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**Sustainable Development through Green Innovations:
Economic Strategies of China and the EU Compared**

Denys ILNYTSKYI¹, Olga DROBOTIUK², Vladyslav ANDRUSYK^{3*}

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Abstract

The paper examines the economic strategies of China and the European Union in promoting sustainable development through green innovations. Sustainable development, essential for economic growth, environmental protection, and social equity, necessitates the adoption of environmentally friendly technologies and practices. Numerous studies have explored these concepts separately, but only some have compared the economic strategies of major players like China and the EU, which account for about 1/3 of global GDP. The comparative analysis methodology was used to investigate the economic strategies of China and the EU, including insights from government policies and key sectors targeted for green innovation. Research questions concern the effectiveness of these strategies in promoting sustainable development and the differences in approaches between China and the EU. The results reveal significant disparities in their approaches and impact on the way to the development of green economies. China leans towards top-down government interventions and investments, while the EU emphasises regulatory frameworks and collaborative efforts focusing on bottom-up initiatives. Both global actors grapple with balancing economic growth and environmental sustainability. Statistical data underscores the burgeoning growth of industries embracing green innovations, with the global market for green technology reaching \$13.7 billion in 2022. While the development of Industry 4.0 is a common feature of both economies, their specialisations differ, so the need for further cooperation and exchange of goods remains. The paper also explores the impact of green innovations on industry competitiveness, showing that companies investing in environmentally friendly technologies gain market share. These findings underscore the importance of the country's strategies and international cooperation to tackle global environmental challenges. The paper offers a benchmarking of China and the EU's economic strategies for promoting sustainable development through green innovations. By synthesising the existing literature and providing insights into their differing approaches, it contributes to a better understanding of the effective strategies for global sustainable development.

¹ Kyiv National Economic University, Kyiv, Ukraine; Akaki Tsereteli State University, Kutaisi, Georgia, ilnytskyi@kneu.edu.ua.

² Kyiv National Economic University, Kyiv, Ukraine, khomenko@kneu.edu.ua.

³ Kyiv National Economic University, Kyiv, Ukraine, andrusykvladyslav@gmail.com.

* Corresponding author.

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1. Introduction

China has become a world-fast growing leader in green technology, dominating sectors such as wind, solar, hydropower, lithium batteries, and electric vehicles. Chinese companies, often state-backed, are major players in these industries or the supply chains that support them. On the other hand, the EU has been putting forward ambitious strategies to sustain global leadership through innovations, especially green innovations. It is trying to combine high value-added investments within the EU and relatively lower technology transfer to less developed countries.

These two regions are key for the global economy from ecological and economic points of view even though they have rather different models and strategies of development. Both are moving towards Industry 4.0 and support principles of sustainable development. This calls for an important task to compare them to define the fields where they could cooperate and where to compete.

The participation in international sustainable frameworks (Task Force on Climate-Related Financial Disclosures, Partnership for Carbon Accounting Financials, Carbon Disclosure Project, Principles for Responsible Investment, World Business Council For Sustainable Development, IFC's Sustainability Framework and Equator Principles) and standards (Global Reporting Initiative, European Sustainability Reporting Standards, Financial Accounting Standards Board, International Financial Reporting Standards, International Accounting Standards Board, OECD Guidelines for responsible business conduct) also is quite uneven for the EU and China on their way to net zero.

Climate change conferences in Kyoto (1997), Copenhagen (2009), Paris (2015), Glasgow (2021) call for the growth of nations' inputs into reduction of CO² and other GHG emissions.

2. Problem Statement

We support the idea outlined by Kivimaa and Kern (2016) that in the times of the transition to the values of sustainable development, green and digital transformations, innovation systems act as engines of creative destruction. Incremental innovations may dramatically impact the structure of the global economy, the relationships between key players, and thus change the global economic order.

It is vital to address the actors and factors of sustainable development to solve the global ecological problem through green innovations. The EU and China are responsible for 1/3 of global greenhouse gas emissions which puts them among key polluters, so their input will impact the whole global ecosystem. Differences in national models of green innovations lead to asymmetric impact on nature,

so they should be investigated in the together with the best practices which should to be shared.

3. Aims of the Research

The purpose is to conduct a comprehensive comparative analysis of the economic strategies employed by China and the EU in promoting sustainable development through green innovations. By examining government policies, initiatives, and key sectors targeted for green innovations, as well as main results on the way in both regions, the article aims to identify differences and similarities in their strategic approaches. Through this analysis, the article seeks to assess the effectiveness of these strategies in achieving sustainable development goals and to highlight their implications for global environmental challenges.

4. Research Methods

The study uses a mixed-methods approach to analyze green innovation strategies in the EU and China. It uses a literature review, content analysis, and bibliometric analysis to understand the topic comprehensively. The literature review covers academic publications, policy documents, and reports on green innovations in the EU and China, using databases like Eurostat, OECD, WIPO, the SDG Transformation Center, the Global Green Growth Institute, SCOPUS, and SCImago. The bibliometric analysis extracts publications related to green innovation, while the content analysis identifies common themes, strategies, and outcomes. The comparative analysis compares the effectiveness of green innovation strategies in the EU and China, using key indicators like publications, patents, investments in green technologies, and outcomes related to sustainable development goals. The case studies are selected to examine the EU and Chinese initiatives' objectives, implementation strategies, challenges, and outcomes.

5. Findings

5.1 Literature Review

Strategies for green innovations in the EU and China vary in several dimensions, but the starting point is the research on the topic. Having built a word map of keywords of publications with “green innovation” we observe variety of related topics (Figure 1). Only one of the word clusters is heavily connected with China, others are more universal, while the EU is not among them at all. This is probably related to the fact that European researchers pay most of their attention to corporate level of analysis, while for China the most vital is state regulation and leadership. Although China outperforms the EU in the total number of publications with ecology problem and innovations, the key is in the field of their quality and impact.

Green and digital transformations have got different levels of maturity as factors of economic development of national economies. The study by Banelienė and Strazdas (2023) provides empirical evidence showing that green innovations have

socioeconomic outcomes, including increased exports and employment in environmental sectors. According to the European Environment Agency (EEA, 2023), the European Green Deal's ambitious goals have driven a steady increase in eco-innovation in the EU, highlighting its crucial role in achieving sustainable development objectives. By examining the roles of natural gas and oil imports in EU countries amidst the backdrop of the Russia-Ukraine war, the study conducted by Zhijie et al. (2023), highlights the vital importance of transitioning to cleaner energy sources to foster sustainable growth and prevent negative climate change. The findings underscore the need for policy interventions to accelerate the energy transition and promote green innovation in response to the challenges posed by energy dependencies and geopolitical conflicts.

When it comes to large companies the valuable insights into green innovation, emphasising the need for organisations to address environmental challenges through sustainable practices are disclosed at study made by Chavira et al. (2023). The benefits of green innovations in enhancing corporate performance and competitiveness, underscoring the importance of managerial concern, and the use of digital tools in driving successful green initiatives. Markets and industries vary by the maturity of sustainability. So, green innovations in the aviation industry, exemplified by initiatives like the SAGE programme, have led to significant reductions in CO₂ emissions from commercial aircraft, contributing to sustainable development by mitigating the industry's impact on climate change. According to Smith (2016), these innovations have also spurred technological advancements, influenced regulatory changes, and emphasised the importance of strategic business approaches to support the adoption of environmentally friendly technologies in aviation.

On the other hand, the study of semiconductor industry role in the development of green innovations revealed that semiconductors contribute significantly to sustainable development through green innovations (Hsieh et al., 2023). Companies like Taiwan Semiconductor Manufacturing Company Limited (TSMC) and Intel have committed to renewable energy goals to support sustainable practices. They play a crucial role in many industries – advancing green energy, promoting health monitoring, improving environmental technologies, and addressing industrial wastewater challenges. These findings highlight the potential of the semiconductor industry to drive sustainable practices and align with the Sustainable Development Goals.

Green innovation and sustainability are constantly in the focus of the Chinese leaders, which is due to the rapid development of the manufacturing industry in the country and the environmental effect that was caused. Even in the Chinese economic model Huang et al. (2021) identified the impact mechanism of marketisation and local government competition on green innovation efficiency in China, bridging the research gap by exploring the roles of the market and the government in driving sustainable development through technological innovation. It was revealed that local government competition not only directly inhibits green innovation efficiency but also hinders the promotional effect of marketisation, shedding light on the complex

dynamics of government actions and market forces in green innovation development. Investigating the impact of green investment on sustainable development in China, with a focus on promoting sustainable consumption and production patterns Li and Wang (2023) revealed that green investment plays a crucial role in enhancing production efficiency, reducing energy consumption and environmental pollution, ultimately leading to more inclusive and sustained production patterns. It leads us to the conclusion that increasing green investment can drive technological innovation, improve pollution control and energy-saving technologies, as well as foster breakthroughs in cultivating sustainable consumption and production patterns.

Being the leader in the search for green innovations the EU faces the challenge of lack of comparative studies with key competitors leading to possible global gaps. For instance, Dima et al. (2022) investigated bioeconomy in the European countries only. While we must admit that there are some researchers in the field, like comparative study of green organisational identity and sustainability in China and Portugal (Lopes Cancela et al., 2023). Our research is one of the few attempts to make these gaps shorter.

5.2 EU's Green Innovation Efforts

The European Green Deal is the key strategy for developing green economy in the EU, which is supported by wide variety of sectoral strategies and plans. These include, universal (Strategic plan 2020-2024 for research and innovation, Horizon Europe programme for 2021-2027, Circular Economy Action Plan) and sectoral strategies (transport – Sustainable and Smart Mobility Strategy, Zero-Emission Vehicles Strategy and Fit for 55 Package till 2030; food and natural ecosystems – Farm to Fork Strategy and Biodiversity Strategy till 2030; social & regional cohesion – NextGenerationEU, Just Transition Mechanism, skills development programmes, social inclusion initiatives; energy – REPowerEU, Renovation Wave Initiative; new industrialisation – EU Industrial Strategy).

Various sectors play an important role in the realm of green innovations. Energy is one of the most valuable. That was the reason why the European Strategic Energy Technology Plan had been adopted in 2008 for the period till 2030. In 2023 the EU announced plans to make it fit the strategies of European Green Deal, REPowerEU and policy within Energy Efficiency Directive.

Many spheres remain under strategic administration by national governments. For instance, although the EU waste policy is an important part of European Green Deal, it is still within the competence and autonomy of national and regional governments.

Most of modern EU strategies stand on the results of “A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development” which had been adopted in 2001. Changes in greening strategic priorities start to bring results. That is why the findings of the European Climate Neutral Industry Scoreboard suggest that the EU creates more than half of global high-value inventions in four technologies: permanent magnets, wind rotors, biomethane, heating and cooling networks (Kuokkanen et al., 2023).

There were about 25% of European Inventor Awards winners who worked in the field of green innovations in the EU from 2006 to 2020 (Vimalnath et al., 2020). They tend to choose closed and semi-open IP, particularly non-exclusive licensing, to drive green innovations in the EU while in China the IP commercialisation market depends on governmental strategic choices. We should admit that in recent years there have been some changes in this field as China started to implement a new IP commercialisation strategy (Zhang et al., 2017). However, as we know this sector dramatic changes take decades to happen.

5.3 Chinese Green Innovation and Sustainable Development Policy

In 1979, the People's Republic of China passed the Environmental Protection Law (SCNPC, 1979) and the first steps towards environmental protection were taken at the legislative level. In 2008, the Circular Economy Promotion Law of the People's Republic of China (SCNPC, 2008) was adopted, entering into force on January 1, 2009. The purpose of this law is to promote the efficient use of resources, environmental protection, and sustainable development. According to the legislation, the new industrial policy must meet the criteria of the circular economy. With the law, the government encourages research and development, as well as international scientific cooperation on closed-loop economy issues. The 12th Five-Year of the People's Republic of China for 2011-2015 encompassed several green energy development tasks. These included reducing energy consumption, promoting the extraction of alternative energy, and gradually establishing a carbon market. The initiative fostered the growth of a low-carbon economy. In 2013, the Circular Economy Development Strategy and Short-Term Action Plan (SC PRC, 2013) was adopted, which defined three levels of the circular economy: within the enterprise, industrial park, city, and province. According to the Action Plan, the coal industry should be improved in five aspects: "green" mining, comprehensive exploitation and utilisation of coal, energy conservation and reduction of consumption, environmental protection, and construction of industrial networks. In the 13th Five-Year Plan of the People's Republic of China 2016-2020, the circular economy was one of the key areas focused on ecosystem development and environmental protection. During this five-year period, the plan aimed to achieve several objectives: the implementation of the cyclical development management plan, the promotion of the implementation of closed-loop processes at industrial enterprises, and the creation of waste disposal demonstration areas (Khomenko (Drobotiuk), 2018). It is important to note that a key difference between the European and Chinese concepts of circular economy lies in their focus. The European approach concentrates on business opportunities to minimise waste and transform it into a resource. In contrast, the Chinese approach is broader, encompassing pollution, industrial eco-parks, ecological civilisation, and waste and resource management challenges (Kemp et al., 2019).

In 2015, the strategy "Made in China 2025" was adopted. Its implementation is aimed at advancing manufacturing industries towards smart, green, and service-oriented development. The focus lies on strengthening potential for innovation

and basic competitiveness in key sectors such as next-generation information technology, modern equipment, new materials, and biomedicine (SC PRC, 2017).

In 2016, according to the UN Global Sustainable Development Goals, the Chinese government adopted China's National Plan for Implementation of the 2030 Agenda for Sustainable Development. The plan emphasises compliance with the main national policy of resource conservation and environmental protection, following a civilised path of development that ensures a higher level of production and quality of life. The goal is “green” development based on a low-carbon economy, as well as solving the problem of climate change and protecting the ecological system through a system of “green” technological innovations.

The green development and innovation are among the key priorities for the medium-term perspective in the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Vision 2035 of the People’s Republic of China (14thFYP, 2021). Prioritising the ecology and pursuing green development, the Chinese government promotes “overall resource management, scientific allocation, comprehensive conservation, and recycling, and coordinates efforts to drive high-quality economic development and high-level ecological environment protection” (14thFYP, 2021).

5.4 Comparison of Effectiveness in Promoting Sustainable Development Through Green Innovations

The European Green Deal and Horizon Europe programmes prioritise sustainability and innovation, these policy frameworks target for reducing greenhouse gas emissions, promoting renewable energy, and fostering sustainable consumption and production. China has implemented several policies aimed at promoting green innovation, including its 13th and 14th Five-Year Plans and the Made in China 2025 strategy, which emphasise technological upgrading and environmental protection. In the implementation of sustainable development policies, the European Union employs a combination of regulatory measures, economic incentives, and public-private partnership mechanisms to promote green innovations. Notably, the Chinese policy features state intervention (top-down directives) and state initiatives that include subsidies and incentives for the development of green innovations.

The success of the efforts by the European Union and China in ensuring sustainable development through green innovations is demonstrated by the Sustainable Development Goals Index (SDGI). According to the SDGI (Sachs et al., 2023), European Union countries hold leading positions in achieving sustainable development goals (SDG). China has also made significant progress in implementing policies aimed at achieving sustainable development goals, especially before the Covid-19 pandemic. In 2019, China ranked 39th and improved its scores by 14.1 points compared to 2016. However, post-pandemic, China has not yet fully recovered its positions, while EU countries continue to lead (see Table 1). The major challenges for both EU countries and China remain in achieving the following Sustainable Development Goals: SDG2: No Hunger; SDG12: Responsible

Consumption and Production; SDG13: Climate Action. Success has been achieved by the majority of EU countries and China in implementing the goal of SDG1: No Poverty.

Table 1. Changes in the Sustainable Development Goals Index in the EU and China

Country	2016		2019		2023	
	Score	Rank	Score	Rank	Score	Rank
Finland	81.0	4	82.8	3	86.8	1
Sweden	84.5	1	85.0	2	86.0	2
Denmark	83.9	2	85.2	1	85.7	3
Germany	80.5	6	81.1	6	83.4	4
Austria	79.1	7	81.1	5	82.3	5
France	77.9	11	81.5	4	82.0	6
Czech Rep.	76.7	15	80.7	7	81.9	8
Poland	69.8	38	75.9	29	81.8	9
Estonia	74.5	21	80.2	10	81.7	10
Croatia	70.7	36	77.8	22	81.5	12
Slovenia	76.6	17	79.4	12	81.0	13
Latvia	72.5	28	77.1	24	80.7	14
Spain	72.2	30	77.8	21	80.4	16
Ireland	76.7	14	78.2	19	80.1	17
Portugal	71.5	34	76.4	26	80.0	18
Belgium	77.4	12	78.9	16	79.5	19
Netherlands	78.9	8	80.4	9	79.4	20
Hungary	73.4	24	76.9	25	79.4	22
Slovak Rep.	72.7	26	76.2	27	79.1	23
Italy	70.9	35	75.8	30	78.8	24
Greece	69.9	37	71.4	50	78.4	28
Luxembourg	76.7	16	74.8	34	77.6	33
Romania	67.5	41	72.7	42	77.5	35
Lithuania	72.1	31	75.1	32	76.8	37
Malta	72.0	32	76.1	28	75.5	41
Bulgaria	71.8	33	74.5	36	74.6	44
Cyprus	66.5	45	70.1	61	72.5	59
China	59.1	76	73.2	39	72.0	63

Source: compiled by the authors based on Sachs et al. (2016, 2019), Sachs et al. (2023).

The EU is one of the global leaders in investing in renewable energy sources and clean technologies. In 2022, the EU’s environmental protection expenditures accounted for 0.8% of GDP (€130 billion) (Eurostat, 2022). The EU directs its investments toward research and development in areas such as renewable energy, energy efficiency, and circular economy solutions (as indicated in Table 3). This commitment is reflected in the number of patents (Table 2) and publications (Table 3) in these fields.

China increases investments in green technologies, including public expenditures on energy conservation and environmental protection that accounted for 0.45% of GDP (541.3 billion yuan) in 2022 (Statista, 2024). Additionally, China subsidises industries such as solar and wind energy, and invests in electric vehicles and battery technologies. By the end of 2022, China became the largest producer of solar energy

with an installed capacity of 393 GW, surpassing the EU’s capacity of 205 GW (Venditti, 2024).

Table 2. Input into global sustainable technology patents

Green technologies	Number of patents, units		Grand total	Global share, %		EU-China gap, times
	EU	China		EU	China	
transportation	8229	1899	25542	32.2%	7.4%	4.3
energy	15228	3754	56650	26.9%	6.6%	4.1
water	698	249	3329	21.0%	7.5%	2.8
farming & forestry	3265	998	13171	24.8%	7.6%	3.3
pollution & waste	5515	1093	17906	30.8%	6.1%	5.0
product, materials & processes	2957	685	11503	25.7%	6.0%	4.3
building & construction	4326	1563	13537	32.0%	11.5%	2.8
All types	36752	9566	129677	28.3%	7.4%	3.8

Source: authors calculations based on WIPO GREEN Database of Innovative Technologies and Needs as of May 1st, 2024.

Analysing the indicators of sustainable development policy implementation through green innovations in the EU and China, we can conclude that Northern European countries have a relatively high share of employment in green production and patent publications related to environmental technologies, indicating a strong emphasis on green innovations. Germany and Austria also demonstrate ecological sustainability, with a high proportion of employment in green production and significant funding allocated to green technologies. The indicators for the Czech Republic and Poland suggest the involvement in innovations in the field of environmental technologies, as evidenced by their high share of patent publications in this area. However, there is a significant gap among EU countries, with Greece and Malta showing relatively lower indicators compared to others. China leads in the highest number of publications in Environmental Science. The indicators for China suggest a minor lag in the share of employment in green manufacturing and the allocation of funding for green technologies.

Table 3. Performance indicators of Promoting Sustainable Development through Green Innovations

Country	Share of green manufacturing employment in total manufacturing employment (%)	Share of patent publications in environmental technology to total patent (%)	Share of export of environmental goods to total export (%)	Total amount of funding to promote environmentally sound technologies per GDP, (%)	Number of publications in Environmental Science, units
Finland	0.112	12.99	7.37	0.04	2301
Sweden	0.075	12.21	6.80	0.04	4090
Denmark	0.127	21.95	7.96	0.06	2911

Country	Share of green manufacturing in total manufacturing employment (%)	Share of patent publications in environmental technology to total patent (%)	Share of export of environmental goods to total export (%)	Total amount of funding to promote environmentally sound technologies per GDP, (%)	Number of publications in Environmental Science, units
Germany	0.134	13.32	12.34	0.06	12146
Austria	0.097	13.96	9.34	0.06	2168
France	0.074	12.54	5.80	0.03	7905
Czech Rep.	0.133	11.59	10.12	0.12	2323
Poland	0.092	9.03	6.10	0.07	5102
Estonia	0.076	3.30	6.91	0.09	472
Croatia	0.079	2.73	3.75	0.05	829
Slovenia	0.099	9.18	6.44	0.10	634
Latvia	0.068	11.90	3.58	0.04	407
Spain	0.087	10.94	3.89	0.02	10092
Ireland	0.018	6.29	1.73	0.01	1251
Portugal	0.070	6.71	7.37	0.04	3832
Belgium	0.069	8.43	4.45	0.06	3019
Netherlands	0.081	9.52	4.96	n.a.	5217
Hungary	0.092	6.95	8.40	0.15	1197
Slovak Rep.	0.102	11.75	7.72	n.a.	769
Italy	0.096	9.63	9.12	n.a.	10245
Greece	0.053	7.10	3.08	0.02	2360
Luxembourg	0.020	10.21	6.81	0.03	174
Romania	0.076	7.22	11.73	0.05	1469
Lithuania	0.058	6.91	6.21	0.07	601
Malta	0.012	7.57	3.81	0.02	116
Bulgaria	0.074	12.41	4.37	0.05	607
Cyprus	0.046	16.59	1.80	0.01	440
China	0.074	8.73	6.07	0.02	105988

Source: compiled by the authors based on the Green Growth Index (2022) and SJR (2023).

6. Conclusions

Our comparative analysis of the economic strategies employed by China and the EU in the field of green innovations has recovered that both global players have put systematic efforts to support sustainable development. Researchers from these two regions make considerable input into international knowledge base by research papers and patents. While making this research authors had permanent feeling that countries concentrate on their competitiveness in policies, initiatives, and key sectors targeted for green innovations more than sustainable development goals.

Benchmarking of EU and Chinese strategies has demonstrated differences in approaches and levels of effectiveness in promoting sustainable development through green innovation. The leading role of government in China gives little space for manoeuvre for local bodies, while in the EU strategies serve as guiding star to national governments which are responsible within national borders for the input into reaching SDGs with uneven successfulness. The EU's approach is focused on public-private partnerships, while in China, the role of the state is of leading importance.

Although the EU takes the lead in green patents in transportation, energy, water, farming & forestry, pollution & waste, product, materials & processes, building & construction pushing them into Industry 4.0, for both global actors the weak side is international cooperation and transfer of technologies.

Both the EU and China have made significant progress in promoting green innovation and sustainable development. This is evidenced by the leading positions of the EU and China in the development of alternative energy, the introduction of green innovations in production, and the development of the circular economy. However, challenges remain for both the EU and China in achieving sustainable development goals, particularly in areas such as climate change and responsible consumption and production.

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