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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Green Port and City Integration: Sustainable Approaches in Location Selection

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Abstract: The concept of green ports is becoming increasingly important as global concerns about environmental sustainability grow. However, operating existing ports as green ports or planning newly constructed ports as green ports brings certain requirements. It is seen that the importance of location selection in green ports significantly affects the efficiency of the port and its suitability to its name. Selecting an appropriate location for green ports constitutes a multifaceted decision-making challenge that necessitates a balance among environmental, economic, and operational factors. In this study, the criteria affecting the selection of green port locations were evaluated using the Analytical Hierarchy Process (AHP), which is a multi-criteria decision-making method (MCDM). The study aims to hierarchically classify the relationship between ports and cities for more livable cities and prioritize green port needs. The study results show that the most important criterion among the criteria considered in the selection of green port locations is Environmental and Social Sustainability (29.27%). Geographical and Natural Conditions (24.78%) emerge as the second most important criterion. Infrastructure and Operational Efficiency (18.47%) and Economic and Commercial Issues (16.8%) are also emphasized in close competition with each other in terms of weight. Management and Strategic Importance (10.68%) are in the last place. In the selection of green ports, it is necessary to adopt a business style that respects the environment and humanity. Before the industrial revolution, the port-city relationship has given way to distant relations today. In this respect, for a clean future, integrated systems need to be created not only from green ports but also with green hinterlands and green cities.

Keywords: Analytical hierarchy process, green port, port-city integration, multi-criteria decision making, sustainability.

Yeşil Liman ve Şehir Entegrasyonu: Lokasyon Seçiminde Sürdürülebilir Yaklaşımlar

***Sorumlu yazar:**
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Öz: Çevresel sürdürülebilirliğe ilişkin küresel endişelerin artmasıyla birlikte yeşil liman kavramı giderek daha da önemli hale geliyor. Ancak mevcut limanların yeşil liman olarak işletilmesi veya yeni inşa edilecek limanların yeşil liman olarak planlanması belirli gereklilikleri beraberinde getirmektedir. Yeşil limanlarda lokasyon seçiminin öneminin limanın verimliliğini ve ismine uygunluğunu önemli ölçüde etkilediği görülmektedir. Yeşil limanlar için uygun bir yer seçmek, çevresel, ekonomik ve operasyonel faktörler arasında bir denge gerektiren çok yönlü bir karar alma zorluğunu oluşturmaktadır. Bu çalışmada, yeşil liman lokasyonlarının seçimini etkileyen kriterler, çok kriterli karar verme yöntemlerinden (ÇKKV) Analitik Hiyerarşi Süreci (AHS) kullanılarak değerlendirilmiştir. Çalışmanın amacı, daha yaşanabilir şehirler için limanlar ve şehirler arasındaki ilişkiyi hiyerarşik olarak sınıflandırmak ve yeşil liman ihtiyaçlarını önceliklendirmektir. Çalışma sonuçlarına göre yeşil liman lokasyonlarının seçiminde dikkate alınan kriterler arasında en önemli kriter Çevresel ve Sosyal Sürdürülebilirlik (%29,27) olmuştur. Coğrafi ve Doğal Koşullar (%24,78) ikinci en önemli kriter olarak ortaya çıkmaktadır. Altyapı ve Operasyonel Verimlilik (%18,47) ile Ekonomik ve Ticari Konular (%16,8) da ağırlık bakımından birbirleriyle sıkı rekabet halindedir. Yönetim ve Stratejik Önem (%10,68) son sırada yer almaktadır. Yeşil limanların seçiminde çevreye ve insanlığa saygılı bir iş yapma tarzı benimsemek gerekir. Sanayi devriminden önce liman-şehir ilişkisi yerini günümüzde uzak ilişkilere bırakmıştır. Bu bağlamda temiz bir gelecek için sadece yeşil limanlardan değil yeşil hinterland ve yeşil şehirler ile entegre sistemler oluşturulması gerekmektedir.

Anahtar kelimeler: analitik hiyerarşi süreci, liman şehir entegrasyonu, yeşil liman, çok kriterli karar verme, sürdürülebilirlik.

INTRODUCTION

Maritime transport plays a key role in world trade that carries out approximately 80% of global trade (UNCTAD, 2019). Low cost and energy efficiency advantages have made maritime transport more appealing than other transportation modes (Witte et al., 2014). Ports are essential centers for maritime transport, which plays a vital role in sustaining the global economy. For this reason, ports' management, infrastructure, and efficiency are critical. Major ports such as Shanghai, Singapore, Rotterdam, and Hamburg are interesting examples of technological innovation and sustainable development in this context. (Merk & Hesse, 2012; Zhao et al., 2017). Historically, ports and cities have had a mutually efficient relationship, such that ports are important for the global trade of a city and the urban economy in general. These hubs attracted new business toward regional wealth by encouraging industrial development while offering bridges to the global marketplace (Yu et al., 2020; Monios et al., 2018). However, the port-city interaction has become more complicated by growing urbanization and, therefore, globalization has caused challenges between integration and division of their growth (Kong & Liu, 2021). Now, ports have much economic importance because of the unexpected rise of international commerce and turn into major networks for global supply chains that affect the hinterland. Directly through the achievement of further development in containerization and intermodal transport, ports may now serve areas well beyond their local metropolitan borders (Ducruet & Guerrero, 2022). As a result, expansion has created numerous problems. Social and environmental costs in cities frequently accompany port activities, including excessive noise pollution, air pollution, traffic jams, and conflicts over land use (Kotowska et al., 2018). It is quite an expected result that the air pollutants already present in certain amounts in big cities like Istanbul (Çolak et al., 2024), will be supplemented by air pollution originating from ships.

The issues have thus rekindled discussion on port-city interaction, especially as far as sustainability and quality of life in the cities are concerned (Aregall et al., 2018). Nowadays environmental concerns are becoming the center of port development discussions. Ports contribute significantly to greenhouse gas emissions not only through maritime operations but also through road-based hinterland connections (Kotowska et al., 2018). Moreover, although ballast water from ships has been purified from microorganisms by the improved Ballast Water Treatment System, the transport of some accompanying inorganic wastes has still not been completely prevented (Lakshmi et al., 2021). Ports such as Rotterdam are pioneers in logistics processes thanks to their strong hinterland connections (Aregall et al., 2018). However, port-city integration can also bring problems such as traffic congestion, air pollution, and noise (Witte et al., 2014). In this context, green port strategies and smart port technologies offer important solutions to facilitate integration (Kong and Liu, 2021; Zhao et al., 2017). The common point among all these solutions is that environmental and social values should not be lost for the economic interests of humanity (Bin et al., 2023). Implementing business plans that take into account both present and future port requirements is another challenging task for ports. Köse (2020) assessed the impact of port activities on the city of Trabzon, and it was determined that particles originating from the port could spread 2-3 km wide in the city. Ports need to expand their capacity and foster economic development, but this growth must be balanced with efforts to minimize negative impacts on nearby communities. The implementation of green port policy is one of the levers that can be applied to have an impact towards minimizing environmental effects and having sustainable long-term operations. Satır et al. (2018) define a green port as "a green port is defined as meeting all applicable environmental standards and focusing on sustainability and eco-friendliness". The green port policy aims to develop a habitat in terms of marine life, reduce air pollution from and for port users, and create a clean and safe environment. Major ports have begun adopting such measures as putting in place the green port strategies and promoting environmentally friendly mode transport so that they will have a dent in the region's air pollution (Aregall et al., 2018). Ports such as Rotterdam and Hamburg have shown that public benefit ports can deliver in terms of contributing towards regional environmental targets by proactive measures reducing emissions and increasing sustainability (Merk Hesse, 2012). Economic variables play a significant role in the interaction between ports and cities. Monios et al. (2018) conducted an in-depth study on how logistics distribution impacts the dynamics between ports and cities. This need for sustainable planning is most evident when considering how logistics activities centered around ports can influence city traffic flow and economic activities. Ports are economic engines of development benefiting trade, foreign direct investment, and employment creation. Lugo and Martínez-Mekler (2022) discuss the theoretical impact of ports on city systems in relation to the interdependence of these two systems. Ports may pose severe limitations to spatial planning, even as they contribute to the economy of the cities. Because of this circumstance, port-city integration becomes really complicated. Discussions continue in this context regarding whether this situation weakens the economic ties between ports and cities or opens new avenues for urban renewal (Zhao et al., 2017). According to the study

done especially for the Port of Hamburg, port and city integration provides answers for both economic expansion and environmental issues. The Organisation for Economic Co-Operation and Development (OECD) Hamburg research emphasizes how this integration boosts cities' competitiveness (OECD, 2020).

Possible criteria affecting the location selection for a green port are listed as follows.

Geographical and Natural Conditions

Deep water access and natural harbors require deep water to meet the draft requirements of large ships, and natural harbors are often used to minimize infrastructure costs (Ducruet & Notteboom, 2012). This situation paves the way for the expansion of historically used natural harbors. Climatic and hydrological factors are favored for operational efficiency, stability in weather patterns, and minimum sedimentation (Merk & Hesse, 2012). In this way, prevailing winds, currents, and rivers' drainage are taken into account.

Economic and Commercial Issues

Strategic locations on important shipping routes and close to economic centers reduce transportation costs (Monios et al., 2018; Zhao et al., 2017). Efficient connection roads, railways, and inland waterway connections are critical for accessing regional markets thanks to hinterland connectivity (Kotowska et al., 2018). The biggest deficiency, especially for Eastern Black Sea ports in Turkey, is the lack of railway connectivity. The integration of railway transportation, which is the most economical transportation method after sea transportation, into ports significantly affects costs and various environmental pollution. Industrial proximity is one of the important issues for ports. The industry in the region increases the cargo volume; therefore, being close to industrial production centers contributes positively to the port's processing volume. (Ducruet & Guerrero, 2022).

Infrastructure and Operational Efficiency

In transport integration, seamless transitions between sea, rail, and road ensure the smooth operation of intermodal transport (Kotowska et al., 2018). The completeness of infrastructure and superstructure formations such as railways, which also affect economic issues, will ensure that the port operates more efficiently and cleanly. Ports equipped with technological readiness, automation and digital logistics technologies gain a competitive advantage in terms of being both economical and green ports thanks to increased efficiency (Aregall et al., 2018). Ports with land suitable for expansion make it easier to adapt to future growth demands (Merk & Hesse, 2012). Having land suitable for the expansion of ports is, in a sense, significantly and positively related to the distance from the city. There will be a gap in terms of cost between the resources and time spent for the expansion of the port in the city center and the expansion activity to be carried out outside the city.

Environmental and Social Sustainability

For green port initiatives, sustainability practices such as emission reduction and renewable energy use are increasingly prioritized (Sharifi, 2020). In urban areas, addressing social concerns such as congestion, pollution, and displacement is of vital importance (Yu et al., 2020). This issue should be taken into account in the establishment of new ports, and settlements that are somewhat distant from the city should be considered for the establishment of ports. Ports located in areas that are far from extreme weather events and high tides are more sustainable (Aregall et al., 2018). While tides are not seen much in regions such as the Black Sea and the Mediterranean, tidal amplitude is an important criterion in port construction in areas with oceanic coasts. Finally, before large-scale construction activities such as ports are carried out in the region, the importance of the region for marine life should be evaluated, and extra care should be taken for areas that are critical to species (Gill, 2005).

Management and Strategic Importance

Countries' policies, incentives, and legislation at different times affect the choice of location (Ducruet Guerrero, 2022). The area where the port investment will be carried out should not contain security risks. In addition, ports with long-term trade agreements with other countries are preferred (Monios et al., 2018). This situation can be done not only for economic reasons but also for bilateral relations and strategies. Since ports are strategically important, their security should be controlled meticulously. The crowded and traffic in the region passing through the port areas is directly important in terms of security (Zhao et al., 2017). For these reasons, the distance between the ports and the city should be calculated in a very balanced way.

How is the relationship between urban areas and ports affected by the concept of green ports? How are port location selection criteria affecting the interaction between ports and cities? This paper evaluates the economic, social, and environmental balances involved using case studies, theoretical frameworks, and empirical evidence from literature. For this purpose, the analytical hierarchy method (AHP) of the multi-criteria decision-making (MCDM) technique is applied to analyze the weight of critical criteria in green port location selection. The factors affecting the port location are summarized into five broad categories by reviewing the literature and reaching expert consensus.

MATERIAL AND METHOD

In this study, the AHP was used to evaluate and prioritize the criteria to be considered in port site selection considering the interaction of cities with ports. AHP, developed by Thomas Saaty, is a methodical and quantitative approach to decision-making that gauges expert opinions

according to a number of criteria (Saaty, 2008). By comparing the criteria both among themselves and in pairs, the AHP makes it possible to synthesize qualitative expert assessments into quantitative rankings (Özdemir et al., 2018). In this study, the AHP method was preferred in order to reveal the weighting and priority order of the criteria. The initial criteria identified in the literature review were subsequently refined through preliminary interviews with experts, during which the suitability of each criterion was discussed. Five key criteria were ultimately established after a thorough consensus process involving experts. After selecting the criteria, a group of nine experts consisting of experienced captains and academicians from the operations department evaluated the criteria. As a result of the research and interviews, five main criteria to be considered in port site selection were determined. The criteria and their explanations are given in Table 1.

Table 1. Description of criteria.

Criteria number	Explanations of criteria.
C1.	Geographical and Natural Conditions
C2.	Economic and Commercial Issues
C3.	Infrastructure and Operational Efficiency
C4.	Environmental and Social Sustainability
C5.	Management and Strategic Importance

AHP uses pairwise comparisons to assess the relative importance of each element. According to the relevance scale shown in Table 2, experts provide a number between 1 and 9 for every pair of criteria, where 1 indicates equal importance, and 9 indicates extraordinary importance of one criterion over the other.

Table 2. Importance scale (Saaty, 2008).

Intensity of importance	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

A pairwise comparison matrix A=[aij] is used to arrange the comparisons, where:

aij represents the relative importance of criterion *i* i over criterion *j* j.

If aij = k then aij = 1/k to maintain matrix consistency.

For instance, the pairwise comparison matrix A would resemble this if it were comparing five criteria, C1, C2, C3, C4, and C5.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & 1 & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & 1 & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & 1 & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 \end{bmatrix} \quad (1)$$

The eigenvector computation step starts after this stage.

Total the columns of the pairwise comparison matrix A.

To normalize each element, divide it by the sum of its columns.

Determine the average of every row in the normalized matrix to obtain the priority vector.

Each criterion's weights are determined using the formula w= [w1, w2, w3, w4, w5,…wn].

For a matrix of size n, the formula for criterion *i* i's priority is:

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right) \quad (2)$$

AHP performs a consistency check to ensure that the choices in the pairwise comparison matrix are reasonably consistent. The Consistency Index (CI) is calculated using the formula below:

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n}-1} \quad (3)$$

Where n is the number of criteria and λ_{max} is the maximum eigenvalue of matrix A. The consistency ratio must be computed as follows in order to test the pairwise comparison matrix's (CR) degree of consistency:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \quad (4)$$

The random index value for the pairwise comparison matrix (A_{nxn}) is represented by RI, and the consistency index value by CI. The random index value RI can be computed using the random index values listed in Table 3.

Table 3. Random index (RI) (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

If the CR value is less than 0.1, pairwise comparisons are consistent (Saaty, 2008). If not, the analysis should be reviewed and, if necessary, updated with new values.

FINDINGS AND DISCUSSION

Normalized decision matrices were created and examined following the assessment of each expert. After that, the specialists created weight eigenvectors for every criterion. The relative relevance score of each criterion in the pairwise comparison matrix is based on the geometric mean of the expert ratings. Professional viewpoints on choosing a green port location significantly overlap. The criterion weights derived from the pairwise comparison matrices are displayed in Table 4.

The study results show that among the criteria considered in the selection of green port locations, the most important criterion is Environmental and Social Sustainability (29.27%). Geographical and Natural

Conditions (24.78%) appear as the second most important criterion. Infrastructure and Operational Efficiency (18.47%) and Economic and Commercial Issues (16.8%) are also emphasized, with both factors competing closely in terms of weight. Management and Strategic Importance (10.68%) are in the last place.

According to AHP results, environmental and social sustainability was found to be the most important criterion (29.27%), and sustainability in port management is a necessary prerequisite for global competition (Aregall et al., 2018). In order to talk about a sustainable port, it is expected that the port is operated in a way that respects its environment and resources. Ensuring intensive particle transport into the city while carrying out port activities does not coincide with green port strategies; much stricter measures should be taken for air quality in ports close to city centers (Köse, 2020). There are negative effects of port activities, such as pollution, noise, traffic, and congestion, on the urban population in port operations (Kotowska et al., 2018). If these effects are eliminated, city and port integration can progress more healthily. For example, sustainable development policies such as the Hong Kong Port have shown that effective coordination between port and city management can increase environmental efficiency while maintaining economic viability (Kong and Liu, 2021).

Table 4. Criteria weights assigned by experts.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	FEW	PCT
C1	0.258	0.273	0.159	0.144	0.252	0.157	0.310	0.253	0.449	0.248	24.78%
C2	0.196	0.223	0.343	0.164	0.133	0.187	0.141	0.130	0.061	0.168	16.80%
C3	0.171	0.193	0.243	0.204	0.144	0.201	0.141	0.145	0.164	0.185	18.47%
C4	0.225	0.213	0.159	0.392	0.377	0.373	0.253	0.373	0.254	0.293	29.27%
C5	0.149	0.098	0.097	0.095	0.094	0.081	0.156	0.100	0.072	0.107	10.68%

*C: Criteria, E: Expert, FEW: Final Expert Weights

According to geographical and natural conditions (24.78%), the role of natural harbors and hinterland connections in port success is quite important (Monios et al., 2018). While natural harbors are important in terms of reducing investment costs, the depth of ports is increasingly important today, thanks to large draft ships. For example, the Port of Gothenburg shows how geographical proximity to deep water channels and urban centers can affect port performance and integration with urban infrastructure (Monios & Bergqvist, 2018). Moreover, hinterland connection is an essential determinant of port competitiveness, emphasizing the importance of intermodal transportation networks (Aregall et al., 2018). Choosing a port location geographically is quite important. It is essential to consider the depth of the port, the distance to the places where rivers flow into the sea, the prevailing wind and current, and tidal factors (Merk & Hesse, 2012). When choosing a port location that is negatively affected by these factors, the effort and resources spent on combating nature reduce the possibility of the port being green.

The weight attributed to infrastructure and operational efficiency (18.47%) reflects the critical role of modernized logistics systems in port operations. Studies show that ports that invest in automation and digitalization, such as container tracking and truck scheduling systems, increase operational efficiency while reducing congestion and emissions (Dos Santos & Pereira, 2021). The introduction of dynamic models for road port access is said to further facilitate operations, as evidenced by emerging hub ports such as Santos in Brazil (Dos Santos & Pereira, 2021). Supporting ports with connections such as railways, roads, and pipelines will increase their efficiency. However, increasing the efficiency of the port should not mean increasing pollution. In other words, the port should not lose its green port feature as it increases its capacity and throughput. If it is not possible to have these features, it should be established in areas as far away from the city as possible, and the port hinterland should be arranged to be a green hinterland (Aregall et al., 2018).

The relatively moderate weight given to economic and commercial issues (16.8%) is consistent with the findings that financial factors, while fundamental, act as constraints rather than drivers of green port development. For example, ports in developing regions face challenges in balancing economic pressures with environmental objectives, as highlighted in studies on the role of competition and investment in port efficiency (De Oliveira & Cariou, 2015).

Finally, there is a lower importance of governance and strategic importance (10.68%). Government policies or bilateral agreements are important in port location selection. However, governments need to adopt green port policies for green port location selection. Countries with the world's largest share of greenhouse gas emissions are moving very slowly in this regard. Studies also show that high-income people are not very enthusiastic about green transformation (Nielsen et al., 2021). The port industry needs to be seriously monitored, and its work within the scope of green transformation should be monitored.

CONCLUSION AND RECOMMENDATIONS

It is clear that prioritizing sustainability, benefiting from geographical advantages, and modernizing the infrastructure are of vital importance when choosing a

green port location. Considering the primitiveness of transportation vehicles and the security risks that emerged during transportation, the intertwining of ports and cities was quite important in choosing a port location before the Industrial Revolution. Nowadays, with economic and technological developments, sustainability emerges as an important indicator. In line with these indicators, we may need to move away from old patterns and lengthen the distance between cities and ports. Future studies can investigate how these criteria interact in different regional contexts, especially in developing economies where economic and social challenges are evident. Predictions can be made about the ports with the potential to become new-generation green ports.

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