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DIGITAL SUPPORT FOR SUSTAINABLE DEVELOPMENT OF THE ARCTIC ZONE

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Abstract. Development of the Arctic zone, known for its ecological significance and economic potential, faces a number of challenges: inaccessibility of territories, difficult climatic conditions, low population density, the growing threat of climate change, insufficient development of certain technologies, etc. In response to this, it becomes imperative to give priority attention sustainable development strategies that balance economic growth, social policy with environmental conservation. The article examines the views of various researchers on the transformative role of digital technologies in achieving these goals. The purpose of the study is to show the prospects for sustainable development of the Arctic zone and the potential for its digital support. The article discusses various aspects of digitalization of the Arctic. The article reviews the literature on the use of digital technologies to ensure sustainable development of the Arctic zone, identifies key aspects on which various researchers focus, and also provides a list of factors for the sustainable development of the Arctic zone, the effect of which can be "strengthened" by the use of digital technologies.

Keywords: digital support, sustainable development, Arctic, innovations, digital platform

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ЦИФРОВАЯ ПОДДЕРЖКА УСТОЙЧИВОГО РАЗВИТИЯ АРКТИЧЕСКОЙ ЗОНЫ

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Аннотация. Освоение Арктической зоны, известной своей экологической значимостью и экономическим потенциалом, сталкивается с рядом вызовов: труднодоступность территорий, сложность климатических условий, низкая плотность населения, растущая угроза изменения климата, недостаточный уровень развития отдельных технологий и др. В ответ на это становится обязательным уделять приоритетное внимание стратегиям устойчивого развития, которые уравновешивают экономический рост, социальную политику с сохранением окружающей среды. В статье рассматривается взгляд различных исследователей на преобразующую роль цифровых технологий в достижении этих целей. Цель исследования – показать перспективы устойчивого развития Арктической зоны и потенциал её цифрового обеспечения. В статье рассмотрены различные аспекты цифровизации Арктики. В статье проведён обзор литературы по проблематике применения цифровых технологий для обеспечения устойчивого развития Арктической зоны, выявлены ключевые аспекты, на которых фокусируются различные исследователи, а также приведён перечень факторов устойчивого развития Арктической зоны, действие которых может быть «усилено» использованием цифровых технологий.

Ключевые слова: цифровая поддержка, устойчивое развитие, Арктика, инновации, цифровая платформа

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Introduction

The Arctic zone is a region of immense ecological importance and economic potential. As the effects of climate change continue to impact this vulnerable area, it is crucial to prioritize sustainable development strategies that minimize environmental harm while fostering economic growth. In the era of digital transformation, there lies a unique opportunity to leverage technology as a vital tool for achieving these goals. This article explores the concept of digital support for the sustainable development of the Arctic zone, highlighting the various ways in which digital solutions can contribute to preserving the fragile Arctic ecosystem, empowering local communities, and facilitating responsible economic activities. By understanding the power of digitalization in the context of Arctic development, we can unlock a new era of balanced progress in this vital corner of our planet. In this context, digital technologies emerge as powerful

tools offering innovative solutions for sustainable growth in the Arctic.

Materials and Methods

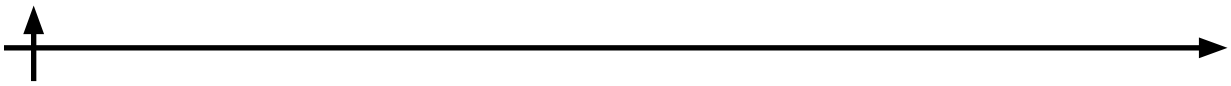
To comprehensively investigate the multifaceted relationship between digital transformation and sustainable development in the Arctic Zone of Russia, this study follows a methodological framework structured around literature review and synthesis. Literature review was conducted, spanning the years 2019 to 2023, to capture the evolving landscape of research in the field. The literature bases as Web of Science and Google Scholar were used during the research. The articles were mainly written by Russian scientists and research is also made by Swedish, some article mention the development of China and British robots which help to explore the Arctic. Based on the analysis of the literature, aspects of considering the digital transformation of the Arctic zone of the Russian Federation were highlighted. Based on a generalization of aspects, factors for sustainable development of the Arctic related to the capabilities of digital technologies were identified

"Technological Innovations for a Sustainable Arctic" by Jong Deog Kim, Sungwoo Lee, Minsu Kim, and Jeehye Kim (Kim, 2020) discusses the challenges and opportunities presented by the melting of Arctic ice due to climate change. The authors highlight the potential of the fourth industrial revolution to address these challenges, suggesting the use of innovative technologies to improve environmental monitoring, biodiversity management, and the development of sustainable ports and infrastructure. They also emphasize the need for international cooperation and scientific research to effectively address the risks and challenges posed by climate change in the Arctic. Overall, the article highlights the potential role of technology in promoting sustainable development in the Arctic zone and the importance of addressing the unique challenges faced by this region.

To reduce the gap in innovative technologies in the Arctic, policy initiatives and international co-operation are necessary. Investment in R&D relating to innovative technologies can have a socio-economic ripple effect through the industrial network, including the environment-resource-infrastructure-shipping-logistics network. Technological exchange and co-operation, including joint research with other technologically advanced countries, should also be considered. South Korea, as the most innovative country according to the World Economic Forum, has potential to contribute to sustainable and responsible development in the Arctic. However, a more comprehensive analysis is needed to arrive at a more accurate picture of the role and importance of technologies across applicable areas and types. The Covid-19 pandemic is further isolating the Arctic region, but also accelerating the development of "un-tact" technologies. Winterization of innovative technologies will be necessary in the Arctic. Differences in approach among Arctic states with regard to their policies, investments, and existing uses of innovative technologies exist, but co-operative initiatives are necessary to safeguard the Arctic region from the adverse impacts of global warming.

Some people are trying to understand climate change through a digital twin of some area. PolArctic, an Alaskan startup, is developing a digital twin of the Arctic Ocean to tackle challenges posed by climate change, with the aim of managing Arctic fish stocks more effectively (Stepanova, 2020). Climate change is affecting the Arctic significantly, leading to the disappearance of summer sea ice and affecting local species such as the snow crab. This digital twin will be the first virtual model to forecast the impact of climate change on Arctic fisheries, aiming to make the fishing industry more efficient and sustainable.

Leveraging AI and ML, PolArctic plans to integrate various types of data, including indigenous knowledge and scientific research, to create this comprehensive digital twin. This simulated ocean environment will help in understanding the complex dynamics of ocean ecosystems,



thus supporting the commercial fishing sector and potentially benefiting other sectors as argued by Mads Qvist Frederiksen of the Arctic Economic Council.

The initiative is expected to help the fishing industry by optimizing fishery output, setting accurate catch limits, and helping with the navigation of vessels through dynamic protected areas that take species biomass and climate change into account. PolArctic's unique approach combines multiscale data utilizing advanced algorithms and traditional insight from local indigenous populations, an integration that CEO Leslie Canavera points out as key to the project's success.

The digital model will simulate real-world oceanic conditions such as acidification and temperature changes, and it will also address issues like illegal fishing and intricate predator-prey relationships. This allows for precision-fishing practices that enhance profitability while promoting sustainable fishing practices.

The digital twin model extends its potential benefits beyond the fishing industry to shipping, climate research, and defense sectors. The increased model accuracy can aid the shipping industry by predicting navigational challenges like sea ice, potentially leading to safer routes and lower insurance costs. For defense purposes, the model can assist in identifying trends in illegal fishing, aiding Coast Guard missions. Furthermore, the model will support local Arctic communities by aiding subsistence activities and ensuring food security, while also providing valuable data for climate research, particularly for the High Seas Fisheries Agreement in the Central Arctic Ocean.

The article "The Potential of Digital Platforms for Sustainable Development Using the Example of the Arctic Digital Platform 2035" (Samylovskaya, 2022) unpacks the potential of digital platforms to revolutionize the economy, streamline public administration, and expedite societal transformations. Notable examples include business platforms like Uber and education platforms like Uchi.ru, promoting efficiency and accessibility. The paper underscores the state's pivotal role in fostering an environment conducive to digital platform success and regulating actions to safeguard user interests.

From a public administration perspective, digital platforms as depicted by Baranov and Glazkov, are systems of algorithmic relationships supported by a single digital technology application. Platforms like GovWeb illustrate the trend toward a unified digital government ecosystem, providing user-friendly, accessible online services.

Special attention is given to the "Arctic Digital Platform 2035," developed to garner ideas for the strategic sustainable development of the Arctic zone in Russia. This platform exemplifies how digital tools can gather public input, structure it meaningfully, and drive regional development policies by involving citizens, experts, and government in a participatory dialogue.

In conclusion, the paper posits that while digital platforms enable a comprehensive approach to sustainable development, they are not without risks, particularly concerning cybersecurity and data protection. A careful balance of innovation and regulation is deemed essential for safeguarding personal data and ensuring the overall success of digital platforms as tools for sustainable progress.

The paper (Fadeev, 2023) analyzes the integration of digital technologies into the oil and gas mining industry of the Russian Arctic, addressing the current state and foreseeable future trends in the sector. The authors examine global digitalization trends and the experiences of Russian companies, focusing on the implications for the Arctic region. Several trends and prospects are identified, underlining the significance of digital technologies in enhancing business process management and dealing with challenges like severe climatic conditions, cybersecurity threats, and the sensitivity to foreign technological reliance. The abstract suggests that digitalization in the Arctic oil and gas sector is primarily driven by the need to increase enterprise management efficiency. The introduction of digital measures is seen as a response to the necessity for

improved operational optimization, especially in the harsh and remote conditions of the Russian Arctic. The paper outlines that while companies like Gazprom Neft PJSC are leaders in digital innovation, the sector's overall digital transformation is hampered by a lack of qualified personnel, insufficient material and technical foundations, and growing cyber-security threats. Key concerns include the potential impact of sanctions, which could either spur on domestic software innovation or hinder Arctic project development through increased operational costs. Furthermore, the COVID-19 pandemic has emerged as a catalyst for adopting more automated digital methodologies in production and business processes. It also highlights specific "sensitivity parameters" affecting digitalization in the industry, particularly the reliance on foreign technology and cybersecurity issues. Power outages in the Arctic pose a fundamental technological risk, necessitating a reliable, adaptive power supply capable of supporting the digital infrastructure (Lyevkina, 2018).

Lastly, the paper postulates that while renewable energy sources (RES) are set to play a more significant role in the Arctic regions, the oil and gas sector—bolstered by digital technologies—will dominate the energy market for the foreseeable future. Despite the progress, digital transformation in the sector remains complex, with virtual and augmented reality, Internet of Things, and AI being integral yet underutilized technologies due to the challenges in operational integration.

Future research, as outlined in the paper, aims to delve deeper into understanding the digitalization nuances of Russian Arctic oil and gas projects, especially considering international sanctions and to conduct a wider survey among industry professionals. In summary, the paper underscores the importance and complexities of digital technology implementation in the development of oil and gas resources in the Russian Arctic, with particular emphasis on the socio-economic, technological, and security challenges inherent in this transformative process.

This article outlines the development and application of artificial intelligence (AI) and robotics in the Arctic region of the Russian Federation, emphasizing the strategic importance of this area for Russia's economy and geopolitical stance. The text reveals an ambitious approach aimed at leveraging AI and robotics to overcome the challenges associated with the harsh Arctic conditions, and it identifies multiple areas where these technologies could have a significant impact.

The document establishes the context based on two pivotal strategies—the State Policy of the Russian Federation in the Arctic until 2035 and the Strategy for the Development of Artificial Intelligence in the Russian Federation until 2030. These strategic frameworks underscore the intent of the Russian government to harness the potential of AI and robotics to further exploit the Arctic's rich mineral resources while mitigating environmental impacts and dealing with extreme local conditions.

AI's role in the Arctic is multifaceted, spanning mining, safety, medical care, transportation, construction, energy, historical preservation, environmental monitoring, and even tourism. Notable applications include intelligent automated process control systems to address gas production complexities and the development of robotic systems for search and rescue operations. The document also discusses medical care improvements through telemedicine, which is critical for remote Arctic communities.

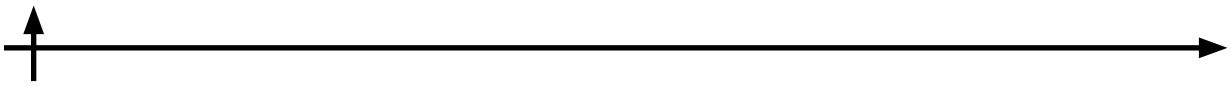
In detailing the progression of AI and robotics in the Arctic, several initiatives are highlighted:

– Oceanos marine robots for environmental monitoring.

– The "Iceberg" project, aiming to develop technologies for underwater exploration of minerals.

– Robotic underwater and surface vehicles with adjustable hull geometry for versatility in research and logistical applications.

– Chinese development of an autonomous deep-sea robot, Tan'so 4500, suitable for Arctic



research.

– IceNet, a new AI tool for sea ice prediction from the British Antarctic Survey and the Alan Turing Institute.

The document concludes by acknowledging Russia's significant potential and current progress in integrating AI and robotics into its Arctic strategy. Despite recognized advancements by Western and other international counterparts, Russia's initiatives show promise, although full-scale implementation may take longer due to socio-economic and policy-development hurdles across the nation. The piece underscores the competitiveness and environmental concerns within the Arctic region. As various Arctic nations intensify their efforts to harness the region's resources, international agreements such as the Reykjavik Declaration are crucial for enhanced biodiversity conservation and environmental management.

The development of offshore hydrocarbon fields in the Arctic is a crucial strategic objective for the Russian Federation (Andreychuk, 2022). Addressing this task requires a unified effort across all levels of government. The extraction of Arctic resources not only enhances the state's resource base, providing a competitive edge, but also fuels key industries, generates employment, expands the tax base, stimulates scientific advancements, and positively impacts the demographic situation by attracting skilled professionals to Arctic regions.

Current foreign economic and political challenges serve as a catalyst for reducing import dependence, enabling the Russian Federation to pursue an independent technology policy. This policy advocates collaborative efforts involving the state, energy companies, science, and industry. Furthermore, the authors underscore the significance of developing the Russian system of standardization in the energy sector. This initiative is viewed as a direct and effective means for import substitution, aiming to swiftly achieve technological sovereignty within the Russian oil and gas complex.

The article "Digital technologies and ILK in the Arctic: in search of epistemological pluralism" by Samuel Roturier and Rйmi Beau covers various aspects concerned with the intersection between digital technologies and Indigenous and Local Knowledge (ILK) within the context of the Arctic, specifically looking at the Sбmi reindeer husbandry in Sweden.

The article explores the implications of digital technology adoption in Indigenous contexts and how these technologies interact with traditional knowledge systems. The authors raise concerns about whether the integration of digital tools might undermine the value of ILK by promoting a Westernized worldview and oversimplifying complex Indigenous knowledge into quantitative data that can be understood and manipulated within Western scientific frameworks.

The text acknowledges the benefits of digital tools, such as saving time and providing new means for ecological management and advocacy. However, it critically examines the potential loss of in-depth, sensory, and experiential learning traditionally acquired through physical engagement with the environment (Kudryashov, 2020).

Roturier and Beau tackle the ethical considerations for researchers working with Indigenous communities and digital technologies, emphasizing that technology should be employed responsibly and with awareness of its potential to alter Indigenous ways of life. The authors propose two ethical frameworks: co-construction, which suggests collaborative development of technologies with Indigenous communities; and strong epistemological pluralism, defending the coexistence of diverse knowledge systems without necessarily merging them.

The article underscores the potential intellectual self-determination issues raised by digital technology adoption, arguing that true empowerment of Indigenous communities would involve the creation and use of digital tools that are defined, controlled, and understood from an Indigenous perspective rather than being imposed from outside.

Overall, the article appeals for greater sensitivity to cultural nuances, the risks of knowledge

monopolization by digital means, and the political dimensions of technology implementation in Indigenous settings. It prompts an inclusive dialogue that respects the integrity and validity of Indigenous knowledge systems alongside scientific inquiry, aiming for an ethical and pluralistic approach to environmental stewardship and technological advancement.

This article by Timur Ablyazov and Veronika Asaul focuses on improving the Arctic's transport infrastructure within the framework of the digital economy, specifically by incorporating smart city concepts in Arctic cities. Smart cities are defined as urban areas where infrastructure and services are interlinked through information and communication technologies to improve efficiency, optimize resources, and enhance the quality of life for residents.

The Arctic is emphasized as a strategic region for Russia due to the Northern Sea Route, which offers a shorter corridor between the Far East and Europe compared to southern maritime paths. Despite challenges including harsh climatic conditions, the digitalization of transport infrastructure in the Arctic region is presented as a necessity for enhancing accessibility, boosting international trade, and promoting development.

The authors propose the development of digital platforms to facilitate interaction among transport entities and accumulate data for analyzing and predicting the current and future states of the transport ecosystem. The goal is to harmonize sea, rail, road, and air transport, leading to optimized routes, improved transport safety, and coordination of infrastructure maintenance activities.

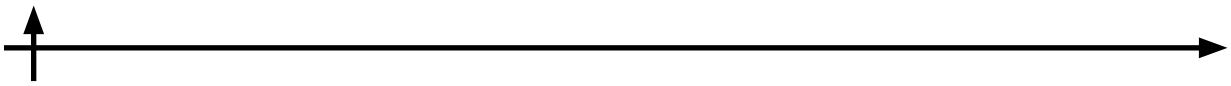
Examples from Anchorage (USA) and Bodш (Norway) demonstrate how Arctic cities are progressively incorporating smart technologies to improve their transport systems. In Russia, the authors point out the significance of maritime transport, particularly the Northern Sea Route, and the importance of port cities like Murmansk and Sabetta. Innovative projects such as the "Yamal LNG" and the "Integrated Development of the Murmansk Transport Hub" highlight the Russian government's commitment to developing the Arctic's infrastructure (Kikkas, 2023).

The authors suggest implementing smart city elements through digital platforms in the Arctic's largest cities as a starting point for improving logistics services, eventually aiming to extend these platforms for full-scale smart city development. These suggestions align with Russia's "Strategy for the Development of the Arctic Zone of the Russian Federation and Assurance of National Security for the period up to 2035," which prioritizes transport infrastructure improvement.

The article highlights the implementation of information and communication infrastructure as a crucial step in the Arctic's development, pointing towards ongoing projects like the Arctic Connect communication line and the digital platform "Arctic Labs" as vital initiatives towards this goal. The authors conclude that developing the Arctic transport infrastructure following smart city concepts is important to create a comfortable and safe living environment in the digital economy.

The article proposes leveraging digital economy concepts to transform Arctic cities into smart cities, improving efficiency and quality of life. Improvement of transport infrastructure in the Arctic is associated with enhancing regional accessibility and international trade capabilities. There is a particular focus on developing digital platforms enabling coordination across various forms of transport in the Arctic. Development of comprehensive communication infrastructure is integral to facilitating the spread of smart city principles in the Arctic region. Ongoing initiatives and projects reflect a significant effort towards incorporating smart technology in the Arctic's evolution, aligning with Russia's Arctic development strategy up to 2035.

The Arctic zone of Russia’s transport support data analysis suggests key proposals for infrastructure development (Abramov, 2019). These include prioritizing eco-friendly pipeline transport with advanced safety measures and constructing new trunk pipelines. The plan involves



calculating and adjusting for high-power icebreaker construction, determining optimal public-private partnership parameters, and formulating a program for modern vessels. Additional focus areas encompass the modernization of railways, creation of all-terrain vehicles, resolution of road departmental affiliation issues, building Arctic helicopters, and analyzing alternative transport modes. Finally, a comprehensive approach involves developing air traffic, calculating aircraft parameters, and reconstructing and constructing airports in the region.

The authors (Didenko, 2021) explore the adaptation of the "smart city" concept to the Arctic Zone of the Russian Federation (AZRF), acknowledging the unique challenges of the region, including extremely low population density, harsh climatic conditions, and a focus on industrial development. It suggests that "smart" technologies could provide innovative solutions tailored to Arctic settlements, and could help in sustainable development, improving living conditions, and managing the area's natural resources more effectively.

The paper emphasizes the growing interest in employing advanced Information and Communication Technologies, robotics, and intelligent solutions in developing "smart city" projects and addressing the peculiarities of the Arctic region through these technologies. It outlines how smart cities have evolved in response to challenges such as rapid population growth, limited resources, and environmental sustainability concerns. The successful implementation of "smart" features in European cities (e.g., Barcelona, Amsterdam) is also discussed. The paper proposes the application of smart city technologies—not just in metropolitan areas but across the diverse settlement network of the Arctic. This includes the potential use of technologies such as IoT, WSNs, cloud computing, fog computing, big data analytics, and unmanned transport vehicles (UTVs), including Unmanned Aerial Vehicle (UAVs).

The concept of a digital real-world virtual cyberspace is introduced, which is a self-organizing distributed computer network embedded with multifunctional UAVs. This system could assist in various logistical and computational tasks, helping in managing the Arctic zone's development more effectively. The paper delves into understanding the physical, informational, and social dimensions of cyberspace in the Arctic (Rodionov, 2023). This includes the technological infrastructure, nodes and hubs for communication, institutional organization, and electronic spaces for social interaction.

In conclusion, the authors argue for the application of smart settlement concepts as a path towards sustainable development. They envision a comprehensive and interconnected digital environment that leverages ICT and smart technologies to facilitate the management and development of the Arctic region. This approach could not only preserve the environment but also improve the quality of life and economic prospects of those living and working in one of the most challenging environments on Earth.

Results and Discussion

Based on the literature review the table below (Table 1) was made. It shows the review of different aspects and authors point of view and (or) advice regarding it.

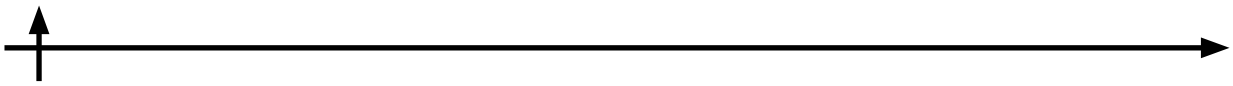
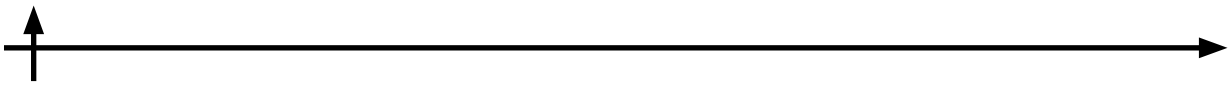


Table 1. Key sources review

Aspect	Authors' Point or Advice and Source (Article)
Melting of Arctic ice due to climate change	Discusses challenges and opportunities presented by melting Arctic ice (Kim, 2020).
Fourth industrial revolution in the Arctic	Suggests using innovative technologies for environmental monitoring, biodiversity management, and sustainable infrastructure (Kim, 2020).
Role of international cooperation in addressing climate change in the Arctic	Emphasizes the need for international cooperation and scientific research to address risks and challenges in the Arctic (Kim, 2020).
Digital twin of the Arctic Ocean by PolArctic	Developing a digital twin of the Arctic Ocean to address climate change challenges, focusing on managing Arctic fish stocks efficiently (Stepanova, 2020).
Integration of AI and ML in PolArctic's digital twin	Plans to integrate various types of data, including indigenous knowledge and scientific research, to create a comprehensive digital twin (Stepanova, 2020).
Benefits of PolArctic's digital twin for fishing industry	Optimizing fishery output, setting accurate catch limits, and navigating vessels through dynamic protected areas for sustainable practices (Stepanova, 2020).
PolArctic's approach to combining data and insights	Combines multiscale data using advanced algorithms and traditional insight from local indigenous populations for project success (Stepanova, 2020).
Other/Extended benefits of PolArctic's digital twin	Extends benefits beyond the fishing industry to shipping, climate research, and defense sectors, aiding in navigation, defense missions, community support, and climate research (Stepanova, 2020).
Potential of digital platforms for sustainable development	Unpacks the potential of digital platforms to revolutionize the economy, streamline public administration, and expedite societal transformations (Samylovskaya, 2022).
Digital platforms as systems of algorithmic relationships	Describes digital platforms as systems of algorithmic relationships supported by a single digital technology application (Samylovskaya, 2022).
"Arctic Digital Platform 2035"	Highlights the Arctic Digital Platform 2035 as an example of how digital tools can gather public input, structure it meaningfully, and drive regional development policies through participatory dialogue (Samylovskaya, 2022).
Risks associated with digital platforms	Points out risks, especially concerning cybersecurity and data protection, and emphasizes the need for a balance of innovation and regulation (Samylovskaya, 2022).
Addresses current state and future trends	Analyzes the integration of digital technologies into the oil and gas mining industry of the Russian Arctic (Fadeev, 2023).
Highlights challenges	Challenges: severe climatic conditions, cybersecurity threats, and reliance on foreign technology (Fadeev, 2023).
Emphasizes digitalization's importance for business process management.	Discusses the role of digital measures in operational optimization, especially in harsh Arctic conditions (Fadeev, 2023).
Sensitivity parameters	Identifies "sensitivity parameters" affecting digitalization, including reliance on foreign technology and cybersecurity (Fadeev, 2023).
Reliable power supply	Acknowledges the significance of a reliable power supply in the Arctic (Fadeev, 2023).
Support of digital technologies	Postulates that the oil and gas sector, supported by digital technologies, will dominate the energy market in the Arctic despite the rise of renewable energy sources (Fadeev, 2023).
Challenges in the operational integration	Discusses challenges in the operational integration of virtual and augmented reality, Internet of Things, and AI (Fadeev, 2023).
Outlines the development and application of AI and robotics in the Arctic region of the Russian Federation	Emphasizes the strategic importance of the Arctic for Russia's economy and geopolitical stance. Discusses the ambitious approach to leverage AI and robotics to overcome challenges in the harsh Arctic conditions (Andreychuk, 2022).
Highlights multiple areas where AI and robotics could have a significant impact	Describes AI's multifaceted role in mining, safety, medical care, transportation, construction, energy, historical preservation, environmental monitoring, and tourism (Andreychuk, 2022).



The idea to use blockchain and big data technologies	To analyze Arctic and find ways to explore its full potential (George, 2021).
Digital technologies in the Arctic	The article explores the implications of digital technology adoption in Indigenous contexts, particularly in Sбmi reindeer husbandry in Sweden (Roturier, 2021).
Interaction with Indigenous and Local Knowledge	Raises concerns about potential negative impacts on ILK, such as the promotion of a Westernized worldview and oversimplification of complex Indigenous knowledge into quantitative data (Roturier, 2021).
Benefits of digital tools	Acknowledges benefits like time-saving and providing new means for ecological management and advocacy (Roturier, 2021).
Critique of digital tools	Critically examines the potential loss of in-depth, sensory, and experiential learning traditionally acquired through physical engagement with the environment (Roturier, 2021).
Indigenous Knowledge	The authors highlight the risk of digital tools undermining the value of ILK by reducing it to quantitative data that fits within Western scientific frameworks. They emphasize the importance of preserving in-depth, experiential learning gained through physical engagement with the environment (Roturier, 2021).
Ethical Considerations	Roturier and Beau stress the ethical responsibility of researchers when working with Indigenous communities and digital technologies. They propose ethical frameworks like co-construction and strong epistemological pluralism to ensure collaborative development and respect for diverse knowledge systems (Roturier, 2021).
Intellectual Empowerment	The article discusses the importance of intellectual self-determination for Indigenous communities in adopting digital technologies. It advocates for tools that are defined and controlled from an Indigenous perspective to empower communities rather than impose external influences (Roturier, 2021).
Cultural Sensitivity	The authors call for greater sensitivity to cultural nuances, risks of knowledge monopolization through digital means, and political dimensions of technology implementation in Indigenous settings. They advocate for inclusive dialogue that respects Indigenous knowledge systems alongside scientific inquiry for ethical environmental stewardship and technological progress (Roturier, 2021).
Pipeline Transport Development	Prioritize the development of eco-friendly pipeline transport with advanced safety technologies. Construct new trunk pipelines to sea terminals, incorporating means to detect, localize, and eliminate pipeline accidents efficiently (Ablyazov, 2021).
High-Power Icebreakers	Calculate and adjust plans for the construction of a new generation of high-power icebreakers to meet the region's specific needs and challenges (Ablyazov, 2021).
Public-Private Partnership Parameters	Determine optimal parameters for public-private partnerships in the construction of transport infrastructure and vehicles, emphasizing effective collaboration for sustainable development (Ablyazov, 2021).
Modern Vessels and Icebreakers	Formulate a comprehensive program for the construction of modern supply vessels, Arctic container ships, and multifunctional nuclear and diesel-electric icebreakers. Aim to equip vessels with dynamic positioning systems (Ablyazov, 2021).
Railway Modernization	Prioritize the modernization and new construction of railway sections, focusing on transport corridors, meridian railways, and connections between resource regions and oil production zones with industrial areas in the Urals (Ablyazov, 2021).
Creation of All-Terrain Vehicles	Emphasize the creation of all-terrain vehicles to enhance transportation capabilities in challenging Arctic terrains (Ablyazov, 2021).
Transport Infrastructure	The authors highlight the necessity of digitalizing transport infrastructure in the Arctic to overcome challenges posed by harsh climatic conditions and enhance accessibility. They advocate for the development of digital platforms to facilitate coordination among different transport modes, optimize routes, improve safety, and streamline infrastructure maintenance activities (Abramov, 2019).
Case Studies	Examples from cities like Anchorage, Воднш, Murmansk, and Sabetta illustrate the gradual integration of smart technologies in Arctic transport systems. Projects such as "Yamal LNG" and the "Integrated Development of the Murmansk Transport Hub" showcase Russia's commitment to enhancing Arctic infrastructure (Abramov, 2019).

Digital Economy	The article underscores the role of information and communication infrastructure in driving the Arctic's development, citing initiatives like the Arctic Connect communication line and "Arctic Labs" digital platform as key steps towards implementing smart city principles. It aligns with Russia's strategic vision for Arctic development up to 2035 (Abramov, 2019).
Future Prospects	The authors propose expanding smart city elements in Arctic cities to enhance logistics services and ultimately achieve full-scale smart city development. They argue that leveraging digital economy concepts is essential for creating a comfortable and safe living environment in the Arctic region (Abramov, 2019).
Smart City Concepts	The authors define smart cities as urban areas where information and communication technologies interconnect infrastructure and services to optimize resources, enhance efficiency, and improve residents' quality of life. They propose applying these concepts to Arctic cities to modernize transport systems and promote development (Abramov, 2019).
Smart City Concepts	The paper defines smart cities as urban areas that utilize advanced ICT, robotics, and intelligent solutions to address challenges and improve living conditions. It emphasizes the relevance of smart technologies in Arctic settlements due to their specific needs and conditions (Didenko, 2021).
Technology Integration	The authors discuss the evolution of smart cities in response to population growth, resource limitations, and environmental concerns, citing successful examples from European cities like Barcelona and Amsterdam. They propose integrating technologies such as IoT, WSNs, cloud computing, big data analytics, and unmanned transport vehicles (UTVs) in Arctic settlements to enhance efficiency and connectivity (Didenko, 2021).
Digital Real-World Virtual Cyberspace	The concept of a self-organizing distributed computer network embedded with multifunctional UAVs is introduced as a tool for managing logistical and computational tasks in the Arctic zone. The paper explores the physical, informational, and social dimensions of cyberspace in the Arctic, emphasizing its role in facilitating development and communication (Didenko, 2021).

Before talking about digital support for sustainable development of the Arctic, it is important to understand what factors of sustainable development in the Arctic exist in general. Figure 1 shows the factors of sustainable development in Arctic.

Fig. 1. Features of sustainable development of the Arctic region

Digital technologies are helping to solve grand challenges to slow down climate change and promote sustainable development (Berezikov, 2019). Diverse phenomenological lenses co-exist and offer unique perspectives on addressing climate change, sustainable development, and socioecological value creation. The road to a sustainable economy is hard, yet some scientists remain optimistic that some entrepreneurial ventures hold the potential to create impactful solutions.

The catalyzing role of digital transformation in localizing SDGs is highlighted in another paper that also examines how digital transformation can impact the localization and achievement of the Sustainable Development Goals (SDGs) (Arctic Economic Council; ElMassah, 2020). The integration of Big Data and e-government proves instrumental in effective SDG implementation, especially in regions with higher levels of decentralization which may be used in some areas of the Arctic. Digital solutions enable progress in technological advancements, offering a promising avenue for improving living standards globally.

Conclusion

In summary, the message is clear: Arctic is of immense importance to global ecology and the economy. While faced with challenges, there's a drive towards collaborative efforts to balance resource development with sustainability and safety, in which AI and robotics may play a pivotal role.

In conclusion, innovative technologies, particularly AI and digital twins, are pivotal in adapting to changing Arctic conditions. The case of PolArctic's digital twin model demonstrates a promising approach to optimizing fishery outputs and managing resources while simultaneously extending benefits to shipping, defense, and climate research. The digital platforms highlighted in the papers offer a blueprint for revolutionizing public administration and public engagement, fostering a more inclusive and efficient socioeconomic ecosystem in the Arctic.

As the digital landscape evolves, the importance of incorporating smart city concepts is evident to improve the logistics and quality of life for Arctic residents. The integration of digital technologies in the Arctic's oil and gas industry is being explored to enhance operational efficiency, despite challenges related to extreme weather and the heavy reliance on external technologies.

While there are concerns about cybersecurity, data protection, and the potential overreliance on foreign technologies, the articles advocate for international cooperation and robust policy initiatives that could catalyze the socio-economic development of the Arctic.

From AI and robotics in resource extraction to the push for smart infrastructure, there is a clear indication that technology could be a game-changer for the Arctic. However, its success hinges on striking a careful balance between innovation and the preservation of the Arctic's delicate ecosystems. Embracing smart settlement concepts may be the key to transforming the Arctic into an area of strategic significance while also securing a sustainable future for one of the planet's most pristine frontiers.

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