





Digital technologies as a driver of infrastructure modernization and innovative progress in the context of sustainable development goal 9

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Citation: Pomaza-Ponomarenko, A., Akhmedova, O., Naumenko, M., Kurtsev, O., & Kyrkovskiy, V. (2026). Digital technologies as a driver of infrastructure modernization and innovative progress in the context of sustainable development goal 9. *European Journal of Sustainable Development Research*, 10(2), em0392. <https://doi.org/10.29333/ejosdr/18308>

ARTICLE INFO

Received: 10 Oct 2025

Accepted: 08 Jan 2026

ABSTRACT

The integration of digital technologies into national policies in developed countries supports the achievement of Sustainable Development Goal 9 (SDG 9) by fostering innovation and infrastructure development. This study aims to analyze how digital technologies contribute to SDG 9 through the experience of Scandinavian countries. The methodology combines mixed design and multi-criteria analysis of the Digital Economy and Society Index (DESI) from 2017 to 2024 to compare digitalization policies, institutional frameworks, and outcomes. Structural content analysis of EU digital strategies was conducted, focusing on budget priorities and areas such as information and communication technologies (ICT) infrastructure, digital skills, artificial intelligence, open data, and cloud technologies. The findings reveal that Finland, Sweden, and Denmark demonstrate significant progress in digital public services, basic digital skills, and ICT workforce development. However, challenges remain in AI implementation and small and medium enterprise (SME) digitalization. Denmark leads in DESI performance, Sweden in innovation, and Finland in accessibility, highlighting the need for context-specific digital strategies.

Keywords: digital technologies, artificial intelligence, data analytics, public administration, anti-corruption policy, european integration

INTRODUCTION

Achievement of Sustainable Development Goal 9 (further – SDG 9) is identified as a strategic priority in promoting sustainable economic growth, and the latest digital technologies should ensure increased resilience of critical infrastructure (Ahmad et al., 2023; Argyroudis et al., 2022; Küfeoğlu, 2022). Technology is recognized as a means for rapid decision-making, adaptation to environmental changes, and accurate, rapid assessment of existing assets (Hales & Birdthistle, 2022). The operability and functionality of critical infrastructure are at constant risk due to numerous threats and the growing demand for digitalization (Clark et al., 2022). The latest and most revolutionary digital technologies can increase the level of climate resilience of critical infrastructure, ensuring its adaptation to the needs of users (Argyroudis et al., 2022). The integration of technological innovation and data analysis into sustainable development provides an

opportunity to address pressing global issues such as climate change, resource scarcity, and social inequality (Gavkalova et al., 2024, 2025; Harfouche et al., 2024). Digital technologies in industry can replace workers, significantly reducing the costs of enterprises. The introduction of communication, information, computing and other digital technologies (Internet of Things, digital twins, artificial intelligence, cloud solutions) has become a prerequisite for ensuring sustainable growth in different countries.

The purpose of this article is to characterize the introduction of digital technologies in promoting innovation and infrastructure development under SDG 9.

LITERATURE REVIEW

The scientific literature considers digital transformation as a driver for achieving SDG 9 (Du & Wang, 2024; Fura et al.,

2025; Hajikhani & Suominen, 2022; Leal Filho et al., 2022). In this regard, Du and Wang (2024) consider the importance of digital infrastructure in ensuring symbiotic relationships between innovation actors, noting the regional heterogeneity of digital development in China in the period 2013-2018. As a result, there is a gap in the innovative development of the provinces within the established innovation ecosystem. Modernization of the industrial structure is proposed as a way to bridge these gaps. In opposite, the article by Fura et al. (2025) assesses the level of digital transformation in 27 EU countries in 2015 and 2020, including in industry, innovation, and infrastructure. The countries of Central, Eastern and Southern Europe face significant challenges in achieving SDG 9. The study by Leal Filho et al. (2022) explain the reason for such challenges, their found that mobilization of financial resources and improved government policy coordination should become drivers in the digitalization of infrastructure and the achievement of SDG 9 based on a bibliometric analysis of scientific publications since 2015.

A separate area of research is to identify the role of digital technologies in the processes of industrialization and sustainable infrastructure development (Kasinathan et al., 2022; Lekan et al., 2022; Mhlanga 2021; Pigola et al., 2021; Wang et al., 2025). In this regard, infrastructure modernization is the process of significantly and fundamental update and improving communication system, transportation networks, utilities, including research and technology infrastructure (European Commission, 2025, n.d. - f). Thus, Lekan et al. (2022) and Kasinathan et al. (2022) link the impact of the fourth and fifth industrial revolutions to the modernization of infrastructure and the construction of new facilities. The authors assign an important role to disruptive innovations in achieving SDG 9 (Lekan et al., 2022). More specific, Mhlanga (2021) and Pigola et al. (2021) show the impact of artificial intelligence technologies on infrastructure development in developing countries. In particular, Pigola et al. (2021) examine the Portuguese and Brazilian experience of using artificial intelligence as a means of raising digital awareness of the population, as well as improving cooperation between universities and the state within the framework of research and development (including the field of open data). Another paper addresses the issue of bridging the digital divide between urban and rural areas in innovative development (Pomaza-Ponomarenko et al., 2020, 2021, 2023; Prieto-Egido et al., 2023). Another research of Wang et al. (2025) focus on the study of artificial intelligence in shaping the competitive advantages of innovative development of urbanized markets. At the same time, artificial intelligence has the greatest impact on the development of innovations in the field of R&D, with a lesser impact on infrastructure development. The stimulating effect of artificial intelligence is strongest in countries with a high level of sustainable development. Urbanization is a favorable factor for sustainable development with the use of technology in innovation and infrastructure. The importance of industrialization, new technological developments and skills as a prerequisite for sustainable economic growth, promotion of transport, information and communication infrastructure, and value creation highlighted by Küfeoğlu (2022). Besides that, Ige et al. (2024) points out the irreplaceable role of cyber defense technologies in maintaining

the resilience of digital infrastructure, emphasizing the potential of blockchain technologies and artificial intelligence in strengthening cybersecurity measures.

A number of studies have examined the role of digital technologies in supporting innovation, which are defined as processes of implementing new ideas; introducing new or significantly improved products to the market; or adopting new or substantially enhanced methods and processes in production (European Commission, n.d. - a). The bibliometric analysis of the importance of digital technologies in achieving the SDGs by Dzhunushalieva and Teuber (2024) for 2015-2023 confirms their economic, social and environmental impact. In particular, the authors highlighted the importance of eco-innovations, technological innovations, and socially oriented innovations in sustainable development. Based on 2496 sustainable business practices, Varriale et al. (2024) demonstrate how blockchain, the Internet of Things, geospatial technologies, and artificial intelligence contribute to SDGs 6, 7, 12, 13. The authors also consider production systems and digitalization as mechanisms for innovative development.

A number of articles measure the extent to which digitalization affects the implementation of the SDGs. For example, Brodny and Tutak (2023a, 2023b) calculate indices for assessing the implementation of SDG 9 in Poland for 2015-2021 at the regional level and in the EU-27 for 2015-2020 based on the MCDM methodology (multi-criteria decision-making approach). In Poland, there is a significant differentiation of spatial regional development with a high degree of development in the Mazovian, Lower Silesian and Pomeranian Voivodeships, and a low degree in the Sviato-Krestovozivske Voivodeship. The results also show that there is a link between the degree of innovation, industrialization and stable infrastructure, as well as economic development and living standards in the regions (Brodny & Tutak, 2023a). Within EU27, there is also a differentiation in sustainable development. Denmark, Germany, Luxembourg, Sweden, the Netherlands, and Finland have made the most progress on SDG 9. In contrast, Greece, Portugal, Lithuania, and Bulgaria have identified a number of problems and challenges (Brodny & Tutak, 2023b).

Another research of Desyatnyuk et al. (2025) and Saqib et al. (2023) prove the importance of financial technology development in leading economies over 1990-2020 in ensuring a green transition. In all advanced economies, there is a significant correlation between financial technologies and renewable energy. Similar conclusions are presented in Farahani et al. (2022), who found that the use of artificial intelligence in the financial sector mediates sustainable economic growth. Based on an analysis of the importance of the information and communication technologies (ICT) sector in the development of municipalities, Mantovani Ribeiro et al. (2021) determined that the intensive use of technology does not always ensure an increase in sustainable development indicators, as not all cases ensure the strategic use of technology to support the goals.

A number of studies have examined the impact of institutional support and policies to promote digitalization. According to Singh and Ru (2023), the authorities responsible for formulating and implementing digitalization policies

should focus on overcoming digital inequality, ensuring digital equity, and expanding Internet and mobile broadband access, particularly in rural areas. With regard to the introduction of technologies, the authors recommend reforming industrial policy and integrating technologies into the relevant sector, increasing funding for R&D and relevant initiatives. Another study (Sinha et al., 2024) points to poor infrastructure development, a lack of skills and knowledge to use technology, and a lack of financial resources and incentives to invest in technology to support innovation in 21 of the 32 countries ranked in the 2021 Global Innovation Index. At the same time, other scholars have found much smaller effects of ICT on the SDGs, despite ICT policies and infrastructure, so it is necessary to improve policies and institutions that should ensure the use of technology for sustainable development (Vyas-Doorgapersad, 2022). According to Bachmann et al. (2022), data analytics and data analysis tools contribute to the achievement of the SDGs by providing a higher degree of information reliability for making informed policy decisions, which is then used to implement data-driven policies.

As a result of factor analysis of the interdependencies between institutions, digital technologies, and the SDGs, Popkova et al. (2022) found that the development of institutions in developed countries contributes to the achievement of only SDG 3 and SDG 17, while in developing countries it contributes to the achievement of SDG 16. The use of digital technologies and digitized knowledge determine the level of globalization of countries, their innovation capacity, and the quality of institutions. The Digital Technology Index and Digital Knowledge Index have contributed to improved governance in developed countries.

To summarize, digital technologies are seen as a factor in achieving SDG 9, which contributes to infrastructure modernization, innovative development, green transition, and industrialization. At the same time, there is a significant gap between the technological potential and the political institutional capacity to realize it, especially in developing countries. Institutions responsible for integrating digital transformation measures into public policy may hinder progress in achieving the SDGs. This study aims to analyze how digital technologies and digital transformation contribute to SDG 9 through the experience of Scandinavian countries.

MATERIALS AND METHODS

The research is based on an interdisciplinary approach and a combination of qualitative and quantitative methods of analysis. The mixed methods research approach combines methods for analyzing collected quantitative closed data and qualitative open data. The mixed design made it possible to supplement quantitative data on digitalization, innovative development, and transport efficiency with qualitative information on digitalization strategies as a tool for promoting digital innovation development. Data collection and analysis procedures were carried out on the basis of a sample of countries selected according to the criteria below. The data was collected exclusively from official sources of information. The analysis procedures were carried out sequentially: In the first stage, countries were selected for analysis of their level of

digitalisation according to the criteria listed above; in the second stage, quantitative data reflecting the overall results of digitalisation in the country were analysed; in the third stage, data synthesis was used to summarize quantitative data on digitalization and qualitative data on digitalization strategies in order to understand the factors that contributed to the high level of digitalization effectiveness in each country; in the fourth stage, a quantitative statistical analysis of the country's innovation development and transport efficiency indicators was carried out.

European Union (EU) countries (Finland, Sweden, Denmark) were selected to study the role of digital technologies in promoting the achievement of SDG 9 based on the following criteria:

- High level of achievement of SDG 9 according to the Eurostat SDG Index (SDG 9: Industry, Innovation and Infrastructure);
- Countries occupy leading positions in the Digital Economy and Society Index (DESI) ranking for 2017-2024 in the following components: digital infrastructure, digital public services, and digitalization of enterprises (European Commission, 2022a);
- Governments are implementing measures within the framework of national digital strategies that are aligned with the EU's EU Digital Decade 2030 program, including the implementation of roadmaps and budget funding for programs;
- Availability of official data and strategic documents on innovation and infrastructure development policy as a prerequisite for comparative analysis of countries (Eurostat, European Commission).

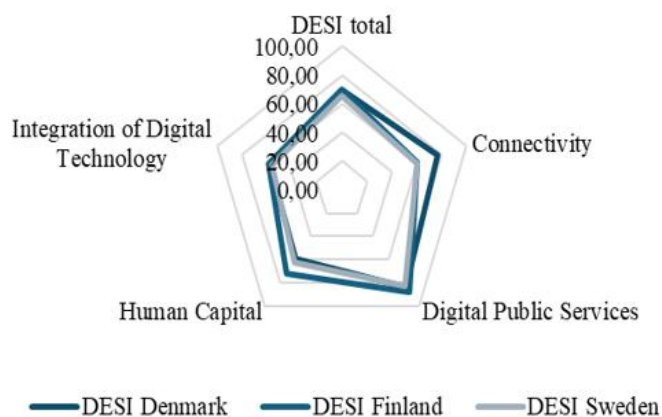
The second stage of the study involved combining various methods of analyzing the collected quantitative closed data. Multidimensional structural analysis (Fura et al., 2025) was used to compare countries by the components of the Digital Economy and Society Index (further – DESI) during 2020-2024: Digital infrastructure, digital public services, and digitalization of enterprises. The third stage of the study involved the use of structural content analysis and multi-criteria analysis to synthesize qualitative data. Structural content analysis was used as a method of studying the official digital strategies of EU countries according to the following criteria: Budget priorities, areas of digitalization (ICT infrastructure, digital skills, artificial intelligence, open data, cloud technologies); institutional mechanisms for ensuring digital development in the country. The multi-criteria analysis method was applied to support a qualitative assessment of the implementation of SDG 9 in EU countries, following the methodology proposed by Brodny and Tutak (2023a), where this approach is used to critically compare digitalization policies, institutional models of digital development, and achieved results. The fourth stage of the study involved analyzing indicators of innovative development and transport efficiency in each country.

Secondary data from official databases were analyzed to determine the extent to which countries have achieved SDG 9, including: The Eurostat SDG 9 database (R&D expenditure, high-tech exports, patent applications, VHCN coverage);

Table 1. Dynamics of the DESI index in Finland, Sweden and Denmark in 2017-2022

Country	2017	2018	2019	2020	2021	2022
Denmark	46,48	48,69	52,05	55,97	65,25	69,33
Finland	47,85	50,37	54,14	58,43	63,16	69,60
Sweden	45,71	48,74	51,96	55,75	60,49	65,22
European Union	33,72	35,92	38,64	41,67	46,20	52,28

Source: European Commission, 2022a

**Figure 1.** DESI index and sub-indices in Finland, Sweden and Denmark, 2022 (European Commission, 2022b)

aggregate estimates of the Digital Economy and Society Index (DESI) ranking; the Organization for Economic Cooperation and Development (OECD) database and indicators of investment in innovation, public spending on R&D, and the level of digital inclusion.

RESULTS

The strategic guidelines for digital transformation are set out in the EU's Digital Decade 2030 program, which focuses on the development of digital skills, digital infrastructure, and the digitalization of business and public services (European Commission, 2021). The Recovery and Resilience Facility 2021-2026 is defined as the main instrument for the digital transition in the EU, financed through the debt market. To develop the EU's artificial intelligence sector, the European Office for Artificial Intelligence was established, responsible for expertise, innovation, policy coordination, and implementation of relevant legislation (European Commission, n.d. – a).

The European Commission's State of the Digital Decade 2025 report contains the results of achieving the goals in these areas. Despite the introduction of cloud technologies, big data, and artificial intelligence by businesses, digital business

development needs to be accelerated. There are problems with building digital infrastructure. About 55% of EU residents have digital skills. The availability of specialists with ICT skills is assessed at a low level, which leads to problems in cybersecurity and the use of artificial intelligence. Stability is evident in achieving the goals of digitalizing public services, but there is a dependence on the providers of these services to develop digital infrastructure. The main difficulties of digital development are related to complex regulations, the EU's strategic dependence on other markets, and the fragmentation of the internal digital market (European Commission, 2021).

During 2017-2022, Finland, Sweden, and Denmark were significantly ahead of other EU countries in the DESI index (Table 1), with an average value of 69.6 points, 69.33 points, and 65.22 points, while the EU average was 52.28 points in 2022. In general, since 2017, there has been a significant increase in the level of economic digitalization in the EU and in Finland, Sweden, and Denmark.

The development of digital public services in these countries was at the highest level, with the corresponding sub-index in all three countries exceeding 80 points. Internet connectivity and human capital development received somewhat lower scores, while the least developed area was the integration of digital technologies (Figure 1).

The level of digital intensity was 67.05% in Finland, 65.15% in Denmark, and 62.13% in Sweden in 2022, significantly outpacing other EU countries. This indicates the high digitalization of enterprises, particularly in the areas of cloud technologies, artificial intelligence, and big data.

In 2023, Denmark made significant progress in achieving the goals of the EU's Digital Decade 2030 program, namely in the digitalization of public services and the increase in ICT professionals. The introduction of digital technologies by small and medium enterprise (SMEs) and artificial intelligence remains problematic. New strategies for digital development in the country include increasing the level of digital literacy of the population, strengthening cybersecurity, and environmental transition using technology. Denmark is actively involved in EU initiatives to use digital twins and create innovation hubs (European Commission, 2025, n.d. – a, n.d. – c, n.d. – d) (Table 2).

Table 2. DESI indicators in Finland, Sweden and Denmark, 2023-2024

Indicator	Denmark		Finland		Sweden	
	2023	2024	2023	2024	2023	2024
Fixed very high-capacity network (VHCN)	96,3%	97,2%	70,8%	77,7%	81,6%	88,5%
Fibre to the premises (FTTP) coverage	77,9%	84,0%	50,3%	61,2%	81,5%	83,9%
Total 5G coverage	97,8%	100,0%	94,7%	98,4%	20,5%	90,3%
SMEs with at least a basic level of digital intensity	79,4%	75,3%	81,6%	85,6%	86,1%	79,9%
Cloud technologies	62,2%	66,2%	66,3%	73,0%	69,2%	66,0%
Artificial intelligence	23,9%	15,2%	15,8%	15,1%	9,9%	10,4%

Source: Systematized by the author according to the European Commission (2024a, b, c)

Table 2 (Continued). DESI indicators in Finland, Sweden and Denmark, 2023-2024

Indicator	Denmark		Finland		Sweden	
	2023	2024	2023	2024	2023	2024
Data analytics	NA	49,5%	NA	40,6%	NA	35%
Basic digital skills	68,7%	69,6%	79,2%	82,0%	66,6%	66,4%
ICT specialists	5,7%	5,9%	7,6%	7,6%	8,6%	8,7%
Digital public services	84,1%	84,2%	91,6%	90,6%	88,2%	93,3%

Source: Systematized by the author according to the European Commission (2024a, b, c)

Denmark's national roadmap envisages strengthening the competitiveness of enterprises, improving public services and green transition. In November 2023, the Digitalization Strategy for 2023-2027 was updated, which will provide funding for initiatives to strengthen technological knowledge in primary school, increase the use of digital technologies (robotics, artificial intelligence, open data) in the amount of 100 million euros. Digitalization is based on strategies: The Joint Government Digital Strategy 2022-2025, the Danish National Strategy for Quantum Technologies, and the Cybersecurity and Information Security Strategy (European Commission, 2024a).

Finland has lower estimates of digital development of the economy compared to Denmark, including a less developed fixed very high-capacity network (VHCN), an average degree of FTTP coverage, although high coverage of high-speed Internet, a higher degree of digital intensity of SMEs and digitalization of public services in 2023-2024. The use of cloud technologies is above average, while artificial intelligence technologies and big data analytics are less used. In 2023-2024, the level of basic digital skills increased, and the share of ICT specialists remained at 7.6%.

Finland's National Digital Transformation Strategy is based on the principles of the EU's 2030 Digital Decade roadmap, according to which the introduction of digital technologies in the country should promote the development of digital skills, digital infrastructure, SME digitalization, and digital public services. The roadmap for the implementation of Finland's strategy provides for the allocation of financial resources in the amount of 559 million euros (0.2% of GDP) to improve the accessibility of the Internet. Government programs, such as the National Digital Architecture and AuroraAI, provide for the creation of an integrated ecosystem of public services based on artificial intelligence and open data technologies (Ministry of Transport and Communications of Finland, 2023). With 82 percent of citizens having basic digital skills and 85.6 percent of SMEs demonstrating high digital intensity, Finland maintains near-universal 5G coverage and ranks among the highest in the EU in terms of e-government (European Commission, 2024b).

Sweden is in an intermediate position between Denmark and Finland in terms of fixed-line network development and FTTP coverage. Between 2023 and 2024, 5G coverage increased significantly, but the share of SMEs with a basic level of digitalization decreased to 79.9%. The use of cloud technologies by businesses is at an average level, and artificial intelligence is the least widespread among all countries. There has been no progress in the development of basic digital skills of citizens and the share of ICT professionals, although the level of digitalization of public services has increased slightly.

High-speed Internet coverage is defined as the basis for building digital infrastructure in the innovation economy and achieving other sustainable development goals. Denmark has increased its coverage from 93.0% in 2019 to 96.8% in 2024, which means more households have access to a fixed network connection. Finland managed to increase its coverage from 61.8% in 2019 to 81.7% in 2024, and Sweden - from 77.1% to 89.7%, respectively. For comparison, the average coverage in the EU was 50.3% in 2019 and 82.5% in 2024 (European Commission, n. d - b). Denmark managed to achieve such progress due to the introduction of IoT technologies in the industrial sector, Sweden - due to government incentives to expand the digital network, and Finland - due to the digitalization of infrastructure.

Sweden is a leader among countries in terms of R&D expenditures, which exceeded 3% of GDP in 2017-2023, as well as in terms of R&D labor force employment with an increase of 0.52% of the total labor force. This indicates the use of available human capital and its involvement in the development of innovations. Finland shows a steady increase in R&D expenditures, with a slightly lower growth in R&D by specialists. In Denmark, there were practically no changes in R&D funding, and the share of specialists increased by 0.26% in 2017-2023 (Table 3). Sweden also has significantly higher patent activity, and the number of applications for patents increased by 1342 units. In contrast, in Denmark and Finland, the indicator is much lower with a slow upward trend.

In the context of SDG 9, transport efficiency indicators (passenger and freight transportation) in Finland, Sweden and

Table 3. Innovation development indicators in Finland, Sweden and Denmark, 2017-2023

Country	2017	2018	2019	2020	2021	2022	2023	Deviation, +/-
Gross domestic expenditure on R&D								
Sweden	3,39	3,35	3,4	3,5	3,42	3,47	3,6	0,20
Finland	2,75	2,78	2,82	2,93	3,01	2,98	3,09	0,27
Denmark	2,94	2,98	2,95	2,97	2,74	2,87	2,99	0,04
EU-27	2,14	2,17	2,21	2,28	2,24	2,23	2,24	0,03
R&D personnel, Percentage of population in the labor force – numerator in full-time equivalent (FTE)								
Denmark	2,1	2,07	2,12	2,12	2,11	2,36	2,36	0,26
Sweden	1,73	1,77	1,75	1,81	2,18	2,25	2,25	0,52

Source: Systematized by the author according to the European Commission (2024a, n. d. - b, n. d. - c)

Table 3 (Continued). Innovation development indicators in Finland, Sweden and Denmark, 2017-2023

Country	2017	2018	2019	2020	2021	2022	2023	Deviation, +/-
Finland	1,88	1,9	1,95	2,04	2,11	2,1	2,19	0,31
European Union - 27	1,3	1,37	1,4	1,44	1,49	1,53	1,56	0,26
Patent applications to the European Patent Office by applicants' / inventors' country of residence								
Denmark	2089	2385	2415	2420	2646	2685	2597	508
Finland	1797	1728	1705	1899	2108	2140	2336	539
Sweden	3783	4055	4395	4422	4947	5040	5125	1342
European Union - 27	63897	66181	66510	65925	67820	67612	68647	4750

Source: Calculated by the author according to European Commission (n.d. - c, n.d. - d, n.d. - e)

Table 4. Transport efficiency indicators in Finland, Sweden and Denmark, 2017-2023

Country	2017	2018	2019	2020	2021	2022	2023	Deviation, +/-
Share of buses and trains in inland passenger transport, %								
European Union - 27	16,9	17,0	17,2	12,8	13,3	16,4	16,9	0,00
Denmark	18,4	18,0	17,3	12,8	13,1	18,8	18,2	-0,20
Finland	15,8	15,8	16,1	13,0	12,3	15,8	17,0	1,20
Sweden	19,6	19,6	20,5	16,0	15,9	19,0	18,2	-1,40
Share of rail and inland waterways in inland freight transport, %								
European Union - 27	25,0	24,7	24,0	22,6	22,7	22,2	21,9	-3,10
Denmark	11,5	11,8	11,5	10,8	8,7	9,6	8,2	-3,30
Finland	27,7	29,3	27,2	26,2	27,3	23,0	22,6	-5,10
Sweden	30,2	30,2	30,2	29,8	29,0	28,9	29,9	-0,30

Source: European Commission (2022b, n.d. - h)

Denmark for 2017-2023 indicate a lack of progress in the implementation of certain sustainable development targets. The share of bus and rail passenger transportation in the countries remained virtually unchanged (with the exception of Finland), indicating no changes in sustainable mobility, challenges to sustainable transition, and difficulties in expanding the availability of transport for the population. The share of rail and inland waterway transportation in domestic freight transportation (road, rail, and inland waterway) slightly decreased in 2017-2023, especially in Finland (**Table 4**). This indicator is directly related to the increase in the environmental friendliness of transportation and the development of the countries' infrastructure (Andriyiv et al., 2022). However, compared to other EU countries, Denmark, Finland, and Sweden have slightly higher ground passenger transport efficiency rates. Digital technologies, such as 5G coverage, are transforming passenger transport, providing a number of benefits: Greater accessibility and connectivity, and greater mobility. At the same time, the increase in passenger transport efficiency in Finland may be due to the higher level of digital skills among the population, which was significantly higher than in Denmark and Sweden. This makes passenger transport services more accessible to citizens.

It should be noted that Finland had the largest investments in multimodal transport development projects in 2020, amounting to EUR 21.2 million. For comparison, in Sweden, the figure was €10.2 million in 2020, and Denmark had the highest total infrastructure investment of €824.5 million in 2020, of which €719.5 million was invested in railways (Krzykowska-Piotrowska et al., 2022). Finland focused on the development of high-speed railways in 2017-2023 with funding from EU structural funds, in particular in the form of subsidies. Sweden has invested in multimodal solutions for the modernization of railways, ports, and water transport.

The intensity of air pollutant emissions from the manufacturing sector per unit of industrial value added was at

the lowest level in all countries in 2017-2023. The average value of the emissions intensity indicator was estimated at 0.01% in Denmark, 0.07% in Finland, and 0.05% in Sweden (0.07% in the EU) (European Commission, n. d-h). The indicator indicates high efficiency of industrial production. In Denmark, the introduction of a tax on industrial gas emissions in 2020 (24 euros per ton of emissions) and the use of alternative energy sources have provided incentives to reduce emissions. Sweden abandoned the use of coal in 2020, and 54% of its energy is generated through renewable energy sources. An additional factor in decarbonization was the introduction of industrial innovations and R&D results in ensuring sustainable production. Finland has introduced carbon taxes, especially in energy-intensive production.

DISCUSSION

The findings of this study are consistent with and extend the growing body of literature that emphasizes the key role of digital technologies in achieving Sustainable Development Goal 9 (SDG 9). At the same time, the article emphasizes the importance of national digital transition plans alongside financing infrastructure development and directing investments into transport networks. National strategies or roadmaps for the digital transformation of infrastructure through increased high-speed Internet coverage. A comparative analysis of the digitalization of Denmark, Sweden, and Finland confirms the importance of digital development strategies at the EU level and their coherence with national strategic documents. The Scandinavian countries have achieved a high level of digitalization of public services, development of basic digital skills of citizens, and digital infrastructure by increasing broadband coverage. Denmark is a leader in the development of digital infrastructure in terms of Internet accessibility. Finland is

distinguished by its leadership in digital governance and digital innovation for business, while Sweden is the undisputed leader in terms of R&D spending and patent activity. All countries have an average level of use of cloud technologies, a below-average level of use of data analytics, and a low level of use of artificial intelligence.

The results are in line with the findings of Argyroudis et al. (2022), which emphasize the role of digital technologies in increasing the climate resilience of digital infrastructure. At the same time, Scandinavian countries have different factors for ensuring digital infrastructure development. Finland has managed to achieve progress by strengthening digital governance and focusing on the development of digital skills and high-speed Internet coverage. At the same time, the country's government has allocated significantly more funding to implement the National Digital Transformation Strategy until 2030, the development of digital infrastructure remaining a priority. Therefore, in the absence of significant changes in transport efficiency and substantial funding, there are problems with managing the digitalization of the country's transport sector. Clearly, the country needs direct investment in the digitalization of its transport infrastructure. High-speed Internet coverage is considered the basis for developing digital infrastructure in an innovative economy and achieving other sustainable development goals in Sweden, which has also made significant progress in this area. Denmark and Sweden use digital twins and the Internet of Things in manufacturing. The study by Bachmann et al. (2022) confirms the crucial role of digital solutions in achieving the SDGs, which correlates with the example of Finland and its National Digital Architecture and AuroraAI artificial intelligence programs. However, governments need to find further solutions to increase the level of digitalization of countries' transport infrastructure, which, when combined with investment in skills and business investment in technology, will significantly improve the accessibility of transport services and mobility and promote a sustainable transition of the sector. At present, the main problem and challenge for governments remains ensuring synergy between investments in infrastructure, digital skills, and technology.

Instead, the results differ from the findings of Brodny and Tutak (2023a, 2023b), who showed the fragmentation of digitalization in the EU and Poland in particular. This is due to the coverage of the peculiarities of digitalization in the Scandinavian countries, their systematic approaches to the use of digital technologies and the alignment of national policies with the EU's 2030 Digital Decade.

The results also correlate with the findings of Dzhunushalieva and Teuber (2024), who found that countries with more effective innovation policies, such as Sweden, achieve higher results in achieving the SDGs. Thus, the Scandinavian approach demonstrates the use of digital potential in promoting sustainable development, in particular by bridging the gap in Internet accessibility through high levels of coverage. The analysis also demonstrates the importance of strategic digitalization planning for the development of innovation, infrastructure, and industrial digitalization, which is in line with the findings of Singh and Ru (2023), who emphasize structured national planning and investment in infrastructure as a prerequisite for achieving

SDG 9. Finally, the study adds to the existing academic literature with empirical evidence on the importance of digitalization in the innovative development of the Nordic countries and the achievement of SDG 9. A comparative analysis of the latest data on SDG 9 indicators in Finland, Sweden, and Denmark has allowed us to empirically substantiate the importance of the European Digital Agenda and national government actions in ensuring sustainable development.

CONCLUSIONS

The Scandinavian countries are significantly ahead of the EU average in the digital transformation of the economy, digitalization of public services, and implementation of high-speed coverage. Denmark demonstrates the highest level of digital integration with an overall Internet coverage of 100% in 2024, while Sweden is a leader in innovation and R&D due to the highest R&D expenditures in 2017-2023 and a high share of ICT professionals. Finland has secured leadership in SME digitalization and the development of digital skills of the population. At the same time, the use of artificial intelligence and data analytics remain problematic in all countries. The countries' transport efficiency indicators indicate a slow pace in achieving SDG 9, while the introduction of taxes and decarbonization policies have ensured the achievement of industrial emission minimization targets and strengthened the environmental efficiency of industrial production. Overall, these findings show that the role of digital technologies in achieving SDG 9 remains low, as despite significant spending on innovation and R&D, the use of artificial intelligence and data analytics is below average. Digitalization policies should include increased support for SMEs in the adoption of artificial intelligence, big data, and cloud technologies through financial incentives. The Scandinavian countries also have opportunities to create a unified digital ecosystem of public services based on data analytics and artificial intelligence.

Author contributions: **AP-P:** conceptualization, theoretical framework, supervision; **OA:** literature review, data interpretation, methodology; **MN:** methodology, formal analysis. **OK:** project administration; **VK:** data curation, writing – review & editing. All authors reviewed and approved the final version of the manuscript.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethical statement: The authors stated that the research presented in this manuscript was conducted in accordance with internationally accepted ethical standards. The study did not involve human participants, personal data, animals, or sensitive materials requiring formal ethical approval.

AI statement: The authors stated that no generative artificial intelligence (AI) tools or AI-based technologies were used in the conceptualization, data analysis, interpretation, writing, editing, or preparation of this manuscript.

Declaration of interest: The authors declare that they have no known financial, institutional, or personal conflicts of interest that could have appeared to influence the work reported in this paper.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

REFERENCES

- Ahmad, N., Youjin, L., Žiković, S., & Belyaeva, Z. (2023). The effects of technological innovation on sustainable development and environmental degradation: Evidence from China. *Technology in Society*, 72, Article 102184. <https://doi.org/10.1016/j.techsoc.2022.102184>
- Andriyiv, N., Voloshchuk, K., Petrukha, S., Orlovska, O., Kurylo, O. (2022). Impact of the main threats from COVID-19 on the labor market in the context of ensuring economic security. *International Journal of Safety and Security Engineering*, 12(1), 71-76. <https://doi.org/10.18280/ijss.120109>
- Argyroudis, S. A., Mitoulis, S. A., Chatzi, E., Baker, J. W., Brilakis, I., Gkoumas, K., Vousdoukas, M., Hynes, W., Carluccio, S., Keou, O., Frangopol, D. M., & Linkov, I. (2022). Digital technologies can enhance climate resilience of critical infrastructure. *Climate Risk Management*, 35, Article 100387. <https://doi.org/10.1016/j.crm.2021.100387>
- Bachmann, N., Tripathi, S., Brunner, M., & Jodlbauer, H. (2022). The contribution of data-driven technologies in achieving the sustainable development goals. *Sustainability*, 14(5), Article 2497. <https://doi.org/10.3390/su14052497>
- Brodny, J., & Tutak, M. (2023a). Assessing regional implementation of Sustainable Development Goal 9 “Build resilient infrastructure, promote sustainable industrialization and foster innovation” in Poland. *Technological Forecasting and Social Change*, 195, Article 122773. <https://doi.org/10.1016/j.techfore.2023.122773>
- Brodny, J., & Tutak, M. (2023b). The level of implementing sustainable development goal industry, innovation and infrastructure of Agenda 2030 in the European Union countries: Application of MCDM methods. *Oeconomia Copernicana*, 14(1), 47-102. <https://doi.org/10.24136/oc.2023.002>
- Clark, S., MacLachlan, M., Marshall, K., Morahan, N., Carroll, C., Hand, K., Boyle, N., & O’Sullivan, K. (2022). Including digital connection in the United Nations sustainable development goals: A systems thinking approach for achieving the SDGs. *Sustainability*, 14(3), Article 1883. <https://doi.org/10.3390/su14031883>
- Desyatnyuk, O., Krysovaty, A., Ptashchenko, O., & Kyrylenko, O. (2025). The role of financial inclusion in fostering ecoentrepreneurship within the digital economy. *International Journal of Ecosystems and Ecology Science (IJEES)*, 15(1), 77-86. <https://doi.org/10.31407/ije.15.109>
- Du, Z. Y., & Wang, Q. (2024). Digital infrastructure and innovation: Digital divide or digital dividend? *Journal of Innovation & Knowledge*, 9(3), Article 100542. <https://doi.org/10.1016/j.jik.2024.100542>
- Dzhunushalieva, G., & Teuber, R. (2024). Roles of innovation in achieving the sustainable development goals: A bibliometric analysis. *Journal of Innovation & Knowledge*, 9(2), Article 100472. <https://doi.org/10.1016/j.jik.2024.100472>
- European Commission. (2021). *2030 Digital compass: The European way for the digital decade*. <https://digital-strategy.ec.europa.eu>
- European Commission. (2022a). *Digital economy and society index (DESI) 2022: Compare countries’ progress – Overall DESI scores* [Interactive chart]. Digital Strategy. https://digital-decade-desi.digital-strategy.ec.europa.eu/datasets/desi-2022/charts/desi-compare-countries-progress?indicator=desi_total&breakdown=desi_total&unit=pc_desi&country=EU,DK,FI,SE
- European Commission. (2022b). *Digital economy and society index (DESI) 2022: Charts and data explorer* [Interactive data visualisation].
- European Commission. (2024a). *Report on the state of the digital decade 2024 Annex short country report 2024. Denmark*. <https://digital-strategy.ec.europa.eu/en/library/report-state-digital-decade-2024>
- European Commission. (2024b). *Report on the state of the digital decade 2024 Annex short country report 2024. Finland*. <https://digital-strategy.ec.europa.eu/en/library/report-state-digital-decade-2024>
- European Commission. (2024c). *Report on the state of the digital decade 2024 Annex short country report 2024. Sweden*. <https://digital-strategy.ec.europa.eu/en/library/report-state-digital-decade-2024>
- European Commission. (2025). The European strategy on research and technology infrastructures. https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/our-digital-future/european-strategy-research-and-technology-infrastructures_en
- European Commission. (n.d. – a). *AI office. Digital strategy*. Eurostat. <https://digital-strategy.ec.europa.eu/en/policies/ai-office#ecl-inpage-the-structure-of-the-ai-office>
- European Commission. (n. d – b). *High-speed internet coverage, by type of area*. Eurostat. https://doi.org/10.2908/SDG_17_60
- European Commission. (n.d. – c). *Gross domestic expenditure on R&D (GERD) by sector* [Data set]. Eurostat. https://doi.org/10.2908/SDG_09_10
- European Commission. (n.d. – d). *R&D personnel by sector*. Eurostat. https://doi.org/10.2908/SDG_09_30
- European Commission. (n.d. – e). *Patent applications to the European Patent Office by applicants’ / inventors’ country of residence*. Eurostat. https://doi.org/10.2908/SDG_09_40
- European Commission. (n.d. - f). *Glossary: Innovation*. <https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Innovation>
- European Commission. (n. d – f). *Share of buses and trains in inland passenger transport*. Eurostat. https://doi.org/10.2908/SDG_09_50

- European Commission. (n. d – g). *Share of rail and inland waterways in inland freight transport*. Eurostat. https://doi.org/10.2908/SDG_09_60
- European Commission. (n. d – h). *Air emission intensity from industry*. Eurostat. https://doi.org/10.2908/SDG_09_70
- Farahani, M. S., Esfahani, A., Moghaddam, M. N. F., & Ramezani, A. (2022). The impact of Fintech and artificial intelligence on COVID 19 and sustainable development goals. *International Journal of Innovation in Management, Economics and Social Sciences*, 2(3), 14-31.
- Fura, B., Karasek, A., & Hysa, B. (2025). Statistical assessment of digital transformation in European Union countries under sustainable development goal 9. *Quality & Quantity*, 59(1), 937-972. <https://doi.org/10.1007/s11135-024-01972-0>
- Gavkalova, N., Smereka, S., Kadyrus, I., Kyrylenko, S., & Kasatkina, M. (2025). Energy-saving technologies and innovations: Driving competitiveness in contemporary business. *Grassroots Journal of Natural Resources*, 8(1), 138-162. <https://doi.org/10.33002/nr2581.6853.080105>
- Gavkalova, N., Smereka, S., Kadyrus, I., Kyrylenko, S., & Kasatkina, M. (2024). Using innovation and energy efficiency technologies to drive business competitiveness. *Grassroots Journal of Natural Resources*, 7(3), S212-S229. <https://doi.org/10.33002/nr2581.6853.0703ukr11>
- Hajikhani, A., & Suominen, A. (2022). Mapping the sustainable development goals (SDGs) in science, technology and innovation: Application of machine learning in SDG-oriented artefact detection. *Scientometrics*, 127(11), 6661-6693. <https://doi.org/10.1007/s11192-022-04358-x>
- Hales, R., & Birdthistle, N. (2022). The sustainable development goals–SDG# 9 industry, innovation and infrastructure. In *Attaining the 2030 Sustainable Development Goal of Industry, Innovation and Infrastructure* (pp. 1-8). Emerald Publishing Limited. <https://doi.org/10.1108/978-1-80382-573-120221001>
- Harfouche, A., Merhi, M. I., Albizri, A., Dennehy, D., & Thatcher, J. B. (2024). Sustainable development through technological innovations and data analytics. *Information Systems Frontiers*, 26(6), 1989-1996. <https://doi.org/10.1007/s10796-024-10570-2>
- Ige, A. B., Kupa, E., & Ilori, O. (2024). Aligning sustainable development goals with cybersecurity strategies: Ensuring a secure and sustainable future. *GSC Adv. Res. Rev*, 19(3), 344-360. <https://doi.org/10.30574/gscarr.2024.19.3.0236>
- Kasinathan, P., Pugazhendhi, R., Elavarasan, R. M., Ramachandaramurthy, V. K., Ramanathan, V., Subramanian, S., Kumar, S., Nandhagopal, K., Raghavan, R. R. V., Rangasamy, S., Devendiran, R., & Alsharif, M. H. (2022). Realization of sustainable development goals with disruptive technologies by integrating industry 5.0, society 5.0, smart cities and villages. *Sustainability*, 14(22), Article 15258. <https://doi.org/10.3390/su142215258>
- Krzykowska-Piotrowska, K., Piotrowski, M., Organiściak-Krzykowska, A., & Kwiatkowska, E. (2022). Maritime or rail: Which of these will save the planet? eu macro-regional strategies and reality. *Sustainability*, 14(6), Article 3555. <https://doi.org/10.3390/su14063555>
- Küfeoğlu, S. (2022). SDG-9: Industry, innovation and infrastructure. In *Emerging technologies: Value creation for sustainable development* (pp. 349-369). Springer International Publishing. https://doi.org/10.1007/978-3-031-07127-0_11
- Leal Filho, W., Vidal, D. G., Chen, C., Petrova, M., Dinis, M. A. P., Yang, P., Rogers, S., Álvarez-Castañón, L., Djekic, I., Sharifi, A., & Neiva, S. (2022). An assessment of requirements in investments, new technologies, and infrastructures to achieve the SDGs. *Environmental Sciences Europe*, 34(1), 1-17. <https://doi.org/10.1186/s12302-022-00629-9>
- Lekan, A., Aigbavboa, C., Babatunde, O., Olabosipo, F., & Christiana, A. (2022). Disruptive technological innovations in construction field and fourth industrial revolution intervention in the achievement of the sustainable development goal 9. *International Journal of Construction Management*, 22(14), 2647-2658. <https://doi.org/10.1080/15623599.2020.1819522>
- Mantovani Ribeiro, D. M. N., Hourneaux Junior, F., Lara Cunha, C. L., Kaetsu, P. T., Dionizio-Leite, P. F., & Machado Junior, C. (2021). Digital sustainability: How information and communication technologies (ICTs) support sustainable development goals (SDGs) assessment in municipalities. *Digital Policy, Regulation and Governance*, 23(3), 229-247. <https://doi.org/10.1108/DPRG-11-2020-0159>
- Mhlanga, D. (2021). Artificial intelligence in the industry 4.0, and its impact on poverty, innovation, infrastructure development, and the sustainable development goals: Lessons from emerging economies? *Sustainability*, 13(11), Article 5788. <https://doi.org/10.3390/su13115788>
- Pigola, A., Da Costa, P. R., Carvalho, L. C., Silva, L. F. D., Kniess, C. T., & Maccari, E. A. (2021). Artificial intelligence-driven digital technologies to the implementation of the sustainable development goals: A perspective from Brazil and Portugal. *Sustainability*, 13(24), Article 13669.
- Pomaza-Ponomarenko, A., Hren, L., Durman, O., Bondarchuk, N., Vorobets, V. (2020). Management mechanisms in the context of digitalization of all spheres of society. *Revista San Gregorio*, 42. <http://revista.sangregorio.edu.ec/index.php/REVISTASANGREGORIO/issue/view/RSAN42/showToC>
- Pomaza-Ponomarenko, A., Kryvova, S., Hordieiev, A., Hanzhyuk, A., & Halunko, O. (2023). Innovative risk management: Identification, assessment and management of risks in the context of innovative project management. *Economic Affairs*, 68(4), 2263-2275. <https://doi.org/10.46852/0424-2513.4.2023.34>
- Pomaza-Ponomarenko, A., Nazarov, O., Udyanskyi, M., Moroz, S., Khmyrov, I., & Akhmedova, O. (2021). Methodical approaches to state policy forecasting of sustainable development of Ukraine's regions. *Financial and Credit Activities: Problems of Theory and Practice*, 1(36), 171-178.

- Popkova, E. G., De Bernardi, P., Tyurina, Y. G., & Sergi, B. S. (2022). A theory of digital technology advancement to address the grand challenges of sustainable development. *Technology in Society*, 68, Article 101831. <https://doi.org/10.1016/j.techsoc.2021.101831>
- Prieto-Egido, I., Sanchez-Chaparro, T., & Urquijo-Reguera, J. (2023). Impacts of information and communication technologies on the SDGs: The case of Mayu Telecomunicaciones in rural areas of Peru. *Information Technology for Development*, 29(1), 103-127. <https://doi.org/10.1080/02681102.2022.2073581>
- Saqib, N., Mahmood, H., Murshed, M., Duran, I. A., & Douissa, I. B. (2023). Harnessing digital solutions for sustainable development: A quantile-based framework for designing an SDG framework for green transition. *Environmental Science and Pollution Research*, 30(51), 110851-110868. <https://doi.org/10.1007/s11356-023-30066-x>
- Singh, S., & Ru, J. (2023). Goals of sustainable infrastructure, industry, and innovation: A review and future agenda for research. *Environmental Science and Pollution Research*, 30(11), 28446-28458. <https://doi.org/10.1007/s11356-023-25281-5>
- Sinha, S., Mazwane, S., Makhura, M. N., & du Toit, A. (2024). Sustainable Development Goal 9: Industry, innovation and infrastructure. In *Handbook on Public Policy and Food Security* (pp. 223-233). Edward Elgar Publishing. <https://doi.org/10.4337/9781839105449.00027>
- Varriale, V., Cammarano, A., Michelino, F., & Caputo, M. (2024). The role of digital technologies in production systems for achieving sustainable development goals. *Sustainable Production and Consumption*, 47, 87-104. <https://doi.org/10.1016/j.spc.2024.03.035>
- Vyas-Doorgapersad, S. (2022). The use of digitalization (ICTs) in achieving sustainable development goals. *Global Journal of Emerging Market Economies*, 14(2), 265-278. <https://doi.org/10.1177/09749101211067295>
- Wang, Q., Zhang, F., & Li, R. (2025). Artificial intelligence and sustainable development during urbanization: Perspectives on AI R&D innovation, AI infrastructure, and AI market advantage. *Sustainable Development*, 33(1), 1136-1156. <https://doi.org/10.1002/sd.3150>