Acta logistica - International Scientific Journal about Logistics
Volume: 10 2023 Issue: 2 Pages: 291-304 ISSN 1339-5629

**Lean 4.0 in port management: an alternative to support the development of the circular economy in the sector**
Andrei Bonamigo, Pamela Oliveira Arcanjo, Maria Juliane Goncalves, Newton Narciso Pereira, Dierci Marcio Cunha da Silveira

*https://doi.org/10.22306/al.v10i2.395 Received: 03 Mar. 2023; Revised: 22 Apr. 2023; Accepted: 09 May 2023*

# Lean 4.0 in port management: an alternative to support the development of the circular economy in the sector

**Andrei Bonamigo**
Department of Production Engineering, Universidade Federal Fluminense-UFF, Volta Redonda/RJ, Brazil, andreibonamigo@gmail.com (corresponding author)
**Pamela Oliveira Arcanjo**
Department of Administration and Public Administration, Universidade Federal Fluminense-UFF, Volta Redonda/RJ, Brazil, arcanjopamela3@gmail.com
**Maria Juliane Goncalves**
Department of Production Engineering, Universidade Federal Fluminense-UFF, Volta Redonda/RJ, Brazil, juliane_goncalves@id.uff.br
**Newton Narciso Pereira**
Department of Production Engineering, Universidade Federal Fluminense-UFF, Volta Redonda/RJ, Brazil, newtonpereira@id.uff.br
**Dierci Marcio Cunha da Silveira**
Department of Production Engineering, Universidade Federal Fluminense-UFF, Volta Redonda/RJ, Brazil, diercisilveira@id.uff.br

***Keywords:*** circular economy, lean port terminal, port management, Lean 4.0.
***Abstract:*** Ports and terminals are directly related to world economic development due to international trade. In this sense, port management has expanded actions in terms of sustainability and mainly linked to circular economy (CE). The port environment is not alien to society's developments and for that it needs to improve its efficiency and operability, reducing the waste of time, processes and waste generated within it. In this context, this research links the Lean 4.0 concept with the circular economy as an alternative for the development of the port sector. The study is based on highlighting the challenges and advantages of implementing CE in ports through Lean 4.0. To achieve the objective of this research, a literature review was carried out based on the Sytematic Research Flow - SSF method proposed by Ferenhof and Fernandes (2016), followed by a content analysis based on Bardin (2011). Based on the findings, it was possible to list the key elements linked to Lean 4.0 correlated with the circular economy to stimulate the sustainability of the port sector. It was identified that Lean 4.0 presents itself as a simplifier for the implementation of the circular economy culture, since it enables the alignment of people to identify waste, stimulates innovation and the development of a culture aimed at continuous improvement in the sector.

## 1 Introduction

The advance of international trade and its expansion are important factors for the economic growth of countries [1]. Seaports have an impact on the economy of the port region and the environment in which they are located, they are the gateway to international trade. A large portion of international trade is handled by seaports [2]. In this way, policies aimed at the port system play a role directly related to the economic development of countries [3]. The port sector presents itself as one of the major obstacles to international trade in Brazil. The need for adequate infrastructure implies significant investment to ensure that cargo can flow through ports and terminals [4].

With the increase in cargo movement in ports, it becomes even more necessary to preserve the ecosystem and the search for resources that reduce environmental impacts. Research shows that activities related to this subject in ports are low, in order to develop initiatives focusing on environmental challenges, followed by economic ones, this article elucidates positive contributions about Lean 4.0 in the port circular economy as an alternative for the development of management port [5].

The circular economy (CE) has become increasingly evident in the political sphere, after the release of the plan that describes actions for the circular economy published in 2015 to the Green Deal, launched in 2019 by the European Commission, and the circular economy representing the port authorities belonging to the Member States of the European Union, legitimizing ports as components of great importance when it comes to achieving sustainability goals [6].

Based on the above, this article seeks to link Lean 4.0 as a tool to foster the circular economy for the development of management in ports. The Lean Port Terminal concept comprises a management system based on the Lean Thinking concept, which comprises principles, tools, methods and management practices for continuous improvement, increased earnings and elimination of waste

in the port sector from the perspective of the customer [7]. The elimination of this waste results in operational processes that are more focused on quality, productivity and low cost, creating a basis for operational excellence and ensuring competitiveness [8].

With the implementation of this management system, it is possible to create proposals aimed at ensuring the ability to compete, maintain, manage and operate the entire port system based on the application of the Green Deal (GD) using circular economy resources [5].

In this way, this research links the Lean 4.0 concept with the circular economy as an alternative for the development of port management.-We hope to answer the following research question: How can the Lean 4.0 approach support ports and terminals in the context of the circular port economy? Then, this study is based on highlighting the challenges and advantages of implementing CE in ports through Lean 4.0. To achieve the objective of this research, a Systematic Literature Review - SLR literature review was carried out based on the Systematic Research Flow - SSF method and a content analysis.

The main contribution of this article is to address a topic that is still little discussed in the port environment, as well as to present alternatives to maximize gains in terms of port sustainability with the adoption of Lean Thinking and the circular economy. By combining these two approaches, it is possible to encourage sustainable management for ports, in order to provide operational efficiency and reduce the environmental impact with the implementation of environmental management systems and certifications related to sustainability, based on Lean management. together with technologies arising from industry 4.0. Lean 4.0 allows the adoption of cutting-edge technologies and equipment that promote energy efficiency and the reduction of emissions, fostering the circular economy through the implementation of reuse programs, reduction and recycling of materials, investments in research and development of new technologies and solutions to promote the circular economy and port sustainability.

## 2 Research background

Lean emerged in Japan, in view of the observation by the Toyota automobile industry that it would not be possible to fund the reconstruction of its facilities, which were dismantled in the Second World War, and even in this scenario it was possible to manufacture a wide range of products and reduce defects, inventories, investments and workers' efforts [9].

One of the pillars of Lean is addressed as the human factor, successfully challenged mass production practices, providing greater flexibility of production systems and processes, resulting in products and supply chains, with less waste [10]. The elimination of waste is guided by five basic principles established in the book Lean Thinking, by Womack and Jones (1996):

1) Specify value: identify which activities add value;
2) Map the value stream: create a visual representation of all activities to easily identify waste;
3) Flow: products and services must move immediately between activities that add value;
4) Pull: customer demand should dictate the flow rate;
5) Perfection: improvement must be continuous

Lean brings benefits for organizations to be more competitive, as it creates value for customers by eliminating all waste from activities and obtaining lean processes with high economic efficiency. Due to this there has been a wide adoption of Lean practices in different sectors and scenarios in the last three decades [12-14].

Through research in manufacturing companies in developed countries it is possible to conclude that Lean can be a prerequisite for digital technology using technologies in production [15]. In this context, Industry 4.0, which emerged in Germany, with the idea of an integrated industry and expanded to other countries in the world with different government initiatives as a global technological trend, can help in the prerequisites of Lean [16].

Industry 4.0 is characterized by digital transformation and is considered the fourth industrial revolution. The core of this environment is the integrated use of technologies, such as: Internet of Things, Cybersecurity, Augmented Reality, Big Data – analysis and interpretation of large volumes of data, Robotic Automation, Additive Manufacturing, Simulation, Systems Integration, The Cloud - Managing Systems in the Clouds [17].

Taking the Technische Universität Dortmund study as a reference, there are four key components for the realization of Industry 4.0 [18]. These elements are classified as Cyber-Physical Systems (CPS), Internet of Things (IoT) and Internet of Services (IoS) and Smart Factory [19]. With Industry 4.0 components, such as the use of intelligent transport equipment in order to implement a system to gather materials driven by demand, it shows when a certain component is ready to be collected and only authorizes transport when there is demand. With this, there is a reduction of waste, taking employees out of an unnecessary activity [20].

The automation associated with Industry 4.0, questions regarding the integration between approaches and the role of Lean in this industrial revolution are ongoing. As an example, current and future state mapping is available on mobile devices, enabling human-machine integration. As all the data is stored in the “cloud”, the information can be shared between the different departments, enabling fast-time requests for spare parts, dynamic scheduling of maintenance activities and transparency of the information generated. The results show that Industry 4.0 tools can help Lean achieve the objectives [10].

The general objectives of Industry 4.0 are to allow improvements in the value streams of companies, addressing issues related to processes and

products/services [21,22]. Industry 4.0 is decentralized intelligence to facilitate the creation of independent process management through the interaction of the real and virtual worlds. This means that industrial machines no longer just deal with products, but products interact with these machines to tell them exactly what to do [23].

The increase in international competition, the growing volatility of the market, the great demand for diversified services stands out as the main challenges for organizations. Ports are facing a myriad of new complex challenges to meet the high complexity in the production environment while focusing on customer benefit. [24]

The combination of Lean Production and Industry 4.0, known as Lean 4.0, are interconnected and complex elements to implement. It is essential to develop a reference implementation strategy for the port system. Faced with numerous challenges for the port sector and considering that exports and imports pass through ports, it is essential to ensure the efficiency of this sector, which is fundamental for trade and development [25].

On the other hand, to extend sustainability throughout the supply chain, companies often choose to implement different management practices. In the literature, the practices used to manage circularity, efficiency and optimization of resources are called Circular Economy (CE) [26]. EC proposes replacing wasteful and inefficient linear and open production cycles with a closed cycle where waste is minimized or transformed into inputs and value is created in the process, enabling the balance between economic growth and a sustainable environment [27,28].

In an EC model, waste becomes resources to be recovered and valued through recycling and reuse, the value of the resources we extract and produce must be kept in circulation through intentional and integrated production chains [29]. Then, a sustainable approach consists of minimizing negative environmental impacts, reducing the ecological footprint, neutralizing emissions and increasing resource efficiency, that is, continuing to do things in the same way, only with less intensity, but not changing direction, just ensure that future generations are not impacted [30,31].

The EC has gained significant attention at the policy level since the publication of the Action Plan for the EC in 2015. In 2019, the European Commission launched the Green Deal (GD), which is a European green deal with a set of strategic policies articulated by the commission European Union in order to contain the threat of global warming. The circular economy represents an essential component for the future sustainability of European society. In addition, the GD recognizes ports as extremely important entities for achieving sustainability goals [5].

In early 2020, the European Sea Ports Organization (ESPO), representing port authorities in member states of the European Union. A position paper on a GD and circular economy was presented, mirroring seaports as strategic partners in the implementation of GD objectives. Thus, seaports are identified as excellent entities for EC practice and implementation.

This is due to the fact that ports are interconnected with industry and urban areas, constantly exchanging flows of materials and resources, including waste, with the environment of their neighborhood and the interior, so they are essential entities to develop the EC, and has focused on this transition [32].

However, there is limited research on ports and their acceleration to a CE, especially from a practical and implementation point of view [33-35]. Current EC activities in ports are low. Still, substantial improvements are anticipated when ports overcome implementation hurdles, causing the current implementation inhibition in adopting a CE [36]

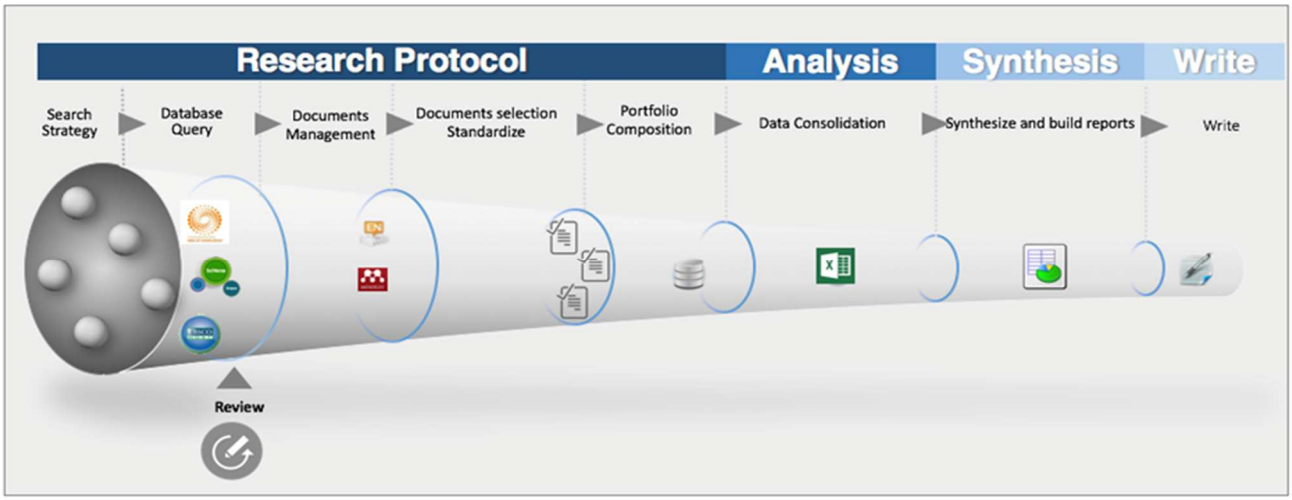
To eliminate waste and ensure an appropriate destination for waste, in 1996 the term Lean and Green (L & G) appears. It addresses the need for environmentally conscious manufacturing, integrating process improvements with reduced environmental impact. Early publications on L&G focused on how to make a link between Lean principles, environmental principles and practices, with emphasis primarily on manufacturing and supply chain management. L&G emerged as a combination of environmental and sustainability concepts. It refers to the synergy between Lean and environmental preservation. More specifically, it focuses on how Lean practices can contribute to reducing environmental impact while keeping profits primarily in operation as well as service and product design. The topic has generated more and more research of interest since 2013 [37]. The different industries in the transport and logistics sector are often targeted for their greenhouse gas (GHG) emissions and their ability to pollute on an intercontinental level. Intercontinental supply chains are strongly centered on seaports, which, due to their interaction with ships that use fossil fuels, generate emissions [38].

## 3 Research methodology

The present study aims to recognize the links of Lean 4.0 in the port circular economy as an alternative for the development of port management. In this sense, the present work has a qualitative approach, where it is not necessary to use statistical techniques, as this research is descriptive in nature, aiming at identifying, pointing out and analyzing the factors, characteristics, or variables that relate to the process [39].

In order to answer the problems highlighted in the research, firstly, a SLR was conducted based on the SSF method, as a way to recognize in the literature the current theoretical context of Lean and circular economy in the port context [40]. The Figure 1 exposes the steps of SLR conducted.

*Figure 1 - SSF method [40]*




Following the method SSF, the Scopus, Emerald, Ebsco and Web of Science databases were consulted. The query was carried out on October 17, 2022. For the calibration of the search string, a set of keywords were evaluated, such as Lean, industry 4.0, among others related to the scope of the search, but there was no return on the queries. searches in the consulted databases. Thus, the search string adopted was ("circular economy" AND Lean AND port*). Boolean operators such as “AND”, “OR” and “NOT” were combined in the string calibration step. Table 1 presents the results from the searches conducted in the databases, according to the SSF method [40].

*Table 1 Number of documents consulted by database*

| Source Database | Number of documents |
|---|---|
| Scopus | 61 |
| Web of Science | 52 |
| Emerald | 44 |
| Ebsco | 23 |
| Total Selected Articles | 180 |
| Duplicated | (-51) |
| **Total Evaluated Articles** | 129 |

As shown in Table 1**,** a total of 180 papers were found in the consulted databases, however, 51 papers were duplicated, which resulted in a total of 151 papers for analysis by the authors. For the analysis of the 151 works, the following research questions were used as criteria for inclusion or for the analysis of the 151 papers, the following research questions were used as criteria for inclusion or exclusion from the resulting portfolio: Does the paper have any managerial implications linked to Lean 4.0 for the development of the circular economy in ports? Does the paper present any insight linked to the development of ports that implies the circular economy? Does the paper have any relationship with the adoption of industry 4.0 for the development of the circular economy in ports?

Then, the title, abstract and keywords of the papers were read, as a first filter. For the resulting papers, the reading of the introduction and conclusion of the papers was carried out. Finally, the complete reading of the resulting papers. Both listed phases were based on the SSF method. A total of 16 papers made up the final portfolio.

Subsequently, the content analysis was conducted. Thus, in the first stage, a pre-analysis was carried out, a bibliographical survey of studies, articles and documents related to the difficulties faced by the port system was carried out, which provided the basis for the study [41].

After that, the interpretation obtained from the previous steps was outlined. In this way, the main limitations to adopting the circular economy in the port system were highlighted, in addition to listing how Lean 4.0 can effectively contribute to solving these challenges for ports. With that, the content analysis was developed with the composition of information that allow the understanding of the researcher in relation to the materials coming from the literature in an orchestrated way [42].

## 4 Result and discussion

Based on the application of the filters proposed by the SSF method, a total of 16 papers resulted. The jobs are listed in Table 2.

*Table 2 Portfolio of works arising from the Bibliographic Review*

| Code | Title | Author (Year) | Source |
|---|---|---|---|
| **A1** | A Conceptual Model for Measuring a Circular Economy of Seaports: A Case Study on Antwerp and Koper Ports | Rebeka et al., (2022) | Sustainability |
| **A2** | System-based barriers for seaports in contributing to Sustainable Development Goals | Hansini et al., (2022) | Maritime Business Review |
| **A3** | Assessing the Possibilities of Integrating Ports into the Circular Economy | Alen et al., (2022) | Tehnicki Vjesnik |
| **A4** | An overview of operations and processes for circular management of dredged sediments | Crocetti et al., (2022) | Waste Management |
| **A5** | Nexus of Circular Economy and Sustainable Business Performance in the Era of Digitalization: A Comprehensive Review and Network Based Analysis | Rohit et al., (2022) | International Journal of Productivity and Performance Management |
| **A6** | Digital Technologies for Sustainable Waste Management On-Board Ships: An Analysis of Best Practices From the Cruise Industry | Assunta et al., (2022) | IEEE Transactions on Engineering Management |
| **A7** | A Virtuous Circle? Increasing Local Benefits from Ports by Adopting Circular Economy Principles | Toby et al., (2021) | Sustainability |
| **A8** | Port City Sustainability: A Review of Its Research Trends | Ying et al., (2020) | Sustainability |
| **A9** | The Role of Seaports in Green Supply Chain Management: Initiatives, Attitudes, and Perspectives in Rotterdam, Antwerp, North Sea Port, and Zeebrugge | Theo et al., (2020) | Sustainability |
| **A10** | Seaports as Nodal Points of Circular Supply Chains: Opportunities and Challenges for Secondary Ports | Marta et al., (2020) | Sustainability |
| **A11** | Patterns of Circular Transition: What Is the Circular Economy Maturity of Belgian Ports | Elvira et al., (2020) | Sustainability (Switzerland) |
| **A12** | Port Strategy for Sustainable Development: Circularization and Value Creation—Introduction to a Special Issue | Elvira et al., (2020) | Sustainability |
| **A13** | Circular economy: benefits, impacts and overlapping | Sehnem, et al., (2019) | Supply Chain Management: An International Journal |
| **A14** | Circular economy approach to facilitate the transition of the port cities into self-sustainable energy ports—a case study in Copenhagen-Malmö Port (CMP) | Reza et al., (2019) | WMU Journal of Maritime Affairs |
| **A15** | Securing a port's future through Circular Economy: Experiences from the Port of Gävle in contributing to sustainability | Carpenter, et al., (2018) | Marine Pollution Bulletin |
| **A16** | Deep decarbonisation pathways for the industrial cluster of the Port of Rotterdam | Sascha et al., (2018) | ECEEE Industrial Summer Study Proceedings |

After analyzing the articles, we highlighted the most relevant methodologies and studies regarding the opportunities and challenges to be addressed by Lean 4.0 in the circular port economy as an alternative for the development of port management. Table 3 was built after a complete analysis of 16 articles, and then it was separated into the most relevant topics, separated into groups according to frequency.

*Table 3 Content analysis*

| Record Unit | Context Unit | Freq |
|---|---|---|
| **Efficiency gains** | A14- Some EC ports have moved towards less dependence on fossil fuels for renewable sources, systematic improvement of energy efficiency and optimization of waste management | 8 |
| | A11- Industries use port facilities that operate beyond port boundaries. | |
| | A10- Circular supply chains generate a higher demand for transport compared to linear supply chains | |
| | A12- EC transition from ports may imply shorter, more regional and local flows of goods when favorable transport modes are used | |
| | A15- EC can help ports respond to challenges and ensure their competitiveness in the face of limited resources, while promoting innovation and reducing environmental impacts port | |

| | | |
|---|---|---|
| | transition can imply shorter, regional and locations when favorable modes of transport are used | |
| | A15- Research on EC in ports is quite limited, although there are several practical examples in European ports | |
| | A15- EC in ports can minimize the use of inputs, eliminate waste and reduce pollution, such as maximizing the value created at each stage, improving the management of bio-based resource flows and recovery of non-renewable resource flows in circuit closed efficiency | |
| | A15- The EC in ports establishes beneficial relationships between companies to promote a circular chain | |
| **Sustainability** | A16- The production of base chemicals in the port can shift from using mineral oil products as a feedstock to natural gas liquids, or it can be radically transformed to rely on plastic waste as a feedstock in a cycle approach. closed carbon. | 7 |
| | A16- Sustainably produced biomass is a scarce resource that is likely to be needed as a feedstock for low-carbon fuel | |
| | A8- Ecology is directly related to ecosystem services and sustainable development | |
| | A8- The development of clean energy technologies contributes to the reduction of pollution in ports and port cities | |
| | A4- Acid wash to remove heavy metals evidenced in container | |
| | A15- The port lifecycle in EC literature presents a case study demonstrating how both can be combined to help secure a sustainable future for one of Sweden's largest containers (industrial) ports | |
| | A15- EC in ports is a synergistic approach that combines economic, logistical and industrial activities with the cultural heritage of the port and the creativity of its wider community, resulting in a dynamic, complex process and a sustainable system. | |
| **Operational Processes** | A1- Transition from linear to circular economy using the 9R method that allows a systematic distribution of ten circular economy strategies. These are recovery, recycling, reuse, remanufacturing, refurbishment, repair, reuse, reduce, rethink, and refuse strategies. | 5 |
| | A3- “Cradle to Cradle” with the systems thinking approach that aims to extend the usage time for all materials | |
| | A4- BioGenesisSM sediment washing technology that uses physical and chemical operations to wash and decontaminate pollutants | |
| | A5- Digitization of processes and documents as one of the CE facilitators | |
| | A5- The 3R principle, reuse, reduce and recycle resources to reduce environmental impacts | |
| **Operations management** | A2- The importance of port management as a success or failure of sustainability | 4 |
| | A6- Adoption of digital technologies for waste management processes improved sustainability goals in ports | |
| | A9- The Sincro Port Platform modality, which aims to implement different means of transport for a logistics service provider in a flexible and sustainable way, as well as digital for waste management processes, has improved sustainability goals in ports | |
| | A6- Technologies reduce GHG emissions, through synthesis gas generators installed on modern ships and the transformation of waste into exploitable fuel | |
| **Integration of actors** | A3- The reverse logistics of materials from the closed cycle effectively contributes to the competitive potential | 4 |
| | A7- Cooperation between ports and cities can be drivers of progress in the circular economy in the port system | |
| | A9- The greening of supply chains building a potential for competitive advantage | |
| | A12- Collaboration between ports and stakeholder co-creation must be organized, this effectively impacts the transition to the circular economy | |
| **Cultural change** | A11- The evolutionary process in ports consists of successive levels of maturity and provides the prerequisites for improvements that lead to the next stage. These levels drive growth based on continuous improvement and incremental changes rather than radical transformations. | 3 |
| | A3- Industrial Ecology aims to help companies to use their main resources | |
| | A7- Land use is one of the biggest obstacles to port industrial development | |

| | | |
|---|---|---|
| **Investment in the sector** | A10- Chains with dangerous loads, require appropriate administrative licenses, or when the production plant in the port uses pollution-intensive technology, obstacles can be overcome by ports through investment in alternative technologies | 2 |
| | A14- There are port challenges such as insufficient budget, allocation of sources to transition from the linear structure of the ports to circular models and integration of port development plans in the city's municipal plans. | |
| **Labor Qualification** | A14-Ports suffer from a lack of specialists, professional role and validated business for new circular models. | 2 |
| | A14- There is no clear balance of responsibilities and gains between the urban areas of the city and the port areas | |

After Aspects related to the findings presented in Table 3 for each of the groups are discussed below, in order to assess the managerial implications and/or correlation of Lean 4.0 for the adoption of the circular economy in the port sector.

**A) Efficiency gains**

From the adoption of Lean 4.0 Lean 4.0 in the port circular economy as an alternative for the development of port management, advantages of efficiency gains can be observed, since the EC can help ports to respond to challenges and ensure their competitiveness in a world with limited resources, so that inefficiencies and waste in the port sector are combated, as well as the flow can be improved in ports [10,12].

In this sense, innovation can be a strategy for mitigating environmental impacts, from the internal perspective of the port and the neighboring community of port regions [15]. In this sense, the reduction of pollution through the use of alternative fuels can be considered as an example, which can impact on the reduction of production costs and environmental protection, via the reduction of emissions from ports [15].

At the same time that it promotes innovation and reduces environmental impacts, considering that ports are relevant indicators for the world economy, due to their role in global production and distribution systems. For this reason, they are under increasing pressure to become increasingly environmentally conscious [31,61].

EC in ports focuses on: minimizing the use of inputs and the elimination of waste and pollution, maximizing the value created at each stage, management of bio-based resource flows and recovery of non-renewable resource flows in a closed loop. In this way, the closed-loop model, based on the circular economy, becomes viable, seeking to add value to the large amount of waste generated in the port sector. Some EU ports have moved towards less dependence on fossil fuels for renewable sources, systematically improving energy efficiency and optimizing waste management, in response to resource performance. With this, the aim is to replace the linear model that the port system currently adopts “take-do-discard” with sustainable structures [43].

Circular supply chains generate a higher demand for transport compared to linear supply chains, which has an impact on the efficiency gain of circular chains [32]. Circular chains are strategies and have the ultimate goal of interactively supporting sustainability [44]. Therefore, via Lean 4.0 applied to the port sector, it can positively impact the reduction of environmental problems, increase its operational efficiency and higher quality of customer services, as well as economic benefits and environmental preservation for the port sector and society [33].

**B) Sustainability**

Sustainability has become one of the main issues when related to development in society and in the industrial sector. In port cities, the sustainability relationship related to the operating limits between ports and ships is one of the factors promoting a with Lean 4.0 approaches, and many ports operate beyond their limit. Lean 4.0 brings sustainable gains in the sector port, the sustainability category brings techniques to reduce gas emissions through systems for transforming waste into fuel, which acquire the possibilities of being explored by ports [45].

The production of base chemicals in ports can shift from using mineral oil products as a feedstock to natural gas liquids, or it can be radically modified to give rise to plastic waste as a feedstock in a cycle approach. closed carbon. Sustainably produced biomass, on the other hand, is a scarce resource that is likely to be needed as a feedstock for low-carbon fuel [46].

In this way, the development of clean energy technologies seeks to generate a broad perspective for the reduction of pollution in ports and cities [47]. For this reason, the EC concept is an important factor for ports to respond to challenges and ensure their competitiveness in the face of limited resources, while promoting innovation and reducing environmental impacts [31]. Another strategy for removing pollutants is acid washing to remove heavy metals and the BioGenesisSM sediment washing technology to wash and decontaminate sediments. This technology has already been adopted in ports of Venice, New York and New Jersey, its removal varies from 60 to 80%, depending on the sedimentary matrix [48]. In this way, we can highlight as an important factor for the impact of the environment a “green” management for companies that get involved in the supply chain, allowing to obtain a competitive advantage and, even so, to contribute to a sustainable environment [50].

In this sense, studies demonstrate the advancement of technology in equipment at container terminals as the main factor in creating value in terms of port sustainability, as the use of advanced technologies can reduce operating costs and improve efficiency, while at the same time minimizes the environmental impact.

For example, equipment such as cranes, forklifts and conveyors are responsible for handling cargo within ports and with the advancement of technology they have become more efficient and less polluting. In addition, the technology can also be used to improve safety in the workplace by reducing the risk of accidents, with sensors and cameras to monitor the movement of equipment and loads, and the implementation of warning systems to avoid collisions and other risk situations. It is, therefore, a crucial sustainability factor in ports, allowing them to become more efficient, safe and environmentally responsible [57].

**C) Methodological tools**

In the topic of methodological tools, we highlight the use of technologies to assist the port system in the transition to EC that can be implemented through the Lean 4.0 methodology. Smart digitization stands out as one of the transitions to EC, creating possibilities for new flows and greater data control, reducing the number of leaves that are usually used in these processes, and consequently reducing carbon emissions into the atmosphere [49,62].

The 3R principle is an important approach to sustainability in the port sector, as it seeks to minimize waste and reduce environmental damage in ports, promoting the most efficient use of resources and waste reduction. Reuse involves the practice of reusing materials or products before discarding them, this can include reusing transport packaging such as wooden or plastic crates rather than simply discarding them after use. The reduction, on the other hand, brings a decrease in the consumption of resources and materials, involving the reduction in the use of energy, water and raw materials in the port operation.

While, recycling, seeks to transform waste into new products or materials, reducing the amount of waste that ends up in landfills or in the environment, with programs for selective collection and recycling of solid waste, such as cardboard, plastic and metal. In addition to the 3R, other sustainable practices in the port sector include the proper management of hazardous waste, the conservation of local biodiversity, the use of renewable energy sources and the promotion of environmental education among port workers and the local community [49].

The importance of the transition from the linear to the circular economy is highlighted, through the 9R method, which uses recovery, recycling, reuse, remanufacturing, reform, repair, reuse, reduction, rethink and refuse strategies, enabling a systemic structuring of ten circular strategies of the economy through the recognition of weaknesses, strengths, opportunities and possibilities for improvement. This method provides us with a detailed view of the circular processes of seaports from the indicators and makes it possible to use the method as a facilitator for the implementation of this new model in the port system, enabling the construction of a human behavior in commitment to environment [5]. The Cradle-to-Cradle approach of Lean, which consists of creating products and industrial processes inspired by natural methods, increasing the useful life of materials used in ports, contributing to environmental preservation, reducing pollution and soil contamination, in addition to energy savings [49].

**D) Operations management**

The Operations Management category shows how the perception of port management of a port can influence the success or decline in development and recognize the implications of Lean 4.0 for the development of the port circular economy. In this case, an innovative port management is necessary in terms of managing the system and implementing a new philosophy in the sector [7,52].

Ports and maritime shipping networks are essential for transporting goods and materials in the global supply chain, but they can also be significant sources of energy consumption and pollution. Ships and port operations consume large amounts of fossil fuels, emitting greenhouse gases and other pollutants that affect air and water quality. To mitigate emissions from ships in ports, it is essential that port managers adopt sustainable practices and seek innovative solutions to reduce the environmental impact and promote sustainability in their operations [51].

Investment and the search for digital technologies are presented as a contribution to the development of a “green” culture in ports. The adoption of these technologies aims to bring about improvements in indicators in the fulfillment of sustainability goals when applied, for example, in waste management processes. In this way, it is possible for ships to map the stages of waste disposal or recycling and establish short-term events during the voyage, not only sharing data regarding the use of digital technologies in individual processes, but also developing best practices in the port system [45].

At the same time, the flexible and sustainable deployment of diverse transport modes in a logistics service provider framework. This allows the customer (shipper or dispatcher) to obtain an integrated transport solution called Synchro modality. Thus, it is defined as the flexible and sustainable deployment of different modes of transport in a network under the direction of a logistics service provider [48].

**E) Integration of actors**

From the adoption of Lean 4.0 to promoting a CE in the port sector, one can observe the advantages of cultural change in the face of the challenges of the sector. Despite the existing conceptual diversity, it is possible to note that the idea of innovation is related to changes and new factors that disrupt the existing balance [53].

In view of this, it is essential that this change be promoted in view of the transformation of procedures and the need for adaptability of employees, resulting in the recognition of the benefits achieved with the development of the port circular economy. The evolutionary process in ports at successive levels of maturity provides the prerequisites for improvements leading to the next stage.

Integration between actors from a Lean 4.0 perspective can be characterized, for example, with the collaboration of ports with other actors in the business environment, which go beyond the value stream (value chain), such as universities and centers of research, which require knowledge and information to help build the circular economy in the port system and can bring many benefits to the implementation of this new approach such as knowledge sharing, since universities are institutions that constantly produce knowledge and innovation, and can bring new perspectives and solutions for the challenges faced by the port sector and the awareness and engagement of the population with the active participation of the whole society, including companies, consumers and governments, resulting in the development of research projects that seek innovative solutions for specific challenges faced by the port sector [36,63,65].

Industrial ecology and the contribution to the use of key resources by companies account for a product throughout its life cycle, such as tracking the flows of materials, energy and water [52]. At the same time, the use of land as the main obstacle in port industrial development, both approaches cause a change of culture due to greater exploitation of existing resources [36].

**F) Cultural change**

From the adoption of Lean 4.0 to promote a CE in the port sector, one can observe the advantages of cultural change in the face of the challenges of the sector. Despite the existing conceptual diversity, it is possible to note that the idea of innovation is related to changes and new factors that disrupt the existing balance [53].

In view of this, it is essential that this change be promoted in view of the transformation of procedures and the need for adaptability of employees, resulting in the recognition of the benefits achieved with the development of the port circular economy. The evolutionary process in ports at successive levels of maturity provides the prerequisites for improvements leading to the next stage. Tiers drive growth based on continuous improvement and incremental change rather than radical transformations [35].

These changes involve the transformation of procedures, the need for adaptation of employees and the recognition of the benefits achieved with the development of the circular port economy. Employees in the port sector play a key role in adopting more sustainable practices and promoting the circular economy, and it is important that they are engaged and committed to this change in the routine of professional activities [56] and that they receive adequate training and support to become adapt to new ways of working and thinking, recognizing the benefits achieved with the implementation of the circular port economy, such as cost reduction, improved operational efficiency, promotion of innovation and strengthening of the institutional image [6].

In this sense, the promotion of cultural change in the port sector requires leadership and commitment on the part of companies and institutions in the sector, in addition to a long-term strategic vision. Only then will it be possible to promote the necessary transformation for the implementation of the circular economy and for the construction of a more sustainable and efficient port sector [36,53,56].

Industrial ecology and the contribution to the use of key resources by companies account for a product throughout its life cycle, such as tracking the flows of materials, energy and water [52]. At the same time, the use of land as the main obstacle in port industrial development, both approaches cause a change of culture due to greater exploitation of existing resources [36].

In addition, citizens play an important role in driving the transition to a circular economy and are increasingly central to the implementation of other strategies in different sectors, influencing the demand for circular and sustainable goods and services, having a positive impact on the transition to a sustainable port [58].

**G) Investment in the sector**

From research on the adoption of Lean 4.0 to promote a circular economy in the port sector, one can observe the need for and importance of investments in the sector. These investments can generate positive results, due to the intense connection with transport modes, technological development, job growth, as well as improvements in the infrastructure of the cities in which they are located and their surroundings [56]. Investment in alternative technologies helping ports to overcome obstacles, such as dangerous cargo chains, appropriate administrative licenses, when the production plant in the port uses pollution-intensive technology [35].

The port system faces challenges such as insufficient budget, allocation of sources to transition from the linear structure of the ports to circular models, integration of port development plans in the city's municipal plans, causing interference and delay in the development of ports.

In this way, some measures and investments can be considered important for the implementation of these practices, such as updating and modernizing the port infrastructure, including the implementation of state-of-the-art technologies and equipment that allow greater operational efficiency and lower energy consumption, qualification and training of employees to adopt Lean 4.0 and the circular economy, in addition to creating incentive programs so that employees are more engaged and committed to sustainability. In addition, the implementation of environmental management systems

and certification by regulatory bodies can be important to ensure that the adopted practices are effective and internationally recognized [54].

Finally, we can highlight the need for investments in research and development of new technologies and solutions for the implementation of the CE in the port sector. This can be done in partnership with universities and research institutions, aiming at innovation and continuous improvement of adopted practices [43,62].

**H) Labor qualification**

With the aim of recognizing the main implications of Lean 4.0 for the development of the circular port economy, the contribution of qualified professionals during this transition is important. The results of an organization are related to the capacity of its professionals, however, the number of companies that prioritize professionals of excellence is still low [55].

The shipping industry is one of the most globalized of all industries, characterized by complex modular supply chains, including a large outsourced workforce of temporary workers from developing countries and countries in transition around the world. Despite long-standing efforts by international bodies to regulate the education and training of seafarers, differences in practices and standards persist [43,60]. In this sense, Lean aims at the continuous development of people, through development through the management of the professionals' routine, thus, the organizational culture of employees in the port sector aimed at continuous improvement, from the perspective of Lean, are based in training and development of people based on the scientific method [56].

Due to the lack of qualified professionals, there is no clear balance of responsibilities in the port sector, in addition to the lack of experts and validated businesses, which makes it difficult to develop circular models in ports [43]. The qualification of the workforce is an important factor for developing professionals, enabling them to understand their responsibilities and obtain results such as qualified labor and operational efficiency for the development of ports in the EC context [10]. In addition, Lean 4.0 allows developing new skills and abilities of employees through learning routines [40], so that obstacles linked to lack of knowledge, methods and techniques for adopting EC in the port sector can be developed from the Lean perspective. The Toyota Kata concept allows the development of a culture of continuous training of employees based on Lean and the scientific method to deal with the continuous improvement of the port sector and change in the culture of the actors in the port sector [56].

## 5 Conclusion

Based on the findings, it was possible to recognize the contributions and support coming from Lean 4.0 in ports and terminals. Among the impacts include gains in efficiency, sustainability, operational processes, management of operations, integration of actors, cultural change, investments in the sector and qualification of the workforce. In addition, Lean 4.0 allows for guidelines for actions aimed at reducing errors and operating time in production, increasing production and reducing costs and using resources, reducing operations and increasing supervision. In addition, the management tools arising from Lean in line with the technologies of industry 4.0 make it possible to streamline support in decision-making in an agile way. Through the listed actions, port processes and operations can be improved from a sustainable perspective. Since Lean 4.0 is an enabling approach for implementing improvements in the sector.

Thus, the tools from Lean 4.0 can help deal with the root cause of the port sector's obstacles in the transition to EC and avoid future problems, driving an improvement in port management within the national and international competition environment. In this way, it is possible to apply the Lean 4.0 concept in the port circular economy and obtain efficiency gains, develop a sustainable port, use methodological tools for the development of port management, promote cultural change and the qualification of the workforce.

Lean 4.0 practices tend to be impactful, as the foundations of Industry 4.0 allow a better understanding of customer demands and accelerate the processes of sharing information in real time. With this, it improves efficiency and port operations in order not to exceed service limits and promote a circular and sustainable port.

The achievement of results in ports will depend on technology and operations strategies, to be able to operate in conjunction with processes, trained and qualified professionals is essential to promote a change in culture and procedures, since the findings indicated that Lean 4.0 presents itself as a simplifier for the implementation of EC and innovative technologies for the development of ports, since it enables the alignment of a new management that identifies waste, develops a culture based on the proposed model and increases the competitiveness of the sector.

Based on the findings of the study, we show that Lean 4.0 allows reducing waste in port processes and operations, as well as presenting lean and technological strategies for the development of a modern and sustainable port. So that the port sector transitions from the linear economy to the circular economy, guided by the Lean 4.0 concept.

This work is limited to theoretical findings arising from systematic searches in the literature. Thus, future studies can be directed to identify in practice the challenges and strategies to adopt EC in ports in the perspective of Lean 4.0.

**Acknowledgement**

The authors acknowledge the financial support from PROAES/UFF for supporting the authors Pâmela Oliveira Arcanjo and Maria Juliane Goncalves in this research.

## References

[1] JUNIOR, A.J.D.A., DA SILVA, A.G., DE MORAES, I.J.B., DOS SANTOS, N.J.C.: *O processo de integração centro-america No para o DesenVolvimento Econômico e social regional por meio do Comércio Internacional*, RUNA - Repositório Universitário da Ânima, Dec. 13, 2021. (Original in Portuguese)

[2] DE LANGEN, P.W., SORNN-FRIESE, H., HALLWORTH, J.: The role of Port Development Companies in transitioning the port business ecosystem; the case of Port of Amsterdam's circular activities, *Sustainability*, Vol. 12, No. 11, p. 4397, 2020. https://doi.org/10.3390/su12114397

[3] JUCÁ, P.R.: *Regulação do setor portuário*, Grupo Almedina, 2021. (Original in Portuguese)

[4] MUSI, M.: *Port, maritime and transport law between legacies of the past and modernization*, Bonomo, 2018.

[5] GURNING, R.O.S., TANGKAU, D.I.: The analysis of the conceptual framework of Green Port Implementation in Indonesia using Circular Economy: The Case Study of Benoa Public and fishing terminals, *Sustainability*, Vol. 14, No. 10, p. 6083, 2022. https://doi.org/10.3390/su14106083

[6] BONAMIGO, A., GONÇALVES, M.J., ARCANJO, P.O., PEREIRA, N.N.: Lean port terminal: Uma estratégia para adoção da gestão enxuta no setor portuário, *Congresso Internacional de Desempenho Portuário*, Vol. 1, No. Nov., 2022. (Original in Portuguese)

[7] JAVAID, M., HALEEM, A., SINGH, R.P., RAB, S., SUMAN, R. KHAN, S.: Exploring relationships between Lean 4.0 and manufacturing industry, *Industrial Robot: the international journal of robotics research and application*, Vol. 49, No. 3, pp. 402-414, 2021. https://doi.org/10.1108/IR-08-2021-0184

[8] KOVAČIČ LUKMAN, R., BRGLEZ, K., KRAJNC, D.: A conceptual model for measuring a circular economy of seaports: A case study on Antwerp and Koper Ports, *Sustainability*, Vol. 14, No. 6, p. 3467, 2022. https://doi.org/10.3390/su14063467

[9] BHAMU, J., SANGWAN, K.S.: Lean manufacturing: literature review and research issues, *International Journal of Operations & Production Management*, Vol. 34, No. 7, pp. 876-940, 2014. https://doi.org/10.1108/IJOPM-08-2012-0315

[10] LIMA, V.B.: *Contribuição de Lean Thinking para a implementação da Indústria 4.0*, Doctoral dissertation, Universidade do Minho, 2018. (Original in Portuguese)

[11] WOMACK, J., JONES, D.T.: *Lean Thinking*, Simon & Schuster, New York, 1996.

[12] LODGAARD, E., INGVALDSEN, J.A., ASCHEHOUG, A.S., GAMME, I.: Barriers to continuous improvement: Perceptions of top managers, middle managers and workers, *Procedia CIRP*, Vol. 41, pp. 1119-1124, 2016. https://doi.org/10.1016/j.procir.2016.01.012

[13] COSTA, F., LISPI, L., STAUDACHER, A.P., ROSSINI, M., KUNDU, K., CIFONE, F.D.: How to Foster Sustainable Continuous Improvement: A cause-effect relations map of Lean Soft Practices, *Operations Research Perspectives*, Vol. 6, p. 100091, 2019. https://doi.org/10.1016/j.orp.2018.100091

[14] PEKARČÍKOVÁ, M., TREBUŇA, P., KLIMENT, M.: Digitalization effects on the usability of Lean Tools, *Acta logistica*, Vol. 6, No. 1, pp. 9-13, 2019. https://doi.org/10.22306/al.v6i1.112

[15] FETTERMANN, D.C., ECHEVESTE, M.E., TORTORELLA, G.L.: The benchmarking of the use of toolkit for mass customization in the automobile industry, *Benchmarking: An International Journal*, Vol. 24, No. 6, pp. 1767-1783, 2017. https://doi.org/10.1108/BIJ-01-2016-0002

[16] HOFMANN, E., RÜSCH, M.: Industry 4.0 and the current status as well as future prospects on Logistics, *Computers in Industry*, Vol. 89, pp. 23-34, 2017. https://doi.org/10.1016/j.compind.2017.04.002

[17] MOURA, D.A.: Logística Portuária Sustentável – uma análise de experiências internacionais, *Produto & Produção*, Vol. 22, No. 3, pp. 2021. https://doi.org/10.22456/1983-8026.109347

[18] MEISSNER, A., MÜLLER, M., HERMANN, A., METTERNICH J.: Digitalization as a catalyst for lean production: A learning factory approach for Digital Shop Floor Management, *Procedia Manufacturing*, Vol. 23, pp. 81-86, 2018. https://doi.org/10.1016/j.promfg.2018.03.165

[19] JARDIM, M.L.P.: *Dispositvo para triagem e Avaliações Qualitativas de Pacientes Atendidos a domicílio por equipes de saúde*, [Online], Available: http://hdl.handle.net/10183/217615 [25 Feb 2023], 2020. (Original in Portuguese)

[20] SCHLICK, J., STEPHAN, P., LOSKYLL, M., LAPPE, D.: *Industrie 4.0 in der praktischen Anwendung*, In: Vogel-Heuser, B., Bauernhansl, T., ten Hompel, M. (eds) Handbuch Industrie 4.0 Bd.2. Springer Reference Technik, Springer Vieweg, Berlin, Heidelberg. 2017. (Original in German) https://doi.org/10.1007/978-3-662-53248-5_46

[21] LIAO, Y., DESCHAMPS, F., DE LOURES, E., RAMOS, L.F.: Past, present and future of Industry 4.0 - A systematic literature review and Research Agenda Proposal, *International Journal of Production Research*, Vol. 55, No. 12, pp. 3609-3629, 2017. https://doi.org/10.1080/00207543.2017.1308576

[22] BUER, S.V., STRANDHAGEN, J.O., CHAN, F.T.: The link between Industry 4.0 and Lean Manufacturing: Mapping Current Research and establishing a research agenda, *International Journal of Production Research*, Vol. 56, No. 8, pp. 2924-2940, 2018.

https://doi.org/10.1080/00207543.2018.1442945
[23] MACDOUGALL, W.: *Industrie 4.0: Smart manufacturing for the future*, Germany Trade & Invest, 2014.
[24] BIANCO, D.: *Competências da Liderança No lean manufacturing e na Indústria 4.0: Identificação e relacionamentos*, [Online], Available: https://repositorio.ufscar.br/handle/ufscar/13240 [25 Feb 2023], 2020. (Original in Portuguese)
[25] DILLINGER, F., KAGERER, M., REINHART, G.: Concept for the development of a lean 4.0 reference implementation strategy for manufacturing companies, *Procedia CIRP*, Vol. 104, pp. 330-335, 2021. https://doi.org/10.1016/j.procir.2021.11.056
[26] SEHNEM, S., VAZQUEZ, D., PEREIRA, S.C., CAMPOS, L.M.S.: Circular economy: Benefits, impacts and overlapping, *Supply Chain Management: An International Journal*, Vol. 24, No. 6, pp. 784-804, 2019. http://dx.doi.org/10.1108/SCM-06-2018-0213
[27] BLOMSMA, F., RENNAN, G.: The emergence of Circular Economy: A new framing around prolonging resource productivity, *Journal of Industrial Ecology*, Vol. 21, No. 3, pp. 603-614, 2017. https://doi.org/10.1111/jiec.12603
[28] DHONDE, B., PATEL, C.: Implementing Circular Economy Concepts for sustainable urban freight transport: Case of Textile Manufacturing Supply Chain, *Acta logistica*, Vol. 7, No. 2, pp. 131-143, 2020. https://doi.org/10.22306/al.v7i2.172
[29] GREGSON, N., CRANG, M., FULLER, S., HOLMES, H.: Interrogating the Circular Economy: The Moral Economy of Resource Recovery in the EU, *Economy and Society*, Vol. 44, No. 2, pp. 218-243, 2015. https://doi.org/10.1080/03085147.2015.1013353
[30] HITCHENS, D.M., CLAUSEN, J., FICHTER, K.: *World Business Council for Sustainable Development – WBCSD*, In: Hitchens, D.M.W.N., Clausen, J., Fichter, K. (eds) International Environmental Management Benchmarks, Springer, Berlin, Heidelberg, 1999. https://doi.org/10.1007/978-3-642-58442-8_35
[31] DYLLICK, T., HOCKERTS, K. Beyond the business case for Corporate Sustainability, *Business Strategy and the Environment*, Vol. 11, No. 2, pp. 130-141, 2002. https://doi.org/10.1002/bse.323
[32] FEIFERYTĖ-SKIRIENĖ, A., STASIŠKIENĖ, Ž.: Seeking circularity: Circular urban metabolism in the context of industrial symbiosis, *Sustainability*, Vol. 13, No. 16, p. 9094, 2021. https://doi.org/10.3390/su13169094
[33] CARPENTER, A., LOZANO, R., SAMMALISTO, K., ASTNER, L.: Securing a port's future through Circular Economy: Experiences from the Port of Gävle in contributing to sustainability, *Marine Pollution Bulletin*, Vol. 128, pp. 539-547, 2018. http://dx.doi.org/10.1016/j.marpolbul.2018.01.065
[34] MAŃKOWSKA, M., KOTOWSKA, I., PLUCIŃSKI, M.: Seaports as Nodal points of circular supply chains: Opportunities and challenges for secondary ports, *Sustainability*, Vol. 12, No. 9, p. 3926, 2020. https://doi.org/10.3390/su12093926
[35] HAEZENDONCK, E.: Port Strategy for Sustainable Development: Circularization and value creation—introduction to a special issue, *Sustainability*, Vol. 12, No. 23, p. 9914, 2020. https://doi.org/10.3390/su12239914
[36] ROBERTS, T., WILLIAMS, I., PRESTON, J., CLARKE, N., ODUM, M., O'GORMAN, S.: A virtuous circle? Increasing local benefits from ports by adopting circular economy principles, *Sustainability*, Vol. 13, No. 13, p. 7079, 2021. https://doi.org/10.3390/su13137079
[37] GIL-VILDA, F., YAGÜE-FABRA, J.A., SUNYER, A.: From Lean Production to Lean 4.0: A Systematic Literature Review with a Historical Perspective, *Applied Sciences*, Vol. 11, No. 21, p. 10318, 2021. https://doi.org/10.3390/app112110318
[38] LAVISSIERE, A., MANDJÁK, T., HOFMANN, J. FEDI, L.: Port marketing as manifestation of sustainable marketing in a B2B context, *Journal of Business & Industrial Marketing*, Vol. 35, No. 3, pp. 524-536, 2020. http://dx.doi.org/10.1108/JBIM-12-2018-0409
[39] BAIRAGI, V.E., MUNOT, M.V.: *Research methodology: A practical and scientific approach*, Boca Raton, CRC Press, 2019.
[40] FERENHOF, H.A., DA CUNHA, A.H. BONAMIGO, A., FORCELLINI, F.A.: Toyota kata as a km solution to the inhibitors of implementing lean service in service companies, *VINE Journal of Information and Knowledge Management Systems*, Vol. 48, No. 3, pp. 404-426, 2018. http://dx.doi.org/10.1108/VJIKMS-11-2017-0083
[41] BARDIN, L. *Análise de Conteúdo*, Lisboa, Edições 70, 2010. (Original in Portuguese)
[42] ZANELLI, J.C.: Pesquisa Qualitativa em Estudos Da Gestão de Pessoas, *Estudos de Psicologia* (Natal), Vol. 7, pp. 79-88, 2002. https://doi.org/10.1590/S1413-294X2002000300009 (Original in Portuguese)
[43] KARIMPOUR, R., BALLINI, F., ÖLCER, A.I.: Circular economy approach to facilitate the transition of the port cities into self-sustainable energy ports—a case study in Copenhagen-Malmö Port (CMP), *WMU Journal of Maritime Affairs*, Vol. 18, No. 2, pp. 225-247, 2019. http://dx.doi.org/10.1007/s13437-019-00170-2
[44] GEISSDOERFER, M., SAVAGET, P., BOCKEN, N.M. HULTINK, E.J.: The circular economy – a new sustainability paradigm?, *Journal of Cleaner*

*Production*, Vol. 143, pp. 757-768, 2017. https://doi.org/10.1016/j.jclepro.2016.12.048

[45] DI VAIO, A., HASSAN, R.A., D'AMORE, G., DELLO STROLOGO, A.: Digital Technologies for Sustainable Waste Management on-board ships: An analysis of best practices from the cruise industry, *IEEE Transactions on Engineering Management*, Vol. 2022, pp. 1-14, 2022. https://doi.org/10.1109/TEM.2022.3197241

[46] SAMADI, S., SCHNEIDER, C., LECHTENBÖHMER, S.: *Deep decarbonisation pathways for the industrial cluster of the Port of Rotterdam*, In ECEEE Industrial Summer Study proceedings, Industrial Efficiency 2018: Leading the low-carbon transition, 2018.

[47] ZHENG, Y., ZHAO, J., SHAO, G.: Port City Sustainability: A review of its research trends, *Sustainability*, Vol. 12, No. 20, p. 8355, 2020. https://doi.org/10.3390/su12208355

[48] CROCETTI, P., GONZÁLEZ-CAMEJO, J., LI, K., FOGLIA, A., EUSEBI, A.L. FATONE, F.: An overview of operations and processes for circular management of dredged sediments, *Waste Management*, Vol. 146, pp. 20-35, 2022. https://doi.org/10.1016/j.wasman.2022.04.040

[49] AGRAWAL, R., WANKHEDE, V.A., KUMAR, A., UPADHYAY, A., GARZA-REYES, J.A.: Garza-Reyes, Nexus of Circular Economy and sustainable business performance in the era of Digitalization, *International Journal of Productivity and Performance Management*, Vol. 71, No. 3, pp. 748-774, 2021. 10.1108/IJPPM-12-2020-0676

[50] KATUWAWALA, H.C., BANDARA, Y.M.: System-based barriers for seaports in contributing to Sustainable Development Goals, *Maritime Business Review*, Vol. 7, No. 3, pp. 255-269, 2022. https://doi.org/10.1108/MABR-02-2021-0007

[51] NOTTEBOOM, T., VAN DER LUGT, L., VAN SAASE, N., SEL, S., NEYENS, K.: The role of seaports in Green Supply Chain Management: Initiatives, attitudes, and perspectives in Rotterdam, Antwerp, North Sea port, and Zeebrugge, *Sustainability*, Vol. 12, No. 4, p. 1688, https://doi.org/10.3390/su12041688

[52] JUGOVIC, A.: Assessing the possibilities of integrating ports into the circular ecoomy, *Tehnicki vjesnik - Technical Gazette*, Vol. 29, No. 2, pp. 420-426, 2022. https://doi.org/10.17559/TV-20200327221233

[53] LOPES, D.P.T.: *Inovação – Conceitos, Metodologias e Aplicabilidade. Articulando um Construto à Formulação de Políticas Públicas – Uma Reflexão sobre a Lei de Inovação de Minas Gerais*, Thesis, XIII Seminário sobre a Economia Mineira, Diamantina, Brazil, 2015. (Original in Portuguese)

[54] SILVA, R.I.D.: Avaliação de flexibilidades em infraestrutura portuária: uma abordagem por opções reais, Valuation of port structure flexibilities: an approach by real options, *BNDES*, Rio de Janeiro, Vol. 27, No. 53, p. 89-121, 2020. http://web.bndes.gov.br/bib/jspui/handle/1408/20344 (Original in Portuguese)

[55] CERTO, S.T., BUSENBARK, J.R., KALM, M., LEPINE, J.A.: Divided we fall: How ratios undermine research in Strategic Management, *Organizational Research Methods*, Vol. 23, No. 2, pp. 211-237, 2020. https://doi.org/10.1177/1094428118773455

[56] ROTHER, M.: *Toyota kata: Managing people for improvement, adaptiveness and superior results*, New York, McGraw-Hill, 2010.

[57] ÇAGLAR, V.: Sustainable container terminal operations: challenges and enhancements, *Journal of Black Sea Studies*, Vol. 49, pp. 141-156, 2016.

[58] CARPENTER, A., LOZANO, R., SAMMALISTO, K., ASTNER, L.: Securing a port's future through Circular Economy: Experiences from the Port of Gävle in contributing to sustainability, *Marine Pollution Bulletin*, Vol. 128, pp. 539-547, 2018. https://doi.org/10.1016/j.marpolbul.2018.01.065

[59] ZHEN, L., ZHUGE, D., MURONG, L., YAN, R., WANG, S.: Operation management of Green Ports and shipping networks: Overview and research opportunities, *Frontiers of Engineering Management*, Vol. 6, No. 2, pp. 152-162, 2019. https://doi.org/10.1007/s42524-019-0027-2

[60] BLOOR, M., SAMPSON, H., GEKARA, V.: Global governance of training standards in an outsourced labor force: The training double bind in seafarer license and certification assessments, *Regulation & Governance*, Vol. 8, No. 4, pp. 455-471, 2013. https://doi.org/10.1111/rego.12042

[61] FAROOQUE, M., ZHANG, A., THÜRER, M., QU, T., HUISINGH, D.: Circular Supply Chain Management: A definition and structured literature review, *Journal of Cleaner Production*, Vol. 228, pp. 882-900, 2019. https://doi.org/10.1016/j.jclepro.2019.04.303

[62] VASCONCELOS, A.F., DE PEREIRA, V.: Trabalhando a modelagem Matemática para tratar problemas ambientais causados pela extinção de Abelhas com Foco No Maracujá, *Meio Ambiente em Foco*, Vol. 12, pp. 47-55, 2020. (Original in Portuguese)

[63] DE MARTINO, M., MORVILLO, A.: Activities, resources and inter-organizational relationships: Key factors in port competitiveness, *Maritime Policy & Management*, Vol. 35, No. 6, pp. 571-589, 2008. https://doi.org/10.1080/03088830802469477

[64] GUO, M.: The 3R principles for applying biochar to improve soil health, *Soil Systems*, Vol. 4, No. 1, pp. 1-15, 2020. https://doi.org/10.3390/soilsystems4010009

[65] BONAMIGO, A., DE AZEREDO, R.R., FILHO, J.E. M., ANDRADE, H.S.: Lean 4.0 in the value co-creation in agro-industrial services: An agenda for future studies for the efficient resource use, *Systems Research and Behavioral Science*, Vol. 1, No. 1, pp. 1-16, 2023. https://doi.org/10.1002/sres.2950

**Review process**
Single-blind peer review process.