

## Article

# Small and Medium-Sized Ports in the TEN-T Network and Nexus of Europe's Twin Transition: The Way towards Sustainable and Digital Port Service Ecosystems

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**Abstract:** Despite high competition among big EU ports, such as Rotterdam, Hamburg, or Valencia, acting as Core Ports in the Trans-European Transport Core and Comprehensive Network (TEN-T), this paper addresses the marginalized decision-making capability for environmental and digital transition immanent in the Small and Medium-Sized Ports (SMSPs) ecosystems in the EU. Irrespective of topical research, little is said about SMSPs ecosystem sustainability robustness and how SMSPs can pursue the transformative way. Here, management and strategic port decision levels are rather patchy and disconnected from the operational port performance. SMSPs are bound to limited resources and low cognitive, organizational, or institutional proximity, compared to their bigger counterparts. This situation provides a lot of room for critical demarche, since in the TEN-T Network, there are 225 Comprehensive and only 104 Core Ports, the majority qualifying, thus, as SMSPs. This research aims at reducing this research-to-practice lacuna by improving limited managerial capacity of SMSPs on environmental responsibility and digital efficiency. Using an ecosystem concept and aggregated empirical data in three EU macro-regions—the Baltic Sea Region, the Adriatic-Ionian Sea Region, and the Mediterranean Sea Region, three specific decision-making tools are suggested for managerial applications to facilitate and reinforce transition in SMSPs for environmental responsibility, social equity, and economic efficiency.

**Keywords:** small and medium-sized ports; comprehensive ports; port ecosystem; European Green Deal; strategic management; environmental and digital transition; sustainable ports; green ports



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## 1. Introduction

Ports play a crucial role in logistics and supply chain management as well as economy on a regional, national, and international level. Ports enable accessibility to essential resources through transportation and services, in terms of energy, health, labor aspects, passenger mobility, and accessibility, especially when it comes to the land-locked or island regions, as well as providing safety and security. Irrespective of their size and location, ports always serve as gateways and act as epicenters of economic and social interactions. They pave the way for regional economic development and social inclusion. Yet, ports are subject to growing interdependencies and imperatives to leverage interests of nature preservation, economic efficiency, legal compliance, and social equity [1,2].

Today, ports, and especially Small and Medium-Sized Ports (SMSPs), are jeopardized due to increasing pressure on them, as they (capacity-based) are not able to face growing pressure in terms of showcasing both environmental credentials, security and policy conformity as well as policy compliance [1]. New initiatives, such as the European Green Deal (EGD) (2019) or the Sustainable and Smart Mobility Strategy (2020) of the European Commission (EC) are increasing the pressure level on ports, in particular when it comes

to set indicators to be achieved by 2035 and 2050. Yet, SMSPs show lower integration into both horizontal value chains and vertical supply chains, thus, suffering from less freight volumes, missing smart specialization, low cognitive, organizational, or institutional proximity to and between macro-regional, national, EU, and international actors, outdated infrastructure, lack of investments and new business models accompanied by missing hands-on strategic foresight. The United Nations (UN) 17 Sustainable Development Goals (SDGs) pose additional challenges for the maritime port sector [3], despite the fact that they are already incorporated as good practice, as “Green Port” or “Port of the Future” in port related sustainability programs, e.g., the World Port Sustainability Program (WPSP) or EcoPorts Initiative by the European Sea Ports Organization (ESPO). In this vein, SMSPs become even more exposed to pressure, compared to their bigger counterparts—Trans-European Transport Core and Comprehensive Network (TEN-T) Core Ports, as they lack international attention, access to investments and national importance. In line with the TEN-T policy, first the Core Ports (by 2030) and then only the Comprehensive Ports (by 2050) shall be updated according to all applicable EU and international regulations enabling sustainable transition.

This epicenter around EU Core Ports evokes the asymmetric development of EU ports and provides a lot of room for critical demarche not only on policy, but are also attracting increased interest in research circles. There are around 225 Comprehensive and only 104 Core seaports in the TEN-T framework [4], and the majority of them are SMSPs. Harsh environmental, competitive, and operational pressures are expected in SMSPs that partly build up the so-called comprehensive TEN-T Network (Connect2SmallPorts project concept). According to the International Transport Forum Forecast [5], waterborne transport will grow with 327% by 2050, thus, producing 238% more CO<sub>2</sub> emissions. In Europe, freight volumes will increase by 216% by 2050, with 174% more CO<sub>2</sub> emissions. There will be an enormous shift in commodity transportation [6]. This also presupposes growing challenges of SMSPs to comply with growing needs, in particular, within the port environmental performance domain. In order to avoid such jeopardizing development, the present research calls for immediate response and action.

Looking at the macro-regional level, 87 ports in the Baltic Sea Region (BSR) are included in the TEN-T Network, with 22—Core Ports, and 65—Comprehensive Ports [7]. As a result, 66% of BSR ports are SMSPs [8]. Total cargo turnover amounts to less than 2 million tons/year. SMSPs, especially in the BSR, suffer from the mentioned growing challenges and, thus, the contribution to Blue and Green Growth in the EU is scant. As noted also by the Baltic Ports Organization (BPO), due to their full commitments to primary tasks—port operations—staff in SMSPs have very limited chances to engage in projects and, thus, have less knowledge and capacity. A chance arises if local authorities join projects, since they are more likely to support comprehensive local ports. In addition, since 2014, only five BSR ports received direct funding from the Connecting Europe Facility (CEF), and Core Ports are not willing to engage into cooperation with comprehensive ports [9].

In the Adriatic, Ionian, and Liguria Sea, the number of SMSPs within and along the Adriatic, Ionian, and Liguria (Mediterranean area) are 93. The Adriatic Sea Region has 67 ports in five countries, of which nine are categorized as Core Ports, while the rest (58) are SMSPs. The Ionian Sea Region has 34 ports in two countries with 31 of the ports falling within the SMSPs category. Out of the six ports around the Liguria Sea Region, four are SMSPs. Unlike what is noticeable among the SMSPs in the BSR, there is a huge gap in spatial interlinkages between critical energy and transport infrastructures (for clean fuels as well their technologies), highlighting the need for intricate harmonization at both the policy and technical level for these ports. Connections and interfaces to the ports are hindered by mountains. Many SMSPs are far from inland urban areas. There is a disconnection between many SMSPs’ home country and international markets, making cooperation and the standardization of an environmental action plan among the ports difficult. Further, because these ports are isolated, they often are exempted during the developmental plan, unlike what is obtainable with many SMSPs in the BSR, where there are interfaces and

connectivity between the ports and international markets and other major ports. The Adriatic and Ionian Region, especially, are deeply affected by a long-term decline in the competitiveness of the regions' main industries. Therefore, for these ports, most efforts are geared toward the preservation of existing conditions and economies rather than toward environmental sustainability [10].

Despite the differentiating nature of ports in the Northern and Southern regions of Europe, there exist, however, no unified definition of what an SMSP is [11]. In this research, the authors do not explicitly claim one single definition of SMSPs. Even within the EU statistical taxonomy, port authorities that manage less or 10 million tons annual volume of goods handled are referred to as small ports, and port authorities that handle yearly more than 10 and up to 50 million tons of goods are medium-sized ports; this should be taken for granted for the entire research. Unfortunately, the EU statistics database Eurostat does not differentiate between small and medium-sized ports. Therefore, addressing the size of a port is always a bit of a problematic question [12] (p. 24). In this sense, regional differentiation influences the notion of small and medium-sized ports. What might be small in the Mediterranean Sea Region (MSR), might rather be referred to as medium-size in the BSR and vice versa. For the regional setting, SMSPs might be, however, of big importance [10]. Thus, in this particular research, all ports that regionally, nationally, or EU-wise are referred to as small or medium-sized belong to the target group. From the TEN-T taxonomy perspective, SMSPs are also including the so-called TEN-T Comprehensive Ports—ports that have either higher than 0.1% annual passenger traffic of all maritime ports in the EU or higher than 0.1% annual cargo volume handled in all EU seaports. In addition, such ports qualify as Comprehensive Ports, if they serve as the sole point of access to a NUTS-3 region, and if they are located in an outermost region or peripheral area within a 200 km radius distance from the other nearest port in the Comprehensive Network [7] (p. 13), whilst some of TEN-T Core Ports might classify as SMSPs according to Eurostat quantification.

Although differing definitions and notions of SMSPs prevail in the topical literature, three main functionalities/characteristics can be applied to all SMSPs: (a) enhancers of the Blue Economy competitiveness; (b) actors in regionalization processes; and (c) key capacity to set up multiport gateway regions [13–15]. In addition, SMSPs also are defined by their limited competitive position in their port cluster regions [13] and their role in a port hierarchy as the lowest, based on cost and efficiency [16]. However, empirical statistics revealed positive relationships between SMSPs and local economies [17]. Finally, SMSPs have not only low trade volume and disproportioned freight turnover, but also geographic, economic, and environmental disadvantages [18,19]. Yet, in the end, ports cannot be narrowed down simply to the geographical notion of a delimited spatial area [20] (p. 229). Moreover, the financial support of European funding programs is in a huge disequilibrium between funds allocated to SMSPs and their ratio on cargo and ferry throughputs, in favor of bigger ports [7].

Considering the challenging nature of SMSPs connecting North and South EU macro-regions, the paper in hand aims at providing managerial tools dedicated to SMSPs' authorities and port managers that would facilitate structure and step-by-step processing, enabling incremental but sustainable improvements in SMSPs, in terms of digital and environmental robustness. By including key principal domains of port interactions and bringing all interacting stakeholders into one multi-governance and shared responsibility platform, individual ports are able to take the first steps towards becoming sustainable SMSPs.

The paper is structured as follows: after this introductory session, theoretical background chapter including positioning of SMSPs in the research field is displayed, followed by showcasing applied research methods and data gathering techniques. Based on the gained data in cooperation with SMSPs, the yielded results are presented, namely, SMSPs measurement (auditing framework), strategic tools for sustainable SMSP ecosystem development and strategic decision-making tools for digital and environmental twin transition. Afterwards, research results are elaborated within other similar research results in

the discussion part, before conclusions and specific managerial tools are discussed in the last chapter.

## 2. Positioning SMSPs within Placed-Based Institutional Arrangements

In spite of the ailing situation of SMSPs in the EU, SMSPs shall contribute to growth and facilitate trade. Acting as cores within regional ecosystems and communities, such ports shall also become lighthouses or flagships in environmental and digital transition, as well as enable accessibility to remote areas and integrate peripheral regions. However, greening EU ports is a colossal job. It is because environmental and digital transition must be twinned when it comes to practical implementation. We cannot reduce energy consumption, e.g., without having specific digital monitoring tools installed in port areas and vice versa. In addition, external and internal sides of the coin, i.e., port interactions within the port and outside with the port city and hinterland should be considered. An efficient integration of green port activities on a macro-regional scale or EU level, i.e., activities that merge resources, capabilities, industry interactions, company performance, and organizational operations from individual EU member states require a two-prong strategic approach. On the one hand, it is argued that an efficient and effective integration of any novel processes (e.g., greening technologies, methods, etc.) presupposes a *common challenge* that can be solved once it is *shared by the entire ecosystem*, which encapsulates diverse industry and social actors and activities.

Indeed, common challenges prevailing in the sustainability transition nexus need strong dialog and involvement of stakeholders as well as development and implementation of Corporate Social Responsibility (CSR) or corporate governance strategies also involving strong stakeholder communication and commitment [21–23]. Next to this, effective environmentally-friendly and sustainable behavior of ports require useful and effective managerial instruments [24] as well as comprehensive port coordination systems and frameworks for decision and policy-making, supporting commonality and collegiality as new cooperation principles and strengthening stronger alliances among the involved stakeholders [25–29]. This is underpinned by the fact that ports should switch to sustainable port operations and increase collaboration patterns, also pushing private port operations to introduce Green Port Management Practices (GPM) [30]. These aspects, in turn, enable achievement of a shared value, once it is reduced or eliminated on the market, i.e., in the entire community or ecosystem [27]. On the other hand, integration can be facilitated by efficiently merging business innovation and governance dimensions from individual regions into one macro-regional strategic approach rooted in a key treatise of regional integration [31,32] and regional innovation [33,34].

As a result, a shared value presupposes, again, integration and expansion of value generation among the involved stakeholders. This requires considering the dimensions of the ecosystem—environmental, technological, legal, economic, governance, and social aspects. Here, ports can be referred to as gateways and epicenters of economic and social interactions [20,35], in that, ports become important nodes of social, environmental, and economic activities—markets, and to articulate it in modern terms—ecosystems. Ecosystems integrate operational, environmental, economic, technological, social, and legal dimensions [36,37]. Since this study addresses interdisciplinary issues concerning natural resources preservation, economic activities (shipping, waterborne port operations, and hinterland activities), technologies used and social impacts (e.g., workplace, public health) in a specific place, the ecosystem approach helps to explain how nature and economic agents (ports and their hinterlands) interact with their environment [38,39].

Considering the aforementioned, there emerges an essential need to redefine the performance in each of the ecosystem's dimensions, thus, aiming at achieving a shared value. Therefore, it is essential to redefine the productivity along the entire value chain. Yet, in order to integrate and afterwards redefine the value chain for better environmental, societal, and corporate performance, we need to build up the integration of the value chain that might lead to a shared value. In this, it is inevitable to draw on the different dimensions



of the value. It is believed that each of different kind of value already, when integrated, might contribute to the achievement of the shared value. In brief, there are differentiated customer, performance, financial and learning, and growth values. These can be derived from the Balanced Scorecard to Strategy [24,40,41]. As a result, within the customer perspective, such indicators as customer satisfaction, profitability, retention, market, and account share are subsumed. Further, proceeding toward the performance dimensions, this includes internal business processes and refers to the satisfaction of shareholder expectations of financial returns and delivery of value propositions of customers in targeted market segments. Further, within the financial perspective, the indicators define the long-run objectives of a company. These include, among others, rapid growth, sustainability, and harvesting. Again, these three cover investments in supply and value chains and customer relationship development, earning returns on the invested capital, maintenance of existing market share, expanding capacity and enhancing continuous improvement, short payback periods, and maximization of cash flow back to the company. Finally, within the learning and growth dimension, such indicators as infrastructure, organizational learning, multi-level governance, improvement of technologies, processes, and capabilities are essential attributes of strategic improvement. In general, it covers people, systems, and organization procedures—sources that enable learning and growing. In order to close these learning and growth gaps, there is a need for investments in training or retraining, enhancing IT technologies and systems, and adopting organizational procedures and routines to a change.

Indeed, all values and value creations are addressed by the twinned environmental and digital transition, aiming at a sustainable and digital economy in Europe. Digital transformation in seaports implies huge potentials and opportunities to improve productivity and efficiency in logistics as well as to increase competitiveness [42,43]. Moreover, ports hold an important role in greening the maritime and logistics sector [29,30,44–47]. It is because ports stand for gateways and important nodes of social, environmental, and economic activities, or, as introduced above, in other words—ecosystems. Thus, they integrate operational, environmental, economic, technological, and legal dimensions [36], creating complex maritime clusters when it comes to digital and environmental transition. Due to their lack of crucial capacities (human/financial) and limited employee skills, which are most effectively increased within a port ecosystem [13], SMSPs' obstacles for a successful transition are multiplied. Another driving force for environmental and digital changes are innovation policies on a governmental level [47–49], applicable for ports as well [50]. Even though quantitative benchmarking is available for such concepts of transition—refer to [51,52]—the literature lacks future-based frameworks for SMSPs ecosystems. Ecosystems and sustainability become crucial for smaller ports, in particular, since they tend to be more dependent on other societal and regional actors [53] or need to search for serving circular supply chains [54]. Indeed, it is essential to provide SMSPs with capacity and tools for decision-making based on environmental and digital transition [55]. This *research problem* is fundamental for the present research conducted and provided in this paper. In particular, it aims at reducing the *research gap* calling for the support of research for port-decision makers in their efforts towards sustainability. As purported by scholars [47] (p. 243), the literature gives insufficient foundation for decision-making in ports, mainly, due to a huge lack of empirical findings. In addition, the present research supports future research directions by pointing out the need to expand the regional scope of the case study through different port learning avenues, to enrich assessment content for sustainable port performance, promoting clean operational and digital technologies' application, and applying land senses' ecology principles that, in turn, are closely linked with ecosystem services and sustainable development [56], including the lack of a comprehensive review of port sustainability performance [57] (p. 48).

Ports are not able to kick-start their sustainable avenues also due to the unused potential pertaining to the aspect of customer/user. Port decision makers and, thus, the strategic port management domain shall increase port engagement with stakeholders along

the entire supply and value chains and understand how involved actors and stakeholders interact. Innovative ways in greening port operations evolve through open innovation tools, engagement of customer and user. Since ports are referred to as gateways and the regional economy's service ecosystems, and their main operations are to provide essential primary and secondary services, innovation development should focus on future environmental and digital services the ports will provide. As ports become more and more service hubs and not only gateways, focusing on customer-driven approaches and new servitization logic, they are better at meeting regional customer demands, creating value both internally and externally. Value creation enables them to generate sustainable competitive advantages and deploy their strategies. Since ports operate in a volatile, uncertain, complex, and ambiguous environment, bound to specific conditions given in the social, environmental, and policy dimensions, the dominance and focus on the customer becomes the main feature [58,59].

The idea behind servitization or products-as-a-service is to change the view from selling products rather to sell integrated packages of products and services with a high focus on customer value creation [60,61]. Moreover, it allows institutions to react fast to an increasingly volatile business environment. Thus, the servitization concept is applicable for SMSPs as well in line with digital and environmental transformation—refer to [13], since servitization can be a driving force in organizational changes [62] and has close interactions to digital changes in ports [63,64]. However, only few literature records have focused on servitization in the maritime sector—e.g., [65,66]—but did not incorporate port ecosystems or linkages to future challenges of this particular group in digital and environmental transition. This is a crucial competitive factor for the ports, which are seen as service ecosystems and hubs of national/regional services. To provide services that do not need to be bought by customers but rather rented from the ports, might be feasible business models for port customers (financial, environmental, economic viability), e.g., offshore/onshore power supply for ships laying in ports instead of forcing them to use alternative fuels to run the ships in lay times. Indeed, sharing and cooperation reduce not only the costs, but also potential negative impacts on the environment. In the same vein, digital tools or tracking systems on the environmental impact in ports can be shared among the participating ports, not necessarily developed or bought by each of the ports. In this sense, the topical literature identified missing tools, technologies, and measures for SMSPs to adopt the idea of greening ports [67] (p. 3), [68] (p.15). As a result, this narrows down the identified research gap for SMSPs' ecosystems and strategic frameworks as decision-making tools for future digital and environmental transition for improvement of competitiveness. Therefore, this research paper postulates the following research questions:

- (1) *How can an SMSPs service ecosystem for digital and environmental transition be framed?*
- (2) *How can a strategic decision-making tool for SMSPs be set up to support digital and environmental transition?*

By answering these questions, the conducted research serves as a concept and role model paper for SMSPs service ecosystem analysis. Hence, it contributes theoretically to the scarce literature for the particular group of SMSPs, in particular on port decision-making. Practically, the research provides SMSPs with a practical tool for strategic positioning and strategy development in the specific business fields of environmental and digital development. Having this as the key common thread, this paper analyzes strategic perspectives on a digital and environmental transition for SMSPs and their ecosystems using the concept of servitization. The backbone of this research is a conceptualization based on close cooperation with 16 SMSPs and data gathering on 37 ports in the frame of the European Interreg project "Connect2SmallPorts", part-financed by the South Baltic Program 2014–2020. This research considers insights from SMSPs in the BSR as well as Adriatic, Ionian, and Liguria Sea Regions (Mediterranean area) alongside the four TEN-T corridors of the Baltic-Adriatic, Orient-East Med, North Sea-Baltic, and Scandinavian-Mediterranean. The rationale for connecting SMSPs from the Northern and Southern parts of Europe is simple: BSR is one of the top seas worldwide in terms of maritime traffic [69] and, consequently, a forerunner and

role model region for good compliance with tighter environmental limits and innovation application to achieve aspired greening of the maritime sector. SMSPs in the South are not yet subject to a bulk of the policy regulation and environmental restrictions, such as heavy Sulfur Cap in the BSR. Thus, they face less pressure to act now and position themselves strategically for the short and long term. As a result, bridging SMSPs that act as forerunners in the environmental and digital transition with those that will have to undertake huge upscaling in the next years and are lagging behind, highlights and underpins the mindset of coherence in the EU as well as harmonizing tools and removing bottlenecks in the entire EU, by providing access, open innovation, and exchange opportunities for SMSPs despite their geographical location, whether on the periphery or in a locked position.

### 3. Materials and Methods

Based on the formulated ambitious goals of the research and impacts of policy and practice in the port discourse, we can claim it to be highly exploratory. Exploratory research usually implies a qualitative research methodology, since it is concerned with the underdeveloped topic [70] or aims at revealing social impacts [71]. This is crucial bearing in mind the formulated research gap in the previous chapter. Indeed, the qualitative research underpins scrutiny of the underdeveloped or new aspects [72,73]. Yet, building on the Yinian proposition, it is not sufficient to deploy only a single case, especially in order to answer the research questions circled around “why” and “how”, as stipulated in Chapter 2. It is because the researchers examine real life constructs (port performance) and the boundaries between the phenomenon (port environmental and digital transition), and the context (policy, ecosystem interactions, stakeholder’s involvement, etc.) is less controllable by the researchers [74,75]. Yet, the authors of this contribution do not completely refuse Merriam’s perception of a case study. In particular, Merriam’s definition of a case as a specific institution or social construct can be also applied in the given research [76] (p. xiii), in particular when considering ports and especially their ecosystems as modern markets and, thus, institutions [36,37]. In sum, recognizing the intertwining conceptual links between different case study approaches, the present research combines the main particularities in Yin’s and Merriam’s theoretical foundations, giving priority to the Yinian conceptual considerations pinpointing the essence of connecting empirical data to the raised research question and conclusions, and using combined quantitative and qualitative data [74] (p. 20). Bearing this in mind, the authors argue for applying an umbrella research approach that, in theoretical treatises, is referred to as a hybrid research approach [77] (p. 80), combining deductive and inductive perspectives in the face of exploration.

When it comes to the case study design, the research in hand deploys multiple holistic designs and, therefore, utilizes multiple case study approaches, which aim at supporting theoretical foundations when it comes to decision-making and strategic capacity building of SMSPs in the face of environmental and digital transition urgency. This makes the research more inductive in terms of aiming at conceptual and managerial tools dedicated to port performance assessment and improvement [78,79]. The driving research impetus is an anticipated and projected construction of knowledge and reality. In turn, these can be created in an objective way by using the methodological *actor’s approach*. In this particular sense, the reality is constructed independently from its observers, individuals. This is applicable to the present research perceiving ports as social constructs, independent from individuals but constructed by a number of meanings that are shared by a larger and small number of people [80] (p. 66). Indeed, understanding of the observed and analyzed reality as a social construct lends strength to the present research. First, it is because the research is located at the crossroads of diverse disciplines, such as business and management, mathematics, environmental engineering, social sciences, and humanities [47] (p. 255). Ports address, thus, organizational studies, as they can be referred to as social constructs. Moreover, the research aims at not defining in a direct sense, but tracing and constructing meanings of environmental and digital transition potential and success within the port province, where meanings encapsulate scanning, understanding, interpretation, and

action—conceptualization and new understanding resulting in contributions to research and science. Second, the research aims at understanding how the organizational (strategic management) domain can be enhanced, thus, addressing learning, capacity absorption, and similar organizational traits. In this, the research is circled around organizational context. It constructs conceptual approaches and models. Third, the advantage of the actor’s approach is also associated with the fact that ports and their research break the boundaries of a single discipline and research domain. In this regard, employing the actor approach is argued to be feasible and beneficial both to science and management practice.

The Yinian approach calls for the combination of quantitative and qualitative data. The data used for conducted research is two-folded—qualitative and quantitative. First, the data was recorded in the frame of two research strands; as quantitative data in the frame of the Connect2SmallPorts project [81], part-financed by Interreg South Baltic Program 2014–2020, which is based on the goal of digital auditing to measure the digital readiness in ports [82] and the benchmarking of SMSPs’ performance against their digital forerunners. Here, quantitative data was compiled from the project survey on digitalization performance in ports and supported by expert interviews conducted with individual port managers. Second, quantitative and qualitative data was aggregated in the frame of the Horizon 2020 project proposal SEAD4Ports, aimed at supporting SMSPs’ decision-making towards environmental and digital transition in the nexus of the EGD implementation.

For the mapping purpose of SMSPs performance within the second research discourse, the researchers applied content analysis based on the developed template as shown in Table 1. The principal idea behind this mapping process is to provide a harmonized tool for data gathering applicable for all kinds of ports—independently of size and type. This template was used to gather both quantitative and qualitative data from port authorities and port managers. Following this, expert interviews with responsible managers substantiated already collected data.

**Table 1.** Port Environmental and Digital Performance Mapping Template.

Identification of Green Port Issue	Port Responsiveness
1. Overview of the port	Description of geographical, legal, economic, and environmental framework conditions
2. Used cases demonstration	Quantification and qualification of the pilot with specification of each of the used cases
3. Implementation plan of the pilot	Description of the four performance areas including qualification and quantification of performance in the following: (a) Operational and technological performance (b) Environmental performance (c) Quality (economic) performance (d) Institutional governance performance
4. Implementation requirements	Description of necessary architecture, data collection procedures and techniques, data storage, analysis and synthesis, framework conditions (regulations, standards, public acceptance)
5. Hardware and software requirements	Description of equipment parameters, its qualification and quantification
6. Target groups and stakeholder involvement	Description and quantification of all affected stakeholders, e.g., public authorities, operators, forwarders, investors, private companies including their involvement, responsibilities, and value creation

Source: compiled by the authors.

Overall, data collection pathways and its quantification are showcased in the research trajectory matrix below (Table 2). All cases as well as quantitative and qualitative data



were subject to thorough content analysis [83–87]. Field notes, filled-in templates, port performance records, diagrams, and memos were analyzed and assessed.

**Table 2.** Aggregated Case Study Research Methodology.

Overall Research Journey		
1. Research Scope	Interreg VA project Connect2SmallPorts	Horizon 2020 proposal SEAD4Ports
2. Geographical Coverage	South Baltic Sea Region Baltic Sea Region North Sea Region Mediterranean Sea Region	Baltic Sea Region Adriatic-Ionian Sea Region Mediterranean Sea Region
3. Research Scale	33 SBSR + BSR Ports 2 NSR Ports (Esbjerg, Hivde Sande) 1 MSR Port (Valencia)	19 SBSR + BSR Ports 5 AISR Ports (SASPA) 2 MSR Ports (La Spezia, Corfu)
4. Research Time Lapse	10/2019–12/2020	09/2020–01/2021
5. Research Approach	Inductive	Inductive
6. Research Methods	Eclectic: Survey Expert interviews Field observation Study visits	Eclectic: Template analysis Expert interviews Field observation
7. Research Data	Quantitative + Qualitative Manifold: 36 questionnaires 36 port audits 10 expert (port) interviews Reports from 2 study visits	Quantitative + Qualitative Manifold: 26 port audits 12 in-depth interviews with ports (authorities, managers)
8. Research Techniques	Pattern matching Explanation building Data analysis Cross-case synthesis	Content analysis Pattern matching Cross-case synthesis Program logic modeling
9. Research Validation	Use of multiple sources External validity Reliability through case protocols, data records Triangulation (theory, cases)	Participatory research Triangulation (multiple sources deployment) Multi-site observation

Source: compiled by the authors.

The research team was directly involved in the concerned projects. The researchers' bias was reduced through external expert involvement and twin research contribution of two authors, thus, enabling independent perception and reciprocal questioning and verification. The research is based on equal access and inclusive research principles. The research was implemented to the best of the researchers' knowledge, paying attention to research ethics and habits. During open calls for participation, all potential ports were invited to take part in the research in both research discourses, thus, avoiding any market distortion and impossibility to access knowledge and new tools. The researchers approach further ports, including inland ports, for data gathering but due to low respond rate or data quality, deeper cooperation and information gathering was not possible at this stage of the research. The provided data and insights were expanded by a deep literature review and desk research in the particular research field with focus on postulated research questions. Thus, the researchers aim to substantially increase the quality of research results by combining different theoretical concepts—digital and environmental transition, ecosystem and servitization, within SMSPs in order to reinforce an interdisciplinary research.

#### 4. Aggregated Result Portfolio—SMSPs Decision-Making Tools for Sustainability

The present research sets out to provide answers to critical, but essential and truly marginalized questions pertaining to port management and demanded decision-making capacity as well as future learning avenues in face of environmental and digital transition. In this vein, the research aims at reducing the located research gaps and providing a structured and practical step-by-step processual tools and roadmaps. As a result, the sound data collected in the frame of the research journey in almost one year enables the research team to arrive at grassroots tools dedicated both to research and management teams dealing with SMSPs as well as formulate future demanded actions. In this research, three different constructive tools are proposed that serve as a managerial stepping stone for SMSPs and enable critical assessment, re-allocation of sources, steered capacity and capabilities building, as well as first steps towards future foresight: (a) green port performance measurement (auditing) framework; (b) green port service ecosystem model; and (c) decision-making tools for SMSPs environmental and digital twin transition. All these tools are presented and explained in the next sections. The viability, reliability, and usability of these tools for future port (SMSPs) development and research are positioned within topical empirical studies in the next chapter.

##### 4.1. Green Port Performance Measurement (Auditing) Framework

The proposed auditing tool for SMSPs' environmental and digital readiness and robustness is built on two-pronged empirical results following digital auditing in the BSR ports (mainly SMSPs) and their benchmarking within the pool of the 33 BSR ports, two North Sea ports, and one Mediterranean port on the one hand. On the other hand, the design of the tool in hand was also based on 12 conducted interviews with SMSPs' authorities that are connected by the four TEN-T corridors and audits of all ports governed by the responsible port authorities, thus, preserving a pool of 26 ports. As a result, in the BSR we used data from 19 ports: two ports in Lithuania, 10 ports in Estonia, two ports in Germany, two ports in Denmark, and three ports in Sweden; whereas in the MSR we relied on data from seven ports—six ports in Italy and one port in Greece.

Building upon analysis and synthesis of the comprehensive data available, the authors compared the developed Digital Readiness Index in Ports (DRIP) within the Connect2SmallPorts project (Interreg, European Regional Development Fund (ERDF) part-financed) with data gathered from the interviews and port audits. Using the DRIP performance domains—management, human capital, IT functionality, technology readiness, and information flows (with in total 38 individual indicators)—the researchers could scrutinize any persisting or emerging dovetailing with key port performance areas using sustainability pillars, as adopted in this research paradigm; operational and technological efficiency, environmental responsibility, economic efficiency, and institutional stability with all potential indicators that could be located within each individual sustainability performance area in the literature [88–93] as well as from conducted audits in the ports (Table 3).

Following this, the research reveals that in the face of the EGD implementation and reinforcement of a sustainable mindset followed by the UN SDGs, in particular, SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities); SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land), where major challenges are to be expected in the implementation of the SDG12 and SDG 13, all ports, but in particular SMSPs, should put their operational and strategic focus on operational and technological efficiency in terms of the reduction of environmental footprints and ensuring ecological resilience. Similar insights were observed regarding green port government and the call for increasing sustainability in port operations [30]. The authors argue that this fact can be traced back to the fact that SMSPs lack financial resources for operational (equipment) and technological upgrade and are instead bound to allocation of municipal resources enabling provision of essential port services.

**Table 3.** Green Port Performance Measurement (Auditing) Framework.

Performance Domain	Performance Area KPIs			
Operational and technological efficiency	■	Transportation distance	■	Installation of sensors and actuators
	■	Connectivity of modes	■	IoT measurement of environmental impacts (water, air, noise, lightning
	■	Ship productivity	■	IT system installation
	■	Gate utilization	■	Cloud computing
	■	Berth utilization	■	Data management and decision-making easing
	■	Mooring	■	Time management system
	■	Towage	■	Blockchain
	■	Transshipment points	■	Artificial Intelligence (AI)
	■	Automation of port equipment	■	Drones
	■	Intermodal infrastructure efficiency	■	Robotics
	■	Modal continuity	■	Virtual/augmented reality
	■	Interchange among transport modes	■	Corporate digital governance strategy
	■	Energy supply	■	IT knowledge and competencies of internal employees
	■	Bunkering	■	Key Enabling Technologies (KETs)
	■	Waiting time		
	■	Automation of ship equipment and machinery		
	■	Intelligent infrastructure (hardware and software)		
Environmental responsibility	■	Energy consumption of ships	■	Dust pollution
	■	Energy Efficiency Design Index	■	Vibration pollution
	■	Environmental Ship Index	■	Population exposed to high level traffic noise
	■	Clean Shipping Index	■	Waste Management
	■	Green Award	■	Water management (sewage and dredging disposal)
	■	Blue Angel label	■	Ballast water treatment
	■	Carbon footprint/unit	■	Ship recycling
	■	Oil spill	■	Dredging
	■	CO <sub>2</sub> , NO <sub>x</sub> , SO <sub>x</sub> , Particular matter emissions	■	Resources and fuel efficiency
	■	Noise pollution	■	Use of alternative fuels
	■	Light spillage	■	Production and use of renewables
	■	Ecological resilience	■	Environmental monitoring
	■	Biodiversity gains		
	Socio-economic efficiency	■	Jobs creation	■
■		Equal employment opportunities	■	Port operational efficiency
■		Employees skills upgrade	■	Terminal's profitability
■		Regional economy development	■	Operating revenues/unit
■		Return on Investment (ROI)	■	Operating benefits/unit
■		Disturbance robustness	■	Modernized port facilities
			■	Maintenance costs
			■	Circular economy roadmap
Institutional stability	■	Collaboration among different transport modes	■	Forms of collaboration and its effects
	■	Safety issues	■	Securing the compliance with applicable regulations and rules (environmental regulations, non-discriminatory, fair and equal access)
	■	Body of applicable regulations		
	■	Institutional capacity and its building	■	Standardization and increasing harmonization of the applicable rules, laws, incentives, processes, etc.
	■	Innovation development and transfer capability		
	■	Investment facilitation mechanisms (incentives, funding schemes)		

Source: compiled by the authors.

A second strategic priority area is institutional capacity, where collaboration, multi-level governance, and port (region) community stakeholder involvement become inevitable preconditions paving the way for environmental and digital transition. In this vein, the previous research supports the importance of network connections for ports [18,57]. Here, a special notion should be given to the contribution to the respective SDGs of the UN, as similar recent research confirms [3]. As the results demonstrate, environmental responsibility and compliance with the binding environmental regulations is being implemented by the applicable SMSPs, and appears to be mostly governed by the impetus to comply with the policies and regulations levied by the responsible authorities. Finally, the socio-economic efficiency plays a crucial role in the sense that SMSPs, in particular, port authorities, and

managers shall focus on environmental consciousness building and empathy development supporting an inclusive and holistic integration of all affected ecosystem stakeholders, starting with ports and their employees, followed by port or stevedoring companies and all other stakeholders that affect port development—port city and hinterland policy makers, businesses, and customers. Sustainable thinking and acting shall be underpinned by a circular economy principle application within the port business and design of respective roadmaps. In this sense, the present research underscores the demand for a circular mindset genesis and its maintenance throughout the entire port business [54] as well as knowledge transfer and qualification and training of personnel, where a combination of knowledge with financial and personnel resource are proven to be success factors for policy compliance and transition rather than a simple amount of resources [94].

Overall, it is apparent that this research goes beyond the established and rather statically determined port performance areas, when it comes to digital robustness, as claimed in the proceeding research [55,82]. The authors argue that environmental and digital transition and respective auditing in terms of environmentally responsible and digitally robust port performance should be circled around operational and institutional (management) domains, where human capital capacity and information flows are integrated as horizontally intertwining domains, facilitating desirable transition on the one hand and enabling command and improvement of operations via human interactions and information exchange on the other. With this, the present Green Port Performance (Auditing) Framework aligns with the sustainability concept and includes all relevant Key Performance Indicators (KPIs) in each respective sustainability domain. In addition, the presented tool contributes to the call by the SMSPs for simplification of applicable KPIs and the attempt to achieve a certain level of integration, in particular, through the lens of the UN SDGs and sustainability pillars, which are transferable and replicable despite the special setting of the given port.

The research shows that SMSPs are not aware of recent calls (EcoPorts Initiative and Network) on the EU or international levels (e.g., World Port Sustainability Program) to kick-start their environmental sustainability or digital transition projects. Indeed, existing KPIs matrices need more simplification and to provide more general understanding about environmental and digital transition. Thus, the presented framework of indicators aims at a simpler and more user-driven (user-friendly) approach for SMSPs performance measurement. In order to set up the performance domains on green port measurement, further research papers were scrutinized on (a) sustainable port performance [52,88–91] and (b) smart performance [95]. Table 3 provides an overview of the proposed framework, including performance area KPIs.

To put the framework into practice, as a next step it is necessary to harmonize it with indicators used in the applicable EU databases, e.g., European Intelligent Transport (ITS) Platform KPIs as well as performance indicators used for the assessment of TEN-T Corridor performance. In addition, a practice-based utilization of this framework can be applied in any topical research projects dealing with SMSPs as well as environmental and digital transition in ports regardless of their size.

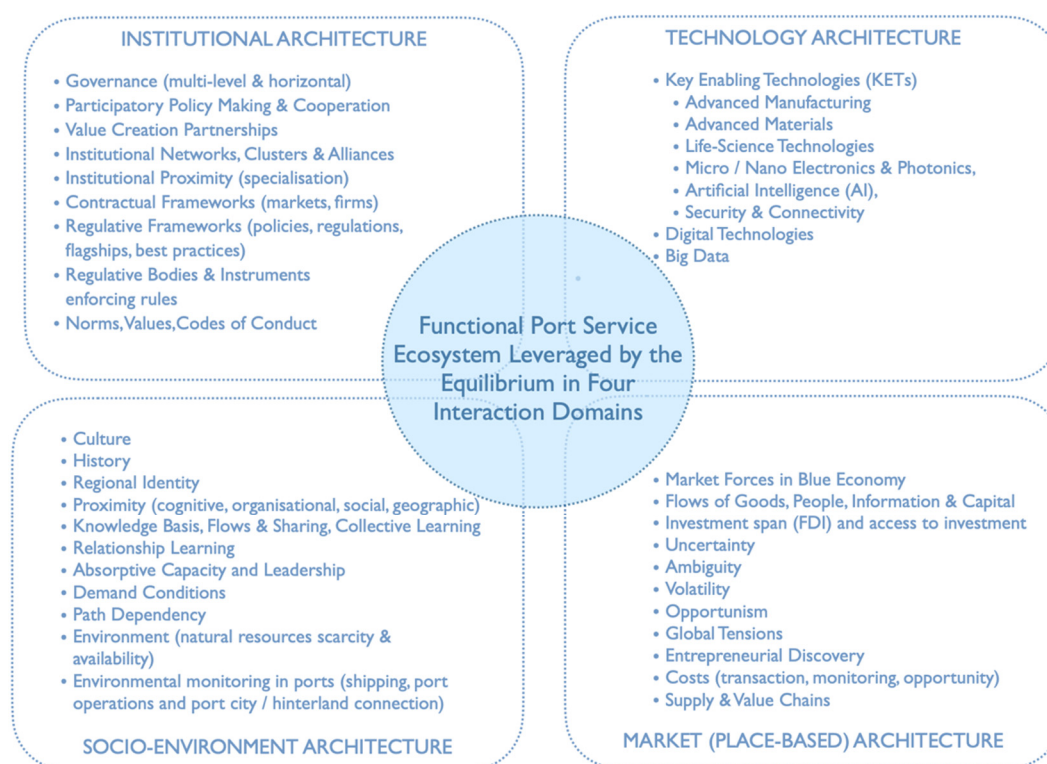
#### *4.2. Small and Medium-Sized Ports' Service Ecosystem Framework*

As mentioned in the first chapter, institutions adopt more and more service components to their products in order to achieve better customer satisfaction and sustain competitive advantages. This is a crucial competitive factor for ports, which are seen as service ecosystems and hubs of national/regional services. In this manner, providing services that do not need to be bought by customers but rather rented from the ports might be feasible business models for port customers (financial, environmental, economic viability), e.g., offshore/onshore power supply for ships laying in ports instead of forcing them to use alternative fuels to run the ships in lay times. Indeed, sharing and cooperation reduces not only the costs, but also potential negative impacts on the environment. In the same vein, digital tools or tracking systems on environmental impact in ports can be shared among the participating ports, not necessarily developed or bought by each of the port. This, in turn,

plays a major role in the future on circular economy due to resource savings, prolonged service life of products [66]. When it comes to maritime-borne businesses and ports, the industry lags behind as a result of existing data silos and resistance to change. Traditional methods led towards data isolation and automation islands, where each operator is doing its own thing. This makes operations rather difficult to optimize or systemize. Indeed, servitization brings the following main benefits for port ecosystems:

1. Flexibility of production/service operations;
2. Satisfying customers' requirements and needs; and
3. Reduction of overall production/operational costs.

As a result, Figure 1 provides a Port Service Ecosystem and its key building blocks. In order to underpin growing needs of port service ecosystem, SMSPs shall consider building-up closer relationships and interactions with their customers in all four ecosystem areas. The framework shows that institutional stability and extent of interactions play a crucial role in supporting port transition towards sustainability, as more interactions lead to an increased service extent, thus, also enabling saving of operational or management costs. Furthermore, solid technology architecture and listed determinants are principle enablers for service-led development, whereas social and environmental architecture affect sustainability of ports through the cultural, mental, and historical attributes of actors. Finally, SMSPs should mind increasing external forces on the market, funding resources and port-related industry competition through the servitization logic, i.e., moving from the sole product-based solutions towards service-driven innovation solutions in ports and port ecosystems, e.g., software solutions regarding data on efficiency and security exchange, environmental-friendly and zero-emissions solutions shared along the corridors, maintenance provided, new share vision driven service contracts with service providers of energy, and waste and sewage water management. In addition, servitization, e.g., through real-time analysis of data, enables operators to shift from prescriptive to predictive maintenance, and ultimately reduces the amount of maintenance required, e.g., when sensors are used.



**Figure 1.** Port Service Ecosystem Framework for Small and Medium-Sized Ports (SMSPs). Source: compiled by the authors.



Overall, using yielded data and the concept of servitization, SMSPs can achieve the demanded smart and sustainable future transition through innovation application within the ecosystem. With understanding of integrative ecosystem and different aspects that meet within the ecosystem—social, environmental, human, economic, technological, and legal—it will be possible to sustain innovation and enhance future competitiveness.

#### *4.3. Decision-Making Tool for Small and Medium-Sized Ports' Digital and Environmental Transition*

The present tool is a result of aggregated data gathered from (a) digital auditing as implemented in the Connect2SmallPorts project, and (b) SMSPs environmental and digital audits from the Horizon 2020 SEAD4Ports project field research. The designed strategic tool builds upon a combination of priority indicators from the overall pool of 38 indicators in the areas of management, human capital, IT functionality, technology, and information, as revealed from the quantitative benchmarking of 36 individual SMSPs in the frame of the Connect2SmallPorts project, and KPIs ranked during 26 SMSPs audits and 12 in-depth interviews deploying sustainability concepts and allocating applicable KPIs to concerned sustainability pillars—environment, society, economy, and institutional stability. In the research amalgamation step, the most prioritized indicators by the participating ports from the digitalization field (mainly implemented within the Connect2SmallPorts project) were underpinned by the second parallel path—environmental and sustainable development—with indicators mostly prioritized within the individual port audits and complementary interviews. Respectively, the research delivers a strategic tool that can be referred to as an entrepreneurial functional strategic scorecard along operational/functional (essential) and managerial and strategic/functional (positioning) levels within a single port, showing this port the way and direction for step-by-step efficient governance opportunities leading to environmental and digital transition.

Compared to the other two tools discussed above, which presuppose consideration of place-based interactions, multi-level governance, and the notion of the ecosystem and stakeholder engagement, and which are oriented towards operational and tactical performance evaluation and (re)direction, this particular strategic tool is intended for individual port (company level) strategic future forecasting. How can this scorecard be interpreted? In the first step, potential users (ports) shall read the indication of different level (or penetration) following the well-known Likert scale. Here, we use fixed levels for scaling importance of environmental and digital indicators, using ordinal data and its interpretation in the following way:

- (a) “+ +”—“easy gains” for a port, i.e., fast possible adaptation of ports and activities leading to gains in terms of environmental and digital transition in the short-run, thus, improving port strategic positioning, competitiveness, and access to new markets. In this category, the port has a necessary capacity to kick start the concerned transition, but might need (re)allocation of resources or an external push up (e.g., auditing, training, engagement in a new networking community, etc.).
- (b) “+”—“grass root potentials”, i.e., a given port possesses needed potential, but needs a certain upgrade within operational or management performance area. Mainly, potentials need to be caught up in more than two focus areas in both environmental and digital transition.
- (c) “0”—“neutral impacts”, i.e., a specific indicator or focus area does not impede or facilitate the transition extremely, but nevertheless makes a substantial footprint in each of the individual transition domains—either environmental or digital.
- (d) “—”—“grass root challenges”, this implies that this specific domain or indicator is considered rather as a bottleneck or barrier at the specific stage, whether functional, management/operational, or strategic foresight level. Nevertheless, this can be balanced out through improvement in other basket categories or leveraged by coupling area improvement—whether environmental or digital.

- (e) “— —” — “burgeoning challenges”, i.e., challenges easy accumulate and bring a port into a stagnating or locked position. This situation cannot be easily overcome, and mainly requires a substantial resource pool, policy support, and port openness to networking and collaboration as well as changing framework conditions (investment incentives, public–private partnerships, regulations etc.).

In the second step, users of this tool should read it from the bottom to the top by understanding highest gains in that area, in which environmental and digital transition complement each other and demonstrate grass root potentials or easy gains. Those areas that are rated as “0” also have potential once framework conditions are improved, whereas highest endeavors are associated with areas that are specified as having grass roots or burgeoning challenges. As a result, the research underpins the need and postulates that easy gains can be achieved in areas that involve human interactions, management capabilities’ integration for design of roadmaps and strategies, as well as integration of digital operating systems that are also deployed for energy (resource) consumption and circular management of resources. In this sense, the paper endorses topical literature and purports a lack of strategic capabilities, missing new or external knowledge absorptive capacity, when it comes to environmental and digital transition. Within the domain of Management, performance in indicators such as “Digitalization Strategy”, “Digital Business Model”, “Innovation Cooperation”, and “Investments in Digitalization” yield the lowest average score among all available performance areas in the sample of audited SMSPs, with a value of 2.778 out of 6, as conducted in the frame of the Connect2SmallPorts project. This clearly underlines the high demand for the research to support SMSPs with strategic and organizational tools when it comes to the envisaged twin transformation. Even though technological readiness might be available (an average of 3.66 out of 6 in audit results), the main obstacles for sufficient and successful transition of SMSPs have to be traced back to the management and strategic level, followed by operational and technological capacity boosting.

In this vein, the researchers perceive environmental and digital transition as twin horizontal parallel paths that are intertwining with operational, managerial, and strategic level of an organization (port/company performance). As a result, the paper claims that once environmental and digital tenets get absorbed and the emerging mindset becomes an integral part of the entire port ecosystem, ports are provided with comprehensive and holistic tools for sustainable development. This, in turn, accelerates port sustainability and opens up new (niche) market entrances and growth opportunities, as highlighted also by the topical research. Future research will need to investigate enablers and drivers that support and maximize positive impacts of sustainability performance, also through mechanisms that simultaneously recognize environmental and social values, and economic feasibility [57] (p. 60).

Additionally, the results allow us to identify focus areas on digital transition for SMSPs as well as to evaluate their bottlenecks for immediate application in port service ecosystems using an adaptation of the Balanced Scoreboard approach [39,40]. The same idea and approach are applied for Environmental Focus Areas of SMSPs, using the insights gained from port mapping as introduced in the methodology chapter. For both, evaluation is done in a simplified manner. In Table 4, the researchers present the process-based approach towards improving environmental and digital transition related to decision-making.

As can be seen in Table 4, SMSPs, which usually lack substantial capacity in greening their port operations, are provided with a simple roadmap or avenue on how to navigate through these intertwined and complex aspects of environmental and digital transition. The research proposes that ports should work simultaneously on both the environmental and digital track. In many cases, environmental transition is even impossible without the digital one, especially when it comes to, e.g., port environmental monitoring and interoperability of operational and digital systems of port management. In this respect, the present research provides a twin approach to how to deal with both environmental and digital transition,

especially in SMSPs. It is at the core of this research and the overall research journey of the researchers to help SMSPs to step into environmental and digital transition.

**Table 4.** Strategic Decision-Making Tool on Digital and Environmental Twinning.

Digital Focus Areas	Transition	Strategic Twinning Level	Transition	Environmental Focus Areas
Holistic Digitalization Strategy	+	Strategic/Foresight Level	+	Green Port Ecosystem Strategy
Digital Business Models	0		0	Disturbance Robustness
Digital Innovation Policies	—		—	Responsible Innovation Policies
Digital Investment Portfolio	—		+	Circular Economy
Digital Energy Monitoring	+		+	Environment Protection Plan
(Cross-)Port Collaboration	+	Management/ Governance Level	+	Energy Circularity
Intelligent Infrastructure	0		0	Renewables
Port Community Systems	+		+	Emission Management
Digital Capacity Building	++		+	Biodiversity/Conservation
IT Knowledge and Skills	0		+	Environmental Compliance
Multi-Level Stakeholder Engagement	+		—	Alternative/Hybrid Resources (Re-allocation)
Usage of Blockchain	—	Functional/ Operational Level	+	Energy Consumption/Supply
Integration of IoT	— —		—	Waste/Water Management
Big Data Analytics	—		+	Intermodal Connectivity and Interoperability
Usage of Drones	— —		+	E-Mobility
Autonomous Solutions	— —		— —	Green Construction/Facilities
Digital Operating Systems and Processes	+		—	Port Electrification/Cold Ironing
Integration Robotics and Artificial Intelligence	— —		+	Emission Monitoring

Source: compiled by the authors.

## 5. Discussing Small- and Medium-Sized Ports Avenues in the Ecosystem Paradigm

It is of particular importance to start the twinning of environmental and digital transition in SMSPs, since, as underlined previously, global forecasted growth and, thus, increasing environmental footprints will also jeopardize SMSPs in Europe and especially on a regional level. This is because SMSPs co-exist with big ones and are involved in global supply and value chains. Being European, SMSPs already show a sound record of acting as role models in environmental transition. With increasing negative environmental effects, it is expected that SMSPs in the EU will take a substantial step further to sustain their forerunner positioning in environmental responsibility. This is especially visible for the BSR and projected sustainability-driven growth [96–99]. Furthermore, for the future perspective, it is important to understand that one day, SMSPs can become the backbone of the EU port economy, and big Core Ports lagged back, as all port performance in Europe is subject to interdependencies and economic interactions among the main world regions and key economies. What is big now, can become small in the next future, if we take globalization or even “glocalization” issues into account.

The umbrella term of ecosystems is very suitable for the analysis and design of the capacity of greening European ports. It is because, first, an ecosystem is characterized by resource allocation in a bounded area; a specific and limited geographical space. This is essential for ports in terms of their geographical position and location in urban or rural populated areas. Second, efficient and effective resource allocation enable twin creation for environmental, economic, technological, and societal benefits. Third, ecosystem implies causality and independencies, as, like in nature, people and agents (ports, shipping companies, hinterland logistics providers, multinational enterprises (Small and Medium-Sized Enterprises (SMEs) and other actors) co-exist, co-create, and co-evolve in the common setting—geographical region, economic agglomeration, and bounded social sphere—port regions. Interdependency includes also aspects of physical and intangible assets (infrastructure), institutions, sources of knowledge, human capital interactions, spillovers, and network effects [100,101]. As a result, ports act not only as ecosystems but also as clusters of interrelating actors [102], different people, materials, goods, and activities under different governance [39]. Port service ecosystems enable, therefore, the development and growth

of dynamic, goal-driven communities, characterized by complexity, dynamism, adaption, and an emergence perspective [103]. Furthermore, service ecosystems are based on the interplay of strong relations that presuppose collaboration, trust, and co-creation of value and share of complementary technologies and competencies [104,105].

Ecosystems are essential also from the systemic point of view. They bring all affected agents together for the interaction that leads to goal achievement and involves several domains and integrates their peculiarities. The port service ecosystem includes environmental, technological, legal, economic, governance (policy), and socio-cultural dimensions. The recognition of an ecosystem approach is crucial in the context of greening EU seaports, as greening initiatives should achieve environmental, technological, legal, economic and governance (social) feasibility and value creation. Indeed, all dimensions in an ecosystem are intertwining to propose environmental benefits, technological feasibility, business economic considerations, governance (regulative frameworks, legal compliance, coordination, collaboration, internationalization), and social quality (public acceptance, social responsibility, interactions, exchanges of practices, knowledge, and competences).

A comprehensive port service ecosystem approach enables achieving better innovation. It is argued that the regional dimension of innovation, which encapsulates both top-down (external) and bottom-up (internal) sets of characteristics, shape innovation emergence and management. Externally, the dimension refers to the role of institutions, crucial for the knowledge creation on the local level and governance of innovations, whereas internally it includes internal characteristics of interaction and collaboration among different actors of a system. In aggregate, the focus is given to issues, components, and processes in a system of innovation that operates at a localized level. Thus, a systematic view on integration, ecosystem and, thus, innovation underpins the emphasis of spatial proximity and agglomeration in the dynamics of innovation and economic growth [106]. This, in turn, allows us to bridge innovation, competitiveness, and growth within the regional context—the bounded area of the port ecosystem.

In this line, it is important to understand how the ecosystems work, in particular port service ecosystems, since ports have, although not necessarily, physical boundaries, and are associated with entry and exit barriers. All actors involved (species, people, economic agents) absorb necessary resources from the ecosystem and also generate critical resources for others with accompanying spillovers and crossover effects beyond the ecosystem itself [36]. As a result, the ecosystem approach is regarded as the most suitable for the analysis of greening initiatives and providing capacity for ports, since it carries with it the integrative perspective, and the multi-level and multidisciplinary aspects.

In this respect, the present research supports the existing scientific literature in that, in order to make environmental and digital transition in ports, in particular SMSPs, a reality, efficient cooperation between public bodies and private companies is necessary [107]. In addition, green ports necessitate understanding the role of contextual factors that might play in the face of green port measures from the potential bulk of tools and technologies [68] (p. 15). The research made clear that environmental transition presupposes suitable institutional and situational arrangements that emerge as a result of process-based approach and sense making [108]. The present research underpins this finding and claims that ports need to be sensitized and a huge amount of empathy needs to be placed on SMSPs when dealing with their environmental and digital transition. In doing this, the research reduces the concerned gap in literature of missing decision-making for ports in terms of sustainability, integration of stakeholders, and learning avenues [53,54,58,94,109]. In contrast to the existing literature on smaller ports that utilize only case studies for making contributions [53,54,110], this research builds upon a rich body of cases and makes use of cross-case analysis, thus, making the results more transferable, reliable, and replicable. Indeed, SMSPs will need to learn and find resources in order to play on the stage with their big counterparts Core Ports, in order to balance the triple bottom lines of port operation; economic, environmental, and social performance [110,111]. This is true. Our research adds one important key layer—institutional arrangements and governance, which will have

pivotal importance in the future, as ports, the same as all economic agents, will need to find tools and solutions that would enable them to better adopt to volatile, uncertain, complex, and ambiguous environments and more rapid pace of change enabled by technological readiness and its progress.

## 6. Conclusions

The present research is aimed at providing SMSPs with practical insights on how they could kick start environmental and digital transition that needs to comply with the EGD objectives and all accompanying international regulations applying to shipping and port operations and hinterland connections. In this vein, the research delivers three practical tools that can be used by SMSPs both on a short-term daily basis (tactical and operational level) as well as be incorporated into the design of long-term management and strategic foresight plans (strategic and visioning level).

The first tool—Green Port Performance Measurement Framework—provides a harmonized auditing tool for SMSPs regardless of their differing size (being small or medium-sized). The tool can be transferable and replicable, therefore. Since several bottlenecks in SMSPs related to misunderstanding or a lack of knowledge on how digital and environmental monitoring can be implemented with limited resources, the present tool simplifies the understanding by adopting a sustainability concept and pinpointing to port authorities which areas need auditing and improvement in the priority list. Namely, port managers need to start first with their operational capacity auditing by addressing three specific domains of intertwined interactions—(a) shipping and waterborne activities including port reception facilities (e.g., mooring, towage, bunkering, ballast water treatment, nautical technical assistance); (b) daily port operations including port services (e.g., cargo handling, consignment of ships, passenger transport, stowing, dredging); and (c) hinterland connection (intermodal access, passenger accessibility, tourism services, safety and security). A second layer or domain of port performance auditing that enables digital and environmental transition refers to environmental responsibility. Here, in contrast to existing monitoring variables, applicable KPIs were merged together from different port performances expanding the pool of existing KPIs with international or Pan-European pools, including also macro-regional incentives and environmental performance indicators that go beyond simply known indicators, such as Environmental Ship Index, Clean Shipping Award, environmental protection, etc. In doing this, the application of this tool enables also cross-linkage of existing initiatives and their multiplication, thus, supporting also macro-regional environmental performance monitoring, networking, and competence exchange among SMSPs, which are bound to limited resources.

Shedding the light on the remaining domains—economic efficiency and institutional stability, these two areas of interactions shall be audited by SMSPs with a particular lens on sustainability and performance maintenance, including robustness and resilience in times of disturbances. For instance, while focusing on economic efficiency, SMSPs' managers should not forget screening opportunities and integrating the port's daily challenges into the European funding schemes. As the empirical data underpins, SMSPs stay a step back when it comes to external funding opportunities, because this means additional work with the same limited resources and presupposes suffering in quality of port services they provide regularly. Nevertheless, this research concludes that it is inevitable for ports to establish access to external funding sources, which also enables networking, clustering, and exchange opportunities. Principally, this can be done by means of engagement of responsible port area managers into local and regional networks of cooperation and by developing port auditing report using the proposed matrix. This matrix serves as a crucial precondition for any project preparation and mapping needs that are requested in any funding opportunities. In addition, using this auditing matrix provides a basis for regular port performance improvement and conditions, and accessibility to local, regional, or national pools of funding.



In addition, the second tool—Small and Medium-Sized Ports Service Ecosystem—positions SMSPs as a functional service providing regional hubs and sites essential for the community to access and use potential services. The research claims that in the last decades, the natural functionality and rational understanding of ports was pushed back giving rise to clustering, competitiveness, and growth perspectives. The port ecosystem framework provided here can be deployed by individual ports for the purpose of strengthening competitiveness of ports through the creation or maintenance of new offerings and experience—in particular, expressed via service logic. Therefore, SMSPs can use this tool for searching new niche markets, for designing their strategies on co-existence with their big counterparts, or for long-term customer bonding. Indeed, the dominance of and focus of customers nowadays, especially in volatile, uncertain, complex, and ambiguous (VUCA) environment become a key source of competitive advantage and sustainable behavior. For this, SMSPs can deploy the proposed second tool for designing their business models and maintaining customer relationships.

Finally, the third tool—Strategic Decision-Making Tool on Digital and Environmental Twinning—opens up SMSPs avenues for adapting port performance. The key insight here gathered from the empirical research is that SMSPs managers and port authorities shall first of all tackle digital and environmental transition on a management and strategic level, by, for instance, clearly defining digitalization and green port concept adaptation to the own port—this can be done using the first tool introduced here and by including respective KPIs into the strategic roadmap of the port. In addition, the second highest priority for SMSPs should be capacity development and upgrade including short- and long-term binding strategies of young digitally savvy and environmentally conscious employees or providing capacity building opportunities for older labor force through, for example, inter-project cooperation. Indeed, as the empirical foundation confirms, inter-project cooperation provides direct access to tacit knowledge and exchange opportunities for all-aged employees who in their daily activities remain located in silos and have no interchange points with their peers. This is particularly crucial for SMSPs, as, due to similar challenges those ports face, they tend to cooperate as opposed to their bigger counterparts.

Overall, the proposed managerial tools are dedicated to SMSPs' authorities, which are mainly responsible for the management and development of SMSPs. In addition, having different types of ports in the analysis—whether they be liquid and bulk, cruise and passenger port, or general cargo ports—the proposed tools show a high level of transferability and replicability despite the diverse operational and capacity portfolio of SMSPs. Since SMSPs have great autonomy and are important for regional community development, they are depending on their own and limited resources, smart resources (re)allocation, and resource pooling as well as establishing or maintaining accessibility via competence building, clustering, and exchange. Being smaller than their bigger counterparts—world gateways—SMSPs need mostly to find internal tools for capacity improvement, since access to external knowledge, e.g., consultancy can hardly be covered by the existing resources.

Theoretically, the research in hand reduces the gap in the existing marginalized empirical foundation on environmental and digital transition for port decision makers. In this, the applied qualitative research using sound empirical data from running applied research projects in Europe purports that SMSPs cannot be treated in the same manner as their bigger counterparts—Core Ports in the EU. SMSPs need, first, grass root tools and concepts to initiate their environmental and digital transition. Second, they need to build up necessary competencies and capabilities that would enable capacity building, respectively. Third, SMSPs are more flexible in undertaking environmental and digital transition, as they can better and easier react to changing paradigms, compared to big ports. Practically, the research is based on a rich empirical body of research; the research team have been cooperating with and working for SMSPs for longer than three years. In doing this, the researchers are sure to have heterogeneous, valid, and reliable information gathered that is underpinned by integration, synthesis, and amalgamation of different data. For this, the researchers believe that proposed tools and concepts can be utilized on a daily

basis, since their development and practicability is seen as a natural need emerging based on SMSPs' challenges and bottlenecks.

In this sense, the future research should continue this research avenue and support the inductive approach made in this paper by the deductive reasoning, thus, enabling both quantification and qualification of the proposed solutions. In addition, the future research needs to focus more on the ecosystem interactions, in particular social responsibility and impact of social indicators for port performance along with stakeholders' interactions and how different sustainability pillars and actors within them result in either positive or negative reciprocal relationships. Since several research initiatives are planned in this domain together with the surveyed SMSPs, the researchers intend to continue this promising research path and fill in the located research gaps.

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