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“GREEN” TECHNOLOGIES AS AN INDICATOR OF SUSTAINABILITY, SUSTAINABLE DEVELOPMENT, AND GROWTH IN THE INNOVATION POTENTIAL OF SMEs

Introduction. *In light of the growing risks associated with global warming, the sustainable development of small and medium-sized enterprises (SMEs) has gained strategic importance. Their focus on environmental responsibility, the adoption of “green” technologies, and the reduction of ecological impact position SMEs as key contributors to sustainable economic growth.*

Problem Statement. *The imperative of environmental protection has necessitated the development and adoption of green technologies. These technologies offer substantial potential for improving the performance and competitiveness of SMEs, particularly within the framework of eco-clusters.*

Purpose. *This study aims to examine the legal definition and framework of “green” technologies; to assess the feasibility of their implementation by SMEs as members of eco-clusters; to identify the principal areas of legal regulation related to green technologies; and to determine the current level of SME awareness regarding opportunities, benefits, and barriers associated with green technology.*

Materials and Methods. *The research is based on a combination of general scientific and specialized legal methodologies. The source material includes publications by Ukrainian and international scholars, as well as relevant legislation from Ukraine and the European Union.*

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Results. A comparative analysis of legal doctrine and regulatory practice in Ukraine and the EU has revealed key indicators for guiding the continued green transformation of SMEs in alignment with international standards. Factors influencing SMEs' awareness of the benefits and challenges associated with green technologies have been identified. The study has highlighted the role of eco-clusters as drivers of SME innovation, and has outlined a set of incentive markers essential for motivating SMEs to integrate green technologies in support of sustainable development and responsible environmental behavior.

Conclusions. The implementation of the green technology concept, as a manifestation of sustainable innovation for SMEs, requires further refinement within Ukrainian legal frameworks. The proposed measures have demonstrated their potential to address pressing environmental issues, mitigate ecological impact, and support climate adaptation strategies. The promotion of green technologies among SMEs, particularly through eco-cluster participation, has emerged as a critical pathway for enhancing their innovation capacity and environmental accountability.

Keywords: «green» technologies, environmentally friendly technologies, SMEs, eco-clusters, green energy, green course, environment, greening.

Due to growing concerns over global warming, environmental issues have increasingly become a central focus of academic research.

According to Article 5 of the Law of Ukraine on *Environmental Protection* No. 1264-XII, dated June 25, 1991, the environment is defined as the totality of natural and socio-natural conditions and processes, as well as natural resources — whether currently in economic use or not — including land, subsoil, water, atmospheric air, forests and other vegetation, wildlife, landscapes, and other natural complexes.

The increasing relevance of the human-environment relationship has underscored the need to ensure environmental safety, and to uphold and protect citizens' rights in the field of environmental protection. In 2024, the Environmental Performance Index (EPI) assessed countries based on their environmental conditions and the effectiveness of their environmental policies. Ukraine ranked 41st, with a score of 54.6.

The full-scale invasion of Ukraine by the Russian Federation has exposed Europe's dependence on Russian oil and gas, intensifying the urgency of a transition to green energy — particularly through the development and deployment of alternative energy sources. In this context, Ukraine also requires a green transformation, grounded in the integration of advanced technologies, the creation of conditions for the development of talent in green tech innovation, and the design and use of renewable energy sources as critical com-

ponents of environmental security and *European integration processes* [1]. This situation has further exacerbated long-standing challenges, such as underinvestment in scientific research and technological development, damage to infrastructure, and the erosion of human capital, which has ultimately weakened the innovation potential of SMEs.

Despite the adoption of the Law of Ukraine on *the Specifics of Regulating Business Activities of Certain Types of Legal Entities and Their Associations During the Transition Period* No. 4196-IX, dated January 9, 2025 (to enter into force on August 28, 2025), the outlook for SME operations is unlikely to directly impact the mechanisms for the implementation of green technologies by these enterprises.

One of the key directions of state policy for supporting innovation is improving access to financing — particularly grants, subsidies, tax incentives, and low-interest loans — for research and development, as well as for enterprises investing in innovation projects.

This priority is reflected in the *Strategy for the Digital Development of Innovation in Ukraine Until 2030 and the Adoption of the Operational Plan of Measures for Its Implementation in 2025–2027* (Cabinet Resolution No. 1351-p, dated December 31, 2024).

Green technologies encompass a broad range of scientific research areas, including energy, agriculture, and beyond. Many green technologies aim to reduce carbon dioxide and other greenhouse

gas emissions in order to mitigate climate change. Among the most successful eco-technologies is solar energy that is currently in high demand in many countries.

On March 20, 2024, the European Commission adopted the second Strategic Plan of Horizon Europe for 2025–2027, focusing on research and innovation to support the transition to a green, digital, and resilient future (*Horizon Europe Strategic Plan 2025–2027 for Research and Innovation to Underpin Journey to a Green, Digital and Resilient Future*). This strategic framework reflects the commitment of European institutions to supporting research in *green innovation and technologies*.

Investment in research and development (R&D) is a crucial factor for sustainable development. Highly skilled human resources are essential to maintain the scientific and innovation capacity and competitiveness of a country, as well as to ensure progress in the green transition.

The green industrial transition presents opportunities for the development of green metallurgy, renewable and nuclear energy. Ukraine possesses the potential to become a major energy hub in Europe, as emphasized in the *Strategy for the Digital Development of Innovation in Ukraine Until 2030 and the Adoption of the Operational Plan of Measures for Its Implementation in 2025–2027* (Cabinet Resolution No. 1351-p, dated December 31, 2024).

One of the guiding principles of the *National Economic Strategy of Ukraine*, dated March 3, 2021 (No. 179), is the decarbonization of the economy, which includes improving energy efficiency, advancing renewable energy sources, developing a circular economy, and aligning with *the European Green Deal initiative*.

Ukraine has joined *the European Green Deal* (EGD). On July 6, 2023, the OECD and the Government of Ukraine launched a four-year Country Program that supports Ukraine’s reform agenda, recovery, and reconstruction efforts, and facilitates its ambitions for accession to the OECD and the EU [2]. This program covers six policy domains, one of which is environmental sustainability and energy [3]. *Ukraine’s potential for*

green growth lies primarily in the areas of energy efficiency, renewable energy sources, organic agriculture, waste management, and the development and deployment of advanced environmentally safe technologies and eco-innovations [4].

Ukraine has already undertaken several important steps toward building the foundations for a *green economy and promoting green growth*, including:

- ◆ Approval of the National Environmental Action Plan until 2025 (Cabinet Resolution No. 443-p, dated April 21, 2021), which addresses a wide range of environmental issues such as *the development and adoption of integrated urban green zone development programs; the creation of a monitoring system for green growth indicators*, based on the expanded framework of the UN Sustainable Development Goals (SDGs) baseline indicators;
- ◆ Entry into force of the Law of Ukraine *on the Basic Principles (Strategy) of the State Environmental Policy of Ukraine until 2030* (No. 2697-VIII, dated February 28, 2019), which emphasizes that *the processes of globalization and social transformation have increased the priority of environmental protection and require Ukraine to take urgent action*;
- ◆ Approval of the National Economic Strategy until 2030 (Resolution No. 179, dated March 3, 2021), where the core pillars include *the development of a business support ecosystem, expanded access to financing, and regulatory simplification*;
- ◆ Endorsement of the National Waste Management Strategy until 2030 (Resolution No. 820-p, dated November 8, 2017), which is expected to enable the implementation of an *innovation-based* waste management system, the development of corresponding legislation, environmental improvement, enhanced sanitary and epidemiological conditions, and the adoption of *advanced technologies*;
- ◆ Approval of the Energy Strategy of Ukraine until 2050 (Resolution No. 373-p, dated April 21, 2023), which sets out key principles such as *economic feasibility, environmental sustaina-*

bility, accessibility, social equity, and market competitiveness.

Eco-innovation constitutes a clear objective of the European Union's core policy strategies. Numerous environmental policies effectively require *enterprises* to implement eco-innovations to comply with regulatory standards. At the same time, the alignment between policy-driven and market-driven strategies for environmental innovation is becoming increasingly significant for many businesses. In this context, *barriers* to eco-innovation may become *a critical factor in either obstructing or facilitating EU strategies*, policy implementation, and corporate environmental agendas [5].

The *eco-technology industry* in Europe is predominantly composed of small and medium-sized enterprises (SMEs) that are characterized by high levels of specialization and flexibility. In recent years, *numerous clusters and networks* have been established to enhance innovation and internationalization capacities. The Eco-Innovation Cluster Partnership for Growth and Internationalization (EcoCluP) project was launched with the aim of connecting these clusters at the European level. The multifaceted EcoCluP cluster network was designed to be user-friendly, practical, and capable of generating tangible business impact for SMEs [6].

However, *environmental considerations* are often not a priority for SMEs, particularly those struggling to meet their financial goals and obligations. Moreover, SMEs constitute a heterogeneous group in terms of size and industry diversity, and there is no universal definition of SMEs [7]. Creating enabling conditions for innovation is thus essential for any state to ensure the competitiveness of SMEs that engage in *eco-innovation* and adopt *green technologies*.

Eco-innovation can be conceptualized across micro-, meso-, and macro-levels, with *firms*, industries, and countries acting as the respective agents in these *three dimensions*. The role of SMEs is particularly relevant at the *micro-level* [8]. Accordingly, this study focuses on the micro-level activities of SMEs related to the implementation of green growth models and the adoption of green

technologies, while the macro-level is considered solely in terms of government action in the field of environmental regulation. SMEs face a broad spectrum of *internal and external barriers* – including human, political, structural, and cultural factors – that constrain the expansion of their environmentally sustainable operations [9].

The urgency of regulating these relationships stems from the integration of green technologies into SMEs' activities as participants in *clusters*, which presents opportunities for internationalization through the expansion of clustering processes in the green technology sector. This facilitates the promotion of *sustainable* practices and knowledge among *SMEs*, aiding their transition toward green business models and strengthening their economic resilience. At the same time, such activities *shall not infringe on intellectual property rights* related to green technologies. Furthermore, the adoption of green technologies by SMEs highlights the need to analyze their impact on innovation, particularly the benefits, obstacles, and barriers that may arise in the course of this transition.

At the same time, it has been observed that green technologies *do not provide a comprehensive solution to global environmental issues*, as they are primarily localized innovation responses. These technologies can partially alter environmental conditions, help minimize environmental impact, and enhance SMEs' capacity to contribute to Ukraine's economic growth.

Given that green technologies exhibit specific characteristics compared to other types of technologies, both in Ukrainian and EU legislation, we proceed to analyze SMEs' innovation in Ukraine in the context of green technology adoption.

Various legal and academic sources employ multiple terms related to *environmentally oriented technologies*, including "*environmental technologies*," "*clean technologies (cleantech)*," and "*environmentally friendly technologies*." The most widely used terms are "*environmentally sound technologies*" and "*green technologies (green tech)*."

Although the terms "*green technologies*," "*clean technologies*," and "*environmental technologies*" are

often used interchangeably, they refer to different areas of focus: *Green technologies* encompass any technology that is environmentally sustainable or clean, aiming to reduce our overall ecological footprint. The clean technologies (cleantech) emphasize improving environmental performance, often through greater efficiency and sustainability in production processes. *The environmental technologies*, sometimes referred to as climate technologies, *are explicitly aimed* at addressing challenges caused by climate change and human activity. These may include technologies for reducing greenhouse gas emissions or adapting to climate impacts such as rising sea levels and extreme weather events. *The green technologies* thus serve as important instruments for *protecting the natural environment*. Examples include: renewable energy sources such as solar and wind power; efficiency-enhancing technologies like improved insulation and LED lighting; and conservation technologies, including water filtration systems and sustainable transportation solutions [10].

As shown, *both the green and the environmental technologies* aim to mitigate environmental impacts. However, while the *environmental (or climate) technologies* are directly focused on addressing human-induced climate change, *the green technologies* tend to target more localized challenges, including *climate change and carbon dioxide emissions*, among others.

The objective of this study is to identify the current interlinkages between cluster policy, the sustainable development of SMEs, *green technologies*, and eco-innovation.

In this article, the authors *have contributed to the body of research* by enhancing awareness of the positive environmental impact of *green technologies*, promoting knowledge dissemination on green technologies, and analyzing *the implementation of these technologies by SMEs* participating in eco-clusters, as well as *the barriers that hinder their adoption*.

The authors also aim to present SMEs' activities as participants in eco-clusters in the context of green technology deployment, highlighting

the roles of government and other stakeholders (such as technology developers, technology buyers, and financial support organizations) in supporting this process. These efforts are expected to lead to sustainable development, environmental resilience of SMEs, job creation, and business growth in Ukraine.

Since *there is no* universally accepted definition of "green technologies" in the academic literature, the diversity of scientific viewpoints on this issue is reflected in the works of Bhardwaj M. [11], Guelfo D. [10], Kenton W. [12], and Musina L. A. [13].

Various approaches to *technology development and transfer* have been examined in the studies of Puig D., Haselip J. A., Bakhtiari F. [14], Adamciuk D. I. [15], and Rozghon O. V. [16, 17].

The barriers to the adoption of green technologies have been explored by researchers including Alipour A. et al. [18], Durdyev S. et al. [19], Deng W. et al. [20], and Marin G. et al. [5].

Environmental pollution and climate change have been investigated by Mykyievych M. M. [21] and Musina L. A. [4].

Cluster functioning and SME dynamics have been extensively covered in the literature, with notable contributions from Barsoumian S. et al. [22], Carpinetti L. C. R. et al. [23], de Jesus Pacheco et al. [24], Dohse D. [25], Kurniasih J. [26], López Jiménez J. et al. [27], Hasan M. N. [28], Mercado-Caruso N. et al. [29], Porter M. E. [30], Rodrigues M., Franco M. [31], Prokhorchuk S. V. [32], and Serik O. D. [33].

This study does not address *global environmental protection and natural resource management* issues per se, but rather focuses on the legal, economic, and organizational foundations of regulatory frameworks for activities related to *green technologies*. Specifically, it examines their role in ensuring rational environmental management, efficient use of scientific, technological, and intellectual resources within *clusters*, and the *protection of property rights* related to green technologies both in Ukraine and in other countries where such technologies are or will be implemented.

The development of clusters *is not a new topic*; however, the analysis of their activities in the context of green technology adoption by SMEs as eco-cluster participants requires a comprehensive study. Given the limited attention to this specific aspect of green technology analysis, there is a clear need for more in-depth research into the legal regulation of *green technologies implemented by SMEs within eco-clusters*.

A comprehensive set of *general scientific and specialized research methods* was employed in this study. Based on a *review* of several publications concerning the characteristics of *green technologies* and using the methods of *analysis and synthesis*, the study reveals the features of these technologies, the legal framework governing them, and the prospects for their implementation.

The method of alternatives has made it possible to critically evaluate legal provisions regulating the status of SMEs specifically as enterprises participating in eco-clusters and engaged in the implementation of green technologies.

The comparative legal method has been used to identify key indicators for advancing the green transformation of SME regulation in line with global standards, as well as to assess the current level of awareness among SMEs. *The classification method* has allowed the identification of both advantages and barriers to the adoption of green technologies in SME operations.

The cybernetic method has made it possible to analyze the system of factors essential to *eco-cluster operations*. It enabled consideration of eco-clusters as components of national or regional innovation systems (NIS or RIS), acting as drivers of innovation capacity for SMEs. These drivers support the deployment of green technologies in the context of sustainable development, economic growth, environmental protection, and the promotion of ecological safety, environmental responsibility, and resource efficiency among SMEs.

The objective of the study is to examine the legal nature of the category of green technologies, identify opportunities for their implementation by SMEs as eco-cluster participants, define the main direc-

tions of legal regulation, and assess the current level of SME awareness regarding the possibilities and benefits of green technology adoption, as well as the barriers that hinder this process in SME activities.

To achieve this objective, the article addresses the following research questions:

- ◆ to examine the fundamental issues associated with the effective implementation of green technologies;
- ◆ to study the advantages and barriers to the implementation of projects involving green technologies;
- ◆ to define the optimal conditions for the internationalization of SMEs as eco-cluster participants in Ukraine through the expansion of clustering processes that involve green technologies;
- ◆ to identify potential directions for state support of SMEs to ensure the implementation of green technologies.

DEFINITION OF THE CONCEPT OF "GREEN" TECHNOLOGIES

According to Article 1 of the Law of Ukraine *on Innovation* dated July 4, 2002, No. 40-IV, *innovations* are newly created (applied) and/or improved competitive technologies, products, or services, as well as organizational and technical solutions of a production, administrative, commercial, or other nature that significantly improve the structure and quality of production and/or the social sphere.

Therefore, it is logical to conclude that the main outcomes of innovation are:

- ◆ the production of innovation products;
- ◆ the implementation of innovation projects or the provision of innovation services;
- ◆ the application of *innovation technologies*; and
- ◆ the introduction of innovation production resulting from a combination of various types of innovation (i.e., the creation of production facilities for new or significantly improved products as turnkey solutions) [34].

Accordingly, in this study, *innovation is considered as the end result of innovation activity, particularly in the form of technology*.

Four phases (stages) of the innovation product life cycle are generally distinguished: the creation of innovation (creativity); the production and sales growth (marketing, research, development); the manufacture and market dissemination (process stabilization); the maturity (declining output of innovation products); and the decline and withdrawal from production because of decreased demand.

Innovation products are new competitive goods or services that comply with the requirements set forth in the Law of Ukraine on Innovation No. 40-IV of July 4, 2002. These products may be created using an appropriate technology and may become intellectual property if legal ownership rights are registered [35]. It should be noted that such a *technology may be developed not by the enterprise itself* (e.g., an SME), but by a *technology developer*, as provided by the Law of Ukraine on State Regulation of Activities in the Field of Technology Transfer dated September 14, 2006, No. 143-V.

For example, a developer of technology for producing biodegradable paper from fallen leaves (processing leaves without harmful chemicals by creating cellulose from cleaned leaves for paper bags and boxes) founded the *Releaf Paper* company.

SME may be considered a *startup* (a legal entity) engaged in technology development. The concept of a startup as a type of small or medium-sized enterprise is defined in the Resolution of the Cabinet of Ministers of Ukraine on the Implementation of the Experimental Project for the Creation of a Network of Startup Schools – Incubators – Accelerators Based at Higher Education Institutions and Research Establishments dated April 23, 2024, No. 430.

According to paragraph 11 of Article 1 of the Law of Ukraine on State Regulation of Activities in the Field of Technology Transfer dated September 14, 2006, No. 143-V, a *technology as an object of transfer may be defined as the result of R&D activities*, comprising a set of systematized scientific knowledge, technical, organizational, and other solutions.

D.I. Adamiuk has stated that the legislator effectively acknowledges *the complex nature of tech-*

nology by providing a definition not only of the concept of technology itself but also of its components. *Technology may be fully embodied in a single defined object*. On the other hand, *the technology for processing municipal solid waste using a plasma torch* may encompass several inventions and utility models, know-how, and scientific-technical documentation. Therefore, a technology can be "disassembled" into individual components, each of which contains distinct elements of the technology. When drafting *technology transfer agreements*, the subject of the contract shall clearly specify *the single object* in which the technology is embodied or identify the components of the technology if it consists of multiple objects [15].

Thus, the following conclusions can be drawn regarding the legal nature of a technology:

- ◆ *it is an object of technology transfer*, formalized through the conclusion of bilateral or multilateral civil-law contracts;
- ◆ it may be considered *an object of both civil-law relations* (e.g., the regulation of social relations in the sphere of technology transfer is governed exclusively by the provisions of Chapter 35 of the Civil Code of Ukraine, No. 435-IV of January 16, 2003) and *commercial-law relations* (the material forms of technology embodiment may be used in economic circulation as individual tangible (proprietary) objects of commercial legal relations). This underscores *the multidimensional legal nature of technology* and the contractual relations arising in the field of technology transfer;
- ◆ it is expressed in an objective form as *output of R&D activities*. It includes scholarly research and applied results, intellectual property objects, and know-how. The technology may consist of *intellectual property objects* (in particular, objects of industrial property); however, *the technology itself cannot be considered an object of intellectual property rights* (since the exhaustive list of such objects is defined in Article 420 of the Civil Code of Ukraine, No. 435-IV of January 16, 2003), nor can it exist solely as a synthesized intellectual property object [16].

Typically, definitions of *innovation* are associated with *technology*. However, since this study treats *innovation* as *the ultimate result of innovation* activity (in the form of innovation products, technologies, etc.), it also analyzes the activities of SMEs in eco-clusters concerning the development of *green technologies* and *eco-innovations* more broadly. In particular, *eco-innovations* essentially involve the accumulation and application of ecological knowledge in every stage of the production process. *Technology* enables a firm to move away from traditional production and shift to environmentally clean production methods [36].

There is no universally accepted international definition of *green technologies*. The concept of the *Global Green New Deal*, introduced by the United Nations Environment Programme (UNEP) in 2008–2009, is generally associated with the emergence of the term *green technologies* [13, p. 23]. These are aligned with *environmentally sound technologies* (ESTs) as defined under the United Nations Framework Convention on Climate Change (UNFCCC), and are characterized as the implementation of new or significantly improved products (goods and services), processes, marketing methods, organizational structures, and institutional mechanisms that – intentionally or otherwise – result in improved *environmental outcomes*, as compared with conventional alternatives. *Green innovation* is also understood through the lens of developing and adopting new ideas, inventions, practices, processes, products, and organizational forms that create value for society and the economy while achieving environmental objectives.

P. Bansal [37] has identified a strong link between *innovation and sustainability practices* and advised companies to follow principles of social responsibility in their operations by adopting new, *environmentally sound technologies* [38].

The *environmentally sound technologies* (ESTs) are defined in Agenda 21, with Chapter 34 entirely devoted to the development, implementation, and adaptation of ESTs, as well as ensuring access to and transfer of such technologies – particularly to developing countries. *ESTs* are technolo-

gies designed to: protect the environment; pollute less; use resources in an environmentally sustainable manner; recycle a larger share of their waste and products; and handle all residual waste in a more environmentally acceptable way than the technologies they replace (e.g., through cleaner processing methods) (Chapter 34 of Agenda 21, adopted at the UN Conference on Environment and Development, Rio de Janeiro, 1992). *These are not merely individual technologies* but integrated systems that encompass know-how, goods, services, equipment, as well as organizational and managerial procedures. *They include*: environmental protection technologies; pollution-reducing technologies; resource-efficient technologies; waste and product recycling technologies; and technologies for purification and rational resource use.

Scholars interpret the term *green technologies* differently.

According to D. Guelfo [10], *green technologies* represent the use of science and technology to develop environmentally friendly products and services that protect the natural environment. This includes renewable energy, green transportation, waste management and recycling, and energy-efficient solutions that help advance a more sustainable future. This definition reflects a strictly scientific and technical perspective.

In contrast, M. Bhardwaj [11] defines *green technologies* as the development and application of innovation products, equipment, and systems used to conserve the natural environment and resources, aiming to minimize and reduce the harmful impacts of human activity. This interpretation presents green technology as a continuous process.

In our view, *green technologies* refer to a type of technology that constitutes advanced solutions of a local nature, based on their production processes, and are applied to preserve the natural environment and resources, reduce the negative impact of human activity, support the achievement of the Sustainable Development Goals (SDGs), and promote the circular green economy.

Accordingly, the distinguishing features of *green technologies* include the following:

- ◆ they aim to preserve the natural environment and reduce the negative impact of human activity;
- ◆ they are directed toward minimizing the use of non-renewable natural resources and conserving them, reducing overall resource consumption, and supporting recycling;
- ◆ they contribute to the sustainable development of industry.

Thus, it can be concluded that *green technologies* are technologies that focus on sustainable development and address local environmental protection challenges. *Green technologies* (green tech, short for "green technology") represent a vital tool for integrating economic growth with environmental protection, ensuring ecological safety, environmental responsibility, and resource efficiency.

Green technologies can be broadly classified into *four main categories*: renewable energy technologies, environmentally friendly transport, waste management and recycling, and energy-efficient solutions [10]. Each of these categories plays a critical role in minimizing human impact on the environment and promoting a more sustainable future.

1. *Renewable Energy Sources*. In the context of climate change mitigation, green technologies are centered on the development and deployment of renewable energy sources such as solar, wind, and geothermal power. These technologies harness natural elements to generate electricity, reducing dependence on carbon-emitting fossil fuels. For example, the Law of Ukraine *on the Basic Principles of State Climate Policy* (dated October 8, 2024, No. 3991-IX) defines the legal and organizational foundations of state climate policy aimed at ensuring Ukraine's low-carbon development. The focus here is on *climate change mitigation*.

2. *Environmentally Friendly Transport*. In the context of climate change adaptation, green technologies support the resilience and adaptability of our systems. Examples include the development of *advanced weather forecasting models and the construction of infrastructure* capable of withstanding extreme weather events. Sustainable transportation, such as electric vehicles and hydrogen

fuel cell technologies, also falls into this category, offering viable alternatives that can adapt to evolving energy landscapes. This highlights the *adaptation of transport systems to climate change*.

3. *Waste Management and Recycling*. Green technologies contribute to the sustainable use and protection of water and marine resources through advanced solutions such as water-saving systems, wastewater treatment technologies, and marine life protection initiatives. These range from smart irrigation systems that optimize water usage in agriculture to technologies that safeguard coral reefs from bleaching. For instance, Article 12 of the Law of Ukraine *on Integrated Prevention and Control of Industrial Pollution* (dated July 16, 2024, No. 3855-IX, effective from August 8, 2025) establishes criteria for determining the best available techniques and management methods. In this case, green technologies support *the rational use and conservation of aquatic and marine resources*.

The transition to a circular economy is a key goal, with green technologies playing a critical role in *waste management and recycling*. Methods include converting waste into new products, fostering a continuous-use cycle, and applying innovation waste management approaches such as composting that transforms organic waste into nutrient-rich soil. This emphasizes the importance of *shifting toward a circular economy*. In the area of pollution prevention and control, green technologies are used to develop solutions for monitoring, reducing, and eliminating pollution. This includes air and water filtration systems, *waste-to-energy technologies*, and methods for the safe disposal or repurposing of industrial waste. Here, the focus is on *preventing and controlling environmental pollution*.

4. *Energy-Efficient Solutions*. In terms of biodiversity conservation and ecosystem restoration, green technologies concentrate on *rehabilitating degraded land, protecting endangered species*, and promoting *sustainable agricultural practices* that support ecosystem health. This includes the use of biochar in agriculture, which enhances soil quality and sequesters carbon, aiding in ecosystem regeneration. By embracing these categories

and implementing green technologies within them, we move closer to achieving the objectives outlined in the EU taxonomy, thereby ensuring a *sustainable and regenerative future* for our planet [10]. In this context, green technologies are seen as instrumental in *the protection and restoration of biodiversity and ecosystems*.

Green technologies are also the product of intellectual, creative, and R&D activities expressed in tangible form. They encompass scientific and applied research outcomes, intellectual property rights objects, and know-how in the field of environmental protection.

To ensure that *the intellectual property (IP) system* makes a real and practical contribution to the development, dissemination, and implementation of *green technologies* in developing and transition economies, innovation infrastructure in these countries shall strengthen *the protection and enforcement of IP rights*. This would incentivize the development of intellectual property assets, enabling IP licensing and research and development collaboration as a means of facilitating commercialization.

At the same time, research and development necessary for successful *green technology* innovation represent *only half the solution to environmental challenges*. The journey from *inventing an eco-technology*, even up to prototyping, cannot start mitigating global warming until the invention is actually implemented. Licensing agreements with large manufacturers can help startups scale and commercialize their products [39].

According to Article 360 of the Association Agreement between Ukraine, of the one part, and the European Union, the European Atomic Energy Community and their Member States, of the other part, dated June 27, 2014 (hereinafter — *Association Agreement*), the development and strengthening of cooperation *in the field of environmental protection* is envisaged. This cooperation aims to support the implementation of long-term *sustainable development goals* and *the green economy*, as well as to improve production efficiency through the application of modern technologies. Pursuant to Article 362 of the Agreement, the Parties are

to engage in *joint research activities and information exchange concerning environmentally sound technologies*.

The World Trade Organization (WTO) Agreement on *Trade-Related Aspects of Intellectual Property Rights* (TRIPS) establishes minimum standards for the protection of intellectual property rights (IPR). While the agreement allows for some flexibility, its overall structure favors the rights of IPR holders. At the same time, the Agreement explicitly supports the pursuit of *environmental protection*, public health, and development goals, granting members a degree of discretion in determining when such goals may outweigh typical TRIPS limitations. However, TRIPS significantly constrains the use of competition policy to challenge abuses of intellectual property rights. *Compulsory licensing* is one option available to a developing country when a patent has been filed domestically but the patent holder refuses to *license the technology*; nonetheless, this mechanism is subject to strict limitations [40].

Procedures related to *the protection of intellectual property rights* over technologies should be *fair and equitable*. They shall not be unnecessarily complicated or costly, and should not involve unreasonable time limits or unjustified delays. In Ukraine, such measures include evidence preservation and preliminary injunctions, as provided in the Civil Procedure Code of Ukraine dated March 18, 2004, No. 1618-IV and the Commercial Procedure Code of Ukraine dated November 6, 1991, No. 1798-XII. These measures may be applied by a court at the request of a person whose rights have been violated.

Therefore, *green technologies* — as the result of intellectual, creative, and scientific-technical activity — are aimed at reducing the negative impact of human activity in order to preserve the natural environment.

The concept of *green growth* serves as a tool for achieving *the Sustainable Development Goals* (SDGs). As stated, “Combating climate change and progressing toward sustainable development depends on economic growth that works with the

environment, not against it. Advanced *green technological solutions* can help by enabling us to do more with less – whether through alternative and more efficient energy production and use, new forms of green transport, or more sustainable, environmentally friendly *agricultural and forestry practices*” [41].

The Sustainable Development Goals of Ukraine until 2030 serve as benchmarks for the development of projects, strategic documents, and draft regulations aimed at balancing the economic, social, and environmental dimensions of Ukraine’s sustainable development, as stated in the Presidential Decree of Ukraine “On the Sustainable Development Goals of Ukraine until 2030” dated September 30, 2019, No. 722/2019.

Legal protection regimes for intellectual property serve as regulatory mechanisms that facilitate *technological innovation*, with patent law playing a particularly significant role. Effective *patent protection* supports the international transfer of green technologies and the establishment of technological partnerships [1].

Thus, the effective *protection of intellectual property rights* related to green technologies contributes to technology transfer and ensures economic, social, and environmental outcomes in line with Ukraine’s sustainable development goals.

The development of *technologies and their transfer* concerns both existing and emerging technologies. It includes the dissemination of technologies and technological cooperation regarding equipment, know-how, software, and corresponding management systems. These transactions may be carried out through governmental channels, public-private partnerships, or other forms of cooperation. *Technology transfer* involves not only the provision of equipment across national or international borders, but also the complex processes of knowledge exchange and technology adaptation to local conditions and management requirements [40].

Technology transfer forms part of the broader innovation process. The innovation process includes the creation (development), implementation (adoption), and diffusion (production and

commercialization) of innovations. *Technology transfer* is activated during the later stages of the innovation cycle, when the *idea* has already been developed, research prototypes have been produced and refined *based on the production requirements*, and production readiness has been established – at which point the actual *transfer of technology* begins [17].

The transfer of green technologies may occur in three distinct forms: transfer of green technologies themselves; transfer of knowledge related to green technologies; and transfer of both green technologies and associated knowledge [1].

For instance, the international *Cleantech Network* is a research and management consulting company specializing in global *clean technology innovation*. It facilitates sustainable growth opportunities through innovation, promoting the transition to a more digitized, decarbonized, and resource-efficient industrial future. This network supports the transfer and exchange of knowledge, tracking of innovation trends, and provides personalized advice and assistance necessary for companies to access external innovations.

It may be assumed that *accelerating* the adaptation of green technologies can be enhanced when *technology transfer* encompasses not only the transfer of technologies and knowledge, but also takes into account the *human capital potential and institutional development*. This integrated enterprise development approach fosters a favorable environment that stimulates the implementation of new technologies.

IMPLEMENTATION OF GREEN TECHNOLOGIES IN SME AS ECOCLUSTER MEMBER: ADVANTAGES AND BARRIERS

Clusters are becoming increasingly attractive to investors and serve as a means of supporting the development of small and medium-sized enterprises (SMEs) as their participants. The use of the *cluster-based approach* can effectively facilitate investment attraction. The important role of *clusters* is highlighted in the Strategy for the Reco-

very, Sustainable Development, and Digital Transformation of Small and Medium-Sized Entrepreneurship for the Period up to 2027, approved by Resolution No. 821-p of August 30, 2024.

Given the need to restore significant damage inflicted on enterprise assets and infrastructure — especially in the energy sector — special emphasis should be placed on the so-called “*green transition*” of the economy and the encouragement of SMEs to adopt *sustainable business practices*. This may include incentivizing the adoption of *green technologies*, assisting in achieving energy efficiency, and supporting the circular economy.

According to the Strategy for the Recovery, Sustainable Development, and Digital Transformation of Small and Medium-Sized Entrepreneurship, one of the expected results of the operational goal “Promoting Innovation” is the creation of an innovation environment and the establishment of active cooperation between *SMEs*, research institutions, and higher education institutions through innovation hubs and co-financing programs for research and development aimed at technological improvement and digital integration of *SMEs*. The Strategy also provides for the financing of registration fees for at least 3,000 national inventions, industrial designs, and utility models. These measures are intended to *stimulate collaboration and knowledge exchange* among *SMEs*, research institutions, and key stakeholders, thereby enhancing *SME* competitiveness through access to innovation, new technologies, and markets.

Thus, these challenges require solutions, one of which is the implementation of *green technologies*. However, such implementation may require *investment* as financial support to reduce environmental impact and adapt to climate change.

Green technologies have become a rapidly developing sector, attracting substantial *investment capital*. Although *the green technology market* is still relatively young, it is gaining strong *investor interest* due to the growing *awareness* of the impacts of *climate change and the depletion of natural resources*.

The goal of *green technologies* is to protect the environment, restore damage previously caused

to it, and preserve Earth’s natural resources. The use of *green technologies* can be a declared *objective of a business segment or company*. Increasingly, socially responsible investors aim to limit their potential investments to companies that specifically use or produce *green technologies* [12].

The green economy tends toward what is known as innovation multidimensionality that extends to all areas of human activity, particularly agro-industrial production and rural areas. In essence, *the green economy* is a functional representation of the innovation model, formalized in the form of a *cluster*. Clusters — defined as the geographical concentration of end producers, raw material suppliers, service providers, research laboratories, educational institutions, and other relevant organizations in a particular economic sector — are *crucial drivers of regional economic development* [33].

According to the National Cluster Development Program through 2027, *cluster* is defined as an industry-based, territorially localized, and voluntary *association of organizations* that closely cooperate with one another and with other actors in the value creation chain to enhance the competitiveness of their products, promote exports, and contribute to regional economic development.

A similar view has been shared by Hervás-Oliver J. L. et al. [42], who define *cluster* as a *group of companies* linked by a value chain that may span different industries yet remain interconnected. The companies within a cluster are concentrated within a single geographical area, forming a business network that *enhances efficiency* both individually and collectively. This agglomeration that fosters collaboration and efficiency gains, is known as an *agglomeration economy*.

For small and medium-sized enterprises (*SMEs*), *joining cluster ecosystems* represents one of the most feasible strategies for overcoming challenging economic circumstances. Such integration enables the generation of *synergistic effects* through *the concentration of knowledge, time savings* in assessing export potential, the shared use of resources to develop export contracts, and expanded access to international cluster networks and their

participants [43, p. 72]. Clusters are thus based on *collaborative efforts among participants* and are shaped by a *proactive alignment with the surrounding environment* to realize shared objectives.

European green clusters collaborate across sectors with other clusters supported by the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs of the European Commission, both within Europe and beyond, through the European Cluster Collaboration Platform (ECCP). This robust European infrastructure of collaborative clusters supports green clusters (eco-clusters) and others in sharing knowledge, expertise, and new eco-innovations across sectors and industries. These clusters act as key enablers of the green transformation of SMEs, helping drive the shift toward circularity, implement green policies, and increase the competitiveness of small businesses.

EIT Climate-KIC is a leading European *innovation agency* and community for climate innovation that supports cities, regions, countries, and industries in achieving their climate goals through *systemic innovation and localized transformation*. Its mission is to reshape *the entrepreneurial ecosystem* by embedding climate impact deeply into its structure.

EIT Climate-KIC, in partnership with the IKEA Foundation, GrowthAfrica (a leading African accelerator supporting entrepreneurs and ecosystems), and SecondMuse (an impact and innovation company working with climate-, equity-, and technology-focused communities to build a resilient economy that benefits people and protects the planet), has announced a *strategic collaboration* to address urgent challenges related to *waste management and sustainable urban development* in the rapidly growing cities of Nairobi (Kenya) and Bengaluru (India). This partnership will implement EIT Climate-KIC’s “Innovation Cluster” approach, aimed at fostering collaboration and developing advanced solutions and entrepreneurship. *Innovation clusters* function as collaborative platforms, bringing together a diverse array of stakeholders — including businesses, universities, citizens, investors, government agencies, and non-governmental organizations.

Specifically, the Nairobi Innovation Cluster (East Africa) and the Bengaluru Innovation Cluster (India) have joined the EIT Climate-KIC Innovation Cluster. This is because establishing a resilient innovation ecosystem requires a well-connected *network of entrepreneurs, private enterprises, institutions, investors, business incubators*, as well as mentors in technology and business. These innovation eco-clusters have brought together not only innovators and entrepreneurs but also resources and expertise to support the implementation of green technologies that have an impact on the natural environment.

An example from Ukraine is *the Ukrainian Cluster Alliance* (Vinnytsia) that plays a leading role in coordinating the activities of national clusters. The cluster map, resource centers, and committees of the Ukrainian Cluster Alliance are developed within the framework of the international cooperation program “EU4Business: Recovery, Competitiveness and Internationalization of SMEs,” co-financed by the EU and the German government. *Clusters within this alliance*, which explicitly aim to preserve and reduce the impact on the environment, include: *the Prykarpattia Eco-Energy Cluster* (specialized in renewable energy sources, energy efficiency, and eco-innovation), *the Lviv Energy Innovation Cluster* (focused on the development, implementation, and support of energy-saving programs, methodologies, and technologies), and *the Southern Ukrainian Cluster for Reconstruction and Recovery* (Odesa), which is specialized in promoting innovation and supporting entrepreneurs, researchers, and startups in the Southern region, enhancing their competitiveness and job creation, as well as encouraging interregional innovation projects and improving citizens’ quality of life.

At the same time, eco-clusters exist independently of this alliance. For example, a separately registered eco-cluster in Lviv region actively supports *environmental initiatives* and makes full use of the Association platform to develop business in line with the principles of sustainable development.

As we can see, clusters engaged in waste management, sustainable development, and environ-

mental impact reduction are registered under various organizational forms such as: *eco-cluster*, *innovation cluster (circular economy)*, *eco-energy cluster*, *innovation cluster*, *public union*, etc. What distinguishes them from other clusters is their *core focus on environmental matters*, making them components (elements of the innovation infrastructure) within the national or regional innovation system (NIS or RIS).

Indeed, other innovation structures within the NIS include innovation clusters as mentioned in the Law of Ukraine *on the Priority Directions of Innovation in Ukraine* of 08.09.2011 No. 3715-VI, which outlines the development of innovation infrastructure (such as innovation centers, technology parks, science parks, technopolises, innovation business incubators, technology transfer centers, innovation clusters, venture funds, etc.). The concept of *innovation infrastructure* is also defined in the Law of Ukraine *on Innovation* of 04.07.2002 No. 40-IV.

We assume that *eco-clusters* are a type of sectoral cluster (such as those in the “Safe Environmental Conditions for Communities/Populations” category), focused on specific objectives related to the creation of green jobs and the implementation of circular economy approaches in economic activities (e.g., procurement of renewable energy equipment for SMEs).

Typically, *clusters aim to achieve the following goals* [32]: enhancing the competitiveness of cluster members through the adoption of new technologies; reducing costs and improving the quality of relevant knowledge-intensive services through synergy effects and unified approaches to quality, logistics, engineering, IT, etc.; ensuring employment in the context of restructuring large enterprises and outsourcing; coordinated lobbying of cluster members’ interests across various levels of government.

Eco-clusters, in particular, *support SMEs* in rethinking their business models by providing access to new knowledge and green venture capital, including:

- ◆ assisting SMEs in the development of new processes that support circular transformation and green industry;

- ◆ transferring knowledge to SMEs about the circular economy, and supporting the development of new innovation products or services related to closed-loop systems and green manufacturing;
- ◆ offering a range of services to SMEs, proposing collaborations and linkages with research institutions and companies to enable the adoption of eco-innovations and green technologies;
- ◆ reducing societal risks with public sector clients by supporting SMEs in green production;
- ◆ facilitating access to funding, from innovation vouchers to smart investors, for SMEs to implement green technologies.

Madaleno M. et al. [44] emphasize the increasing importance of *clustering and cluster policy* to understand and leverage *geographic concentration*. They argue that such concentration accelerates creativity, idea exchange, and contributes positively to *innovation and entrepreneurship*. According to Kurniasih J. et al. [26], the sustainable development of SMEs plays a vital role in strengthening and ensuring economic growth, improving citizens’ welfare, facilitating efficient resource allocation, and managing environmental impacts.

Cluster policy is an integral part of SME policy. This means that clusters for small and medium-sized enterprises (SMEs) are primarily considered, with the objective of *overcoming scale-related barriers*. SMEs offer numerous advantages, such as diversification of services and products, providing services tailored to highly specific needs, and supporting local labor markets and overall regional development. One of the main *obstacles* faced by *eco-innovation companies* involves transaction costs associated with entering markets, the absence of networks, and information asymmetries in supply chains [22].

When developing *innovation business models* within *clusters*, it is important to integrate resource efficiency, circular economy principles, and clean production — key aspects introduced by eco-innovation. This not only helps reduce costs, but also contributes to *the formation of businesses that commit to positive environmental responsibilities* [45].

Thus, clusters establish not only a *strong connection to the overarching goal of enhancing competitiveness*, but also enable *close cooperation* among stakeholders, which fosters technological development, commercialization of research outputs, the creation of new areas of demand, and increased potential by making the system more adaptive to changes in the external economy. Thanks to its high growth and innovation capacity, this results in cluster success [27].

Accordingly, *the internationalization* of Ukrainian businesses – especially SMEs – has been becoming increasingly important for economic survival and the shaping of future growth. *SME internationalization* is often examined through the lens of the “born globals” phenomenon that demonstrates the possibility of non-linear internationalization by small firms focused on the development of *innovation products based on advanced technologies*, which actively pursue international expansion from the very start of their existence [46].

The effective support of *Ukrainian SMEs’ internationalization*, particularly regarding the development of *innovation products*, can be considered through *the integration of Ukrainian cluster alliances* in the context of global competition in EU countries.

For example, the Zaporizhzhia IAM Cluster supports this approach and continues to work toward advancing the cluster movement, consolidating the business community, researchers, and innovators in the Zaporizhzhia region. Among the key *internationalization* initiatives within *the cluster alliance*, one can highlight the program “Integration into Global Value Chains”, which facilitates *the integration of Ukrainian SMEs into European and global value chains* through the establishment of dialogue with leading clusters.

The key determinants for *strengthening eco-innovation* within SMEs include:

- ◆ the establishment of supportive policy frameworks;
- ◆ increased recognition of its strategic importance;
- ◆ technological and advisory support;
- ◆ analysis of eco-innovation in products and processes; and

- ◆ collaboration within supply networks [24].

To analyze *the innovation performance of SMEs* in implementing green technologies, it is essential to evaluate *the efficiency of their operations*.

Efficiency refers to the effectiveness of an enterprise’s functioning. The achievement of certain quantitative and qualitative outcomes – i.e., generating positive results while using resources rationally in conditions of uncertainty and a dynamic market environment – is *the core objective of any organization*. The set of indicators used to *assess efficiency* may vary depending on managerial goals, and there is no universal set of criteria. *A common challenge in evaluating enterprise performance* lies in the heterogeneity of *indicators*, which can make it difficult to clearly reflect the economic status of the business. Among the most frequently used *efficiency criteria* are output volume, return on equity, profit, and labor productivity [47]. Therefore, instead of a one-size-fits-all approach, SME managers should identify *the most appropriate partners* who align with their specific eco-innovation goals, ensuring greater effectiveness and targeted action [48].

Hence, collaboration between effective partners, such as eco-clusters and SMEs, may lead to a more efficient alignment of SMEs’ ecological needs and support the resolution of *environmental protection challenges*.

Mercado-Caruso et al. [29] have suggested *considering various factors* that are important for *cluster success*, such as the level of cooperation, the presence of supporting institutions, knowledge management through research, and aspects related to eco-innovation.

Their model incorporates five internal factors that examine business capabilities, and three *external factors* that assess the impact of launching eco-innovation.

The internal factors are as follows: cluster potential that analyzes the availability of human resources, technology, and knowledge transfer mechanisms accessible to firms within the cluster in addressing eco-innovation; the demand factor that considers consumer pressure for environmentally

friendly products and the role of government policies and incentives in shaping collective market awareness; cooperation that builds synergy among actors within the cluster; competitive pressure that encourages companies to differentiate their products or services in order to survive in the market; environmental policies and regulations, which function through government incentives and proper rules for sectoral development; the level of cluster development, reflecting an understanding of the cluster's origins — i.e., whether it is spontaneously formed or a policy-driven cluster initiative.

The external factors include: the economic impact of eco-innovation behavior, associated with cost savings and significant positive externalities; the eco-innovation effect, resulting from proper environmental practices such as cleaner technologies, reduced pollution, the adoption of circular economy principles, more efficient production processes, and material reuse; access to new markets, linked to eco-innovation products and marketing strategies that support the sustainability of high value-added goods.

At the core of addressing these issues, we have proposed *the formation of a comprehensive set of efficiency tools for SMEs*. These tools are intended to assess the level of *green technology* adoption and include both *advantages* and *barriers* associated with the implementation of such technologies.

When SMEs *implement green technologies* within eco-clusters, they benefit from specific competitive advantages. These advantages can be systematized as follows:

1. *Enhancing SME business efficiency, overall eco-cluster productivity, and national economic strength*. The economic *advantages of green technology adoption* are evident, particularly when SMEs can realize profit gains. By becoming *environmentally responsible*, SMEs can access green market niches composed of eco-conscious consumers, thereby *increasing market share and commercial revenues*. At the same time, adopting *greener practices* often leads to cost reductions — for instance, by *shifting to recycled materials* that are often more cost-effective [49].

Competitiveness within cluster creates shared value and a strategic level of performance that surpasses that of an individual firm. As such, a collective strategy can generate a win-win effect for all stakeholders involved. *Competitive advantage* is typically measured in terms of profitability that which can be achieved through product/service differentiation, cost reduction, and profit growth [29].

According to M. E. Porter [30], *collaboration fosters innovation and enhances the overall productivity of clusters*. This improvement spreads vertically across the supply chain, distribution channels, and end users, as well as horizontally across companies and sectors engaged in technology and adjacent industries.

Research on *eco-innovation within cluster structures* — notably by Lopez, D. F. J., and Montalvo, C. [50] — highlights the enabling role of SMEs in stimulating national economies. In response, the EU has developed various *support strategies aimed at enhancing the competitiveness* of such conglomerates on a global scale. These strategies are evident in case studies of clusters in India, Pakistan, Japan, and China [51].

2. *Resource efficiency and higher quality of innovation products*. Firms that invest in diversified capabilities, product innovation, technology development, and job creation in support of eco-innovation benefit from both *economic advantages and process efficiency* [52]. Enterprises shall *invest* in formal R&D structures, where specialized personnel focus on *developing* new production methods and *clean technologies*. This investment expands innovation capacity, *extends the technology life cycle, and supports market longevity* [23].

The economic impact of such actions further enhances resource efficiency and product quality, as cost savings provide a foundation for the continuous development of environmental and general innovations. Eco-innovation behavior supports improved environmental performance that, in turn, contributes to better economic outcomes [53].

However, to gain *access to new markets*, reducing operational costs alone is insufficient. Companies shall also develop socially responsible, *eco-*

friendly, and affordable products [54]. The demand for environmentally sustainable products is rising and can generate higher *returns* [55]. *The premium pricing of green products* helps firms offset the costs of *sustainable production* [56]. Increasing consumer demand for sustainable goods *encourages* firms to adopt environmentally responsible practices and drives eco-innovation.

3. *Job creation, improved living standards, and promotion of local and regional economic growth.* SMEs have a greater capacity *to generate employment and enhance living standards* when they possess the capability to further develop and scale up their adopted technologies [49]. SMEs represent a key segment of the economy, playing a crucial role in *job creation, resource utilization, and profit generation*. In developing economies, SMEs contribute significantly by *absorbing surplus labor* through *creating job places*, promoting economic diversification, supporting trade balances through exports or import substitution, and enhancing eco-innovation and sustainability across the broader economy [57]. Notably, *collaboration between SMEs and eco-clusters* facilitates the development of green technologies, their commercialization, the creation of new demand areas, and the expansion of SMEs’ innovation potential.

4. *Knowledge transfer within the eco-cluster.* M. E. Porter [30] is the first scholar to assert that *firms located within the same geographic area* benefit from better access to *knowledge* and its transfer, whereby both the size of firms and their proximity serve as strategic *advantages*. López Jiménez et al. [27] have identified *the role of turnover power in clusters* as a fundamental factor for their performance, enabling firms to implement innovations through *external knowledge embedded in cluster networks*. This reflects the rate at which resource turnover, SME turnover within eco-clusters, and the adoption of eco-innovations or green technologies can be achieved through networked collaboration.

Moreover, *eco-innovation processes* are closely linked to the management of *environmental knowledge within networks*, and firms with high technological and organizational eco-innovation po-

tential are capable of transferring this knowledge into the cluster network. Given the established notion that “innovation generates innovation”, there is a high probability that *firms previously engaged in innovation will continue to generate further innovations in their internal processes* — supported by the effective adoption of best practices among the actors constituting the cluster [27].

5. *The environmental contribution of SMEs through reduced ecological harm via greener products and materials.* Clusters function as structures that promote *eco-innovation* in tandem with the operations of member firms by *facilitating reduced environmental damage through the adoption of greener products*, eco-processes, novel product/service ideas, and enhanced cooperation among cluster participants, which in turn boosts *business competitiveness* [58]. Accordingly, SMEs integrated into eco-clusters also gain distinct advantages.

For example, Segarra-Oña et al. [59] have stated that eco-innovations are considered successful when there is clear evidence of an environmental contribution to society, the creation of new jobs, and the development of more sustainable organizations. Achieving these *benefits*, however, requires organizational change — in company structure, internal processes, and how firms shape their push-pull marketing strategies. This is where concepts such as *eco-design and the transformation of relationships with suppliers, clients, and distributors* become relevant, and where environmental awareness integrates new activities into the value creation chain [29]. Hence, *the benefits of eco-innovation or green technology adoption* should be analyzed not only from the perspective of economic gain, but also in terms of upholding the right to a *sustainable and healthy environment* and compliance with environmental legislation.

A. Alipour and M. Rahimpour have stated that despite the *benefits*, there are *significant barriers* at various stages of *the green product life cycle*. They highlight that the focus of these *barriers* varies, with the greatest *obstacles to environmental sustainability* arising in production and marketing stages [18].

The inclusion of a variable related to the intensity of investment in eco-innovation allows researchers to assess the extent to which *barriers intersect with actual involvement in green innovation, thereby shaping the development of various eco-clusters*. For instance, some firms face *high perceived barriers* yet may exhibit either strong or weak commitment to eco-innovation investment; the same applies to firms with low perceived barriers. This variation highlights the divergent behavior of firms facing similar challenges, and thus underscores the need to differentiate between them. In other words, *these distinctions reflect the heterogeneity in firms' capabilities and strategies when addressing eco-innovation* [5]. These scholars classify barriers into three groups: *the general barriers* – shared by most firms, such as human resource constraints, financial limitations, or a lack of adequate knowledge about sustainability; *the segment-specific barriers* – related to limited consumer willingness to pay for greener products, which forces companies to incur environmental costs without being able to compete effectively; *the individual barriers* – firm-specific limitations that vary from one company to another, reflecting the uniqueness of each enterprise's context.

The implementation of green technologies encounters barriers that hinder the adoption and use of environmental practices. These barriers may be systematized.

We have proposed the following classification of barriers to green technology implementation aimed at supporting sustainable development by SMEs as eco-cluster participants:

1. *Lack of advanced technological solutions*. J. Á. Del Brío and B. Junquera have emphasized that SMEs encounter considerable difficulties in technological development [60].

2. *Stakeholder attitudes toward green technology transfer*. D. Puig, J. A. Haselip, and F. Bakhtiari point to the *misalignment between internal determinants and the scale of technology transfer initiatives* [14].

3. *Low awareness of sustainable development and environmental literacy*. Several scholars have

noted that *insufficient managerial awareness*, combined with a lack of knowledge on *sustainability* and inaccessible training programs, constitute two *major barriers to sustainable development* among most SMEs [28]. Additionally, *low environmental literacy*, limited understanding of environmental management, and lack of access to relevant data form part of the broader *informational barrier*, making it difficult for some firms to interpret environmental regulations and understand how these might impact their operations [61]. In some cases, providing *clear environmental information* to SMEs proves to be challenging, as they often struggle to *interpret specific requirements of environmental management systems* such as ISO 14001 [62]. Durdyev S. et al. [19] have found that both *lack of awareness and knowledge* and *reluctance to adopt new sustainable technologies* are among the most significant barriers.

A critical variable for analyzing knowledge within cluster networks is the use of Business Intelligence (BI) systems – technologies and procedures that convert raw data into actionable insights for managers, thereby enabling more effective and faster decision-making. BI systems hold substantial potential to *enhance organizational performance*. However, due to the high costs associated with their deployment, the factors enabling successful integration shall be carefully examined and assessed before adoption.

Absorptive capacity (ACAP) – defined as an organization's ability to identify, assimilate, and strategically exploit external knowledge – has a strong theoretical connection to BI systems [63].

However, *knowledge absorption* can be hindered by several *obstacles*, such as the lack of qualified personnel and high-quality equipment, the inability to establish linkages or collaboration with public research institutions, and limited access to external sources of knowledge [25].

4. *Market diffusion constraints for green technologies*. I. Nygaard and U.E. Hansen have pointed to a lack of conceptual clarity in *the categorization of technologies in Technology Needs Assessments (TNAs)*, which may hinder their dissemination [64].

Deng et al. [20] have further identified lack of market recognition as an additional limiting factor.

5. *Need for financial resources due to infrastructure deficits and demand risk. The greening of SMEs may impose a burden on their already limited resources.* The transition toward a green pathway generally entails costs related to investments in technology and infrastructure, regulatory compliance, and innovation. While these costs may vary across sectors and countries – and may ultimately be outweighed by the potential *benefits of green transformation* – access to adequate financing remains a significant barrier for SMEs that often face difficulties securing funding (e.g., bank loans). Moreover, the implementation of green initiatives also requires a certain level of managerial competence, technological understanding, and learning capacity, which SMEs frequently lack [49].

6. *No appropriate regulatory frameworks for green technology development in Ukraine.* As SMEs implement *green technologies* – considered outcomes of sustainable innovation – they shall focus on both current and anticipated environmental challenges to reduce ecological impacts and adapt to climate change.

Successful *cluster policy* should be based on a comprehensive approach that supports and enhances SME innovation performance, particularly in industrial development and the adoption of *green technologies*. SMEs may benefit from *traditional business models* while incorporating *green practices and technologies* to improve sustainability. *These measures include* the use of renewable energy sources, recyclable materials, production process optimization, and the adoption of responsible environmental management practices [31].

However, the deployment of *green technologies* and innovation products requires SMEs – especially those operating within eco-clusters – to comply with environmental standards. Eco-clusters facilitate such compliance by integrating and supporting member firms, yet SMEs still face barriers in this process. It is important to note that *the type and number of barriers may differ depending*

on the stage of the green product life cycle, making it inappropriate to generalize across all enterprises.

To ensure the successful implementation of green technologies, the state can provide support to SMEs through the following measures:

- ◆ Creating an enabling environment for development, fostering a competitive landscape through access to national, regional, and local SME development programs and public support mechanisms;
- ◆ Ensuring access to and supporting the development of SME support infrastructure;
- ◆ Introducing simplified taxation, accounting, and reporting systems for SMEs;
- ◆ Providing public financial support (e.g., seed capital, venture capital, loans and credits), stimulating investment activity, attracting foreign investment, and fostering mutually beneficial international innovation cooperation;
- ◆ Supporting the R&D and innovation potential of SMEs through financial, informational, and advisory instruments, including targeted support in science, innovation, and industrial production, and promoting the supply of innovation products and services for national and regional needs;
- ◆ Improving access to knowledge on sustainable development, raising environmental awareness, and fostering understanding of the importance and advantages of green technologies;
- ◆ Enhancing employment opportunities through support for SME-driven job creation;
- ◆ Introducing mechanisms to promote and incentivize the use of green technologies in SME production;
- ◆ Modernizing the legislative framework governing SME activity, with a focus on strengthening the overall enabling environment for green technology development.

In conclusion, this article addresses the issue of *green technologies*, which encompass a wide range of advanced solutions for SMEs aimed at reducing negative environmental impacts, promoting sustainable development, and fostering a resilient and eco-friendly living environment. These tech-

nologies represent a key component in the fight against climate change and contribute to improving human well-being. The authors have substantiated the role of green technologies in facilitating the transition toward an *environmentally sustainable green economy* and identify the distinguishing features of green technologies that focus on preserving the natural environment, minimizing the adverse effects of human activity, reducing the use of non-renewable natural resources, promoting resource efficiency and recycling, and supporting the sustainable development of industry.

It has been emphasized that *green technologies* are technologies oriented toward sustainable development and aimed at addressing local environmental challenges. *Green tech* represents a vital instrument for reconciling economic growth with environmental protection, ensuring ecological safety, environmental responsibility, and resource efficiency.

The authors have also drawn a distinction between *green technologies* and *environmentally clean technologies* (eco-technologies), based on their target scope. The *eco-technologies* are primarily focused on addressing broader environmental issues caused by climate change and human activities (e.g., the implementation of specific energy-saving technologies). In contrast, *green technologies* are oriented toward solving local problems, including *climate change* and *carbon emissions*, among others.

This study may benefit SMEs seeking to join eco-clusters by implementing strategies to enhance their competitiveness through the advancement of *green technologies*. The concept of *green technologies* is closely linked to the interconnection between the competitiveness of SMEs — as participants in eco-clusters — and their commitment to reducing environmental impacts and adapting to climate change. The green transition can present an opportunity for SMEs to reduce their ecological footprint and increase their resilience. Since many SMEs face similar challenges, participation in eco-clusters may facilitate their operations and strengthen their ability to respond to emerging demands for a sustainable, green, resilient, and global economy.

The authors have attempted to evaluate the performance of SMEs in implementing *green technologies*, identifying both *benefits and barriers*. *The benefits of adopting green technologies by SMEs* within eco-clusters include: improved business efficiency and overall productivity of eco-clusters; strengthening of the national economy; enhanced resource efficiency and the quality of innovation products; job creation and improvements in living standards; support for local and regional economic growth; knowledge transfer within the eco-cluster; and positive environmental contributions through reduced ecological damage by producing greener products and using environmentally friendly materials.

The barriers to the implementation of green technologies by SMEs in eco-clusters include: lack of up-to-date technological solutions; stakeholder attitudes toward technology transfer, low awareness of sustainable development and environmental literacy; market limitations in green technology dissemination; financial constraints due to inadequate infrastructure and demand-side risks, and absence of proper regulatory frameworks for green technology development in Ukraine.

The effectiveness of SME operation should be assessed based on their achieved *eco-outcomes* relative to the resources spent — such as reduced environmental costs, profits from eco-innovation services, the adoption of green technologies, the quality of innovation products, and the development of more competitive SME business strategies.

The performance of SMEs as participants in eco-clusters regarding the adoption of green technologies is also influenced by the efforts of the government and other stakeholders (technology developers, technology adopters, and organizations providing financial support to SMEs). These actors play a critical role in fostering the adoption of green technologies, which in turn supports sustainable development, enhances environmental resilience among SMEs, creates jobs, and fosters business growth in Ukraine.

The article has explored *the features of the innovation component of SME potential as participants*

in *eco-clusters*. This is grounded in the identification, development, and implementation of green technologies that increase the extent to which societal needs are met in addressing environmental challenges and achieving the goals of sustainable development. The main distinction between SMEs with an innovation-oriented potential and those without lies in the deliberate adoption of eco-innovations and green technologies. In contrast, non-innovation SMEs may adopt innovations indirectly, as a by-product of enterprise management strategies or corporate development frameworks.

This study has analyzed eco-clusters as drivers of innovation capacity for SMEs within the context of sustainable development and environmentally responsible behavior, and identifies key incentive markers to promote the adoption of green technologies by SMEs. The authors demonstrate that clusterization serves as an innovation mechanism that accelerates the strategic development of green technologies. The integration of SMEs into eco-clusters can contribute to faster regional recovery in Ukraine and enhance international market access by offering competitive and innovation products that inherently reflect the interconnection between people and the environment.

Based on theoretical insights on eco-cluster development and general findings on green technologies, the study distinguishes among various eco-cluster organizations (associations, alliances, etc.) that address waste management, sustainable development, and environmental impacts. These may be formally registered as eco-clusters, innovation clusters (circular economy), eco-energy clusters, innovation alliances, public unions, etc. Their activities differ from other cluster types by being explicitly focused on environmental goals. The participation of SMEs in eco-clusters generally aligns with regional and locally driven ecological objectives, in compliance with environmental policy frameworks.

For empirical observation, eco-clusters from various countries were examined. This study contributes to the broader discourse on green growth

and the formulation of incentives to support eco-cluster development as a means to strengthen innovation capacity in green technology deployment.

The authors have identified *several directions in which the state can support SMEs in the implementation of green technologies*. It has been demonstrated that this includes: the creation of favorable conditions for development in order to foster a competitive environment by providing access to national, regional, and local SME development programs and state support mechanisms; improving accessibility and facilitating the development of SME support infrastructure; the introduction of simplified taxation, accounting, and reporting systems for SMEs; the provision of financial support (start-up capital, venture capital, loans and credits), the stimulation of investment activity, the attraction of foreign investment, and the development of mutually beneficial international innovation cooperation. Additionally, state support should include: promoting the scientific and innovation potential of SMEs (through financial, informational, and advisory assistance, including support in the areas of innovation, science, and industrial production); organizing the supply of innovation products (works, services) for national and regional needs; expanding access to knowledge on the benefits of sustainable development, raising environmental awareness and understanding of the importance of green technologies; ensuring employment by supporting job creation; implementing incentive mechanisms for the use of green technologies in SME production processes; and updating legislative and regulatory frameworks to strengthen the overall enabling environment for the development of green technologies.

At the same time, *there remain challenges regarding SME strategies* to encourage the adoption of green technologies, the level of *awareness related to sustainable development*, and *environmental literacy*. These challenges are crucial for addressing the consequences of human impact on the environment and climate change.

This study does not exhaust all the issues raised in the research objective. Future research perspec-

tives include exploring European experience in legal doctrine and case law related to green technologies in other sectors and industries, as well as conducting an in-depth study of the national competitiveness of eco-clusters and strategies to promote the adoption of green technologies.

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«ЗЕЛЕНІ» ТЕХНОЛОГІЇ ЯК ІНДИКАТОР СТІЙКОСТІ, СТАЛОГО РОЗВИТКУ, ЗРОСТАННЯ ІННОВАЦІЙНОГО ПОТЕНЦІАЛУ МАЛИХ (СЕРЕДНІХ) ПІДПРИЄМСТВ

Вступ. Через ризики глобального потепління важливим є сталий розвиток малих (середніх) підприємств (МСП), робота яких зосереджена на стійкості, впровадженні «зелених» технологій та зменшенні впливу діяльності на стан довкілля.

Проблематика. Потреби охорони навколишнього середовища передбачають вимоги до розробки, впровадження «зелених» технологій із потенціалом значного покращення у діяльності МСП як учасника екокластеру.

Мета. Виявити рівень поточного стану обізнаності МСП як учасника екокластеру щодо можливостей, переваг та бар'єрів для впровадження «зелених» технологій.

Матеріали й методи. Використано комплекс загальнонаукових та спеціальних методів. Матеріалами для дослідження слугували публікації вітчизняних та зарубіжних учених, норми чинного законодавства України та ЄС.

Результати. Компаративістський аналіз доктрини і практики України та ЄС дав можливість виявити основні МСП, за якими доцільно продовжувати зелену трансформацію регулювання МСП відповідно до стандартів, установлених у світовій спільноті, чинники, які зумовлюють виявити рівень поточного стану обізнаності МСП щодо можливостей, переваг, а також бар'єрів, які перешкоджають впровадженню «зелених» технологій у діяльності МСП. Досліджено екокластери як драйвер інноваційних можливостей для МСП та встановлено необхідні маркери стимулів для МСП як учасників екокластерів щодо сприяння впровадженню «зелених» технологій у контексті сталого розвитку та їхньої екологічної поведінки.

Висновки. Впровадження концепції «зелених технологій» як результату стійких інновацій для МСП у праві України потребує вдосконалення. Доцільність упровадження сформованих пропозицій обґрунтовується їхньою здатністю вирішити існуючі екологічні проблеми для зменшення впливу на навколишнє природне середовище та адаптацію до зміни клімату.

Ключові слова: «зелені» технології, екологічні чисті технології, МСП, екокластери, зелена енергетика, зелений курс, навколишнє природне середовище, екологізація.