technologies are commercially viable and evolving, but their integration poses complexities, particularly due to the variability of energy production; – the development of storage solutions and rapid grid stabilization techniques are crucial to address challenges in renewable energy implementation
Environ-mental	– innovative energy systems offer substantial environmental benefits, including reduced pollution and better climate performance than existing energy sources; – despite these advantages, there's a need to account for the environmental impact of raw material extraction and potential geographical shifts in environmental consequences, especially in developing countries
Legal	– state regulation and the complexities of supranational governance present legal challenges for the energy transition; – current legal frameworks must evolve to better support the integration of innovative energy systems

Environmental. From an environmental perspective, the introduction of innovative energy systems is generally beneficial. They contribute to reduced air pollution, have significantly better climate performance than existing systems and, importantly, do not generate pollution per additional unit of energy. However, it is important to consider the production costs and efforts associated with manufacturing these systems. This includes accounting for the necessary raw materials, such as solar cells. In addition, while the implementation of innovative energy systems mitigates damage to local flora and fauna, it is crucial to recognize that the high demand for raw materials, particularly in developing countries, can lead to a geographical shift of environmental impacts.

Legal. In the legal realm, the challenge lies in state regulation and the normative statute of supranational governance. At present, obstacles related to the prevailing approach, lengthy approval procedures, and numerous bilateral and multilateral treaties pose significant hurdles to the progress of the energy transition [58]. These legal frameworks need to be adapted to facilitate the inevitable integration of innovative energy systems.

5. 5. Affected targets and indicators from SDG 12 to innovative energy technologies

Building on the previous PESTEL method, the various targets and indicators under Sustainable Development Goal 12 can be effectively addressed within specific dimensions of change (Table 3).

Innovative energy technologies are instrumental in advancing the goals of Sustainable Development Goal 12, addressing a wide range of objectives from sustainable consumption and production patterns to waste reduction, public awareness, and responsible economic growth. By integrating these technologies across sectors, from tourism to public procurement, we can foster a holistic approach to sustainability, ensure judicious use of resources, promote economic rationality, and ultimately build a resilient, eco-friendly future in alignment with the aspirations of the UN's SDG targets.

Table 3

Targets and indicators for SDG 12 related to innovative energy technologies

Targets and indicators of SDG 12	Affected targets and indicators from SDG 12 to innovative energy technologies
1	2
12.1	The adoption of the aforementioned plan on innovative energy technologies aligns with target 12.1, facilitating the achievement of a timely and achievable goal. Innovative energy technologies play a pivotal role in achieving this target. From solar panels that harness the power of the sun, to wind turbines that convert gusts into electricity, and energy-efficient appliances that reduce household consumption, these advancements redefine how we produce and consume energy. Furthermore, technologies such as smart grids, energy storage solutions, and green hydrogen offer ways to integrate renewable sources seamlessly into our current systems and infrastructures. They ensure that energy is utilized efficiently, minimizing waste and maximizing benefits to consumers and the environment. By embracing these innovations, we not only mitigate the environmental impacts of traditional energy sources but also lay the foundation for a resilient, sustainable economy. A shift to such sustainable energy consumption and production methods resonates directly with SDG 12.1's objective and sets the path for a more responsible, brighter future

Continuation of Table 3

1	2
12.2	Innovative energy technologies contribute to SDG target 12.2 by promoting more sustainable management and efficient use of natural resources. This is particularly evident in the technological, social and environmental spheres. Technologies like home solar panels and community wind farms enable localized energy production, reducing the need for extensive resource-draining infrastructures, such as long-distance power lines and centralized power plants. Advancements in battery storage, like lithium-ion and flow batteries, allow for the efficient storage of energy, ensuring that excess energy generated during peak times can be used during periods of low energy generation, reducing waste. Newer technologies in lighting (e.g., LEDs), heating, and cooling systems use significantly fewer resources over their lifetimes, both in terms of the materials needed for production and the energy they consume during operation. These dynamically adjust and distribute energy supply based on demand, minimizing wastage and ensuring the most efficient use of generated electricity. Innovations, such as energy from waste technologies, turn discarded materials into valuable energy sources, supporting sustainable management of resources
12.2.1	The introduction of innovative energy technologies impacts indicator 12.2.1, which relates to the material footprint or material footprint per economic indicator. As we transition from fossil fuels to renewable energy sources like wind, solar, and geothermal, there's a reduction in the extraction of coal, oil, and natural gas, thereby reducing the material footprint associated with energy production. Innovative technologies often use fewer materials and less energy. For instance, LED lighting, which lasts longer and uses a fraction of the energy of traditional bulbs, reduces the overall material footprint by needing fewer replacements and consuming less energy. Advanced energy storage systems, like modern batteries, have prompted more rigorous recycling processes to recover and reuse materials. This minimizes the extraction of new resources. Energy from waste technologies reduces the demand for virgin resources by turning discarded materials into energy sources, thus shrinking the material footprint. Localized energy generation through microgrids or individual solar setups can reduce the need for expansive infrastructure projects, which would otherwise contribute significantly to the material footprint
12.2.2	The deployment of innovative energy technologies can have profound implications on this indicator. Transitioning to renewable energy technologies like wind, solar, and hydropower reduces the consumption of coal, oil, and natural gas, thereby lowering the DMC associated with traditional energy production. Modern energy-efficient technologies, from household appliances to industrial machinery, require less energy and often fewer materials over their lifecycle, leading to a reduction in DMC. Converting waste into energy reduces the need for landfills, minimizing the consumption of land as a material resource and simultaneously generating power. Decentralized energy solutions, such as home solar setups or community wind farms, reduce the demand for massive, material-intensive infrastructures like long-distance power transmission systems. As the energy sector innovates, many of the technologies introduced are designed with material efficiency in mind. For instance, newer solar panels might use thinner layers of photovoltaic materials without compromising efficiency, thus using less material per unit of energy produced. Countries adopting domestic renewable energy sources can reduce their reliance on imported fossil fuels, which can significantly lower their imported material consumption
12.3	Reliable energy sources are crucial for maintaining cold chains, which ensure perishable goods like vegetables, fruits, and meats are stored and transported at optimal temperatures. Innovations like solar-powered cold storage can dramatically reduce post-harvest losses, especially in areas with unstable grid power. Energy-efficient technologies can support faster and more efficient processing of agricultural products, minimizing the time and resources between harvesting and consumption and thereby reducing waste. Integrated into the supply chain, these tools can monitor the conditions of stored and transported goods, predicting and preventing spoilage through timely alerts. Such systems can be powered by efficient and renewable energy sources. Food waste can be converted into bioenergy through processes like anaerobic digestion. This not only addresses waste concerns but also contributes to clean energy generation. Powered by energy-efficient devices, precision agriculture uses data to optimize planting, irrigation, and harvesting, ensuring maximum yields and minimizing resource wastage. Energy-powered digital platforms can spread awareness about food waste and educate consumers on how to store and use food products more efficiently. Providing reliable energy to remote and underserved areas can bolster local food processing and preservation capacities, reducing the likelihood of waste
12.4	The use of renewable energy technologies also promotes more sustainable management of chemicals and waste, which aligns with target 12.4. Technological advances and environmental changes in energy production promote greater circularity in the use of energy and materials, highlighting the need for more sustainable and efficient use of resources through innovative energy technologies. Adopting renewable energy sources like solar, wind, and hydroelectric reduces the burning of fossil fuels. This means fewer chemicals, such as sulfur dioxide and nitrogen oxides, are released into the air, reducing air pollution and its associated health impacts. Advances in battery technologies not only improve energy storage but can also lead to safer materials and chemistries that reduce potential environmental hazards. Enhanced recycling techniques can further minimize chemical waste from battery degradation. Waste-to-energy technologies reduce the volume of waste going into landfills, converting them to energy instead. Properly managed, they can mitigate the release of harmful chemicals during waste breakdown. With a shift toward renewable energy, there's a potential decrease in hydraulic fracturing ("fracking") for natural gas. This can reduce the release of harmful chemicals into groundwater and surrounding ecosystems. Innovative carbon capture and storage (CCS) technologies can capture up to 90 % of the carbon dioxide emissions produced from the use of fossil fuels in electricity generation and industrial processes, preventing CO_2 from entering the atmosphere. In the realm of biofuels and other green energy solutions, there's an emphasis on developing processes that are not just energy-efficient but also reduce the use or creation of substances hazardous to the environment
12.5	The use of innovative energy technologies significantly reduces waste and increases recycling rates. This is due to the inherent sustainability of these energy sources, which, unlike fossil fuels, can be recycled or integrated into a circular economy after use. Instead of sending waste to landfills, technologies can now convert waste, especially non-recyclable waste, into valuable energy. This not only reduces waste volume but also harnesses potential energy from discarded materials. As the demand for energy storage and electric vehicles grows, so does the importance of recycling used batteries. Advanced recycling techniques recover valuable metals and materials, reducing the need for new raw materials and minimizing waste. Efficient appliances and systems consume less power and often have longer lifespans, leading to reduced manufacturing waste and longer intervals before disposal. By shifting towards renewable energy sources, we reduce the need for extensive mining and drilling operations, which not only extract but also generate significant waste. Systems like solar panels and home batteries reduce dependence on large infrastructures, thereby minimizing construction waste. Many innovative energy solutions now focus on creating systems where resources are reused, repurposed, or recycled, leading to a significant decrease in waste generation

Continuation of Table 3

1	2
12.6	Innovative energy technologies such as smart grids and energy management systems enable companies to optimize their energy use, leading to cost savings and more sustainable operations. Companies can transition to renewable energy sources, like solar and wind, using innovative solutions tailored to their operational needs. Such a shift not only reduces their carbon footprint but also demonstrates a commitment to sustainable practices. Advanced monitoring technologies provide detailed data on energy consumption and efficiency, enabling companies to include precise and meaningful sustainability metrics in their reporting. By adopting cutting-edge energy solutions, companies can position themselves as leaders in sustainability, garnering trust from consumers, stakeholders, and investors. Reliance on traditional energy sources exposes companies to fluctuating fossil fuel prices and potential supply disruptions. Adopting innovative energy technologies can diversify their energy sources, reducing such risks. As governments tighten environmental regulations, embracing innovative energy technologies can help companies stay compliant, avoid potential penalties, and benefit from incentives
12.7	Of particular importance to target 12.7 is the strong interplay between the deployment of innovative energy technologies and the actions of governments and public regulators to establish appropriate regulations and financing options. This policy influence, as highlighted in the PESTEL method under the policy domain, plays a critical role, particularly in the selection of specific innovative energy technologies. The political implementation of these policies also reflects the societal impact of these initiatives. By incorporating solar, wind, and other renewable energy sources into public buildings and operations, governments can directly support sustainable energy industries, driving market growth and setting an example for private sectors. Governments can invest in energy-efficient or electric public transit solutions, reducing carbon footprints and encouraging citizens to adopt more sustainable transportation methods. For any public infrastructure projects, innovative energy technologies like smart grids, LED street lighting, and energy-efficient building designs can be prioritized, setting a gold standard for sustainable development. When public entities prioritize buying equipment or solutions that are energy-efficient or powered by clean energy, it creates demand, encouraging industries to develop and offer more of such products. By implementing and showcasing innovative energy solutions in public spaces, governments can also play a role in educating the public about the importance and viability of these technologies. Governments can support local green tech industries through their procurement policies, fostering innovation, and creating green jobs in the community
12.8	Advanced energy technologies often come with platforms that educate users about energy consumption, savings, and environmental impacts, fostering a deeper understanding of sustainability. The tangible presence of technologies such as solar panels in urban settings and wind turbines in rural landscapes serves as a constant visual reminder of sustainable energy alternatives. Innovative energy projects, like community solar or local wind farms, often involve public participation and engagement, naturally spreading awareness and understanding about sustainable energy. Smart meters and home energy management systems offer real-time feedback on energy consumption, making individuals more conscious of their energy usage patterns and their environmental footprint. Implementing innovative energy solutions in public spaces, such as solar benches or piezoelectric walkways, can pique public interest and spur conversations about sustainable technologies. Companies and institutions involved in innovative energy solutions often run educational campaigns or partner with schools and universities to incorporate sustainability modules into curricula. Breakthroughs or large-scale deployments of new energy technologies often attract media attention, further spreading awareness and information to the wider public
12.a	The introduction of comprehensive energy technologies serves goals such as supporting scientific and technological development in emerging countries. This allows for better integration of these nations into Western energy markets, potentially through the use of more storable and transportable energy sources, and promotes a transition away from fossil fuels to sustainable and renewable energy. Collaborative international projects can facilitate the transfer of cutting-edge renewable energy technologies to developing countries. This enables these nations to leapfrog older, less efficient technologies, jumping straight to cleaner and more sustainable solutions. Training and workshops centered on innovative energy technologies can equip local professionals in developing countries with the skills needed to implement, manage, and maintain these systems. Developing countries often have unique energy challenges that can be addressed with tailored technologies. For instance, decentralized solar systems might be particularly effective in remote areas without grid access. Partnerships between institutions in developed and developing nations can foster joint research on energy solutions best suited for specific regional challenges. Funding mechanisms, like green bonds or international grants, can support the deployment of innovative energy technologies in developing regions, ensuring that financial constraints don't impede sustainable progress. Establishing centers of excellence or innovation hubs in developing countries can stimulate local research and adaptation of imported energy technologies to local needs
12.a.1	Innovative energy technologies can play a key role in improving this indicator. Investments from international entities, whether governments, corporations, or NGOs, into research and development (R&D) projects in developing countries can bolster the exploration and implementation of innovative energy solutions tailored to local needs. By sharing research findings, methodologies, and best practices, developed nations can empower developing countries to adopt or adapt innovative energy technologies faster and more efficiently. Joint ventures between institutions or researchers from developed and developing nations can harness diverse expertise, leading to energy innovations that are globally relevant and locally applicable. Financial and technical support for workshops, training sessions, and educational programs can equip local professionals and researchers with cutting-edge knowledge on energy technologies, fostering homegrown innovation. Financial assistance can facilitate the establishment of research labs, innovation hubs, and testing facilities in developing countries, creating a conducive environment for energy technology R&D. Funding pilot projects can test the viability of new energy solutions in real-world scenarios, providing valuable data and insights while introducing communities to sustainable technologies
12.b	Hotels and resorts can incorporate renewable energy sources, such as solar panels and wind turbines, to power their operations, significantly reducing their carbon footprint. Electric vehicles (EVs) powered by renewable energy can serve as sustainable alternatives to traditional tourist transportation. Charging stations, powered by renewables, can be set up at tourist hotspots. Locally-generated renewable energy can be showcased as a unique feature of a destination, integrating it into the tourism narrative and promoting a connection between visitors, local technology, and culture. Smart technologies in accommodations can optimize energy consumption, ensuring resources like electricity and water are used efficiently, directly catering to the eco-conscious traveler. Advanced tech solutions can offer real-time monitoring of energy consumption and environmental impact for tourist facilities, enabling them to tweak operations for improved sustainability and share this data with visitors. Tours or workshops focusing on local renewable energy projects can be introduced, giving tourists firsthand insights into sustainable practices while also boosting local job creation. Tourist attractions can aim to be carbon-neutral by leveraging innovative energy technologies, making them more appealing to the globally-conscious traveler

Continuation of Table 3

1	2
12.c	The marketable deployment of energy technologies can create the necessary social and political conditions to achieve SDG target 12.c, which involves dismantling market mechanisms that favor fossil fuels. However, for this to happen, innovative energy technologies must be placed within an acceptable price and environmental framework that is consistent with the political implementation of new market conditions. As renewable energy technologies like solar and wind become more affordable, they challenge the economic logic behind fossil-fuel subsidies, making renewables a more appealing choice even from a purely economic standpoint. By adopting innovative energy solutions, countries can lessen their reliance on fossil fuels, diminishing the perceived need for such subsidies in the first place. Newer technologies, particularly in energy storage and smart grids, enable a clearer understanding of the actual environmental and health costs of fossil fuel use, making subsidies harder to justify. The growth of the renewable energy sector, spurred by technological advancements, can lead to job creation and innovation, offering a compelling alternative economic narrative to fossil fuel-driven growth. Decentralized energy systems can empower local communities to generate their own energy sustainably, reducing the need for large-scale, subsidized fossil fuel projects. As international cooperation grows around clean energy, nations with heavy fossil fuel subsidies might face diplomatic and economic pressures to rationalize these subsidies. Collaborative projects can also offer pathways for countries to transition away from fossil fuels
12.c.1	Innovative energy technologies influences this indicator. As countries adopt and invest more in innovative energy technologies like wind, solar, and hydropower, there's a natural decline in the expenditure on fossil fuels, which in turn affects the subsidies allocated to them. The falling costs of renewable technologies, especially solar panels and wind turbines, make them economically competitive with fossil fuels. As a result, the economic justification for fossil fuel subsidies diminishes. New technologies often lead to better energy efficiency, meaning less energy is wasted. With reduced energy consumption, the dependence on subsidized fossil fuels drops. As innovative, clean energy solutions become more mainstream, public demand may shift towards sustainable energy, putting pressure on governments to reduce fossil-fuel subsidies and redirect funds to support cleaner technologies. International trade and collaborations may exert economic pressures on countries with heavy fossil-fuel subsidies, especially as global markets increasingly value sustainable practices. Recognizing the finite nature of fossil fuels and the long-term economic advantages of renewable technologies, governments may proactively reduce subsidies on fossil fuels in favor of supporting a more sustainable and long-term viable energy sector

6. Discussion of the results of the study on research analysis on the implementation of innovative energy technologies and their alignment with SDG 12

The research provides an in-depth analysis of the characteristics and implications of innovative energy technologies in the broader context of sustainable development and energy transition, as shown in Fig. 1. When interpreting the results, the following points stand out:

– low or no carbon emission. With carbon dioxide accounting for 85 % of global emissions and being a major driver of global warming [43], the move towards low or no carbon emission technologies is of paramount importance. The shift from high-carbon technologies, which heavily depend on fossil fuels, to renewable energy sources like wind, biomass, and solar energy, is a crucial step in reducing the carbon footprint and aligning with SDG 12;

– strategic importance. The research emphasizes that the continued reliance on depleting fossil fuels will hinder economic development in the long run. Renewable energy sources, not only present an alternative but also have the potential to become the backbone of future economic progress, addressing the sustainability goals of SDG 12;

– innovation & Pioneering: One significant insight from the analysis is that the mere introduction of new energy sources is insufficient. The key lies in technological innovation to enhance their performance, market competitiveness, and wider application. This further underscores the role of supportive policies and inter-sectoral coordination to facilitate a smooth transition to low-carbon systems;

– sustainability & environmental friendliness. The role of clean, renewable, and sustainable energy in minimizing environmental harm and fostering balanced development is highlighted through examples like Iceland's use of hydropower and geothermal energy. This aligns perfectly with SDG 12's aim for responsible consumption and production, emphasizing the need for cleaner energy sources;

– uncertainty. It's important to acknowledge the inherent uncertainty and risks associated with innovative energy technologies. Given their nascent stage, these technologies face challenges in securing investments due to the unpredictability in their evolution, market acceptance, and policy support. However, while uncertainty is a feature of innovation, its potential high reward makes it a pivotal focus for future energy solutions.

Analyzing factors of innovative energy technologies, we categorized under the four main factors highlighted, as shown in Fig. 2:

– technical elements. The report accentuates the importance of the technical components of innovative energy technologies. A key takeaway is that for an innovative energy technology to find its place in the market, it must not only be technically sound but also offer distinct advantages over existing technologies. This calls for the need to continually evaluate and phase out outdated technologies, paving the way for newer, more efficient systems. Moreover, as highlighted, the integration of these innovative technologies with pre-existing ones is pivotal [49], suggesting that innovations should not be viewed in isolation but rather in conjunction with the broader energy ecosystem;

– market factors. The dynamic nature of market demand, combined with the inherent risks involved, places entrepreneurs at the forefront of technological innovation. This underscores the importance of a flexible and adaptive market strategy that can respond to changing demands and technological developments. The research emphasizes the need to address barriers inhibiting consumer adoption [28], which may include perceptions about the technology, its cost, or potential risks. With the progression towards commercialization, addressing these barriers is paramount to ensuring innovative energy technologies are not prematurely withdrawn;

– enterprise. Enterprises play a significant role in the trajectory of innovative energy technologies. The research draws attention to the alignment of a firm's strategic goals with the evolving technological landscape. A company's internal resource allocation, shaped by its strategic goals, is instrumental in determining its innovation trajectory. Furthermore, in this intricate interplay between business and technology, a company's positioning in the market and its commitment to innovation significantly influence its overall success and growth;

– environmental factors. The iterative nature of technology development is underscored by the report's emphasis on learning processes. These processes are central to refining, adopting, and improving technologies [53]. This implies that for technologies to thrive, a conducive environment that fosters learning and feedback is essential. Importantly, the analysis suggests that a system that prioritizes innovative technologies over older ones is gradually taking shape, reinforcing the need for regulations and standards that promote innovative solutions [54].

Analysis of the data shows that the aim of this SDG 12 is to strike a balance between humanity's development aspirations and the planet's ability to support them (Table 1). Several points arise from the details of this goal (Table 1).

The role of developed countries. The developed countries need to take the lead in promoting sustainable practices (as outlined in target 12.1). This reflects a recognition of their historical responsibility and greater resources. They are expected to lead by example and provide the necessary financial and technological support to less developed countries.

Resource management. Targets such as 12.2 focus on the prudent management of natural resources. The call for conservation and long-term sustainable use of resources reflects the global concern about dwindling natural resources and the negative impacts of overexploitation.

Food waste and sustainability. The focus on reducing food waste in target 12.3 is particularly relevant. Given that global food security is a concern and food production is environmentally costly, the issue of waste can have both humanitarian and environmental benefits.

Holistic approach to waste. A holistic approach to waste: the management of chemical and general wastes, as outlined in targets 12.4 and 12.5, demonstrates a holistic approach to waste, which includes not only waste minimization, but also its impacts throughout the life cycle. Integration of internationally agreed standards is necessary to maintain consistency and efficiency.

Corporate responsibility. The explicit mention of corporations in target 12.6, especially large and multinational corporations, highlights the role of the private sector in achieving sustainable development. Their influence on global patterns of consumption and production is enormous and their active involvement is therefore crucial.

Public procurement practices. Target 12.7, which emphasizes sustainable public procurement practices, highlights the role of governments as important consumers. By integrating sustainability into public procurement processes, governments can not only reduce environmental impacts, but also influence markets and producers to adopt more sustainable practices.

Public information and education. It is essential that target 12.8 focuses on public information and education. Often change starts with informing people, and this objective ensures that people have the information they need to make sustainable decisions.

Supporting technological progress in developing countries. As technological progress is an essential element of many sustainable solutions, target 12.a emphasizes the need for developed countries to support developing countries in this area. Scientific and technological capacity building can help them move towards more sustainable consumption and production methods without repeating some of the environmentally damaging phases experienced by more developed countries.

Sustainable tourism. Tourism, when done sustainably, has the potential to provide economic benefits without harming the environment. By developing and implementing tools to monitor sustainable tourism impacts, target 12.b ensures that tourism creates jobs, promotes local cultures and products, and contributes to the global sustainable development agenda.

Addressing fossil fuel subsidies. Target 12.c touches on a critical aspect of global energy consumption. Fossil fuel subsidies can distort markets and encourage wasteful consumption. Reassessing these subsidies is essential to align them with environmental objectives. The mention of safeguarding the poor and affected communities underscores the importance of a just transition, ensuring that measures taken do not unduly affect vulnerable groups.

When viewed in totality, these targets present a well-rounded approach to achieving sustainable consumption and production patterns. Each target plays a crucial role, and their interconnectedness means that success in one can have ripple effects, leading to progress in others. It underscores the importance of a collective and concerted effort from all stakeholders, including governments, the private sector, civil society, and individuals.

The results showcase the multifaceted implications of transitioning from fossil fuels to innovative energy technologies, specifically within the PESTEL analytical framework (Table 2). It highlights the diverse challenges and opportunities across political, economic, social, technological, environmental, and legal dimensions. The PESTEL method offers a comprehensive examination of various areas affected by the energy transition. Unlike narrower analyses that may only focus on economic or technological aspects, PESTEL provides a holistic assessment, revealing interconnected challenges and opportunities. The results underscore the significance of political will, the economic viability of renewable energy, social implications of transition, technological advancements, environmental benefits, and the need for legal adaptation. In the work [39], researchers affirm the results emphasizing the necessity of a holistic approach when understanding energy transition. Their study, like ours, argues that a limited focus on just the economic or technological dimensions is insufficient. It's the interplay of multiple factors, as illustrated by the PESTEL method, that dictates the pace and success of the transition.

When examining the alignment between Sustainable Development Goal 12 and analyses related to the integration of innovative energy technologies, a clear and significant link emerges. In the context of Sustainable Development Goal 12, which emphasizes sustainable consumption and production patterns as outlined by the United Nations in 2015, there's a significant alignment with the adoption of innovative energy technologies. Adopting innovative energy technologies, such as renewable energy sources or energy-efficient mechanisms, can promote more sustainable production and consumption patterns. Innovative energy technologies have a significant impact on all aspects of the PESTEL approach (Table 2) and therefore need to be taken into account in all aspects, as evidenced by the studies [39, 67].

In particular, the political domain is reflected in numerous relevant United Nations goals, the implementation of most of which relies on political, regional and supranational legislation and technical regulations. It is evident that political will, strategic partnerships, and cooperation are indispensable for the adoption and scaling up of these innovative technologies. Political will drives the transition to renewable energy, according to the study [68]. Renewable energy subsidies and other government measures accelerate the transition [68].

The economic dimension of our study points to the need for a paradigm shift. The analysis underlines the crucial importance of the economic feasibility of these technologies. It is equally important to promote them and to integrate them properly into economic systems. This is in line with efforts to remove market barriers by abolishing mechanisms that mainly support the use of fossil fuels. By stressing the importance of economically viable renewable energies and their integration, we are equating this with green economy attitudes [69]. Their studies advocate a re-shaping of market dynamics to favor renewable technologies over fossil fuels, reinforcing our point about the importance of removing traditional barriers. Such an initiative would allow the integration of innovative energy technologies, thus further strengthening the transition towards sustainable consumption and production.

Socially, the impacts of these technologies have a broader implication and interlink with other United Nations SDGs. Therefore, their evaluation necessitates a more holistic and inclusive framework, one that underscores the social equity and inclusivity components of these innovative energy solutions. The prioritization of social fairness and inclusivity in the implementation of these technologies aligns with the discourse presented in the reference [70]. The work presented by the authors resonates with our advocacy for a more thorough and inclusive framework for evaluation.

Technologically, innovative energy and environmental technologies are consistent with the objectives of Sustainable Development Goal 12. They contribute to waste reduction and energy efficiency, and include advanced materials that can be effectively integrated into a circular economy. These technologies could pave the way towards a more resource-efficient and sustainable world. The sentiment expressed in the research papers [71, 72] aligns with the notion that these technologies have the capacity to contribute to waste reduction, enhance energy efficiency, and be integrated into a circular economy.

From an ecological standpoint, renewable energy sources such as solar, wind, and hydroelectric power, among others, are devoid of the detrimental emissions commonly linked to traditional fossil fuels. As a result, there is a positive correlation between this phenomenon and the enhancement of air quality, ultimately leading to favorable public health consequences. Conventional energy sources such as coal, oil, and gas play a significant role in the generation of global greenhouse gas emissions. The adoption of innovative energy technologies has the potential to minimize the detrimental effects of climate change through the substantial reduction of carbon footprints. It is noteworthy to mention the distinctive characteristic of these technologies, as they do not produce any pollution for every extra unit of energy generated. This stands in stark contrast to traditional approaches, when a rise in production typically corresponds to an increase in emissions. Based on the findings of the International Renewable Energy Agency (IRENA), it is evident that the utilization of renewable energy technology has substantial promise in mitigating the adverse impacts of air pollution. According to a report published by the International Renewable Energy Agency (IRENA) in 2016, an increase in the worldwide proportion of renewable energy sources by a factor of two has the potential to yield a reduction of up to 70 % in concentrations of particulate matter. This outcome holds significant implications for public health, since it would bring about substantial gains in this domain. The crucial significance of renewable energy in mitigating greenhouse gas emissions has been underscored by the Intergovernmental Panel on Climate Change (IPCC). According to their evaluation, the integration of renewable energy sources alongside energy efficiency strategies has the potential to achieve more than 90 % of the required reductions in energy-related carbon dioxide emissions. According to the U.S. Department of Energy, wind and solar technologies possess the characteristics of modularity and scalability. This implies that after the establishment of the first infrastructure, the expansion of energy generation leads to negligible supplementary environmental consequences.

From a legal perspective, there are still elements of these innovative energy technologies that are under development. These components need to be effectively integrated into the sustainability plans set forth by governments. Proper regulatory frameworks would facilitate the transition towards sustainable technologies while ensuring that it is done in a way that protects the interests of all stakeholders. In line with our approach, the article [73] discusses the urgency of upgrading systems to bring these technologies on stream, highlighting the complexity and challenges of the transition to sustainable energy technologies and the importance of regulatory measures.

The relationship between the PESTEL analytical framework and Sustainable Development Goal 12 (SDG 12) is crucial for understanding the importance and influence of energy technology on sustainability targets. The present study offers comprehensive insights into the aforementioned link, presenting a detailed framework that spans various dimensions of sustainable development. The present analysis provides a comprehensive and intricate examination of research outcomes. The research conducted demonstrates a strong correlation between progressive energy policies and the goals outlined in SDG 12.1 (Table 3). The focus on sustainable resource management and efficient resource utilization aligns well with the goals outlined in SDG 12.2. Technological advancements represent a paradigm shift in approach to resource management, driving us closer to the attainment of SDG indicator 12.2.1. Innovative energy technologies play a pivotal role in advancing SDG indicator 12.2.2, specifically through reductions in DMC. By shifting towards renewable energy sources and employing energy-efficient technologies, there's not only a marked decrease in traditional resource consumption but also a transformative change in material demands, as evidenced by innovations like thinner solar panels and decentralized energy solutions. Moreover, the domestic adoption of renewables cuts down on imported fossil fuel reliance, emphasizing the dual benefit of ensuring energy security while reducing imported material consumption. The significance of renewable energy in achieving SDG 12.3. This study elucidates the interdependence between food and energy sustainability. The utilization of renewable resources in addressing food loss underscores the manifold advantages of green technologies. The concepts inherent in a circular economy are exemplified by the shift from non-renewable to renewable energy sources, as outlined in SDGs 12.4 and 12.5. The sustainable lifetime of energy technologies is enhanced by the resulting decrease in waste creation and the corresponding increase in recycling rates. The incorporation of renewable technology, such as smart grids, by corporations serves to enhance their commitment to sustainability and promotes increased confidence among consumers and investors. This alignment with SDG 12.6 underscores the importance of corporate responsibility in addressing environmental concerns. The complex interplay between the adoption of energy technologies and regulatory frameworks, as identified by our PESTEL research, underscores the importance of strategic policy development and execution in achieving SDG 12.7. The active involvement of the public in renewable energy projects contributes significantly to the promotion of sustainable development, as emphasized by SDG 12.8. This participation serves to cultivate a shared dedication within society towards achieving sustainability goals. The research underscores the pivotal role of renewable energy technologies in advancing SDG target 12.a and its indicator 12.a.1, emphasizing capacity-building in developing countries. The deployment of comprehensive energy technologies not only integrates emerging nations into global energy markets but also facilitates their transition to sustainable solutions, bypassing older, inefficient methods. Through international collaborations, funding mechanisms, and tailored educational endeavors, we highlight the significance of co-developed energy innovations, funding support, and knowledge sharing in driving sustainable progress, ensuring that developing regions harness the benefits of state-of-the-art energy solutions while catering to their unique challenges and needs. The economic and environmental advantages of renewable energy technologies are supported by the growing popularity of eco-tourism and the ongoing transition away from fossil-fuel subsidies, as outlined in SDGs 12.b and 12.c. In the research, the transformative potential of innovative energy technologies in fulfilling the SDG 12 targets is underscored. It is evident that these technologies play a pivotal role in achieving sustainable consumption and production, thus further highlighting the critical need to address the challenges to their implementation. The PESTEL framework provides a thorough exploration of these facets, revealing a roadmap of challenges and opportunities to be navigated for a sustainable future. A comprehensive view of the sustainable energy landscape is presented when policy, economic, societal, technological, environmental, and legal perspectives are woven together.

This research contributes to the existing body of knowledge and provides new perspectives on the application of innovative energy technology as a means to address unsustainable consumption and production patterns. This work makes a valuable contribution towards the realization of SDG 12. This research endeavor has the potential to provide valuable insights to various stakeholders, such as policymakers and corporations. By adopting this approach, it has the potential to make a significant contribution towards the advancement of sustainable and equitable practices within the energy industry, aligning with the goals outlined in SDG 12.

While the present investigation adds to the existing pool of knowledge and offers fresh insights into the utilization of innovative energy technology to tackle unsustainable consumption and production patterns, there are limitations. First, the study largely revolves around the alignment with SDG 12, potentially neglecting other interrelated SDGs and their complexities. Second, the rapidly changing landscape of energy technology might make some findings obsolete within a short time frame. Third, while comprehensive, the PESTEL framework might not capture all nuances of a transition to innovative energy technologies, especially cultural or behavioral dimensions. Fourth, the research findings, while insightful, might not be directly applicable to all geopolitical and socioeconomic contexts. Fifth, reliance on secondary sources such as prior research might limit the fresh data that the study could offer. These limitations can be removed in further studies. First, future studies could provide a comparative analysis. As the study suggests, there's a need for a comparison between innovative energy technologies and conventional ones. By understanding the comparative advantages and disadvantages of both, policymakers and businesses can make more informed decisions. The evolution of these technologies, their efficiencies, costs, and impacts across different settings can provide essential insights into the viability and scalability of renewable energy solutions. Second, a life cycle assessment (LCA). An LCA would provide a cradle-to-grave analysis of the cumulative environmental impacts of these technologies, including their production, operation and disposal. Third, understanding consumer behavior and perception. The study acknowledges the importance of addressing customer adoption hurdles. Further research can delve deeper into understanding consumer perceptions, acceptance levels, and behaviors regarding these technologies. Such insights would help in designing better communication strategies, educational initiatives, and incentive structures. Fourth, policy analysis. The study hints at the importance of political will and regulatory backing. A detailed policy analysis can examine the efficacy of existing policies, identify gaps, and recommend strategic policies that accelerate the transition to renewable energy. Fifth, socio-economic impacts. The effects of these technologies on local communities, particularly concerning employment, skill development, and general well-being, can be a vital research area. This would help in addressing potential socio-economic challenges early on and would aid in framing policies that are not just sustainable but also equitable. Sixth, technical advancements, the continuous evolution of technology necessitates ongoing research into technical advancements. Studying the next generation of renewable energy technologies, their potential efficiencies, and applications can be a natural progression. Seventh, integration with existing infrastructure. As the transition to innovative energy technologies happens, there will be challenges in integrating them with existing infrastructure. Researching optimized methods and techniques for this integration can prove invaluable. Eighth, geographical and demographical variances. Different regions might have varied responses and results with the same technology. Studying these variances can offer customized solutions suitable for specific geographies and demographics. Ninth, economic implications. While the study touches on economic aspects, it would be useful to carry out a more detailed economic analysis that takes into account the dynamics of the global market, the prospects for investment and the return on investment of these technologies.

7. Conclusions

1. In this study, we classified innovative energy technologies, identifying five unique characteristics (low or no carbon emission; strategic importance; innovation focus; sustainability; and inherent uncertainties) that set them apart from traditional energy methods. These technologies, such as wind and

solar, are essential in reducing the carbon dioxide responsible for 85 % of global emissions, which intensify global warming. To counter the dominance of oil and gas, it's not just about using new energy sources; the sector must innovate consistently, tackle existing challenges like high costs, and receive policy support. As seen in Iceland's success with hydropower and geothermal energy, such technologies offer both environmental and economic benefits. However, due to their nascent nature, they come with risks linked to technological changes, human capital shifts, and policy inconsistencies. Therefore, for a sustainable, clean energy future, it's crucial to invest in research, strategic planning, technology development, and policy frameworks. This work emphasizes the importance of innovative energy technologies and outlines the challenges and strategies for their successful implementation.

2. Our research delves into the intricate nature of deploying innovative energy technologies, emphasizing four central domains: technical elements, market factors, enterprise dynamics, and environmental considerations. Technically, these energy innovations demand a balance between complexity and potential. Their integration with existing solutions and the phasing out of outdated technologies become pivotal. Market-wise, while entrepreneurs spearhead these technologies, barriers to consumer adoption exist, necessitating interventions to prevent potential innovators from exiting prematurely. Within enterprises, external shifts can influence strategic goals and resource allocation, underscoring the significance of positioning and continuous technological evolution. Environmentally, the constant evolution of energy technologies prompts adaptations in environmental standards and regulations. Our findings, thus, unveil the multifaceted interplay in introducing advanced energy solutions, serving as a beacon for stakeholders navigating the challenges and opportunities, propelling us towards a greener, more technologically advanced energy future.

3. Our research provides a comprehensive analysis of Sustainable Development Goal (SDG) 12, emphasizing its objective to foster sustainable consumption and production. Key findings emphasize SDG 12's delicate balance between human advancement and planetary limits. Notably, the roles of developed and developing countries differ; the former are expected to lead, while the latter, often resource-constrained, need targeted support to balance sustainability with economic growth. SDG 12 also extends its vision beyond 2030, aiming for a harmonious relationship between economic progress and ecological preservation. In essence, SDG 12 is not merely a goal but a strategic blueprint directing humanity towards sustainable coexistence with the environment. It stresses the immediate need to modify consumption and production habits to ensure both growth and environmental protection.

4. Our extensive research presents a nuanced understanding of the factors influencing the transition to renewable energy sources, evaluated through the PESTEL framework. Political dimension: Developed nations have advanced renewable energy policies while underdeveloped countries face challenges. The study underscores the need for leading powers, especially the U.S., to deepen their commitment. Furthermore, global events, such as Russia's activities related to Ukraine, exemplify the potential influence of external factors on political decisions. Economic perspective: Despite the initial high costs associated with renewable technologies, long-term operational savings counterbalance these expenses. The importance of transparent energy legislation, focusing on broad benefits, is emphasized. Sociological aspects: Our research dives deep into public reception and the socio-economic implications of transitioning to renewables, shedding light on employment prospects and potential community-level conflicts. Technological angle: While renewables offer vast potential, challenges like enhancing system capabilities and managing grid fluctuations need addressing. We emphasize innovative solutions for grid stability amidst renewable integration. Environmental context: Beyond the predominant focus on ecological conservation, the procurement of raw materials, especially in resource-rich developing countries, necessitates a holistic approach. Legal considerations: The current complex regulatory landscape poses hurdles. There's a pressing need for flexible legal structures promoting easier integration of renewables. The findings shed light on the multifaceted journey of transitioning to renewable energy. It's not just about harnessing the potential of renewables; the complexity lies in tackling challenges across political, economic, sociological, technological, environmental, and legal dimensions. Success depends on comprehensive analysis, innovative strategies, and collaborative efforts. Our study's uniqueness lies in its holistic examination of this pivotal shift, potentially revolutionizing the energy landscape for upcoming generations.

5. Our study maps the connection between the PESTEL framework and Sustainable Development Goal 12 (SDG 12). We highlight the central role of innovative energy technologies in achieving SDG 12's objectives, including resource management and energy efficiency. Emphasizing renewables reduces resource consumption and promotes a circular economy. Government policies significantly influence the energy sector, and renewables have transformative potential in areas like tourism and reducing fossil-fuel subsidies. We stress the importance of sustainability awareness and renewable energy's role in developing nations. Through the integration of policy, economics, society, technology, environment and legislation, we offer a complete overview of the prospective trajectory of sustainable energy. Our research champions the integration of advanced energy technology with SDG 12, offering a clear path to a sustainable energy future.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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