AN OVERVIEW OF INNOVATIONS AND TECHNOLOGY FOR SUSTAINABLE DEVELOPMENT OF SEAPORTS

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Keywords

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Abstract

Seaports are important factors in global economies since most of the global trade is operated through maritime sector. Economic importance of seaports can be observed from various positive effects they produce for the area where they are located. At the same time, seaport activities create negative effects on the environment such as marine, air and soil pollution, waste production and noise generation that affect the health and quality of people's lives. The aim of this paper is to analyse the possibility of achieving sustainable development of seaports through the development and implementation of innovations and technology. The implementation of innovations in seaports affects the success of their operations, reduces business costs and creates conditions for maintaining a competitive position on the market; thereby affecting the economy as a whole. Moreover, innovations reduce negative effects on the environment affecting the ecological aspect and improving the quality of citizens' lives, thus affecting the social aspect. The results of the research indicate that innovations in the maritime sector are mostly focused on the existing markets and include a discounted process of small improvements in the areas of vessel design and construction, fuel technology and port infrastructure. However, the development possibilities of seaports can also include innovations that are more focused on information and communication technologies (ICT). Innovations can address economic, environmental and social concerns and can give alternative guidelines for achieving sustainable development of seaports.

1 INTRODUCTION

Maritime transport has been growing over the years, since most of the world's transport takes place by sea, which puts the need to create a balance between economic, environmental and social aspects, that is, to implement the concept of sustainable development in seaport operations. Maritime transport has certain environmental benefits in comparison with other modes of transport such as lower emissions of greenhouse gas per kilometre in regards to road transport, as well as the ability to transport large quantities of cargo at

once and over long distances [1,2]. However, the growth of the global economy and maritime trade imposes indirect costs on the social and environmental segments, such as water pollution, air pollution and noise creation from port activities, which affects the life of the local inhabitants and their health. Furthermore, the seaport, as a central hub of the maritime transport network [3] has a positive impact on job creation and the promotion of local and economic growth [4]. Despite these benefits, between 60-90% of greenhouse gas emissions from maritime transport occur while ships dock in seaports [5]. Therefore, the implementation of innovative solutions is required as advanced technologies seek to reduce the time spent in seaports as much as possible. Moreover, the use of new technologies in business requires additional education of employees, which has a positive impact on the development of society, but also causes additional costs.

Seaport and the port city are two closely related and influential entities, and most port cities were created precisely because of the seaports that were in their immediate vicinity [4]. Seaports are closely linked to the cities in which they are located, so city authority requires seaport management to formulate their plans and strategies in accordance with sustainable development principles. They need to be aware of the impact of their business decisions on modern life and the environment, and to include future generations that will live and work in their area.

The United Nations Member states adopted the 2030 Agenda for Sustainable Development which provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. The Agenda has 17 Sustainable Development Goals (SDGs) and its Goal 9 refers to "Industry, innovation and infrastructure" whose target is to develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure and to support economic development and human well-being, with a focus on affordable and equitable access for all [6]. Seaports' role in achieving sustainable development goals may be in line with abovementioned Sustainable Development Goal 9 since they can put effort in implementing innovation solutions in their business operations as well as improving infrastructure.

The aim of this paper is to analyse the possibility of achieving sustainable development of seaports through the development and implementation of innovations and technology. To achieve this goal, the authors described the sustainability issues facing seaports, identified key innovations that positively impact all three segments of sustainable seaport development (economic, environmental and social), defined certain development opportunities that seaports can implement and explained the benefits of their implementation.

The rest of the paper is structured in the following way: literature review was provided in the second section. Sustainability issues that seaports are facing in their business are described in third section. Current and potential innovations that can be implemented in maritime sector and explanations how they can benefit a sustainable development are presented in the fourth section. Concluding remarks are given in the fifth section.

2 LITERATURE REVIEW

Sustainable development includes three areas; economic, environmental and social area; which are usually represented by three intersecting circles with overall sustainability at the center [7]. Economic sustainability refers to a long-term economic growth including production that satisfies present consumption levels without compromising future needs. Environmental sustainability refers to a responsibility to maintain natural resources and to protect global ecosystem. Social sustainability includes identifying and managing business impacts on employees, workers and customers [8,9].

The concept of sustainable development has become very significant for the maritime sector since it supports and facilitates continued growth in the world's trade by providing freight handling facilities, transshipment and other services without compromising economic, environmental or social aspects [10]. Seaports can have significant positive and negative impact on the areas where they are located. While positive mostly concern

contribution to GDP, increased employment and creation of other port-related activities [11–13], negative mainly concern environmental pollution and impact on the society [14].

Hossain et al. [15] researched various measures that port authorities implement to improve sustainability of port operations. They concluded that European union (EU) seaports adopt sustainability initiatives to a greater extent in comparison to North American and Asian Pacific seaports. Acciaro et al. [16] developed a method for quantifying the success of innovations in seaports that contribute to environmental sustainability. Authors researched which green objectives were achieved in seaports with the assumption that the green objectives that were defined as priority would be achieved more successfully. Based on the research results, the above mentioned was not the case since green innovation success was in most cases achieved incidentally and, in the areas where green objectives were not even a priority.

Lam and Yap [10] gave a stakeholder perspective of sustainable development of port cities and stated that stakeholder engagement is important for implementing strategies for long-term benefit of a port city. Authors suggested that port cities explore and implement new technologies that can contribute to better harmonization of economic, social and environmental aspects which could simultaneously increase productivity, improve safety and reduce negative environmental impacts. Tijan et al. [17] researched the impact of digital technology in the context of the Blue Economy and concluded that the implementation of digital technology in the maritime transport sector has a positive impact on achieving the Blue Economy goals. As a good example, they cited the Port of Rotterdam and its development of the "Pronto" application, which is linked to models for calculation, analysis and optimization of greenhouse emissions.

Various indices are developed that aim to embrace and analyze sustainable development of the maritime sector, such as Environmental Port Index (EPI), Environmental Ship Index (ESI), Clean Shipping Index or Energy Efficiency Design Index (EEDI) [18–21]. Authors Stanković et al. [22] created composite index to compare and monitor sustainability across seaport regions in Mediterranean EU countries. Research results indicate that the larger number of top-rated port regions are in Italy, Spain and France. Široka et al. [23] stated that existing methodologies for estimating impact of seaport activities on environment are mostly qualitive and that there is a need for quantities methodology that will include all of the main environmental aspects. Authors presented the Port Environmental Index (PEI) that collects data in real-time and gives seaports the opportunity to make immediate corrections in their activities. The shortcoming of this approach is that not all seaports have the necessary data collection technology; however, seaports invest more in digital technology and it is likely they will have this kind of data collection in the future.

It is recognized in literature that maritime sector has certain impacts on sustainability, especially on the environmental area. Many authors covered this topic from various perspectives; however, there are only a few academic contributions that connect innovations with sustainable development of seaports, to the best of our knowledge. This paper contributes to fill this gap by researching current and potential future implementation of innovations in the seaports.

3 Sustainability Issues in Seaports

Development of seaports and their increased operations have positive impact on economic growth of the area where seaports are located [11]. The economic advantages of seaports include increasement of employment, reduction of transportation costs, improvement of logistics and attracting other port-related activities that indirectly create their own positive economic effects [12,13,24,25]. Increasement in the freight traffic in EU seaports can be seen on figure 1. However, the growth of seaport operations and international maritime trade, apart from positive effects, creates certain negative effects on the environment and society as well.

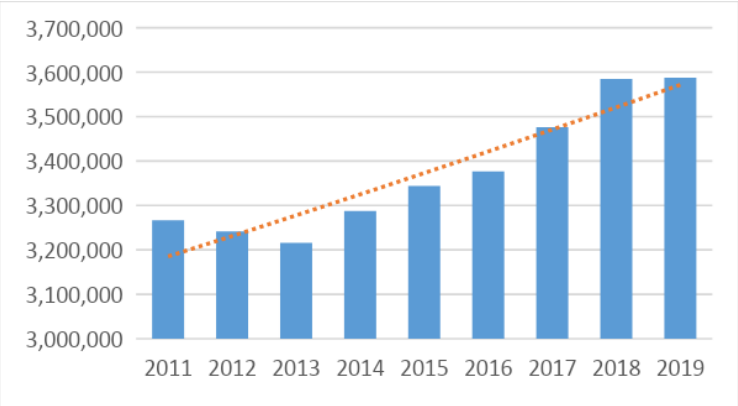

Figure 1. Freight traffic in seaports in EU countries (in thousand tons) [26]

Externalities arising from the economic activities of seaports are one of the negative effects. Seaport activities generate a significant amount of road traffic in their vicinity, due to the increased use of trucks, which leads to congestion of local roads and highways, noise and environmental pollution. Loading and unloading of freight also creates pollution and noise, while storage spaces located near the seaports make the surrounding area less attractive for living conditions. Therefore, seaport operations of industrial seaports may cause less desirability for housing in the surrounding areas. As a result, property prices may fall or rise more slowly than values in other areas [27].

European port environmental monitoring programs show the environmental problems facing seaports. Table 1 shows the most common environmental problems concerning seaports. The numbers refer to the percentage of seaports that improved the way of monitoring certain environmental segments.

Table 1. Environmental monitoring indicators (in %) [14]

INDICATORS	**2013**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2013-2021**
Port waste	67	79	88	84	79	79	80	+13
Energy efficiency	65	73	80	80	76	75	77	+12
Air quality	52	65	69	67	62	67	71	+19
Water consumption	58	62	71	72	68	69	70	+12
Water quality	56	70	75	76	71	67	70	+14
Noise	52	57	64	68	57	54	64	+12
Sediment quality	56	63	65	58	54	59	60	+4
Carbon footprint	48	47	49	47	49	52	59	+11
Marine ecosystems	35	36	44	40	40	46	46	+11
Terrestrial habitants	38	30	37	38	37	41	40	+2
Social quality	42	44	48	38	32	41	40	-2

It can be seen from table 1 that there was an increase in the monitoring parameters over the years. The largest number of seaports improved the monitoring parameters of port waste, more precisely 80% in 2021. According to European Sea Ports Organisation (ESPO) data, the greatest progress in the monitoring of environmental indicators is visible for the air quality, which increased by 19 percentage points in 2021 compared to the initial 2013. Also, it is evident that the least developed monitoring indicator is the one related to social quality. Comparing the value from the initial 2013 with the last observed 2021, it can be seen that there has been a decrease in social quality indicator. Moreover, in the period from 2013 to 2017, the number

of monitoring parameters related to social quality increased, but in the next two years the number decreased significantly. This can also be attributed to the increased number of seaports taken into analysis. After 2019, the number of seaports that monitor social quality indicator was growing; however, in 2021, a decrease compared to 2020 can be seen by one percentage point.

Seaport operations are significant source of air pollutants that will most likely continue to increase in the future [28]. According to ESPO Environmental Report [14] environmental priority of the port sector in 2021 was air quality following by climate change, energy efficiency, noise and relationship with the local community. Moreover, air quality was top priority for the last six years. Air pollution is associated with vessels coming into seaports, seaport operations as well as industrial activities that have arisen as a result of seaport operations nearby. Most of the European seaports are located near cities; therefore, air pollution affects health and well-being of citizens around them. The environmental effects of air pollution include acidification of seas and oceans. They also have a social impact on the health of employees and local population, and cause a number of health problems such as respiratory diseases, cardiovascular diseases, lung cancer etc. [29–32].

Air pollution contributes to the emission of greenhouse gases, which cause climate change that can produce many difficulties for seaports, such as rising sea levels and extreme weather conditions. Figure 2 shows the greenhouse gas emissions in EU countries. Heat stress and downtime are possible consequences of these changes, which can contribute to increased financial costs and negative impacts on employee health [33]. Climate change requires additional investment in seaport infrastructure, and a significant number of seaports still do not consider the need to adapt to changes.

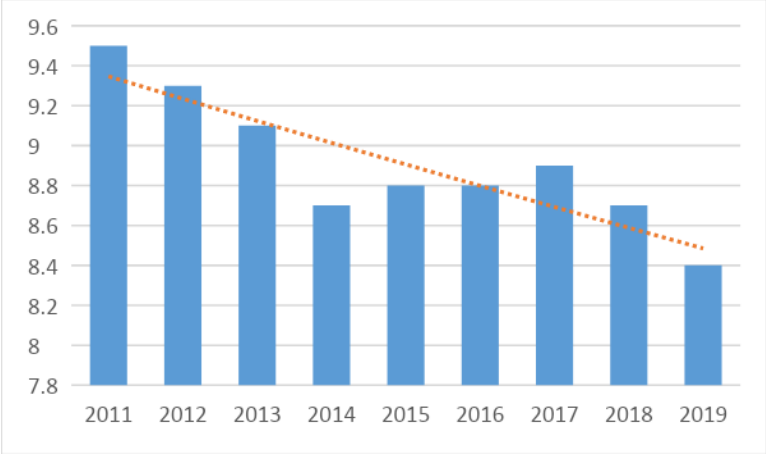

Figure 2. Greenhouse gas emissions per capita in EU countries [34]

Wastewater and toxic substances leaking from ships, stormwater runoff, and dredging are the main forms of water pollution in seaports. Seaport operations and waste materials discharged from ships in the port area affect the quality of the sea and its ecosystem. Oil is discharged from ships in seaports and covers the water surface. Fish that swallow this toxic water die, become sick, and endanger the lives of all those who swallow it. The economic impact of this form of pollution is far-reaching as it affects the sea ecosystem [35,36]. One of the industries that is most vulnerable to this form of pollution is fishing, and the local economies of coastal cities that depend on it can be extremely endangered. In addition to fisheries, water pollution can also affect tourism, which is one of the drivers in many maritime countries. When oil spills into the sea and reaches the coast, it pollutes beaches and threatens their aesthetic beauty.

Solid waste generated in seaports and on ships, such as glass, paper, cardboard, aluminum, steel cans, plastics, etc., disposed of in the marine environment, pose a threat to marine organisms, people, coastal communities,

and the seawater industry [35]. Seaports are paying increasing attention to the way they dispose waste generated in their processes and on ships that dock at the seaport. Although the ecological part of the seaport does not yet bring significant economic benefits, experts believe it will pay off in the long run. In addition, there are still no uniform criteria for waste disposal monitoring. Uniform legislation for all EU seaports would reduce differences in environmental indicators. The same environmental rules and procedures would apply to all seaports, which would lead to better environmental protection and maintaining the competitiveness of seaports [37].

Noise pollution is another challenge that seaports face on a daily basis. Construction work, freight handling, road traffic with heavy vehicles, and rail traffic in the port area are only some of the activities through which the seaport affects the quality of life of the population and wildlife in the port area [38–40]. According to ESPO data (Table 1), it can be seen that in 2021 noise was one of the problems; since noise monitoring was increased by 10 percentage points compared to 2020, indicating that this issue is becoming increasingly important for seaports and that many measures are being taken to limit and mitigate noise above and below the sea.

Although digitalization and the use of new technologies make a significant contribution to economic activity, in accordance with the principles of sustainable development, and are often counted among the most significant advantages, they are also the cause of many problems. This form of the problem is often overlooked in analyzes. The reliance on ICT has led to an increasement of cyber risks on ships and in seaports. Cyber risks can disrupt the operations of the entire seaport and lead to its closure. Therefore, it is necessary to ensure that the improvement of digitalization takes place in parallel with the implementation of new and appropriate security measures [41,42].

4 INNOVATIONS AND SUSTAINABLE DEVELOPMENT IN SEAPORTS

In order to minimize the seaport's external effects, it is important to manage the seaport respecting the principles of sustainable development. Seaport sustainability implies the implementation of business strategies and activities that meet the current and future needs of the seaport and stakeholders while protecting and maintaining human and natural activities [43,44].

Some seaports implement the concept of sustainable development only to comply with the regulations while some view sustainability as an important element of their business strategy that can have an impact on the international competitiveness [45]. Other seaports use incentive programs to encourage port users to adopt innovative measures [15]. However, seaports must be aware that their actions impact the lives of the people who live in their environment as well as affect the lives of future generations and the environment in which they will live and work. Thus, it can be said that seaports operate sustainably only when they make decisions considering long-term economic success and reflect a deep and comprehensive commitment to environmental management, while integrating community requirements into business [38].

Research and development (R&D) investments are mostly associated with the development of new technologies; however, the innovation process can also involve a discounted process of small improvements that can bring benefit to business processes or society in general. It enables the introduction of new products or processes which consequently lead to higher revenues and growth [46]. As shown in figure 3, EU countries allocate a larger proportion of GDP to the R&D every year. Innovations in maritime sector can enhance the concern for sustainable development since many of them are mainly focused on environmental care as well as social and economic enhancements. According to ESPO, European seaports planned to invest about 4% of total investments in ICT or digital structures [47].

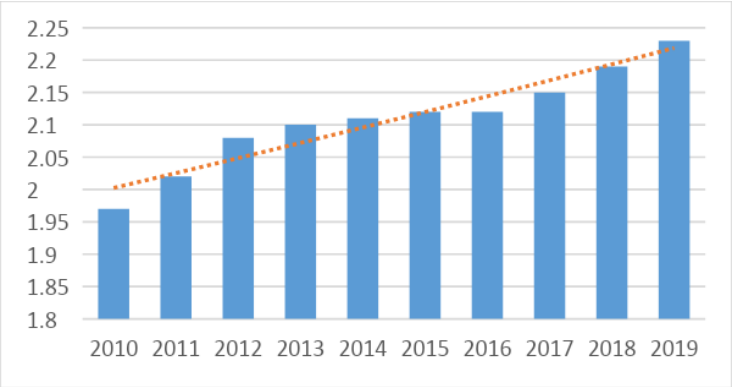

Figure 3. Gross domestic expenditure on R&D in EU countries (% of GDP) [48]

Innovations in the maritime sector are mostly focused on the existing markets. According to Geerlings and Wiegmans [49] innovations in maritime sector can be classified into the following groups:

- Innovations in vessel design and construction
- Innovations in the field of fuel technology
- Innovations in engine technology
- Innovation in infrastructure and seaport development
- The integration of technology
- Innovations in other technological areas

Innovations related to vessel design and construction can directly have positive impact on sustainable development. They are aimed at developing new construction methods, material selection, construction of vessel shape and size, as vessels with lower mass and lower aerodynamic drag will have lower fuel consumption, thus reducing the greenhouse gas emissions. Another segment of innovations that has direct impact on sustainable development are innovations in the field of fuel technology. There are four main parts that can be improved in terms of fuel: (1) electric and (2) hydrogen propulsion, which are associated with renewable energy sources and have less impact on the environment, but have to be derived from other sources. Moreover, there are (3) biofuels and (4) hydrocarbon fuels which are alternative fuels that produce lower greenhouse gas emissions and reduce a dependence on non-renewable sources derived from fossil fuels. Innovations related to engine technology are related to environmental care as well, since they put effort on reduction of harmful gas emissions, reduction of energy losses in internal combustion engines and reduction of engine noise.

Infrastructure and port development innovations affect the separation of traffic from other activities in the city. This contributes to the protection of the quality of life of citizens which has impact on the social component of sustainable development. However, infrastructure can also reduce the quality of life with its visual characteristics, which can be mitigated by the use of new materials and technologies. Regarding the integration of technology; it is important to point out that innovations alone are not enough. Moreover, their acceptance, implementation and usage involve many stakeholders who need to be willing to execute the abovementioned and this process can be challenging. Innovations in other technological areas mostly include traffic control in order to improve traffic flows and address specific environmental aspects [49].

The Maritime National Single Window is a technological advancement that has significantly changed the process of exchanging information between stakeholders in maritime transport as well as improved the business of seaports. The concept allows all stakeholders involved in the business process to enter the data only once and eliminates the need for one stakeholder to submit the same data multiple times to different stakeholders. According to Tijan et al. [50] Maritime National Single Window could have an important role in

making seaport business more sustainable addressing all three aspects; economic, environmental and social. It can reduce or eliminate paper documentation which can improve economic aspect of seaport sustainability by savings and decreasing processing time. Moreover, it can address environmental aspect of sustainability by reducing waiting time for freight loading and unloading and unnecessary freight movements due to inefficient data exchange among stakeholders; therefore, decreasing air pollution. Finally, it can affect social aspect of sustainability by using human resources more efficiently and increasing their productivity as well as improving communication and information exchange between stakeholders and help them with the standardization of business processes.

Seaport development opportunities can go in several directions and are mostly focused on existing markets increasing the use of ICT in business. However, there are certain relatively new concepts that can be introduced into seaports' business processes, such as 5G networks, clouds, Internet of Things, Internet of Vehicles, Blockchain technology or drones.

The implementation of a 5G network can meet the requirements of automation that are more frequent in operational activities in maritime sector. The 5G network can be used in the day-to-day operations of seaports and terminals as it provides the possibility of fast data transfer and can support the digital transformation of the maritime sector by connecting logistics companies and seaports. Digital transformation in general contributes to better sustainable development of seaports. The use of clouds in the maritime sector can help seaports and terminals to connect better and transition more easily to automated processes. They can also be applied to route planning platforms that allow users to share information in real time as well as provide a better opportunity to use the Internet of Things technology [51].

5G network and the use of clouds provide the preconditions for the development of other technologies such as the abovementioned concept of the Internet of Things. The Internet of Things technology in seaports could be used with seaports' equipment that would transmit data via sensors. This would increase the transparency and efficiency of port operations as well as create a large amount of data that ports and terminals can use to optimize their processes and improve services [52]. Port Environmental Index (PEI) developed by authors Široka et al. is designed to use quantitative, data-based information collected using Internet of Things techniques which would make possible to assess the environmental impacts of port operation in real time [23]. Since data would be collected in real time, seaports could make immediate corrections in their activities that could benefit their sustainable development. Internet of Vehicles technology is a concept where sensors can be placed on vehicles as well as port facilities and parking lots. This would provide information about the optimal route, expected costs and available parking lots and addresses the environmental part of sustainable development. The technology would also provide increased traffic safety and fewer vehicle collisions that could affect the social aspect of sustainable development goals.

Blockchain technology provides possibility for achieving transparent and decentralized transactions in business and industry [53]. It is considered suitable for implementation in seaports' business due to the large number of stakeholders involved in the process. However, the technology has not yet been fully implemented and its capabilities are in the testing and prediction phase. Potential areas of blockchain technology implementation can be divided into four groups. First is storage and transfer of freight documentation that could address the environmental part of sustainable development by reducing paper usage and waste production, social part by eliminating the possibility of human error and fraud, and economic part by improving the transparency of the entire process, facilitating origin tracking as well as saving time and money. Second group is improving the visibility of the business process which could improve coordination between all stakeholder, speed up freight transport planning, minimize costs and reduce time delays. Third is reduction of time for the commercial approvals which could improve trade financing allowing the visibility of the business process to third-party participants (e.g. banks, insurance companies) that could lead to resolving the bottlenecks. Fourth is the automatization of the operations using Internet of Things where big amount of data

created could be stored and accessed using blockchain technology [53,54]. Another development possibility could be the use of drones in seaports' operations. It is primarily related to the monitoring and control of gas emissions from vessels, as drones can reach vessels at the sea more easily [55]. However, drones have the potential for further development in logistics, such as performing smaller package delivery operations and warehouse management [56].

The COVID -19 pandemic has greatly affected the accelerated digitalization of processes in seaports. In order to maintain trade activities, it was necessary to facilitate ships' berthing and handling as well as other business activities while maintaining measures of social distancing or teleworking. Therefore, technology and digitalization have been considered a top priority for seaports and maritime transport in recent years [42].

Innovations are, among other things, collective learning and a socially integrated process. In order to be successfully implemented, they need to be accepted and used by all stakeholders involved in the business process, which can sometimes be a challenge. Although seaports, with their human capital and social and cultural spheres, are crucial for successful innovation implantation; innovations, are in return an important source of competitive advantage for the respective seaports and, at the same time, can have an impact on all three aspects of the concept of sustainable development.

5 CONCLUSIONS

Seaports are important participants in the economy since most of the word's trade takes place by the sea. The increasements of the maritime trade causes both positive and negative effects on the countries' economies and environment. The positive impacts are mostly related to economic growth and increased employment while the negative ones are mainly related to environmental issues such as water pollution, air pollution and noise as well as social impacts on the population that lives nearby. In order to minimize negative impacts, seaports can be operated according to the principles of sustainable development; that is creating a balance between economic, environmental and social aspects.

The innovation process and the introduction of new technologies into seaports' business can have certain positive impacts on the sustainable development. The existing innovations are mostly focused on the improvements in the areas of vessel design and construction, fuel technology, engine technology, infrastructure and seaport development. Therefore, they have an impact on reduction of fuel consumption and promotion of renewable energy sources; thus, reducing the greenhouse gas emissions and improving the quality of life of the citizens.

The Maritime National Single Window concept eliminates the need for one stakeholder involved in the business process to submit the same data more than once which can have an impact on the improvement of business processes in seaports as well as on sustainable development. It can address the economic aspect through higher savings and shorter processing time and environmental aspect by decreased air pollution induced by reduction in the waiting time for loading and unloading of freight. The social aspect can be addressed through more efficient use of human resources, increasing their productivity, communication and exchange of information.

The development possibilities of seaports can include innovations that are more focused on ICT. The implementation of the 5G network and the use of clouds in seaports can enable their digital transformation and very fast data transmission, which provides a good foundation for the implementation of the Internet of Things technology and the Internet of Vehicles technology. Abovementioned technologies could increase the efficiency and transparency of port operations and generate a large amount of data that can be used to optimize business processes. Real-time data could help seaports to address environmental issues as well as to reduce business costs and provide increased traffic safety that affects all three segments of sustainable development concept.

Another development opportunity is the use of blockchain technology that could enable better storage and transfer of freight documentation, which would improve the visibility of the processes and coordination between all participants. It would reduce the time for commercial approvals and improve the automation of operations. The positive implications related to sustainable development concern reducing waste production, eliminating the possibility of human error and fraud, facilitating origin tracking, minimizing costs, reducing time delays and overall saving time and money resources. Drones in seaport operations are also one of the development possibilities and can be used to monitor and control the emission of gases from vessels at sea, as well as for logistics processes like small package delivery operations and warehouse management.

The implementation of innovations and new technologies in seaports can greatly improve business processes by reducing costs and bottlenecks, harmonizing processes and enabling better transparency. All of the above have impact on sustainable development of seaports because they consider long-term economic success, care for the environment and improvement of living standards of population.

REFERENCES

[1] Lim, S.; Pettit, S.; Abouarghoub, W.; Beresford, A. Port sustainability and performance: a systematic literature review. *Transportation Research Part D: Transport and Environment* [online]. Elsevier, July 2019, vol. 72, p. 47–64. [Accessed 14 June 2022]. Available at: <https://doi.org/10.1016/j.trd.2019.04.009>.

[2] Skrúcaný, T.; Kendra, M.; Kalina, T.; Jurkovič, M.; Vojtek, M.; Synák, F. Environmental comparison of different transport mode. *Naše more* [online]. Dubrovnik : Universtiy of Dubrovnik, 2018, vol. 65, no. 4 (Special issue), p. 192–196. ISSN 1848-6320. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.17818/NM/2018/4SI.5>.

[3] Lu, C.S.; Shang, K.C.; Lin, C.C. Examining sustainability performance at ports: port managers' perspectives on developing sustainable supply chains. *Maritime Policy and Management* [online]. 2016, vol. 43, no. 8, p. 909–927. eISSN: 1464-5254. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1080/03088839.2016.1199918>.

[4] Zheng, Y.; Zhao, J.; Shao, G. Port city sustainability: a review of its research trends. *Sustainability* [online]. 2020, vol. 12, no. 20, p. 1–17. eISSN 2071-1050. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.3390/su12208355>.

[5] Chen, J.; Huang, T.; Xie, X.; Lee, P.T.W.; Hua, C. Constructing governance framework of a green and smart port. *Journal of Marine Science and Engineering* [online]. 2019, vol. 7, no. 4. ISSN: 2077-1312. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.3390/jmse7040083>.

[6] United Nations. Do you know all 17 SDGs?: Sustainable Development Goals. In: United Nations. *United Nations. Department of Economic and Social Affaris: Sustainable Development* [online]. UN, 20 April 2018. Available at: [Accessed: 4 April 2022]. Available at: <https://sdgs.un.org/goals>. Available at: <https://www.youtube.com/watch?v=0XTBYMfZyrM>.

[7] Purvis, B.; Mao, Y.; Robinson, D. Three pillars of sustainability: in search of conceptual origins. *Sustainability Science* [online]. 2019, vol. 14, no. 3, p. 681–695. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1007/s11625-018-0627-5>.

[8] Basiago, A. D. Economic, social, and environmental sustainability in development theory and urban planning practice. *The Environmentalist* [online]. 1998, vol. 19, p. 145–161. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1023/A:1006697118620>.

[9] United Nations Global Compact. Social Sustainability. In: UN Global Compact. *United Nations Global Compact* [online]. UN Global Compact, 2022. [Accessed: 4 April 2022]. Available at: <https://www.unglobalcompact.org/what-is-gc/our-work/social>.

[10] Lam, J.S.L.; Yap, W.Y. A stakeholder perspective of port city sustainable development. *Sustainability* [online]. 2019, vol. 11, no. 447, p. 1–15. eISSN 2071-1050. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.3390/su11020447>.

[11] Mudronja, G.; Jugović, A.; Škalamera-Alilović, D. Seaports and economic growth: panel data analysis of EU port regions. *Journal of Marine Science and Engineering* [online]. 2020, vol. 8, no. 12, p. 1–17. ISSN: 2077-1312. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.3390/jmse8121017>.

[12] Bottasso, A., Conti, M.; Ferrari, C.; Merk, O.; Tei, A. The impact of port throughput on local employment: evidence from a panel of European regions. *Transport Policy* [online]. Elsevier, May 2013, n. 27, p. 32–38. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1016/j.tranpol.2012.12.001>.

[13] Crescenzi, R.; Rodríguez-Pose, A. Infrastructure and regional growth in the European Union. *Papers in Regional Science* [online]. 2012, vol. 91, no. 3, p. 487–513. eISSN 1435-5957. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1111/j.1435-5957.2012.00439.x>.

[14] Puig, M.; Wooldridge, C.; Darbra, R.M. *ESPO Environmental Report 2021: EcoPortsinSights 2021*. [online]. Brussel: ESPO, 2021. [Accessed: 26 January 2022]. Available at: <https://www.espo.be/news/espo-presents-its-environmental-report-2021-ecopor>.

[15] Hossain, T.; Adams, M.; Walker, T.R. Role of sustainability in global seaports. *Ocean and Coastal Management* [online]. Elsevier, March 2021, vol. 202. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1016/j.ocecoaman.2020.105435>.

[16] Acciaro, M.; Vanelslander, T.; Sys, C.; Ferrari, C.; Roumboutsos, A.; Giuliano, G.; Lam, J.S.L.; Kapros, S. Environmental sustainability in seaports: a framework for successful innovation. *Maritime Policy and Management* [online]. 2014, vol. 41, no. 5, p. 480–500. eISSN: 1464-5254. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1080/03088839.2014.932926>.

[17] Tijan, E.; Jović, M.; Perić Hadžić, A. Achieving Blue Economy goals by implementing digital technologies in the maritime transport sector. *Pomorstvo : Scientific Journal of Maritime Research* [online]. Rijeka: Pomorski fakultet u Rijeci, 2021, vol. 35, no. 2, p. 241–247. eISSN 1846-8438. [Accessed: 14 June 2022]. Available at: <https://hrcak.srce.hr/267177>.

[18] Environmental Port Index. *EPI: Environmental Port index* [online]. Bergen: EPI, 2020. [Accessed: 17 February 2022]. Available at: <https://epiport.org/>.

[19] Environmental Ship Index. *Environmental Ship Index (ESI)* [online]. Rotterdam: ESI, 2022. [Accessed: 17 February 2022]. Available at: <https://www.environmentalshipindex.org/>.

[20] Swedish Environmental Research Institute (IVL). *Clean Shipping Index* [online]. Stockholm: IVL, 2015. [Accessed: 17 February 2022]. Available at: <https://www.cleanshippingindex.com/>.

[21] International Maritime Organization. Energy Efficiency Measures. In: International Maritime

Organization. *IMO International Maritime Organization* [online]. London: IMO, 2019. [Accessed: 17 February 2022]. Available at: <https://www.imo.org/en/OurWork/Environment/Pages/Technical-and-Operational-Measures.aspx

[22] Stanković, J. J.; Marjanović, I.; Papathanasiou, J.; Drezgić, S. Social, economic and environmental sustainability of port regions: MCDM approach in composite index creation. *Journal of Marine Science and Engineering*, [online]. 2021, vol. 9, no. 1, p. 1–17. ISSN: 2077-1312. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.3390/jmse9010074>.

[23] Široka, M.; Piličić, S.; Milošević, T.; Lacalle, I.; Traven, L. A novel approach for assessing the ports' environmental impacts in real time: the IoT based port environmental index. *Ecological Indicators* [online]. Elsevier, January 2021, vol. 120. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1016/j.ecolind.2020.106949>.

[24] Notteboom, T. E.; Winkelmans, W. Structural changes in logistics: how will port authorities face the challenge? *Maritime Policy & Management* [online]. 2001, Vol. 28, no. 1, p. 71–89. eISSN: 1464-5254. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1080/03088830119197>.

[25] Ferrari, C.; Percoco, M.; Tedeschi, A. Ports and local development: evidence from Italy. *International Journal of Transport Economics* [online]. 2010, vol. 37, no. 1, p. 9–30. [Accessed: 14 June 2022]. Available at: <http://www.libraweb.net/articoli3.php?chiave=201006701&rivista=67&articolo=201006701001>. Available at: <https://doi.org/10.1400/133646>.

[26] European Commission. Country level: gross weight of goods handled in all ports. In: *Eurostat* [online] European Commission, 2021. [Accessed 27 January 2022]. Available at: <https://ec.europa.eu/eurostat/databrowser/view/mar_mg_aa_cwh/default/table?lang=en>.

[27] Grobar, L.M. The economic status of areas surrounding major U.S. container ports: evidence and policy issues. *Growth and Change* [online]. Willey, September 2008, vol. 39, no. 3, p. 497–516. ISSN1468-2257. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1111/j.1468-2257.2008.00435.x>.

[28] Viana, M.; Hammingh, P.; Colette, A.; Querol, X.; Degraeuwe, B.; Vlieger, I.D; Van Aardenne, J. Impact of maritime transport emissions on coastal air quality in Europe. *Atmospheric Environment* [online]. Elsevier, June 2014, vol. 90, p. 96–105. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1016/j.atmosenv.2014.03.046>.

[29] Bailey, D.; Solomon, G. Pollution prevention at ports: clearing the air. *Environmental Impact Assessment Review* [online]. October-November 2004, vol. 24, no. 7–8, p. 749–774. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1016/j.eiar.2004.06.005>.

[30] Chang, C.C.; Wang, C.M. Evaluating the effects of green port policy: case study of Kaohsiung harbor in Taiwan. *Transportation Research Part D: Transport and Environment* [online]. Elsevier, May 2012, vol. 17, no. 3, p.185–189. [Accessed 14 June 2022]. Available at: <https://doi.org/10.1016/j.trd.2011.11.006>.

[31] Maritime Technology Cooperation Centre in the Pacific (MTCC Pacific). *Regional workshop on energy management in ports : Auckland, New Zeland, 31 July-2 August, 2017* [online]. MTCC

Pacific, 2017. [Accessed 14 June 2022]. Available at: <https://tuit.cat/0H3li>.

[32] GEF-UNDP-IMO GloMEEP Project and IAPH. *Port Emissions Toolkit, Guide No.2, development of port emissions reduction strategies* [online]. London: GloMeep Project Coordination Unit, 2018. [Accessed: 14 June 2022]. Available at: <https://glomeep.imo.org/news/addressing-emissions-in-ports-in-panama/>.

[33] European Sea Ports Organisation. *ESPO Green Guide 2021: a manual for European ports towards a green future* [online]. Brussel: ESPO, 2021. [Accessed: 25 February 2022]. Available at: <https://www.espo.be/publications/espo-green-guide-2021-a-manual-for-european-ports->.

[34] European Commission. Greenhouse gas emissions per capita. In: *Eurostat* [online]. European Commission, 2021 [Accessed: 27 January 2022]. Available at: <https://ec.europa.eu/eurostat/databrowser/view/t2020_rd300/default/table?lang=en>.

[35] Nitonye, S.; Uyi, O. Analysis of marine pollution of ports and jetties in Rivers State, Nigeria. *Open Journal of Marine Science* [online]. January 2018, vol. 8, no. 1, p. 114–135. ISSN 2161-7392. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.4236/ojms.2018.81006>.

[36] Elenwo, E.I.; Akankali, J.A. The effects of marine pollution on Nigerian Coastal resources. *Journal of Sustainable Development Studies* [online]. 2015, vol. 8, no. 1, p. 209–224. ISSN 2201-4268. [Accessed: 14 June 2022]. Available at: <https://www.infinitypress.info/index.php/jsds/article/view/1099>.

[37] Svaetichin, I.; Inkinen, T. Port waste management in the Baltic Sea Area: a four port study on the legal requirements, processes and collaboration. *Sustainability* [online]. 2017, vol. 9, no. 5. eISSN 2071-1050. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.3390/su9050699>.

[38] International Institute for Sustainable Seaports. *Environmental initiatives at seaports worldwide: a snapshot of best practices*. Portland: Port of Portland, June 2013.

[39] Lirn, T. C.; Wu, Y.C.J.; Chen, Y.J. Green performance criteria for sustainable ports in Asia. *International Journal of Physical Distribution and Logistics Management* [online]. Emerald Publishing, 2013, vol. 43, no. 5, p. 427–451. ISSN 0960-0035. [Accessed: 14 June 2022]. Available at: <https://doi.org/10.1108/IJPDLM-04-2012-0134>.

[40] The World Association for Waterborne Transport Infrastructure (PIANC). *Sustainable ports: a guide for port authorities* [online]. Brussel: PIANC, 2014. Report 150. ISBN 978-2-87223-218-5. [Accessed: 14 June 2022]. Available at: <https://sustainableworldports.org/project/pianc-sustainable-ports-guide/>.

[41] United Nations Conference on Trade and Development (UNCTAD). *Review of maritime transport 2020* [online]. Geneva: UNCTAD, 2020. ISBN 9789210052719. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.18356/9789210052719>.

[42] Alamoush, A.S.; Ballini, F.; Ölçer, A.I. Revisiting port sustainability as a foundation for the implementation of the United Nations Sustainable Development Goals (UN SDGs). *Journal of Shipping and Trade* [online]. 2021, vol. 6, no. 19, p. 1-40. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.1186/s41072-021-00101-6>.

[43] Denktas-Sakar, G.; Karatas-Cetin, C. Port sustainability and stakeholder management in supply chains: a framework on resource dependence theory. *Asian Journal of Shipping and Logistics* [online]. Elsevier, December 2012, vol. 28, n. 3, p. 301–319. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.1016/j.ajsl.2013.01.002>.

[44] Oh, H.; Lee, S.W.; Seo, Y.J. The evaluation of seaport sustainability: the case of South Korea. *Ocean and Coastal Management* [online]. Elsevier, July 2018, vol. 161, p. 50–56. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.1016/j.ocecoaman.2018.04.028>.

[45] Hua, C.; Chen, J.; Wan, Z.; Xu, L.; Bai, Y.; Zheng, T.; Fei, Y. Evaluation and governance of green development practice of port: a sea port case of China. *Journal of Cleaner Production* [online]. Elsevier, 2020, vol. *249*. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.1016/j.jclepro.2019.119434>.

[46] Mudronja, G.; Jugović, A.; Škalamera-Alilović, D. Research and development and rconomic growth: EU port regions. *Zbornik Radova Ekonomskog Fakulteta u Rijeci* [online]. 2019, vol. 37, no. 2, p. 587–602. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.18045/zbefri.2019.2.587>.

[47] De Langen P.; Turró, M.; Fontanet, M.; Caballé, J. *The infrastructure investment needs and financing challenge of European ports* [online]. Brussel: ESPO, 2018. [Accessed: 15 June 2022]. Available at: <https://www.espo.be/media/Port%20Investment%20Study%202018_FINAL_1.pdf>. Available at: <http://hdl.handle.net/2117/128444>.

[48] European Commission. Gross domestic expenditure on R&D by sector. In: *Eurostat* [online]. European Commission, 2021. [Accessed: 16 February 2022]. Available at: <https://ec.europa.eu/eurostat/databrowser/view/sdg_09_10/default/table?lang=en>.

[49] Geerlings, H.; Wiegmans, B. Technological innovations. In: Geerlings, H.; Kuipers, B.; Zuidwijk, R. (eds.). *Ports and networks, strategies, operations and perspectives* [online]. Routledge, 2018, p. 332–347. ISBN 9781472485038. [Accessed: 15 June 2022]. Available at: <https://www.routledge.com/Ports-and-Networks-Strategies-Operations-and-Perspectives/Geerlings-Kuipers-Zuidwijk/p/book/9781472485038>.

[50] Tijan, E.; Agatić, A.; Jović, M.; Aksentijević, S. Maritime National Single Window: a prerequisite for sustainable seaport business. *Sustainability* [online]. 2019, vol. 11, no. 17, p. 1–21. eISSN 2071-1050. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.3390/su11174570>.

[51] Donnelly, J. Ports in the cloud: the next step in automation? In: *Port Technology* [online]. London: Maritime Information Services, 9 November 2018. [Accessed: 16 February 2022]. Available at: <https://www.porttechnology.org/news/ports_in_the_cloud_the_next_step_in_automation/>.

[52] Insight: four trends of ports to watch in 2019.In: *The Motorways of the Sea Digital Multichannel Platform: On the MoS Way* [online]. Circle, 11 January 2019. [Accessed: 16 February 2022]. Available at: <https://www.onthemosway.eu/insight-four-trends-of-ports-to-watch-in-2019/?cn-reloaded=1>.

[53] Tijan, E.; Aksentijević, S.; Ivanić, K.; Jardas, M. Blockchain Technology Implementation in Logistics. *Sustainability* [online]. 2019, vol. 11, no. 4, p. 1–13. eISSN 2071-1050. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.3390/su11041185>.

[54] Francisconi, M. An explorative study on blockchain technology in application to port logistics [online]. Master Thesis, Delft University of Technology, 2017. [Accessed: 16 February 2022]. Available at: <https://repository.tudelft.nl/islandora/object/uuid%3Ab1de98dd-f1a7-456a-b8cb-4d87dc2c4f9f>.

[55] Xia, J.; Wang, K.; Wang, S. Drone scheduling to monitor vessels in emission control areas. *Transportation Research Part B: Methodological* [online]. Elsevier, January 2019, vol. 119, p. 174–196. [Accessed: 15 June 2022]. Available at: <https://doi.org/10.1016/j.trb.2018.10.011>.

[56] Taylor, D. Drones in logistics: a how-to guide for beginners. In: *Capterra blogs* [online]. Arlington: Capterra, 2018. [Accessed: 16 February 2022]. Available at: <https://blog.capterra.com/drones-in-logistics-how-to-guide/>.