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A Sustainability Measurement Framework of Supply Chain Information Flow: The Case of Industry 4.0 Technology Implementation

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Abstract In the presented paper a methodology for evaluation the sustainability of supply chain information flow that allows to find the most sustainable Industry 4.0 technology for implementation in oil & gas industry is developed: it is constructed the tree of key criteria for measuring sustainability of supply chain information flow, the evaluation framework for quantitative measuring sustainability of supply chain information flow is proposed, the recommendations of Industry 4.0 technology implementation are formulated.

Keywords: sustainable supply chain information flow, Industry 4.0, multicriteria problem.

1. Introduction

In the theoretical perspective this study closes the need of developing theory of sustainable supply chain, additionally it solves the issue of lack in academic literature of empirical evidence and applicability of measurement framework that cover both dimensions, sustainability, and innovations while making managerial decision. More than 300 research works have been issued in the last 15 years on the theme of sustainable supply chains and only 36 research works conducted with quantitative models' application (Seuring, 2013). There has been only limited empirical research so far. The presented paper focuses on the sustainable dimension and conducting more empirical studies for future research in supply chain management. The practical motivation of the research can be supported by the following reflections. It is vital to cultivate the competence of arising problem of sustainable development in oil & gas companies due to their fundamental responsibility in driving a global economy, and Russian especially. For oil & gas companies, the requirements for sustainable standards are constantly growing, so it could be seen as a barrier to growth. However, improving financial flows in the supply chain can advance the operational potential of oil & gas companies, with Industry 4.0 technologies giving abundant possibility for developing the sustainability. Additionally, the modernization of informational technology provides efficient implementation of sustainable supply chain finance by bringing advanced facilities and simplifying oil & gas companies' sustainable initiatives. Consequently, new Industry 4.0 technologies such as Internet of things, Cloud Computing, Big Data, Analytics, Artificial Intelligence, 3D Printing, Augmented reality and Informational Modeling have a serious function in the sustainable development and impact of oil & gas companies in the global context. In this regard, oil & gas companies can enrich their sustainable competitiveness by implementing Industry 4.0 technologies for sustainable supply chain finance. The

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nearby paper provides recommendation for choosing sustainable options of Industry 4.0 technologies implementation by developing a sustainability measurement framework of supply chain information flow. This framework allows to make a managerial decision in the situation of extremely high level of uncertainty, as it based on a flexible interactive decision support system APIS (Aggregated Preference Indices System), that provide a solution to difficult problem of decision-making under uncertainty. While there have been efforts to develop sustainability measurement frameworks for supply chains, there is a research gap in terms of understanding the specific challenges and considerations related to the measurement of sustainability in the context of Industry 4.0 technology implementation. While there is a general understanding that Industry 4.0 technologies have the potential to improve supply chain sustainability, there is a lack of empirical evidence on their actual impact. Mainly, the practice of sustainable development implementation requires to select what sustainability criteria should be covered and which type of corporate initiative can meet this criterion. The academic researchers believe that whereas oil & gas companies are prepared to make decisions related to the Industry 4.0 technology implementation to optimize supply chain information flow, they are less acquainted with selecting more sustainable Industry 4.0 technology to satisfy ESG goals and criteria.

2. Modern Sustainability Concepts

2.1. Sustainable development

The first chapter dedicated to literature review can be seen as a solid foundation for understanding the current state of research, identifying gaps, and selecting appropriate evaluation criteria.

In 1987 the Brundtland Commission stated that "sustainable development is development that satisfies the needs of the present without compromising the needs of the future" (WCED, 1987). The concept of sustainability includes a time dimension and often related to the understanding of existence of threats in the long-term prospective. Consequently, the distribution of this concept faces the difficulty of recognizing it as important concern at the observer's present moment.

At the end of the XX century, it was risen the question of the lack of formal analysis of sustainability. A famous problem is that usual cost-benefit analysis discounts the future. Thus, it is biased in contradiction of rules aimed to deliver benefits in the very long run. For instance, the assessment of projects for the harmless removal of waste from a nuclear-powered factory. Another example is guidelines intended to the prevention of global climate change. Even though the benefits of both examples can be tangible in the range from fifty to a hundred years into the future, the costs are required today. In these circumstances, possible misunderstanding of the value of the present moment and future result perplexes investment decisions for great amount of organizations.

Required valuation of sustainability led to the challenge of the appropriate economic theory's development. Some researchers have assessed how people treat the long run (Cropper et al., 1994). Their discoveries conflict with the established discounted method. Society is revealed to treat the present and the future in dissimilar way, but the experiments confirm that the present and the future should be valued equally. Usually, it is necessary to discount the future, but the compromise between current and future moment washes out as the future is becoming closer. The relative load specified to two following phases in the future is inversely associated to their remoteness from present moment. In that situation it was risen a question of adding sense of human's sensitivity to time and integrating it into a criterion of optimality that can be used for a "sustainable cost-benefit analysis".

In the research it was mathematically approved that sustainable preferences bring optimal solutions which are different from those achieved by discounted optimization criteria (Chichilnisky, 1997). As a result, it may be concluded that discounted profit maximization and sustainability provide different value structures. The above-mentioned research presents two axioms seizing the idea of sustainable development and describes the welfare criterion. The axioms state that neither the current moment nor the future moment should be a dominant role in people's choices over time.

There are numerous methods of ensuring sustainability, with extremely distinctive effects for the participants of an organization or system. Some authors tried to offer the application of a sustainable production framework for evaluating the comparative performance of the environmental procedures and management activities, which is convenient for revising and refining sustainable and strategic development (Tseng et al., 2008). Sustainable development questions are mostly beyond a company's principal business; therefore, companies are dared to build new managerial and organizational competences to organize and go towards sustainable development. Furthermore, sustainable development focuses on the promotion of ethics and morals that are associated with the company's principles, and it includes educational activities about the conception of sustainable development and knowledge distribution among all interested participants, i.e., personnel, society, and official representatives. Additionally, other researchers proposed that a company's effectiveness, economic profits, and social corporate responsibility can be shaped by proactive sustainability (Delmas and Toffel, 2004). Sustainability is frequently substituted with the expression sustainable development, and it symbolises the supreme phase of sustainable development achievements and the persistent satisfaction of social needs aligned with the environment, the major ambition that is founded on the beliefs and principles of sustainable development performers. Sustainability is a potentially endless goal considered as a constant development without termination and it includes shifts that must be properly planed, implemented, and improved. In addition, sustainable development needs a competent and precise criteria measurement model.

Despite enlarged consideration of environmental, social, and governance (ESG) problems, remarkably limited number of firms are doing significant progress in ensuring their guarantees. Most companies are not incorporating ESG aspects into their core strategy and are poorly or unclear informing investors of the of such aspects' influence on corporate profits. Based on the published article (Kramer and Pfitzer, 2022), companies should complete 5 steps to include ESG strengths into the principal business models:

1. Detect the ESG problems substantial to the industry.
2. Consider ESG outcomes when ranking strategic, financial, and operational decisions.
3. Cooperate with all business' stakeholders.
4. Restructure administrative positions.
5. Communicate with shareholders and investors.

These 5 steps structure reflect the research methodology of this paper and will be used as basic approach for further improvement, creating evaluation tool for sustainable supply chain finance and making suitable customization for specific industry. The detailed overview of authors' approach to linking sustainability issues, finance and informational flow of supply chain and is provided in the following parts of the chapter.

Initially, it is necessary to refer to the International Sustainability Standards of ESG specialized to the industry, that would mostly touch the financial state or operational implementation of companies. It includes governance, sustainability, and societal criteria. For some industries, the relation between physical ESG problems and financial functioning is clear and easily recognizable. For instance, the revenues of any international oil and gas company apparently derive from its clients' use of fossil fuels, consequently linking its financial performance with amount of greenhouse gas emissions caused by their clients. It can be illustrated by UN Sustainable Development Goals and Indicator 9.4.1 especially, that is defined as carbon dioxide emissions produced per dollar of GDP and measure carbon intensity. The goal itself refers to improvement of infrastructure and retrofit industries to ensure its sustainability, with enlarged energy efficiency and better acceptance of environmentally safe technologies and industrial practices. It can be concluded based on the UN data that the place of Russia is characterized with approximately of 0.5 kg of CO2 emitted per dollar of GDP from the burning of fossil fuels (Our World in Data Team, 2023).

In other types of business, the connection between the social and environmental influence of a corporation's activities and profits can be identified in more sophisticated way. The maximum social and environmental effects of any business will be the consequence of major strategic decision rather than repeated but small advances in operational processes. However, today numerous well-established corporations' functions imply business models that were implemented many years ago, when forerunners usually disregarded social circumstances and the environment shaped by their industries. As best practice, it was proposed to abandon companies' small modification and enhancements in reporting, but in its place, detect innovative prospects and follow the way of clear communicating and convincing policy to form shared value (Kramer and Pfitzer, 2022).

2.2. Oil & Gas Industry's Strategic development

The current strategic development of the oil and gas industry is shaped by two key factors and trends. Firstly, the industry is facing increasing pressure to transition towards a lower-carbon future in response to global climate change concerns. Oil and gas companies are diversifying their portfolios and investing in renewable energy sources, such as wind and solar, as well as exploring opportunities in hydrogen and biofuels. They are also focusing on improving energy efficiency and reducing greenhouse gas emissions in their operations. Companies are adopting ESG frameworks and reporting standards to disclose their performance and demonstrate their commitment to sustainability. Investors and other stakeholders are placing greater emphasis on ESG factors in their investment decisions, driving the need for transparent reporting. Building and maintaining a strong social license to operate is critical for oil and gas companies. They are engaging with local communities, indigenous groups, governments, and other stakeholders to address concerns, promote social development, and ensure responsible resource extraction. This includes initiatives focused on local job creation, community investment, and sustainable development projects. Secondly, the industry is embracing digital technologies and data analytics to optimize operations, increase productivity, and reduce costs. This includes the adoption of advanced analytics, automation, robotics, and artificial intelligence to improve exploration and production efficiency, asset maintenance, and supply chain management. Digitalization also enhances safety and environmental performance through remote monitoring and predictive maintenance.

Overall, the oil and gas industry's strategic development are based on the energy transition, digital transformation, sustainability, stakeholder engagement, and ESG integration. In the following two parts of the work, the trends linked to the digital transformation and sustainability strategy will be addressed.

Sustainability strategy

The strategy can be defined as a combination of organised activities and choices to adjust the company to new circumstances, new prospects for obtaining competitive advantage and mitigating upcoming risks (Marinina et al., 2022). Formulating strategic alternatives means joining a company's current competitive strengths to its business goals in a consistent plan. Today Russian oil and gas companies are described with substantial assets exhaustion (Dmitrieva and Romasheva, 2020). Additionally, potential oil and gas deposits are discovered in the Arctic area and its elaboration is quite problematic due to local particularities. This demonstrates the requirement of an innovative method to the elaboration of the oil and gas potential of the Arctic in the sustainable way.

The authors (Dmitrieva and Romasheva, 2020) give the crucial aspects of Arctic development, explain the impact of innovations in sustainable development based on the research implying Innovation Policy Road mapping (IPRM) technique in accordance with Sustainable Development Goals. As it is known, approximately 12% of Russia's territory is situated outside the Arctic Circle (Gritsenko and Efimova, 2020) and around 12–15% of the country's gross domestic product is made in the Arctic area and it delivers roughly a quarter of exports. The increasing climate change has stimulated worldwide anticipations for a rising supply of northern valuable resources.

Innovations display a fundamental part while focusing on oil and gas industry's issues. The products of oil and gas industry's activity are vital to the progress and stable growth of society. Fossil fuels resource reduction and the difficulty of extraction settings demonstrates the significance of innovative technologies and the energy transformation for the future accessibility of resources. Besides financial concerns, it is indispensable to settle oil and gas industry's activity with ecological safety and to relieve the anxieties of residents. For instance, mining activities, still experiences immoral social representation because of tragic, merciless, and cruel past practices with enormous mortality, and extraordinary amount of pollution (Calas, 2017). Some academics believe that sustainability involves the equivalent contribution of economic, social, and environmental responsibility. Additionally, to accomplish environmental sustainability, utilisation of the planet's physical resources requires to be at a sustainable proportion. To realize economic sustainability, corporations and countries must use their resources professionally, cost-effectively, and conscientiously. Social sustainability approaches when some social organization accomplishes decent social welfare (Ucal and Xydis, 2020).

Furthermore, the subject of whether the consumption of unrenewable assets is sustainable or not differs on evidence and data that is unapproachable to present-day witnesses (Dobra et al., 2018). It might, nevertheless, be obtainable shortly thanks to forthcoming industrial innovations and high-tech improvements. In the perspective of the innovative improvement of the local heavy industry's organizations, it is compulsory to give notice to the current mining, oil & gas businesses and to strengthen the inviting of funds, the improving of tools, the engaging of highly competent employees (Ilinova and Dmitrieva, 2018). Researchers investigate the theme of innovations in the oil and gas industry (Stadler, 2011) and propose that an accessible innovation standard can simplify the procedure of reacting to certain industry risks as well as revise obstacles that disturb the innovation development in the oil industry.

The Russian oil and gas business have puzzling image as principal industry responsible for development of the national strategy and economy, but at the same time environmentally hostile and controversial. Many firms show a carelessness to respect the best worldwide environmental criteria and benchmarks for releasing of data about their environmental influence and effects. The research (Shvarts et al., 2016) studies prerequisites, details, and outcomes of the initial Russian environmental ranking in oil and gas industry based on three topics: environmental managing, environmental influence, and data' release/transparency. The assessment's scores prove that there is large differentiation among Russian oil and gas corporations in their stages of environmental obligations and transparency. Huge and well-established corporations with a primary attention on gas have been rated at the top. Privately managed, minor oil companies have the lowest rate, alongside with the subsidiary firms of main Russian and international conglomerates. Based on the results of the research (Shvarts et al., 2016) it was decided to focus on the best practices of one of the top-3 companies of the rating, Gazprom Group (The Group), as publicly traded at stock exchange company with the participation of the state and without presence of foreign shareholders.

Innovations' implementation strategy

The digital revolution has enormous potential to transform the Russian industry, which has traditionally been considered relatively conservative in adopting digital technologies. The set of modern tools, known as Industry 4.0 technologies, include innovative methods such as big data analysis, machine learning, machine vision, industrial Internet of Things, virtual reality, augmented reality, 3D modelling, 3D printing, and robotics. These technologies are already reshaping industries worldwide, and their full-scale integration into the global economy in the future have an impact on productivity and the labour market comparable to past industrial revolutions. For the global economy, the annual effect of Internet of Things implementation by 2025 could range from \$4 trillion to \$11 trillion USD (Manyika and Chui, 2015). An accurate assessment of the impact of elements of Industry 4.0 has not been conducted yet, but it is evident that they will enhance the positive impact of digitization on the industry. Companies that can use the key value creation by Industry 4.0 technologies will gain a sustainable competitive advantage and strengthen their positions both domestically and internationally. implementation of digital transformations in the industry is a strategic step for Russia, whose economy is closely linked to natural resources extraction, processing, and mechanical engineering. Currently, there are no clear leader countries in the implementation of Industry 4.0 technologies. The pioneers in adopting these technologies will have the opportunity to gain an advantage over competitors through the early- mover effect and even set standards for next-generation industry solutions on a global scale.

The implementation of the Industry 4.0 technologies requires enterprises to deploy industrial Internet of Things (IoT) on their production sites, integrating a complex of necessary software solutions, as well as adopting new types of equipment, e.g., 3D printing machines, automated drones. It was identified eight key value creation procedures resulting from the implementation of Industry 4.0 technologies in production: equipment operation & utilization optimization, productivity and occupational safety improvement, logistics optimization, product quality enhancement, demand forecasting improvement.

For capital-intensive industries such as oil and gas extraction and power generation, Industry 4.0 technologies give opportunities to significantly improved efficiency without radically transforming the business model. In more labour-intensive industries, the optimization potential lies in enhancing the efficiency of the production process through automation, the use of Industrial Internet of Things sensors, and advanced analytics. Substantial benefits from the implementation of digital technologies can be achieved in the manufacturing sector, given its high labour intensity and Russia's technological lag among leading countries. In the manufacturing industry, the efficiency gains can be realized across the entire value chain, including accelerating the development and market introduction of new products, synchronizing production and supply chains, and improving planning, manufacturing, quality control, and after-sales service. By modernizing the Russian machinery sector based on the principles of Industry 4.0, significant improvements in labour productivity can be achieved, reducing the gap with the developed countries.

Today, almost all worldwide oil and gas corporations are realising software and hardware building complex in manufacture practices (Samylovskaya et al., 2022). The enhanced creating of diverse data and the usage of intellectual tools are fundamental elements of quickening the development of optimal solutions in the scope of oil and gas exploration and operational processes. Contemporary logical structures deliver an automation of data gathering, loading, and managing, material processes description, prediction of hydrocarbon production and visualization of crucial factors for the planning and following implementation at all stages of organization (Vlasov and Mozhchil, 2018). Many manufacturing facilities have adopted only previous-generation technologies, such as computer-aided design and manufacturing systems, electronic document management, automation of managerial and accounting processes, supply chain planning and management. This indicates a significant potential for efficiency improvement. Managers have an opportunity to change their approach to decision-making with the implementation of modern Industry 4.0 technologies.

2.3. Supply Chain Informational Flow

Supply Chain Finance and Financial Supply Chain are related concepts but have distinct focuses in supply chain management area. Financial Supply Chain (FSC) is a concept that encompasses the entire financial ecosystem within a supply chain, including both the financial and non-financial activities. FSC goes beyond the management of working capital and financial transactions and incorporates broader financial processes, such as financial planning, budgeting, forecasting, and strategic decision-making.

Supply Chain Finance (SCF) refers to the financial activities and processes involved in managing the monetary aspects of a supply chain. It primarily focuses on optimizing working capital, cash flow, and financial relationships within the supply chain network. SCF involves various financial techniques and solutions that aim to improve liquidity and reduce financial risks for supply chain participants. The term Sustainable Supply Chain Finance was created by Business for Social Responsibility, an American society, in 2018. In general, Sustainable Supply Chain Finance can be described as SCF methods that funding financial operations and relations with sustainable approach for all stakeholders engaged in delivering Supply Chain commodities or services to the market. For instance, that sustainable approach implies stimulation of economic, green, and public benefits and moderation and mitigation of any corresponding damaging effects.

The theory of working capital management (Aminu and Zainudin, 2015) explores strategies for efficiently managing working capital along the supply chain, including inventory, accounts receivable, and accounts payable. It emphasizes the importance of balancing financial resources to support smooth operations and reduce costs. Regarding financial intermediation, supply chain finance theory recognizes the role of banks and other financial institutions, in facilitating financial transactions and providing liquidity to supply chain participants. It examines the different forms of financing, such as factoring, invoice discounting, and supply chain financing programs. Traditional theories (Allen and Santomero, 1998) of intermediation focus on two key factors: transaction costs and asymmetric information. These theories aim to explain how institutions that accept deposits or provide insurance policies help direct funds from savers to borrowers. However, over the past few decades, it was witnessed notable shifts in the financial landscape. Despite a decrease in transaction costs and asymmetric information, intermediation has increased. Moreover, the emergence of new markets, particularly financial futures, and options, is primarily driven by intermediaries rather than individual investors or companies. These changes pose a challenge to the traditional theories of intermediation.

Another part of theory of supply chain finance, risk management, addresses the identification, assessment, and mitigation of financial risks within the supply chain. It considers risks associated with supply chain disruptions, credit defaults, currency fluctuations, and other financial uncertainties. Additionally, supply chain finance theory emphasizes the importance of collaboration and cooperation among supply chain partners to optimize financial outcomes.

Modern supply chain finance theory also integrates considerations of sustainability and innovation. It explores how financial practices can support environmentally and socially responsible supply chains, as well as how innovations in financial technology (fintech) and data analytics can enhance financial decision-making and performance (Metters, 2019). Sustainability has become a critical consideration in supply chain finance theory. It emphasizes the need for environmentally and socially responsible practices throughout the supply chain. This includes reducing carbon emissions, minimizing waste generation, promoting ethical labor practices, and ensuring the responsible sourcing of materials. Sustainable supply chain finance aims to align financial decisions with these sustainability goals. For example, it may involve providing incentives or financing options to suppliers that meet certain environmental or social criteria.

Innovation also plays a vital role in modern supply chain finance theory. As supply chains become more complex and interconnected, innovation is crucial for achieving efficiency, resilience, and competitive advantage. Financial innovations, such as blockchain technology and smart contracts, can enhance transparency, traceability, and trust within supply chains. These innovations can streamline payment processes, improve inventory management, and enable real- time monitoring and risk assessment. By incorporating innovative financial solutions, supply chain finance theory seeks to optimize supply chain operations and drive value creation. Industry 4.0 technologies improve Supply Chain Finance adoption by digitalization of financial flows, involving its effect on sustainability. Consequently, the implementation of such technologies with a regard to Sustainable Supply Chain Finance ensures better Supply Chain's performance (Soni et al., 2022).

Another dimension of supply chain, information flow refers to the movement of data, information, and knowledge across the different entities and stages within a supply chain. It involves the sharing, exchange, and analysis of information to support various activities and decision-making processes throughout the supply chain. The information flow in a supply chain encompasses both internal and external communication. Internally, it involves the sharing of information between different functions or departments within an organization, such as procurement, production, inventory management, and logistics. Externally, it involves the exchange of information with external partners, including suppliers, manufacturers, distributors, retailers, and customers. Effective information flow within the supply chain enables better coordination, visibility, and responsiveness.

Sustainable supply chain information flow is closely linked with supply chain finance, as both aspects are essential for the effective management of a sustainable supply chain. Sustainable supply chain information flow means the competent and responsible exchange of data and knowledge throughout the entire supply chain with the aim of promoting environmental, social, and economic sustainability. In a sustainable supply chain, information flow plays a crucial role in enabling transparency, collaboration, and informed decision-making at every stage of the supply chain. It involves the collection, analysis, and dissemination of relevant data and information related to sustainability practices, such as carbon emissions, resource usage, labour conditions, and product life cycles. Gathering accurate and comprehensive data on sustainability metrics from suppliers, manufacturers, and other stakeholders within the supply chain. Providing visibility into the sustainability practices and performance of suppliers and products, allowing stakeholders to make informed choices and assess the environmental and social impact of their supply chain. Facilitating effective communication and collaboration among supply chain partners to share best practices, set sustainability goals, and jointly address challenges. Leveraging advanced technologies like blockchain, Internet of Things (IoT), and data analytics to enhance the accuracy, timeliness, and reliability of information exchange within the supply chain. Adopting and adhering to recognized sustainability standards and certifications to ensure consistency and credibility in sustainability reporting and information sharing.

To implement the most suitable for business's request Industry 4.0 technology from the sustainable supply chain finance perspective, a decision-maker must initially categorize the criteria that would guarantee sustainable supply chain finance. Despite the raising awareness of sustainability in finance and green investments' attractiveness among key players of global market (Deutsche Bank Group, 2020), the academic literature has not promoted sufficiently enough attention or debate to sustainable supply chain finance yet. Some researchers have lately offered up-to-date visions on sustainable supply chain finance and categorized criteria for assessing it.

The integration of sustainable supply chain information flow with supply chain finance can provide several advantages. Firstly, access to accurate and up-to-date sustainability information enables financial institutions and investors to assess the ESG risks associated with the supply chain. This information helps them make informed decisions regarding financing and investment, reducing the risk of potential sustainability-related troubles. Secondly, supply chain finance programs can be designed to incentivize sustainable practices. For example, suppliers with strong sustainability performance and transparent reporting may be eligible for preferential financing terms, lower interest rates, or extended payment terms. This encourages suppliers to adopt and improve their sustainability practices. Additionally, sustainable supply chain information flow enhances transparency and traceability, providing financial institutions and investors with visibility into the sustainability performance of suppliers and the entire supply chain. This transparency reduces information asymmetry, enhances due diligence, and facilitates risk assessment and evaluation for financial institutions providing supply chain finance. Finally, sustainable supply chain information flow facilitates accurate and credible sustainability reporting and compliance with regulations and standards. Financial institutions and investors can rely on this information to meet their own reporting requirements, satisfy regulatory obligations, and demonstrate their commitment to sustainable finance principles.

Overall, integrating sustainable supply chain information flow with supply chain finance strengthens the connection between sustainability and financial decision-making. It promotes responsible investment, risk mitigation, improved collaboration, and ultimately contributes to the development of a more sustainable and resilient supply chain.

2.4. Criteria for Evaluation

While there has been significant research on sustainability measurement frameworks (Qorri et al., 2018) and the implementation of Industry 4.0 technologies in the context of supply chain management, there is a research gap regarding the development of a comprehensive sustainability measurement framework specifically for the information flow within the supply chain in the context of Industry 4.0 technology implementation. This framework would need to consider various dimensions of sustainability, including environmental, social, and economic factors, and what Industry 4.0 technologies should be chosen for implementation of in the supply chain information flow. Addressing this research gap would not only contribute to the theoretical understanding of sustainable supply chain management and Industry 4.0 implementation but also provide practical guidance for managers seeking to leverage Industry 4.0 technologies for improved sustainability in their supply chain information flow. As can be seen Industry 4.0 technologies improves visibility and transparency by providing accurate and timely information during the whole supply chain management. Supply chain stakeholders can access this information, enabling better decision-making, improved coordination, and reduced uncertainties. According to the study, three clarifications relate to almost all sustainability criteria (Pezzey, 1989):

1. These criteria are long term measures.
2. Most of those grow from a publicly accepted "ecologically sustainable" theories of ethical principles.
3. Sustainability criteria are typically mathematical inequalities and can be seen as constraining criteria, rather than maximizing criteria like optimality.

Obviously, the most suitable criteria for sustainability will depend entirely on the industrial context. A plenty of different scenarios may be sustainable and a sustainability criterion will not provide the proper decision which sustainable alternative is the best to select. The question that rises for collective decision-making is to find the most suitable sustainable alternative to the needs of the decision-maker. As it was previously declared, in this research paper it is discussed the best practices of sustainability initiatives of the Group, leading Russian oil & gas company. The evaluation criteria that will be used as the attributes for the most sustainable Industry 4.0 technology selection are based on the Sustainability report of the Group (Gazprom, 2021). The choice of these criteria is justified by the agreement with the previously mentioned three clarifications as well. The Table 1 provides the explanation and liaison of Industry 4.0 technologies and sustainability measurement criteria.

Table 1. The justification of chosen criteria for evaluation of supply chain information flow (Gathered by the author of this paper)

1	Revenue	Evaluating the revenue generated through sustainable supply chain practices helps: – determine if sustainability initiatives are economically sustainable and contribute to long-term business success. – measure the extent to which the supply chain's sustainability practices contribute to market competitiveness. While revenue should not be the sole criterion for evaluating the sustainability of supply chain information flow, it provides a tangible and measurable indicator of the economic viability of sustainability initiatives.
2	Green investment	Green investment criteria evaluate the extent to which Industry 4.0 technologies contribute to resource efficiency, waste reduction, energy optimization, and emissions reduction. Industry 4.0 technologies can potentially mitigate environmental risks and enhance sustainability resilience. For example, predictive analytics and real-time monitoring systems can enable early detection and response to environmental incidents or supply chain distractions.
3	Community investment	Industry 4.0 technologies have the potential to generate significant social benefits, including job creation, skills development, and community empowerment. Community investment criteria evaluate the extent to which these technologies contribute to social well-being and community development.

The final evaluation criteria for assessing the Industry 4.0 technologies alternatives are provided in the Table 2. It will be used as the attributes which have to

End of the Table 1

4	Total expenditures on research and development	R&D expenditures indicate an organization's commitment to innovation and technological advancement. By evaluating the total expenditures on R&D, organizations can enhance their reputation as innovation leaders and create an encouraging environment for talent attraction and retention.
5	Percentage of local procurement	By including the evaluation criterion of the percentage of local procurement, organizations can assess their contribution to economic development, supply chain resilience, environmental sustainability, quality control, community engagement, innovation, and stakeholder trust. This evaluation ensures that Industry 4.0 technology adoption aligns with responsible and sustainable sourcing practices, supporting local economies, and fostering inclusive and resilient business ecosystems.
6	Greenhouse gas emissions	Greenhouse gas emissions, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), are major contributors to climate change. By evaluating the level of GHG emissions associated with Industry 4.0 technology, organizations can assess their contribution to climate change mitigation.
7	Ozone-depleting substances (ODS) and chemicals	To leverage big data analytics for ODS monitoring, a comprehensive data infrastructure, including data collection systems, data sharing mechanisms, and robust analytical tools, is required. Implementation of Industry 4.0 technologies can potentially ensure effective ODS monitoring and decision-making based on the insights derived from big data analytics.
8	Renewable energy	Industry 4.0 technologies enable the implementation of decentralized energy generation systems. Renewable energy sources, such as solar panels and wind turbines, can be integrated with smart grids and connected devices to generate and distribute electricity at the point of consumption. This decentralization reduces transmission losses, enhances energy resilience, and promotes local energy production, aligning with the principles of Industry 4.0.
9	Proportion of women in managerial positions	Promoting gender equality and diversity is a fundamental aspect of sustainability. By evaluating the proportion of women in managerial positions, organizations can assess their commitment to creating an inclusive work environment. Diverse teams, including gender diversity, have been shown to make better decisions and achieve superior business outcomes. By increasing the proportion of women in managerial positions, organizations can enhance decision-making effectiveness and reduce the risk of groupthink.
10	Average hours of training per year per employee	Industry 4.0 technologies often require new skills and knowledge. By evaluating the average hours of training per year per employee, organizations can assess their commitment to developing the skills necessary to effectively adopt and utilize these technologies. Higher training hours indicate a proactive approach to upskilling and reskilling employees, ensuring their ability to adapt to technological advancements and contribute to long-term sustainability.
11	Expenditures on employee health and safety as a proportion of revenue	Industry 4.0 has the potential to improve employee health and safety by creating safer work environments and reduce the likelihood of accidents or injuries and enable the automation of hazardous or repetitive tasks, minimizing the need for human involvement in high-risk activities. Consequently, this can lead to a decrease in expenditures related to employee health and safety.
12	Frequency/ incident rates of occupational injuries	By evaluating these criteria, it becomes possible to assess the effectiveness of safety measures, training programs, and risk mitigation strategies associated with the adoption of Industry 4.0 technologies. Reduced incident rates indicate that the adoption of Industry 4.0 technologies has contributed to a safer and more efficient work environment. Industry 4.0 technology can enhance risk management capabilities by providing real-time monitoring, predictive analytics, and improved safety protocols.

be filled with grades on the scale from 1 to 10 by experts in innovation and sustainability areas. This evaluation criteria tree postulates the base for the following multi-criteria problem.

Table 2. Sustainable supply chain informational flow criteria (Board of Directors PJSC Gazprom, 2021).

Code	Area	Indicator
ASPECT 1. Economic area		
EC1	Revenue and/or (net) value added	Revenue
EC2	New investment/ expenditures	Green investment
EC3		Community investment
EC4		Total expenditures on research and development
EC5	Local supplier/purchasing programs	Percentage of local procurement
ASPECT 2. Environmental area		
EN1	Greenhouse gas emissions	Greenhouse gas emissions
EN2	Ozone-depleting substances and chemicals	Ozone-depleting substances and chemicals
EN3	Energy consumption	Renewable energy
ASPECT 3. Social area		
SC1	Gender equality	Proportion of women in managerial positions
SC2	Human capital	Average hours of training per year per employee
SC3	Employee health and safety	Expenditures on employee health and safety as a proportion of revenue
SC4		Frequency/incident rates of occupational injuries

The analysis of the academic literature and the best sustainability practices that were presented in this chapter, provides insight of choosing the most appropriate evaluation criteria of supply chain informational flow in oil & gas industry and allows to discover the modern sustainability concepts and its application in oil & gas industry's strategic development. Thus, in this chapter the definition of sustainability was addressed, and the strategic activities of oil & gas companies were analyzed. Moreover, the revision of the research papers let to form the tree of key criteria for measuring sustainability of supply chain information flow.

3. Evaluation of Supply Chain Information Flow

After conducting a comprehensive review of existing literature on supply chain information flow and in the second chapter the Industry 4.0 technologies will be addressed in more details and focus of its implementation in oil and gas industry. In this chapter, for evaluating the Industry 4.0 technologies in the context of sustainable supply chain, it will be selected a suitable multi-criteria method. The framework will be based on the criteria selected previously and quantitative evaluation of the survey results.

3.1. Research Methodology

The research methodology is based on the following academic approaches:

1. Academic literature analysis for sustainability criteria selection.

2. Systematic analysis of the practical approaches and examination of the secondary data such as results of experts' survey for Industry 4.0 technologies' alternatives selection.
3. Development of quantitative framework based on the selected criteria and alternatives.
4. Comparative analysis of methods for multi-criteria selection of alternatives.
5. Academicians and professionals' interviews (the GSOM academic representatives and oil & gas experts) for gathering data and introducing it into framework.
6. Usage of APIS software as a reasonable mathematical solution for multicriterial problem under the case of uncertainty and due to lack of statically significant amount of data, subjective opinions, and ethical questions.
7. Application of quantitative measurement framework to the case of oil & gas company.

Applying quantitative measurement framework to the case study provides a deeper understanding of the application of Industry 4.0 technologies in supply chains. It involves analyzing real organizations that have already implemented these technologies and examining their experience regarding information flow in the supply chain.

3.2. Alternatives of Industry 4.0 technologies

Industry 4.0 or the fourth industrial revolution is basically the usage of digital technologies in the industrial procedures to manufacture commodities with advanced quality at lower costs (Statista, 2023). A definition was primarily announced by the German administration on the Hannover Trade Fair in 2011. According to the European market guide (Bryant and Camerinelli, 2013) Supply Chain Finance is defined as "the use of financial instruments, practices, and technologies to optimize the management of the working capital and liquidity tied up in supply chain processes for collaborating business partners". Each involvement such as finance, risk mitigation or payment in the financial supply chain is pushed by an incident in the material supply chain. The implementation of Industry 4.0 technologies to track and control events in the physical supply chain creates opportunities to automate and digitalize the initiation of SCF interventions. Overall, the European market guide allows to identify key focus to elaborate on:

– To describe the ecosystem for supply chain management and SCF.
– To define drivers that are responsible for constraining take-off and adoption.
– To link SCF to the increasing tendency towards automated and digitalized supply chain processes.
– To find out the benefits from the application of advanced programming technology and B2B (business to business) platform capabilities.

The researchers (Wuttke et al., 2013) investigated the increase of logistics' contribution to corporate performance with particular attention to supply chain innovations. While the most common innovative solutions target the improvement of product or information flow, supply chain finance provide analysis of the financial flow and allow buying firms and their suppliers to enhance working capital and reduce costs. As it was previously mentioned in other studies, the maintaining process of SCF is sophisticated and rather unexplored in the academic sphere. The authors of the research (Wuttke et al., 2013) explore initial steps of creating knowledge about SCF and how firms deploy SCF, the reasons of different type of adoption of SCF. The observed (Rogers, 1998) inductive multiple case study approach with six European firms allowed to close the earliest gap between financial flow innovations and SCF. The findings from these six cases were used to build four sets of propositions to extended SCF adoption framework.

It is important to mention that two literature streams were used as a base for that research: literature on the logistics and finance interface and relevant literature on up and downstream innovation management and organizational innovation adoption.

There were identified aspects driving SCF adoption and growth (Bryant and Camerinelli, 2013):

- The need for alternative sources of finance and efficient credit structures.
- The accessibility of working capital throughout the supply chain for participants involved in raw material sourcing, processing, and refining functions.
- Receivables finance.
- Leveraging the credit strength of highly rated buyers.
- Pre-shipment finance.
- The open account space through the emergence of SCF enablers such as the Bank Payment Obligation.
- Supply chain automation techniques, transparency, and routine data availability.
- B2B automation platforms and networks, e-invoicing.

There are numerous definitions of "innovation" that can be found in the academic literature. One of the earliest definitions was provided in the beginning of the 1900s by Joseph Schumpter, when the economists had made attention to the significance of innovation. He proposed 5 types of innovation (Rogers, 1998):

- Presentation of a new product or a qualitative transformation in a current product.
- Practice innovation new to an industry.
- The introduction of a new market.
- Development of new sources of supply for raw materials.
- Modifications in industrial organisation.

A recently discovered definition of innovation ecosystem can be defined as following: the growing set of players, events, and artifacts, and the organisations and relations, including corresponding and alternative relations, that are essential for the innovative functioning of a player or set of players (Granstrand and Holgersson, 2020). The development of innovation must be considered as a sequence of transformations in a whole organisation not simply of computer hardware, but also of market situation, manufacturing facilities and know-how, and the public perspectives of the innovation effectiveness. To be a competitive player of the market, a company need to pay attention on the quality of supply chain management and in what way it affects company's functioning.

Primarily, a supply chain includes all the events related to satisfying client requests. There are 3 different sorts of streams in supply chain: material resources, information, and money. To run a supply chain, all mentioned streams must be managed cost-effectively. It is worth mention that with the developing of the company the management of the supply chain can be seen as significantly complex and uncertain task due to the participation of numerous stakeholders in the supply chain. Consequently, managing supply chain while fulfilling the aspirations of numerous stakeholders can be perplexing. In the situation of finance planning for management of supply chain the Industry 4.0 technologies are bringing the profits of running finance across the whole supply chain. The Industry 4.0 technologies allow not only the distinctive options of rapid interaction and international networking but may disclose the variety of new type of capital. For instance, an initial coin offering implies raising capital by selling a cryptocurrency, a numerical means of value exchange created on the distributed ledger technology (Fisch, 2019). However, as an example of application of Industry 4.0 technologies into Supply Chain Finance, it was discovered that neither strategy nor technology itself can advance a bank's profitability. It is rather the orientation to digitalization and technological changes by innovation ensure ability to be ahead of the competitors (Niemand et al., 2021).

The beginning of Industry 4.0 has improved the manufacturing value chain and these technologies such as Internet of Things, cloud computing, big data, and analytics can increase connectivity in supply chain allowing progress to financial efficiency. In manufacturing it mainly decreases operational costs, augments quality, develops productivity, and promotes innovation. Additionally, it has been stated that the adoption of digital technologies is positively corelated to company's sustainability and the results (Camodeca and Almici, (2021)) show that a company's investment in digitalization, as revealed in its annual reports, can assist to the achievements of sustainable development. However, the growing uncertainty in adoption of Industry 4.0 technologies can be related to the complicated, ambiguous, and knowledge-intensive sphere of digital technology. Frequently, technology implementation department's manager as a decision- maker may be overcautious when there is a need to choose the right set of cutting-age technologies. This has stimulated the request for the improvement of a measuring framework on digital transformation that can deliver sustainability enlightened evaluation of Industry 4.0 technologies and help oil & gas companies, especially, select the suitable sustainable technologies. This research will provide guidelines for evaluating the sustainability of Industry 4.0 technology implementation based on a study of academic literature and analysis of best practices in oil & gas industry.

While improvements in microchip technology and communication equipment have caused the automation of industrial procedures approximately fifty years ago, it is the recent innovations in digital technologies that are initiating to spread the opportunity of fourth industrial revolution to disrupt. Corporations are nowadays undergoing remarkable profits because of minor costs, enhanced productivities, augmented return, mass customization, and unprecedented income and corporate models. Industry 4.0 technologies are interrupting all fundamentals of the value chain involving production, supply chain, engineering, and consumer experience, while constructing innovative business models. International industrial titans such as Germany, France, the U.S., Japan, and China have started state's leadership supported strategic plans to digitalise manufacture throughout numerous businesses. World-wide analytical team of Statista proposed to be determined on five central Industry 4.0 technologies: internet of things (IoT), analytics, big data, cloud computing, artificial intelligence (AI), 3D printing, augmented and virtual reality (AR/VR), and Informational Modeling.

3.3. The selection of Multi-criteria method

Selecting a suitable multi-criteria method depends on different factors, including the nature of the decision problem, the available data, the decision-makers' preferences, and the desired outcome. A multi-criteria problem, also known as a multiple criteria decision-making problem (MCDM), involves evaluating and selecting alternatives based on multiple criteria or objectives.

Table 3. Multiple criteria decision-making problem of choosing Industry 4.0 technology (Formulated by the author of this paper)

	T1	T2	...	T8
EC1	x_{11}	...	...	...
EC2	x_{21}	...	...	...
EC3	x_{31}	...	...	...
EC4	...	...	...	...
EC5	...	...	...	...
EN1	...	...	...	...
EN2	...	...	...	...
EN3	...	...	...	...
SC1	...	...	...	...
SC2	...	...	...	...
SC3	...	...	...	...
SC4	...	...	...	x_{mn}

In a multi-criteria problem, the decision-maker needs to consider numerous factors simultaneously rather than focusing on a single criterion. Each criterion represents a different aspect that is important for the decision, and the decision-maker needs to balance these criteria to make an informed choice. These problems often arise when there are conflicting objectives or trade-offs between different criteria, and the decision-maker needs to find a compromise solution that best meets their preferences and constraints. The goal is to identify the best alternative or a set of alternatives that optimize the decision-maker's objectives, considering the trade-offs among the criteria.

The problem that is observed in this paper can be described as following: to assess the sustainability of supply chain information flow, to be precise, Industry 4.0 technologies' alternatives, based on the selected sustainability criteria. The Table 3 ensures the base for solving a multi-criteria problem by gathering data about the alternatives, assessing the importance or weight of each criterion, and using a suitable decision-making method to evaluate and rank the alternatives based on their performance on the multiple criteria.

In this paper it was used an adaptable collaborative decision-making support system Aggregated Preference Indices System (APIS), that presents a software created for decision-making under uncertainty. This method is a software with capacity to work with numerical and ordinal data, intervals, and incomplete information. It was chosen according to the decision tree, proposed by generalised framework (Figure 1) for multi-criteria method selection authors (Watróbski et al., 2019). Methods corresponding to notations on the Figure 1 can be find in the appendix of this paper. The logic of selecting the relevant methods for comparison is presented below:

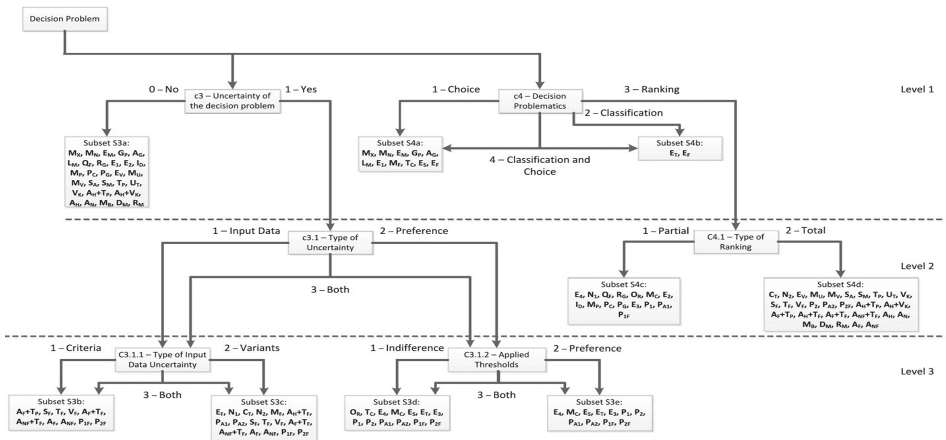

Fig. 1. Part of the decision tree of selecting a suitable MCDM (Watróbski et al., 2019, p. 116)

1. Uncertainty of the decision problem – Yes
   (a) Type of Uncertainty – Input Data – Variants
   (b) Type of Uncertainty – Preference
2. Decision Problematics – Choice

Based on the steps throughout the decision tree there were identified APIS, PAMSSEM (Guitouni et al., 1999), Fuzzy PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation,) as methods for comparison.

Aggregated Preference Indices System (APIS) is a decision-making framework that is used to evaluate complex alternatives based on a range of criteria or factors. APIS is commonly used in multi-criteria decision-making contexts where there are multiple stakeholders with different preferences and perspectives. The APIS framework involves four key steps:

- Criteria Identification: In this step, the decision-makers identify the criteria or factors that are important in evaluating the alternatives. These criteria may be quantitative (such as cost or performance metrics) or qualitative (such as social or environmental impacts).
- Weighting: In this step, the decision-makers assign weights to each of the identified criteria based on their relative importance. This involves a process of preference elicitation, where the stakeholders express their preferences for each criterion.
- Scoring: In this step, the decision-makers score each alternative on each of the identified criteria. This involves a process of data collection, where the decision-makers gather information on how well each alternative performs on each criterion.
- Aggregation: In this final step, the decision-makers combine the scores for each alternative and criterion using a weighted sum. This results in an overall score or ranking for each alternative, which can be used to make a final decision.

APIS is a flexible framework that can be adapted to a wide range of decision-making contexts. It is particularly useful in situations where there are multiple stakeholders with different preferences and perspectives, as it allows for the integration of diverse criteria and the weighting of stakeholder preferences. Experts use their subjective preferences and knowledge to compare pairs of alternatives or criteria, indicating which one is preferable within a specific criterion. Afterwards, the method uses mathematical algorithms to determine the weights of the criteria and rank the alternatives based on the set of comparisons.

This approach is particularly useful when there is limited quantitative information available or when the criteria and alternatives are difficult to measure naturally or by financial data. Instead, APIS allows for the consideration of expert preferences and their knowledge of the system or problem. Thus, while APIS can work with qualitative information, attention should still be given to the quality and reliability of the data provided by the experts. Considering type of uncertainty and decision problematics the APIS software is the most suitable approach for solving multi-criteria problem in context of the observed Industry 4.0 technology alternatives and identified sustainability criteria.

As a result in this Chapter it was discussed the methodology and the detailed steps of research design. Then, alternatives of Industry 4.0 technologies were presented such as Internet of Things, Analytics, Big data, Cloud computing, Artificial Intelligence, 3D Printing, Augmented reality and Informational Modelling and its application in oil & gas industry. The final part of the chapter covered the rationale behind using a multi-criteria approach, the criteria considered in the selection process, and the specific method chosen. Finally, the APIS was selected as the most appropriate method for assessing the alternatives of Industry 4.0 technologies.

4. The Case of Industry 4.0 Technology Implementation

4.1. Digitalization in Russian Oil & Gas industry

Digitalization is gaining momentum in the Russian oil and gas industry, as companies recognize the potential benefits it offers in terms of efficiency, cost reduction, and improved operations. Oil and gas companies are leveraging advanced data management and analytics solutions to collect, store, and analyze vast amounts of data from various sources. The industry is adopting automation and robotics technologies to streamline operations, increase efficiency, and reduce human intervention in hazardous or repetitive tasks. This includes the use of robotic process automation for administrative tasks, drones for inspections and monitoring, and autonomous vehicles for transportation within oil and gas facilities. Digitalization enables real-time remote monitoring and control of oil and gas operations. Digital twin technology is being employed in the industry to create virtual replicas of physical assets, such as wells, pipelines, and refineries. These digital twins enable real-time monitoring, simulation, and predictive maintenance of assets, leading to improved reliability, reduced downtime, and optimized performance.

Digitalization promotes collaboration and integration across different departments and stakeholders within the industry. This includes integrating data and systems from exploration, production, refining, and distribution, enabling a holistic view of operations. It also facilitates collaboration with external partners, such as technology providers and startups, to harness innovation and accelerate digital transformation. Artificial intelligence (AI) and machine learning (ML) algorithms are being utilized to analyze complex datasets and augment various processes. This includes optimizing drilling operations, predicting equipment failures, and improving reservoir modeling. AI and ML also support advanced decision support systems for operational planning and risk management. Digital transformation in the Russian oil and gas industry presents significant opportunities for operational efficiency, cost savings, and enhanced decision-making. Companies are investing in digital technologies and partnerships to drive innovation and stay competitive in an increasingly digital world.

Nowadays, the financial indicators of business organizations are not the only significant markers in a company's performance analysis. The strong attention of investors is dedicated to a range of different Environmental, Social, and Governance (ESG) measures. Recent research showed that stocks of companies with prospects in the low-carbon transition profited, questionably because market members assume strict policy responses boosting renewable energy solutions in the face of the evident dependence of Europe on Russian oil and gas.

Oil and gas industry play meaningful and leading role in Russian economy by ensuring employment for its citizens, developing new strategic infrastructure across all the country's territory, and implementing advanced and sustainable technology into its every day operational process. Currently, Russian oil and gas companies is going under the process of implementation of Industry 4.0 technology considering environmental, economic, and social aspects. However, the evaluation of strategic sustainability in Russian oil and gas industry is lacking up-to-date research. The recent study examined existing approaches to the concept of strategic sustainability of an offshore Arctic oil and gas project and developed a methodological approach to assess strategic sustainability based on the following key objectives: investment, technological, geological, social, and environmental (Cherepovitsyn et al., 2020).

The Gazprom Group (hereinafter - the Group), a global vertically integrated energy company, plays one of the key roles in shaping the competitive economy of the Russian Federation. The group is responsible for meeting numerous environmental and social obligations and makes a significant contribution to ensuring the well-being of current and future generations. The sustainable development goals of the Group support its processes and are incorporated into its strategic, medium-term, and short-term planning systems. The Group's sustainable development goals are set in correlation with the UN Sustainable Development Goals, accepted by the UN General Assembly's resolution in 2015, as well as the values of the Paris Agreement dated December 12, 2015. the following goals, which reflect the fundamental performance indicators indicated in the Sustainable Development Policy of the Group, are indicated as top primacy for the Group (Board of Directors PJSC Gazprom, 2021):

- "Ensure healthy lives and promote well-being for all at all ages." ("Goal 3: Good health and well-being - The Global Goals")
- "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all." ("Goal 4: Quality education - The Global Goals")
- "Ensure access to affordable, reliable, sustainable, and modern energy for all." ("Goal 7—Ensure Access to Affordable, Reliable, Sustainable and Modern ...")
- Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. ("Goal 8: Promote sustained, inclusive and sustainable economic growth ...") ("Goal 8: Promote sustained, inclusive and sustainable economic growth ...")

- "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation." ("Goal 9: Industry, innovation and infrastructure - The Global Goals")
- Take urgent action to combat climate change and its impacts.

Oil and gas supply chain is a compound business process that involves many parties and can be broken down into many tasks and sub-processes. Beside to the most obvious parts, shipment, and transportation, it is necessary to consider trading and customs operations, interaction with ship owners, port services, freight forwarders, terminal owners. It is very difficult to arrange all these steps into a single turnkey service, while ensuring high efficiency and safety at the same time. However, Industry 4.0 technologies can provide such solution, especially in the current state of the world economy, the main characteristic of which is extreme instability. In geographical prospective, a significant diversification of the portfolio assets seemed like unsolvable tasks until Industry 4.0 technologies were introduced into oil and gas industry. So, the very first large-scale projects for the digital transformation were launched for maritime logistics by the initiative of the Russian largest oil producer, Gazprom Neft (The Company). For the supply of oil from the Arctic fields, a unique transport and logistics scheme was developed to ensure year-round export of raw materials.

In general, oil & gas logistics consist of operations among trains, giant tankers, warehouses holding thousands of tons of oil. Additionally, it is also a chain of administrative and organizational processes related to one of its key practice, customs service. For the oil industry, this function is extremely important since oil is still mainly an export commodity. Accurate and fast execution of customs operations helps to increase operational efficiency and reduce economic risks from delays in oil deliveries to consumers. For instance, the cost of mistakes in the customs: from surcharges and protocols on administrative violations to criminal liability, significant financial and image losses of the entire business. As in any activity associated with a lot of routine operations, in the work of the customs function, the human factor becomes the cause of most errors. It can be minimized only in one way, by digitalization of operations that can be performed without human intervention. The Company proved the possibility of such solution back in 2018, when the company issued a customs declaration in 8 minutes in a fully automatic mode being the first among oil exporters. Many professionals of oil & gas industry maintain quite simple logic towards usage of digital solutions: to make routine processes as efficient as possible, and most importantly, correct, and transparent.

The Development Strategy of The Company Customs Service states that the main priorities for them are the speed, convenience, and simplicity of customs clearance, which is planned to be increased through the introduction of Industry 4.0 technologies. The transformation of the customs function by Industry 4.0 technologies implementation is a large-scale multi-stage process, calculated till 2030. However, many important steps have already been taken in this direction. For example, daily online monitoring of the most important services on the portal of the Federal Customs Service of Russia through the personal account of a foreign trade participant has already become commonplace for the company's customs officers. It eliminates the need for advance payments and ensures full transparency of accounting. Now the company's customs department, together with Gazprom Neft Logistics, Russian Railways, and the Federal Customs Service, is launching a pilot project for the use of electronic railway waybills for exporting to the Baltic countries. In the future, this practice may be replicated in other areas.

4.2. Empirical Application of the Proposed Framework

Description of the sample

The sample was created by 9 experts in innovation & sustainability, to whom it was proposed to rate the importance of Sustainability aspects of 1-level and 2-level on a scale of 1-10, additionally, to rate the Sustainability (12 criteria) of an alternative among 8 Industry 4.0 technologies in Supply Chain Finance on a scale of 1-10. The Table 4 provides the description of the respondents that participated in the survey.

Table 4. The sample's description

Type of the respondents' professional occupation	**The organization**	**Number of respondents**
University (professors and heads of specified departments of innovation & sustainability)	Saint Petersburg State University, Graduate School of Management	4
Companies specializing in oil and gas production (managers of Business Intelligence departments, business analysts)	"Gazprom Neft" PJSC	5

The rates provided by all experts were calculated as average for each criterion and afterward introduced as input parameters for Decision Support System APIS. The Table 5 delivers the final scheme of the grades from respondents that participated in the survey. Overall, the final data are presented as a table of:

Row(T8) $\times$ Row(Criteria12) $\times$ Col(Experts)$\times$ Col(Average) = 960 values

Quantitative analysis

The Aggregated Preference Indices (API) computation was completed in three steps: firstly, the indices were estimated for the Economic area, secondly, for Environmental area, and finally, for Social area.

[ASPECT 1. = Economic area] [ASPECT 2. = Environmental area] [ASPECT 3. = Social area]

Attributes (characteristics) of objects (alternatives of choice) for Sustainability Measurement are given below:

EC1 = [1. Revenue]
EC2 = [2. Green investment]
EC3 = [3. Community investment]
EC4 = [4. Total expenditures on research and development]
EC5 = [5. Percentage of local procurement]
EN1 = [6. Greenhouse gas emissions]
EN2 = [7. Ozone - depleting substances and chemicals]
EN3 = [8. Renewable energy]
SC1 = [9. Proportion of women in managerial positions]
SC2 = [10. Average hours of training per year per employee]
SC3 = [11. Expenditures on employee health and safety as a proportion of revenue]
SC4 = [12. Frequency/incident rates of occupational injuries]

Table 5. The final structure of data collected from respondents of the survey (Author's results, 2023)

Technology	Criteria	$Expert_1$	$Expert_2$	...	$Expert_9$	Average
T1	EC1	x_{11}	...	...	x_{19}	...
	EC2	x_{21}	...	...	...	...
	EC3	x_{31}	...	...	...	...
	EC4	...	...	...	...	...
	EC5	...	...	...	...	...
	EN1	...	...	...	...	...
	EN2	...	...	...	...	...
	EN3	...	...	...	...	...
	SC1	...	...	...	...	...
	SC2	...	...	...	...	...
	SC3	...	...	...	...	...
	SC4	...	...	...	...	...
T2	EC1	...	...	...	...	...
	...	...	...	...	...	...
	SC4	...	...	...	...	...
...	...	...	...	...	...	...
T8	SC4	...	...	...	x_{mn}	$\bar{x}_{mn}$

Sustainability Objects (alternatives of choice) under estimation are presented as 8 technologies of Industry 4.0:

T1 = Internet of things
T2= Cloud Computing
T3 = Analytics
T4 = Big Data
T5 = Artificial Intelligence
T6 = 3D Printing
T7 = Augmented reality
T8 = Informational Modeling

The average allocated weights for the 1-level criteria in accordance with its importance are represented in the following Table 6:

Table 6. The data of weights provided by experts for the 1-level criteria (Author's results, 2023)

[ASPECT 1. Economic area]	7,67
[ASPECT 2. Environmental area]	7,67
[ASPECT 3. Social area]	6,33

Economic Area.

The appropriate criteria of the Industry 4.0 technologies under valuation were marked by experts in the developed framework of sustainability measurement. Each score varies from the 1 point as "the least sustainable technology" to the 10 points as "the best sustainable technology". So, the manager has 5 grades of selected criteria of Sustainability of Supply Chain Information flow for 8 technologies. How can she gain the ranking of the Industry 4.0 technologies to make a data-driven decision from the experts' data with sustainability prospective? For building such universal indicator Decision Support System APIS was used. The averaged results are represented in the following Table 7.

Table 7. Values of attributes for alternatives in Economic Area (Author's results, 2023)

	EC1	EC2	EC3	EC4	EC5
T1	7.4400	6.3300	7.5600	7.1100	7.5610
T2	7.1110	5.2200	6.8930	7.0000	7.2210
T3	8.0000	8.1100	7.3330	8.0000	7.4400
T4	7.8900	7.2200	6.7800	7.3300	5.0000
T5	6.7800	6.6700	6.7880	7.3300	6.5400
T6	5.7810	6.1200	5.2230	6.4400	6.0000
T7	5.6710	5.1100	6.0000	4.8900	5.7800
T8	7.3310	7.1120	6.3340	7.5640	5.3320

In the first part of the survey results' processing the input parameters of the project are the following Table 8:

Table 8. Input parameters. Part 1 (Author's results, 2023)

Number of alternatives (objects), k	8
Number of attributes, m	5
Discreteness of weight-coefficients, n	100
Weight-coefficients precision (step), h= 1/n	0,01
Number of all possible variants, N	4598126

The output parameters of the project are the following Table 9:

Table 9. Output parameters. Part 1 (Author's results, 2023)

Number of all admissible variants, N(I)	1232
Amount of information, Inf(I)	11.87 (bits)
Time of Calculation, T	9.87 second(s)

The average allocated weights for the 2-level criteria in accordance with its importance are represented in the following Table 10:

Ordinal information for weight-coefficients values: w(EC1) > w(EC2)

w(EC2) > w(EC3)

w(EC3) > w(EC4)

w(EC4) > w(EC5)

On the Figure 2 there is "Ranking of Single Preference Indices" for 5 sustainable criteria with a diagram of the single preference indices ordering by their significance, i.e., by corresponding weight-coefficients average values. Specifically, on the diagram it can be seen a red (upper one for each criterion) interval displaying an average estimation of a correspondent weight coefficient, while the interval's length is equal to the doubled standard deviation of the weight coefficient. An abscissa of a

Table 10. The data of weights provided by experts for the 2-level criteria in Economic area (Author's results, 2023)

1	[1. Revenue]	8,60
2	[2. Green investment]	6,80
3	[3. Community investment]	5,89
4	[4. Total expenditures on research and development]	5,52
5	[5. Percentage of local procurement]	5,29

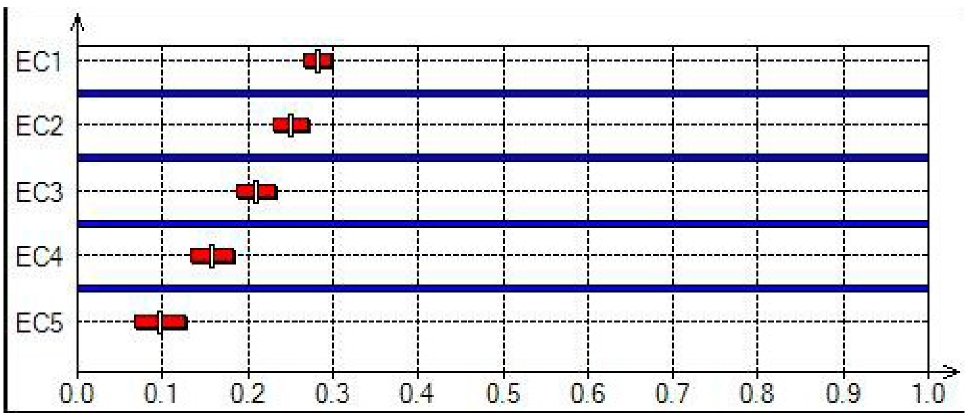

Fig. 2. Visualized aggregated indices for importance of criteria in Economic Area

blue (lower one for each criterion) interval's right end shows the reliability for dominance relation between neighbouring weight-coefficients. In that Economic area the Decision Maker highly rates Revenue and Green investment, rather than Community investment, Total expenditures on research and development, and Percentage of local procurement.

On the Figure 3 it can be seen the main result of the Project.Part 1 – a diagram of the objects (alternatives) ordering by estimated degrees of quality under evaluation. Specifically, on the diagram a red (upper one for each criterion) interval shows an average estimation of a correspondent object, while the interval's length is equal to the doubled standard deviation of the constructed aggregated preference index; an abscissa of a blue (lower one for each criterion) interval's right end shows the reliability for dominance relation between neighbouring aggregated estimations. In the case of the sustainability evaluation, the Industry 4.0 technologies ordering by decreasing degrees of this is shown on the diagram. The Decision Maker may see, for example, that the "best" technology is Analytics with general index of sustainability value being approximately equal to Q(Analytics) = 0,98.

Environmental Area.

The criteria in Environmental area of the Industry 4.0 technologies under valuation were marked by experts in the developed framework of sustainability measurement. Each score varies from the 1 point as "the least sustainable technology" to the 10 points as "the best sustainable technology". In that part, the manager has 3 grades of selected criteria of Sustainability of Supply Chain Information flow for 8 technologies. The averaged results are represented in the following Table 11.

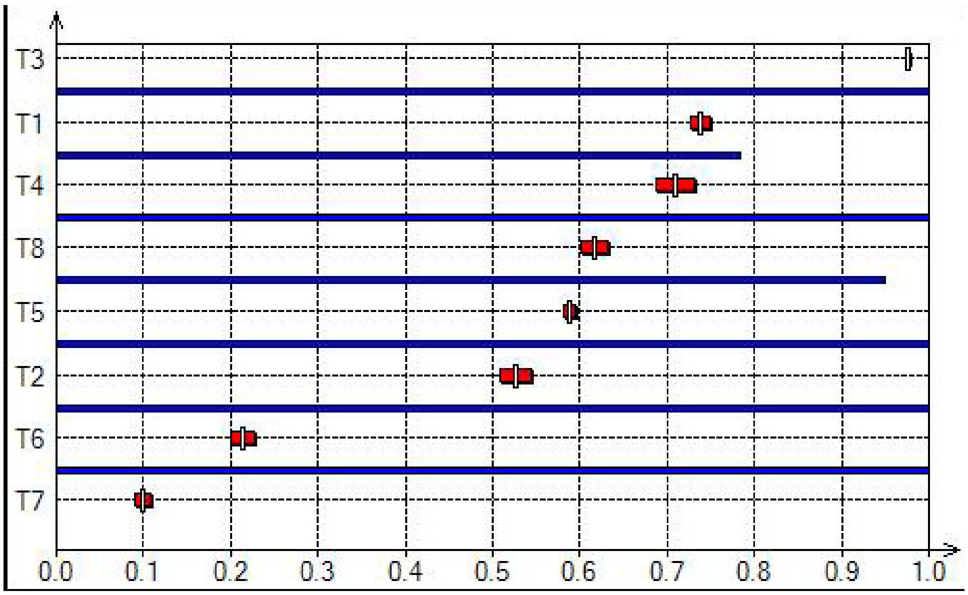

Fig. 3. Alternatives Aggregated Preference Ranking for technologies in Economic Area

Table 11. Values of attributes for alternatives in Environmental area

	EN1	EN2	EN3
T1	6.4400	6.4410	6.7810
T2	4.8930	4.6710	6.2210
T3	8.1110	7.7820	7.0000
T4	6.3300	6.2210	7.0000
T5	6.7800	7.1120	5.6670
T6	5.0000	6.0000	6.1120
T7	4.4430	4.6700	5.8900
T8	6.1120	6.8910	5.8920

In the second part of the survey results' processing the input parameters of the project are the following Table 12.

Table 12. Input parameters. Part 2 (Author's results, 2023)

Number of alternatives (objects), k	8
Number of attributes, m	3
Discreteness of weight-coefficients, n	100
Weight-coefficients precision (step), h= 1/n	0,01
Number of all possible variants, N	5151

The output parameters of the project are the Table 13.

Table 13. Output parameters. Part 2 (Author's results, 2023)

Number of all admissible variants, N(I)	12
Amount of information, Inf(I)	8.75 (bits)
Time of Calculation, T	0.02 second(s)

The average allocated weights for the 2-level criteria in Environmental area in accordance with its importance are represented in the table 14.

Table 14. The data of weights provided by experts for the 2-level criteria in Environmental area (Author's results, 2023)

1	[6. Greenhouse gas emissions]	7,15
2	[8. Renewable energy]	6,22
3	[7. Ozone-depleting substances and chemicals]	5,37

On the Figure 4, there is Ranking for 3 sustainable criteria with a diagram of the single preference indices ordering by their significance. In the Environmental area the Decision Maker highly rates Greenhouse gas emissions and Renewable energy, rather than Ozone-depleting substances and chemicals.

On the Figure 5 it can be seen the main result of the Project.Part 2 – a diagram of the objects (alternatives) ordering by estimated degrees of quality under evaluation. In the case of the sustainability evaluation, the Industry 4.0 technologies ordering by decreasing degrees of this is shown on the diagram. The Decision Maker may conclude that the most sustainable technology in Environmental area is Analytics as well, the second preferable choice is Big Data with general index of sustainability value being approximately equal to Q(Big Data) = 0,68.

Social Area.

The criteria in Social area of the Industry 4.0 technologies under valuation are provided below. Each score varies from the 1 point as "the least sustainable technology" to the 10 points as "the best sustainable technology". In the third part, the manager has 4 grades of selected criteria of Sustainability of Supply Chain Information flow for 8 technologies. The averaged results are represented in the Table 15.

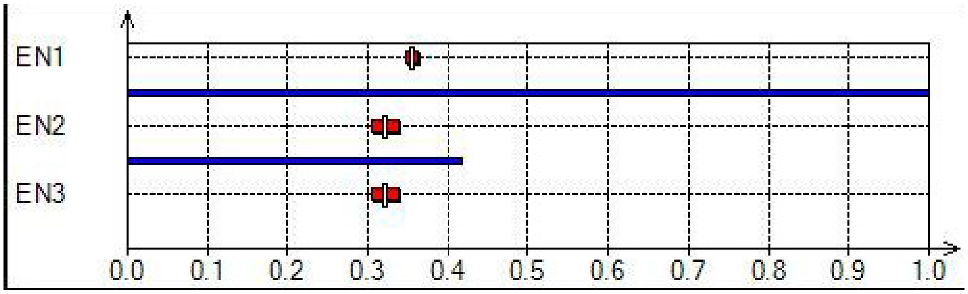

Fig. 4. Visualized aggregated indices for importance of criteria in Environmental Area

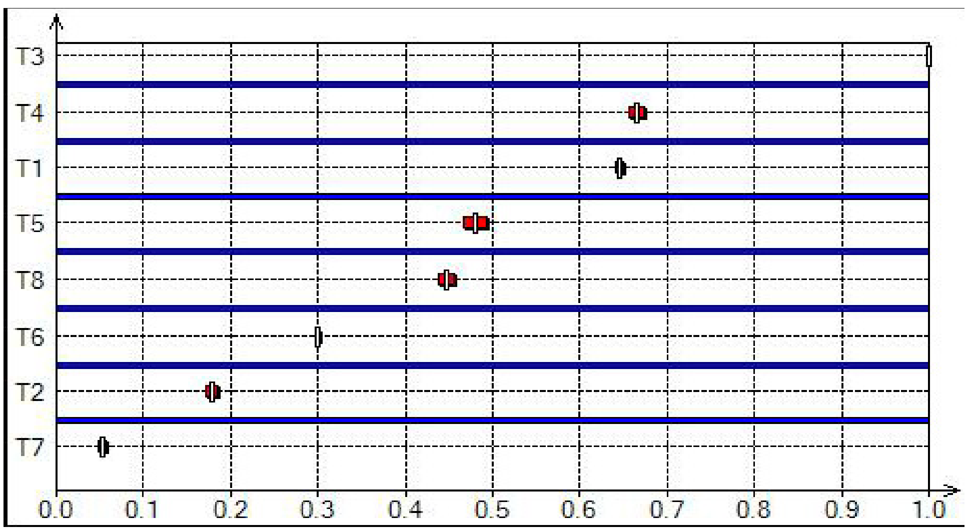

Fig. 5. Alternatives Aggregated Preference Ranking for technologies in Environmental Area

Table 15. Values of attributes for alternatives in Social area

	SC1	SC2	SC3	SC4
T1	6.6700	7.0000	6.6710	6.6730
T2	6.0000	7.7800	6.8910	6.2230
T3	7.7800	7.8900	8.1100	8.5600
T4	6.7800	8.0000	6.3320	7.4430
T5	6.0000	5.3310	5.7810	5.4410
T6	5.2230	6.3320	6.3340	7.1120
T7	5.2210	4.2210	5.5640	6.6700
T8	6.3310	6.6710	7.5610	5.5630

In the third part of the survey results' processing the input parameters of the project are the represented in the Table 16.

Table 16. Input parameters. Part 3 (Author's results, 2023)

Number of alternatives (objects), k	8
Number of attributes, m	4
Discreteness of weight-coefficients, n	100
Weight-coefficients precision (step), h= 1/n	0,01
Number of all possible variants, N	176851

The output parameters of the project are on the Table 17.

Table 17. Output parameters. Part 3 (Author's results, 2023)

Number of all admissible variants, N(I)	24
Amount of information, Inf(I)	12.85 (bits)
Time of Calculation, T	0.33 second(s)

Table 18. The data of weights provided by experts for the 2-level criteria in Social area (Author's results, 2023)

1	[9. Proportion of women in managerial positions]	8,00
2	[11. Expenditures on employee health and safety as a proportion of revenue]	6,52
3	[12. Frequency/incident rates of occupational injuries]	6,33
4	[10. Average hours of training per year per employee]	5,69

Ordinal information for weight-coefficients values
w(SC1) > w(SC2)
w(SC1) > w(SC3)
w(SC1) > w(SC4)
On the Figure 7 it can be seen the main result of the Project. Part 3 – a diagram of the objects (alternatives) ordering by estimated degrees of quality under evaluation. The Decision Maker may conclude that the most sustainable technology in Social area is again Analytics, the second preferable choice is Big Data as well, while the Internet of things with general index of sustainability value being approximately equal to Q(Internet of things) = 0,52 is placed on the third place in the ranking.

Limitations and Future Research Directions

As Industry 4.0 technologies are still relatively new, and their long-term impacts on sustainability are not yet fully understood, there are certain limitations and areas for future research that can be explored. The number of experts is currently limited because of the intersection of two fundamental knowledge area such as innovations and sustainability and upraising trend of implementation of Industry 4.0 technologies. Additionally, the survey can be made on the regular basis with aim to customize the weights allocated to the experts' grades. Future research can

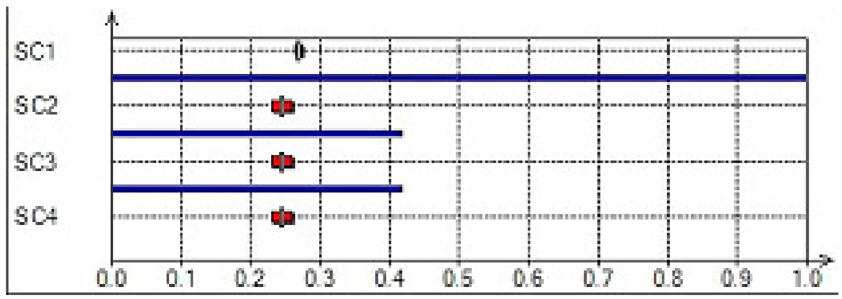

Fig. 6. Visualized aggregated indices for importance of criteria in Social Area

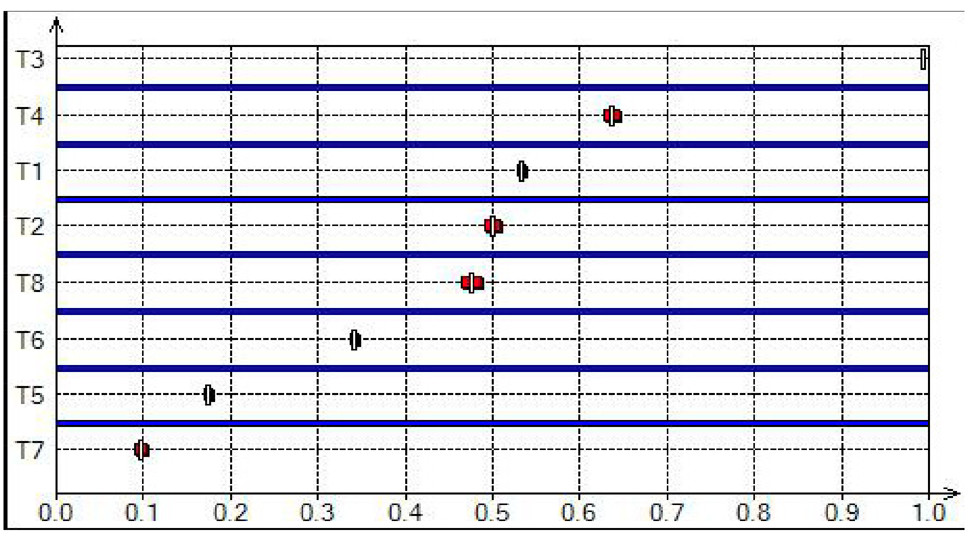

Fig. 7. Alternatives Aggregated Preference Ranking for technologies in Social Area

explore methods for improving data availability and quality by engaging various stakeholders, such as suppliers, customers, and local communities.

Additionally, it is possible to conduct comparative analyses between organizations in heavy industries that can provide valuable insights into best practices and areas for improvement.

5. Conclusion

The main goal of the research that stated as creating a decision-making framework for oil & gas industry companies, was achieved by developing a methodology for evaluation the sustainability of supply chain information flow that allowed to find Analytics and the Big Data as the most sustainable Industry 4.0 technologies for implementation in oil& gas industry. The goal was realised by three consecutive steps: selecting key criteria, building quantitative evaluation framework for assessing sustainability and applying of the evaluation framework for ensuring evidence of framework's applicability.

From the theoretical angle this paper added the new piece of theory for sustainable supply chain management topic that enlarge such dimensions as sustainability and innovations for ensuring right managerial decision. Additionally, the tree of key criteria and the methodology for measuring sustainability of supply chain informational flow were presented. The various alternatives of Industry 4.0 technologies were identified. These technologies include Internet of Things, Analytics, Big Data, Cloud Computing, Artificial Intelligence, 3D Printing, Augmented Reality, and Informational Modelling. Each technology was examined in terms of its application and potential benefits within the oil and gas sector. Moreover, the usage of APIS multi-criteria decision-making method for sustainability problem can be used to validate freshly collected data and improve the insights obtained from this paper research. The rationale behind choosing APIS was explained, emphasizing its ability to handle decision-making under uncertainty and provide a flexible and interactive decision support system.

The recommendations of Industry 4.0 technology implementation regarding ESG criteria and Oil & Gas industry specialization can be seen as managerial implications. In the case of the sustainability evaluation, the Decision Maker may see, that the "best" technologies among all sustainability area are Analytics followed by Big Data with the highest general index of sustainability value.

Appendix

The set of properties of the considered MCDA methods (Watróbski et al., 2019).

M_i	MCDA method	Abbr.	m_{i1}	$m_{i1.1}$	m_{i2}	m_{i3}	$m_{i3.1}$	$m_{i3.1.1}$	$m_{i3.1.2}$	m_{i4}	$m_{i4.1}$
M_1	AHP	A_H	1	3	3	0	0	0	0	3	2
M_2	AHP + TOPSIS	$A_H + T_P$	1	3	2	0	0	0	0	3	2
M_3	ANP	A_N	1	3	3	0	0	0	0	3	2
M_4	ARGUS	A_G	1	1	1	0	0	0	0	1	0
M_5	COMET	C_T	0	0	2	1	1	2	0	3	2
M_6	ELECTRE I	E_1	1	2	1	0	0	0	0	1	0
M_7	ELECTRE II	E_2	1	2	1	0	0	0	0	3	1
M_8	ELECTRE III	E_3	1	2	2	1	2	0	3	3	1
M_9	ELECTRE IS	E_S	1	2	2	1	2	0	3	1	0
M_{10}	ELECTRE IV	E_4	0	0	1	1	2	0	3	3	1
M_{11}	ELECTRE TRI	E_T	1	2	2	1	2	0	3	2	0
M_{12}	EVAMIX	E_V	1	2	2	0	0	0	0	3	2
M_{13}	Fuzzy AHP	A_F	1	3	3	1	1	3	0	3	2
M_{14}	Fuzzy AHP + fuzzy TOPSIS	$A_F + T_F$	1	3	2	1	1	3	0	3	2
M_{15}	Fuzzy ANP	A_{NF}	1	3	3	1	1	3	0	3	2
M_{16}	Fuzzy ANP + fuzzy TOPSIS	$A_{NF} + T_F$	1	3	2	1	1	3	0	3	2
M_{17}	Fuzzy MIN_MAX[1]	E_F	0	0	1	1	1	2	0	4	0
M_{18}	Fuzzy PROMETHEE I	P_{1F}	1	2	2	1	3	3	3	3	1
M_{19}	Fuzzy PROMETHEE II	P_{2F}	1	2	2	1	3	3	3	3	2
M_{20}	Fuzzy SAW	S_F	1	2	2	1	1	3	0	3	2
M_{21}	Fuzzy TOPSIS	T_F	1	2	2	1	1	3	0	3	2
M_{22}	Fuzzy VIKOR	V_F	1	2	2	1	1	3	0	3	2
M_{23}	Goal Programming	G_P	0	0	2	0	0	0	0	1	0
M_{24}	IDRA	I_D	1	2	2	0	0	0	0	3	1
M_{25}	Lexicographic method	L_M	1	1	1	0	0	0	0	1	0
M_{26}	MACBETH	M_B	1	3	3	0	0	0	0	3	2
M_{27}	MAPPAC	M_P	1	2	2	0	0	0	0	3	1
M_{28}	MAUT	M_U	1	2	2	0	0	0	0	3	2
M_{29}	MAVT	M_V	1	2	2	0	0	0	0	3	2
M_{30}	Maximax	M_X	0	0	1	0	0	0	0	1	0
M_{31}	Maximin	M_N	0	0	1	0	0	0	0	1	0
M_{32}	Maximin fuzzy method	M_F	1	2	2	1	1	2	0	1	0
M_{33}	MELCHIOR	M_C	1	1	2	1	2	0	3	3	1
M_{34}	MIN_MAX[1]	E_M	0	0	1	0	0	0	0	1	0
M_{35}	NAIADE I	N_1	0	0	2	1	1	2	0	3	1
M_{36}	NAIADE II	N_2	0	0	2	1	1	2	0	3	2
M_{37}	ORESTE	O_R	1	1	2	1	2	0	1	3	1
M_{38}	PACMAN	P_C	1	2	2	0	0	0	0	3	1
M_{39}	PAMSSEM I	P_{A1}	1	2	2	1	3	2	3	3	1
M_{40}	PAMSSEM II	P_{A2}	1	2	2	1	3	2	3	3	2
M_{41}	PRAGMA	P_G	1	2	2	0	0	0	0	3	1
M_{42}	PROMETHEE I	P_1	1	2	2	1	2	0	3	3	1
M_{43}	PROMETHEE II	P_2	1	2	2	1	2	0	3	3	2
M_{44}	QUALIFLEX'	Q_F	1	1	1	0	0	0	0	3	1
M_{45}	REGIME	R_G	1	1	1	0	0	0	0	3	1
M_{46}	SAW	S_A	1	2	2	0	0	0	0	3	2
M_{47}	SMART	S_M	1	2	2	0	0	0	0	3	2
M_{48}	TACTIC	T_C	1	2	2	1	2	0	1	1	0
M_{49}	TOPSIS	T_P	1	2	2	0	0	0	0	3	2
M_{50}	UTA	U_T	1	2	2	0	0	0	0	3	2
M_{51}	VIKOR	V_K	1	2	2	0	0	0	0	3	2
M_{52}	AHP + fuzzy TOPSIS	$A_H + T_F$	1	3	2	1	1	2	0	3	2
M_{53}	Fuzzy AHP + TOPSIS	$A_F + T_P$	1	3	2	1	1	1	0	3	2
M_{54}	AHP + VIKOR	$A_H + V_K$	1	3	2	0	0	0	0	3	2
M_{55}	DEMATEL	D_M	1	3	3	0	0	0	0	3	2
M_{56}	REMBRANDT	R_M	1	3	3	0	0	0	0	3	2

MIN_MAX[1] - Methods of extracting the minimum and maximum values of the attribute.

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