The influence of service level on the economic viability of Onshore Power Supply (OPS) systems - A case study

Ávila, Paulo[1,2], Moreira, Paulo[1], Mota, Alzira[1,2], Castro, Hélio[1,2], Bastos, João[1,2], Pinto Ferreira, Luís[1,3], O. Fernandes, Nuno[4,5], Santos, António[6,7], Moreira, Paulo Mendes[8]

[1]ISEP, Polytechnic of Porto, 4200-072 Porto, Portugal
[2]INESC TEC - Instituto de Engenharia de Sistemas e Computadores, Tecnologia e Ciência, Campus da FEUP, Rua Dr. Roberto Frias, 4200 - 465 Porto, Portugal
[3]INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, 4200-465 Porto, Portugal
[4]Instituto Politécnico de Castelo Branco, Av. do Empresário, 6000-767 Castelo Branco – Portugal
[5]Cento ALGORITMI/LASI, Universidade do Minho, 4710-057 Braga, Portugal
[6]Autonomous University of Lisbon, Rua de Santa Marta, 1150-293 Lisboa, Portugal
[7]Department of Economic and Business Sciences, Rua de Santa Marta, 1150-293 Lisboa, Portugal,
[8]APDL – Administração dos Portos do Douro, Leixões e Viana do Castelo, SA

Abstract

The implementation of Onshore Power Supply (OPS) systems is recognised as an effective strategy to reduce air emissions and noise pollution from ships at berth, thereby supporting decarbonization goals established by the European Union. Despite its environmental advantages, the economic viability of OPS remains one of the main barriers to its widespread adoption in ports. In particular, limited research attention has paid to the extent to which the service level provided by OPS infrastructure affects the financial performance of such investments.
This paper addresses this gap by analysing the relationship between service level and economic viability through a case study of the Southern Container Terminal at the Port of Leixões (Portugal). Three investment scenarios were evaluated, corresponding to the installation of one, two, and three OPS systems, delivering service levels of 65%, 94%, and 100%, respectively. A 20-year financial analysis (2025–2044) was conducted using Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period as key indicators, under discount rates of 3% and 5%.
The results demonstrate that service level significantly influences investment feasibility. The scenario with a 65% service level is economically unviable, presenting negative NPVs and an IRR below the cost of capital. In contrast, the 94% and 100% service level scenarios generate positive NPVs (at 3%) and IRRs slightly above 5%, indicating moderate but acceptable profitability. However, increasing the service level from 94% to 100% does not produce a proportional improvement in financial returns, revealing diminishing marginal gains relative to the intermediate scenario.
The findings indicate that maximising service level does not necessarily maximise economic attractiveness. Instead, an optimal balance between infrastructure capacity and expected demand is essential to ensure financial sustainability while delivering substantial environmental benefits. These findings offer practical guidance for port authorities and policymakers seeking to design economically viable OPS systems.

Keywords: onshore power supply, sustainable development, case study, port management, service level, financial analysis.

1 Introduction

In recent years, there has been a growing concern with environmental challenges, driven by increasing pollution, biodiversity loss, and global warming (World Bank, 2025). In response, companies and international organisations have become progressively more aware of these issues, taking concerted action to address this crisis by developing increasingly sustainable business models. In a society whose concern with the environment is increasingly present, the use of alternative solutions that allow for the reduction of consumption of the planet's existing natural resources is a necessary condition (Ávila et al., 2024). In addition, the negative implications for enterprises that do not look for better utilization of their resources are quite high. So, the way is to think/plan and act (not react) faster and beyond than the common in order to promote the rational resource utilization (Ávila and Putnik, 2016). This study falls within this theme and deals more specifically with the energy consumption of the ships when they are at berth.
Onshore power supply **(**OPS) is a system that enables a berthed (docked) ship to connect to the local electrical grid. This connection allows the vessel to power its onboard systems, such as lighting, heating, and air conditioning, without having to run its auxiliary engines or generators, thereby reducing fuel consumption and

emissions. An OPS installation typically requires a building, or a shelter, containing the necessary technical equipment that include switchgear, transformers and frequency converters which aim is to adapt the shore electrical characteristics to the ship's ones, such as voltage, frequency (see Figure 1).

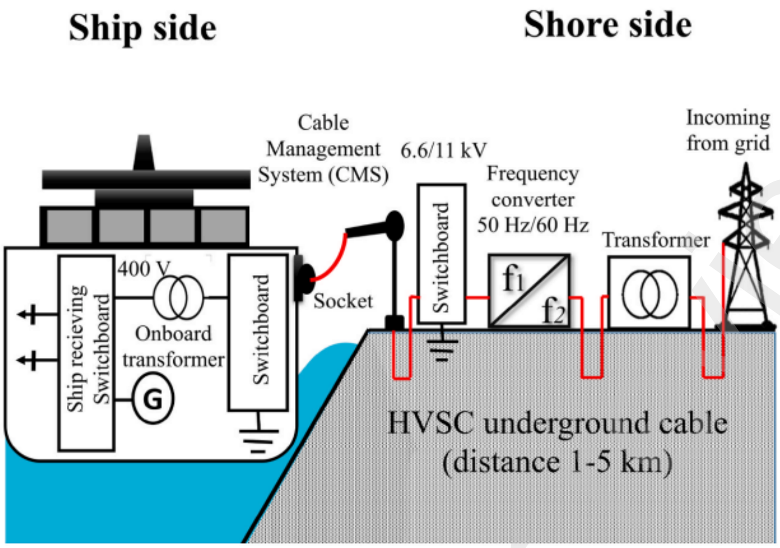

Figure 1 – Main components of the typical OPS system (Bakar et al., 2023).

The proposed Fuel European Union Maritime regulation aims to boost the production and uptake of sustainable, low-carbon fuels in maritime transport, and obliges ships to use on-shore power supply (OPS, also known as cold ironing, shore-side electricity, or shore-side power), ports are expected to facilitate both. The rules apply to ships of more than 5.000 gross tonnes (GT), regardless of their flag. From 2025, limits would be introduced on the carbon intensity of the energy used by vessels, covering approximately 90% of emissions. From January 2030, ships staying for more than two hours in a port would have to connect to OPS, unless they used another zero-emission technology. Responsibility would lie with the shipping companies. Non-compliance would result in penalties, which would be allocated to an innovative fund to finance the production of renewable maritime fuels and other greening actions in the sector. The Commission estimates the total cost of investment in alternative fuels infrastructure over the 2025-2050 period at €9.9 billion: €2.5 billion for hydrogen infrastructure and €7.4 billion for OPS (Jacobs, 2022).
Ports also have a strong impact on global warming, and it is estimated that between 2% and 3% of global pollution is caused by them (Barberi et al., 2021). It is also known that a large part of all pollution caused by ports is due to docked ships. For example, the Leixões port in Portugal reports that 79% of its pollution is attributable to ships at berth. While ships stay in ports, they run auxiliary engines to provide power for cargo handling operations. Replacing the auxiliary engines' power from the on-board use of fossil fuels with OPS can reduce CO2 and pollutant emissions (Stolz et al., 2021). The study of Stolz et al. (2021) on CO2 emissions data collected through the EU monitoring, reporting and verification system shows significant potential savings if the replacement electricity were clean. Italy would have the highest savings in absolute terms (487 kilotons (kt)), Sweden the highest reduction in relative saved share (99 %). For oil-reliant countries (e.g. Greece, Cyprus) or coal-dominated ones (e.g. Poland, Estonia), the reduced share is low or negative (Figure 2).

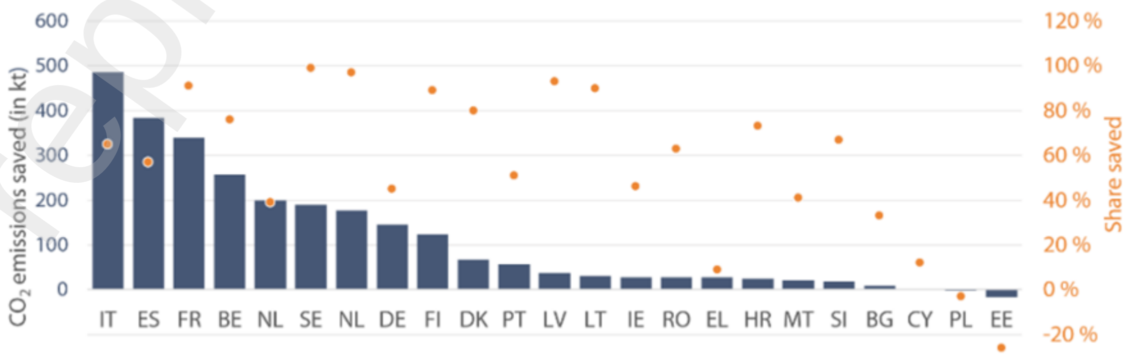

Figure 2 – Amount of CO2 emissions saved (absolute and relative) in coastal EU Member States, by using OPS (Jacobs, 2022, adapted from Stolz et al., 2021)

Another environmental problem is the noise pollution caused by ship operations while moored (Budi, 2024). This problem affects not only the workers carrying out their duties on board and/or in the vicinity of vessels, but also the populations residing near the port. To assess the acoustic impact of OPS implementation, APDL (Administração dos Portos do Douro, Leixões e Viana do Castelo) produced a study in 2021 that categorises the effects of noise pollution by vessel type, gross tonnage (GT), and year of construction (see Table 1).

Table 1 – Amount of sound power level saved by using OPS in the port of Leixões - Portugal (APDL, 2021)

Type of ship	**Year of construction**	**Sound power levels LWA (dBA)**		
		Actual situation	**Implementation of OPS**	**Noise reduction**
Cruise ships (10.000 < GT < 99.000)	< 1980	112	103	8.6
	1981 - 2005	105	95	9.9
	> 2005	103	98	5.5
Cruise ships (GT > 10.000)	< 2005	106	99	7.4
	> 2005	106	96	9.3
Ro-Ro of passengers	-	115	113	1.5
Ro-Ro of general cargo ship	-	111	109	2.2
Container vessels	< 2005	97	92	5.1
Container vessels	> 2005	94	92	1.7

As can be inferred from the final column of Table 1, the implementation of OPS in ports results in a reduction of sound power levels for all vessel types, regardless of year of construction. Accordingly, it can be concluded that OPS systems also offer acoustic benefits. It should be noted, however, that a study based on sound pressure levels, rather than sound power levels, would yield more meaningful results, as it would enable assessment of noise at a specific point within the port rather than measuring emissions at the source, which attenuate with distance.

Given the above, there is no doubt that implementing OPS in ports offers clear benefits with respect to both air and noise pollution. However, the slow spread of OPS is caused by considerable barriers to adoption (Zis, 2019). It has been suggested that the comparative cost of fuel versus electricity, the cost of investments in hardware, as well as underdeveloped standards and weak legislation have formed obstacles that are difficult to overcome for prospective users (Arduino, et al., 2011). According to Bjerkan and Seter (2019) an overview of research on OPS indicates that publications mainly discuss anticipated barriers and drivers rather than exploring successful cases.

There is no doubt that the main barrier for ports to invest in OPS systems is their financial viability. However, the existing literature does not present studies that relate the level of service provided by ports in making OPS systems available to the economic viability of the investment. In this sense, this work aims to answer the following research question (RQ):

RQ: Does the service level of OPS systems influence the economic viability of the investment?

To answer the research question, this work proposes an analysis of a case study of a port that intends to implement OPS systems, but simultaneously aims for the best possible economic viability of the investment.

The remaining paper is organised as follows. Section 2 identifies some research works in the area of the implementation of OPS systems, subdivided in the barriers for its implementation and the case studies available in the literature. In this last one, the research gap that justifies the present work is identified, which this paper seeks to address through a case study. Section 3 introduces the case study, covering the topics: the problem; assessment of the service level as a function of the number of OPS systems to be implemented; financial analysis; and discussion of the results. To finalise, some conclusions and future work are made in Section 4.

2 Literature review

2.1 Barriers for the Implementation of OPS systems

The FuelEU Maritime Regulation, implemented from January 2025, mandates a progressive reduction in the Greenhouse Gases intensity of the energy used onboard ships (2% decrease by 2025, 6% by 2030, and an 80% reduction by 2050), which aims at incentivising the uptake of low and zero-carbon fuels as well as creating the demand for OPS. Concurrently, the Alternative Fuel Infrastructure Regulation (AFIR) ensures the development of infrastructure for alternative fuels as well as the deployment of OPS (European Environment Agency and European Maritime Safety Agency, 2025). The FuelEU Maritime Regulation (EU, 2023) on the use of renewable and low-carbon fuels in maritime transport entered into force on 1 January 2025. This Regulation also mandates the use of onshore power supply (OPS) for passenger ships and container ships above 5,000 gross tonnes in main EU ports from 1 January 2030 (and in all ports that develop such capacity from 1 January 2035). Zero-emission technologies as alternatives to OPS will also be allowed.

Economic viability has been the most significant constraint on the deployment of OPS systems in ports worldwide. Nevertheless, in countries with stronger economies, this factor appears to be less restrictive, as it is precisely in such contexts that the greatest uptake of OPS systems has been observed. Notable examples include the United States, Canada, China, Japan, South Korea, Australia, Brazil, and several European countries. With more than 80% of OPS facilities built, Europe leads the world in OPS deployment (Tariq, 2021). In the European context, Figure 3 shows an overview of the degree of implementation of OPS systems.

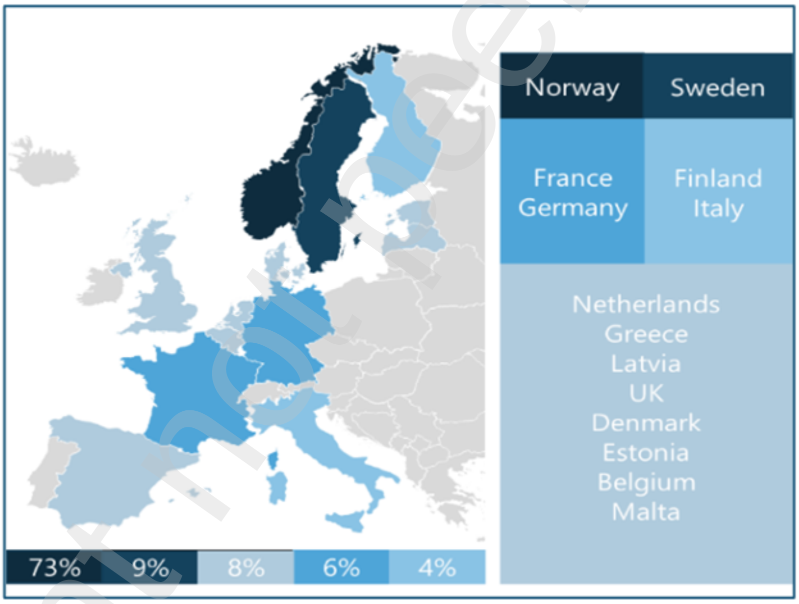

Figure 3 – Degree of OPS system deployment in Europe (Tariq, 2021).

With more than 50 ports offering shore-side power to vessels, corresponding to 73% of the total in Europe, Norway has led the way in the deployment of shore power facilities among all European countries. The second, third, fourth and fifth position is occupied by Sweden, Germany, France and Italy, respectively. However, according to the European Maritime Transport Environmental Report 2025 (EEA and EMSA, 2025), a limited number of ships in the world are equipped with the necessary elements for OPS, with the European Alternative Fuels Observatory reporting this number to be 33 ships. In the EU, there are three container ships, nine cruise ships and 15 Ro-Pax ships calling at ports equipped with OPS.

Winkel et al. (2016) quantify the economic and environmental potential for OPS in European ports, provide insights into the barriers for implementation and formulate recommendations on policy action that could be undertaken to accelerate the implementation of OPS in European harbours. In their economic quantification, were estimated the total anticipated health benefits (for NO_x, SO_2 and PM) by using OPS in EU. The monetary results for health benefits are estimated to be 2.63 and 2.94 billion € for 2010 and 2020, respectively. One of the barriers that are pointe out by Winkel et al. (2016) is that the actors who are typically requested to invest on the shore side by current regulations are not the ones with the highest benefits from the reduction of the harmful emissions. This creates a difficult starting point for the development of OPS.

In the work of Kumar et al. (2019) were identified four central economic barriers stand in the way for OPS: (i) uncertainty about who should invest and own the OPS infrastructure; (ii) the high cost to retrofit vessels; (iii) existing tax systems that favour electricity generation onboard; and (iv) OPS infrastructure that is not suitable from a business model perspective due to for example design choices or outdated technology. Based on a systematic literature review, the work of

The European Sea Ports Organisation, in its report (ESPO, 2021), refers that the cost for developing OPS in ports varies from port to port, and from location to location in the port, but overall, the cost is high with almost no return on investment for the investing party. So far, there are no cases known where OPS has been deployed on a commercial basis, not even in countries where renewable electricity is cheaper than the fuel used on board. The report also emphasises that so far, every OPS facility has been supported by up to 50% of public financing and that OPS development plan in ports must be accompanied by substantial amounts of public funding to enable deployment of OPS in ports.

Williamsson et al. (2022) identified an increased growing of works about OPS in the Web of Science. Their work presents a framework for categorising barriers and drivers to the implementation of OPS and identifies potential areas for future research. The barriers and drivers were categorised at the economic level into three areas of concern: port, vessel, and transmission. Table 2 summarises their results for the economic issue.

Table 2 – Economic barriers and drivers by three areas of concern: port, vessel, and transmission (adapted from Williamsson et al., 2022).

Port	Vessel	Transmission
Barriers: - Investments in port infrastructure - Operating costs, including maintenance - Finding an attractive business model	Barriers: - Investments in new vessels or the retrofitting of old vessels - The comparative cost of energy (fuel vs. electricity) - Tax systems favouring vessel-based power generation - Weak incentives and subsidies - Operating costs, including maintenance	Barriers: - Costly investments and uncertainty About who should take on the investments - High operating costs driven by high electricity prices, grid fees, taxes, etc.
Drivers: - Designing pricing to entice use while covering costs; - Incentives and subsidies.	Drivers: (not identified)	Drivers: (not identified)

A review of the scientific achievements, conducted between 2014 and 2023 by Kizielewicz (2024), related to the issue of OPS, had shown that this issue is very topical and subject to analysis within different areas of knowledge, which can basically be divided into four main research areas, i.e.,: 1) environmental analysis (protection, pollution, emissions, etc.) 2) engineering analysis (technology, technical, etc.), 3) socio-economic analysis (financial, fiscal, business, management, etc.), and 4) legal analysis (legal standards, law regulations, etc.). For the socio-economic analysis, most related to the scope of our work, the author identified the following research topics:

- Cooperative optimisation of OPS;
- Barriers and drivers to the implementation of OPS;
- Strategy for OPS systems;
- Control strategy for OPS;
- Energy management in seaports;
- Government subsidize for OPS;
- Electricity subsidy efficiency of OPS;
- Economic Benefits of OPS;
- Cost-effective optimisation analysis of OPS;
- Optimisation of daily use of OPS;

- Sale mechanism of OPS;
- Pricing strategy of OPS;
- Improving OPS project economics;
- Techno-economic analysis of OPS;
- Socio-economic benefit of OPS technology;
- Managing shipboard energy;
- Ship berthing forecasting for OPS;
- Future electricity and hydrogen demands for shipping.

In the work of Bakar et al. (2023) the high investment cost for port operators, the retrofitting cost for ship owners, and electricity cost and taxes are the biggest barriers of OPS establishment. In addition, the investment appears to have a long payback period. Hence, it requires a fair trade-off in decision-making and determining whether the benefits will outweigh the costs. The authors enforce that a strategic framework for financial support which can provide mutual benefit to all parties involved is urgently needed.
Kizielewicz (2024) also stresses that one of the future research fields should concern with the economic analyses using an indicator analysis of the economic efficiency of individual OPS solutions together with a prospective analysis of the economic effects of these solutions in various variants for the region.
According to the literature review, the economic factor is where OPS systems present some weaknesses. Because these systems depend not only on ports but also on ship participation, ports fear that shipowners might decide not to deploy these systems now. This would result in a much later ROI ("Return on Investment") for the ports. This possibility means that European ports may feel more secure in deploying these systems as close as possible to 2030 (the year the law mandates their deployment) to achieve a more advantageous ROI.
Compounding the decision-making challenge for ports, ships may even choose not to use OPS systems and instead have their own systems that filter emissions or use neutral fuels. According to the European Parliamentary Research Service (Jacobs 2022), from January 2030, ships staying for more than two hours in a port would have to connect to OPS, unless they used another zero-emission technology. Responsibility would lie with the shipping companies. Consequently, the profitability that ports can reasonably expect over time is highly uncertain. Furthermore, investment in OPS systems is substantial, attributable not only to the installation of connection boxes but also to new high-voltage infrastructure (where required), frequency converters (since not all vessels operate at the same frequency), and the cost of connecting cables. Therefore, it is expected that the payback period may be longer than desired. According to ports that have already implemented OPS technology, shoreside investment cost can range from $300,000 to $4 million per berth (WPSP 2022). On the shipside, the cost of the retrofitting is between $300,000 to $1–2 million per ship. In addition, operations and maintenance (O&M) costs for the shoreside can be up to 12% of the capital cost.

2.2 Case studies that analyse the Implementation of OPS systems in ports

There are not so many case studies that evaluate the economic viability of implementing OPS systems; however, the cases identified will serve to identify the research gap that supports our research question (Does the service level of OPS systems influence the economic viability of the investment?), which has not yet been directly addressed by any of the known case studies, as we will see below.
In the case study of the port of Aberdeen in Scotland, developed by Innes and Monios (2018), the total capital estimated cost was €7.4 million, and the system could save annual emissions of 108 tonnes of NOx, 2.7 tonnes of PM and 4,767 tonnes of CO2 emissions worth €1.4 million. Payback scenarios were examined via SCBA (Social Cost-Benefit Analysis), based on the external costs of potential emission savings. In the best case scenario, the substantial external cost benefits would return the system capital and operating costs in only 7.0 years, or 3.5 years if subsidized 50% by the EU.
In the case study of the port of Cartagena in Spain, developed by Gutierrez-Romero et al. (2019), were analysed three different alternatives to supply energy from shore which comes from renewable sources: Onshore wind, solar, and offshore wind. From the obtained data, it was concluded that the generating capacity of the solar and any wind farm facilities can supply energy consumption in the most unfavorable condition, taking into account future needs from increments in port traffic. However, in this case study no economic analyses were performed.

The most closely related published case study is that of Amaral et al. (2023) for the Port of Lisbon. In that work, economic viability is analysed across three scenarios, although none explicitly specifies the service level achievable by the OPS system. In the study conducted by the authors, to install the OPS at the Port of Lisbon for all the terminals, the payback corresponds to a period of 36 years. However, considering the OPS installation only for the three terminals with the highest energy demand, the payback is reduced to 23 years. Imposing a payback period of 20 years (a reasonable period for this kind of infrastructure), external financing was calculated for both cases and the results were 44% and 12.5% of the total cost of installing OPS, respectively.
Drawing on the analysis of the case studies reviewed, the following observations can be made:

- There are few case studies evaluating the feasibility of implementing OPS systems in ports;
- The payback period for investment in OPS systems is significantly reduced when considering social cost-benefits.
- None of the case studies evaluate how the service level of OPS systems influences the economic viability of the investment.

From this analysis and from the final observation, the research gap that justifies the present work is identified, which this paper seeks to address through a case study.

3 Case Study

3.1 The problem

This project, which aims to assess the economic viability of implementing OPS systems, is part of promoting the commitment that the company APDL – Administração dos Portos do Douro, Leixões e Viana do Castelo, S.A. has to society in an attempt to minimize environmental problems in the port of Leixões, in Portugal, as well as in complying with its obligations under EU directives, as part of a member country of the European Union. The Port of Leixões is the second largest artificial port in Portugal, constructed in the late nineteenth century and progressively expanded and modernised to the present day. It is located 4 km north of the mouth of the River Douro, in the municipality of Matosinhos, near the city of Porto. Strategically positioned on the north-western façade of the Iberian Peninsula and benefiting from a hinterland of high industrial density, the Port of Leixões constitutes the largest port infrastructure in northern Portugal.
Among the 15 quays and terminals in the port of Leixões, and considering the criteria of terminal occupancy rates, the percentage of ships already prepared for the OPS system, and the availability of space for the construction of land-based infrastructure, the Southern Container Terminal (SCT) was chosen for this case study. The SCT has a 540m long berth with depths at 12m, equipped with 4 quay gantries with a capacity of up to: two of 40/2x30/75 tonnes (on the single/twin-lift/under-dash spreader), one of 40/2x20/65 tonnes (on the single/twin-lift/under-dash spreader) and one of 35/45 tonnes capacity (on the spreader/under-dash). However, the terminal never receives four ships simultaneously because its length is too short to accommodate them.

3.2 Assessment of the service level as a function of the Number of OPS Systems to be implemented

The SCT can accommodate up to three vessels simultaneously; accordingly, a maximum of three OPS systems would be required to achieve a 100% service level, provided that the terminal exhibits periods of concurrent occupation by three vessels. Terminal occupancy rates at the SCT were assessed for the year 2025, covering all 12 months, considering scenarios of 0, 1, 2, and 3 vessels berthed simultaneously. The results, presented in Figure 4, indicate that the highest average occupancy rate in 2024 was recorded for two simultaneous vessels (42%), followed by 1 vessel (31%), 3 vessels (15%), and 0 vessels (12%). It was further observed that, in every month of the year, there were periods with no vessel occupancy, and that in February and March, no instances of 3 simultaneously berthed vessels were recorded. Cumulatively, it was found that the occupancy rates of the SCT have not varied significantly in recent years; therefore, in this study, their value will be considered constant throughout the time horizon under analysis.

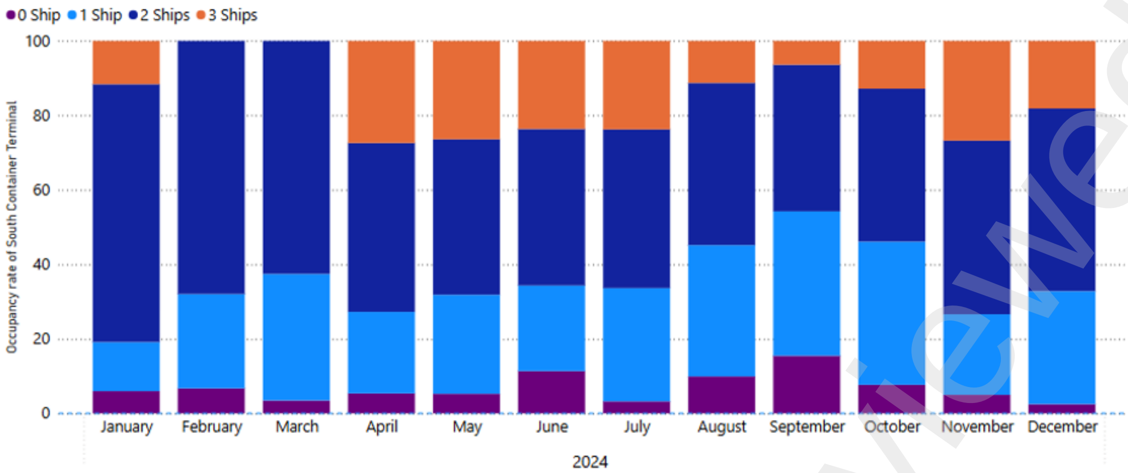

Figure 4 – Occupancy rates of the SCT for the year 2024, for 0, 1, 2, and 3 vessels.

Based on the SCT occupancy rates, three scenarios can be defined to evaluate the economic viability of the investment as a function of the service level provided, which is itself a function of the number of OPS systems to be installed — specifically, 1, 2, and 3 OPS systems. For simplicity, these are referred to as OPS systems; in practice, this denotes the provision of the electrical capacity required to supply each vessel simultaneously. That is, the installation of one OPS system implies the capacity to supply 1 vessel, the same logic applying to 2 and 3 OPS systems, respectively.

For all three scenarios, it will be considered that only 10% of ships will have an OPS linkage system in 2025 (actual value), assuming that this value increases by 18% each year, reaching 100% in January 2030, the year in which European legislation must be applied to European ports integrated into the Trans-European Transport Network. Specifically, from this date onwards, ships must have an OPS linkage system or use equivalent zero-emission technology while docked.

In accordance with the European Commission (2014), cost-benefit analyses of large public projects typically adopt time horizons of 25 to 30 years for infrastructure investments, which may be shortened to 15 to 20 years for technology-intensive projects owing to obsolescence and greater uncertainty. Hence, the financial analysis for all three scenarios was conducted over a 20-year horizon, spanning 2025 to 2044, even though the OPS system installation is treated, within the European Union regulatory framework, as a component of port and energy infrastructure (European Parliament & Council of the European Union, 2023).

Given the above, during the 2025-2044 time horizon of our study, the level of service will be characterized differently in two time periods: 2025 to 2030 – a period in which the percentage of ships with OPS connection systems will increase until it reaches 100% in 2030; 2031 to 2044 – a period in which our study considers that 100% of ships will have the OPS connection system implemented.

3.3 Assessment of OPS Occupancy Rates and Service Level from 2025 to 2030

Considering the possible installation of three OPS systems at the SCT, based on terminal occupancy data for 2024, and if only 10% of vessels possessed OPS connection capability at the end of 2024, Figure 5 illustrates the projected utilisation rate of each of the three OPS systems for the year 2025. Summarising the results obtained, the average annual utilisation rates for OPS1, OPS2, and OPS3 would be 8.8%, 5.7%, and 1.5%, respectively, in 2025. These values will increase progressively through to 2030, as the proportion of vessels equipped with OPS connection systems is expected to grow annually.

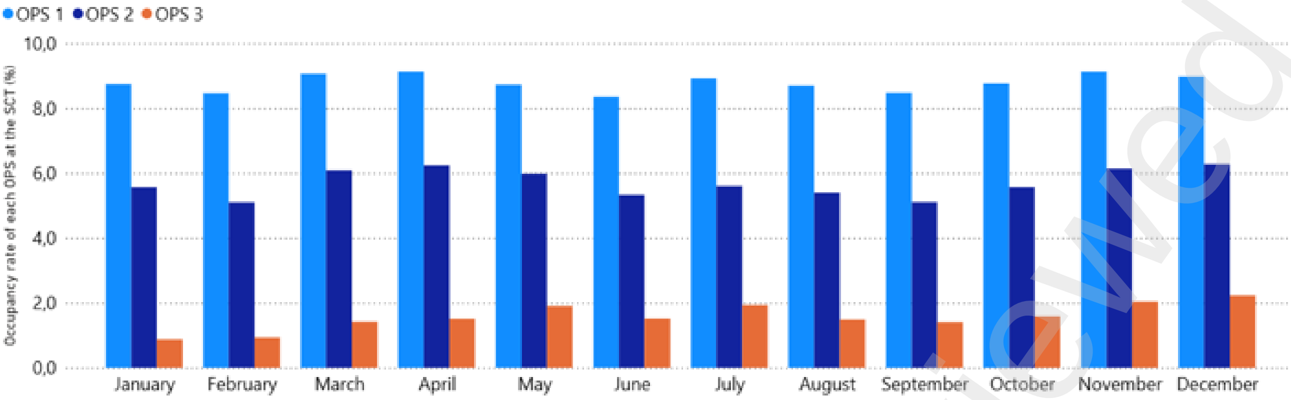

Figure 5 – Projected monthly occupancy rates for OPS1, OPS2, and OPS3 in the SCT for 2025.

Assessing the service level (total hours of energy supply via OPS divided by the total hours of demand for energy supply via OPS) foreseeable with the implementation of 1, 2, and 3 OPS in the SCT during 2025, the result achieved would be as shown in Figure 6. Thus, summarising the values obtained, the average service levels with 1, 2, and 3 OPS will be 65%, 94%, and 100%, respectively. These values will remain constant from 2025 to 2030.

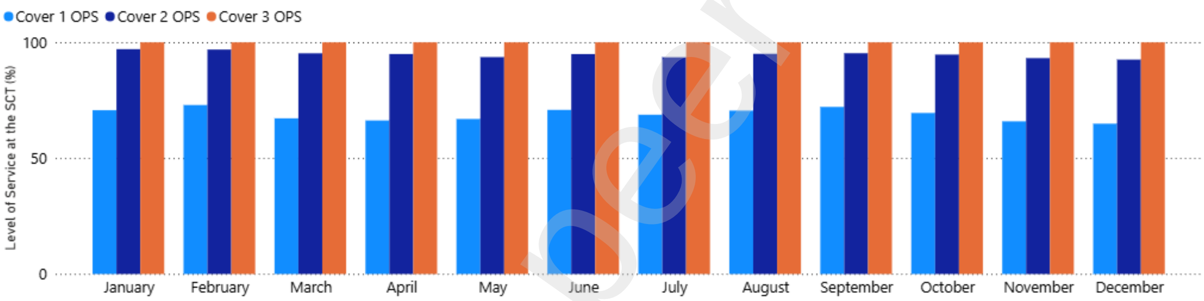

Figure 6 – Projected service levels provided by one, two, and three OPS systems at the SCT, for 2025.

Summarising the annual average values, the figures to be considered from 2025 to 2030 are those presented in Table 4. Whilst the SCT occupancy rates and service level remain constant throughout this period, the OPS occupancy rates and total annual energy demand will increase year on year. Accordingly, the OPS occupancy rates and total energy demand in 2025 will correspond to 10% – reflecting the proportion of vessels with OPS connection capability in 2025 – of the total potential energy demand from vessels, estimated at 27,223.44 MWh per year. In subsequent years, this percentage will be updated annually by 18 percentage points per year, as shown in Table 3, reaching 100% in 2030.

Table 3 – Values for occupancy rates, total energy demand, and service level, from 2025 to 2030.

Year	SCT Occupancy Rates (%)	Ships with OPS connection (%)	Total energy demand (MWh) per year	OPS Occupancy Rates (%)	Service Level (%)
2025	0 ship: 12% 1 ship: 31% 2 ships: 42% 3 ships: 15%	10%	0.10*27 223.44= 2 722.34MWh	1st OPS: 0.10*88=8.8% 2nd OPS: 0.10*57=5.7% 3rd OPS: 0.10*15=1.5%	with 1 OPS: 65% with 2 OPS: 94% with 3 OPS: 100%
2026	0 ship: 12% 1 ship: 31% 2 ships: 42% 3 ships: 15%	28%	0.28*27 223.44= 7 622.56MWh	1st OPS: 0.28*88=24.64% 2nd OPS: 0.28*57=15.96% 3rd OPS: 0.28*15=4.2%	with 1 OPS: 65% with 2 OPS: 94% with 3 OPS: 100%
2027	0 ship: 12% 1 ship: 31% 2 ships: 42% 3 ships: 15%	46%	0.46*27 223.44= 12 522.78MWh	1st OPS: 0.46*88=40.48% 2nd OPS: 0.46*57=26.22% 3rd OPS: 0.46*15=6.9%	with 1 OPS: 65% with 2 OPS: 94% with 3 OPS: 100%
2028	0 ship: 12%	64%	0.64*27 223.44=	1st OPS: 0.64*88=56.32%	with 1 OPS: 65%

	1 ship: 31% 2 ships: 42% 3 ships: 15%		17 423.00MWh	2nd OPS: 0.64*57=36.48% 3rd OPS: 0.64*15=9.6%	with 2 OPS: 94% with 3 OPS: 100%
2029	0 ship: 12% 1 ship: 31% 2 ships: 42% 3 ships: 15%	82%	0.82*27 223.44= 22 323.22MWh	1st OPS: 0.82*88=72.16% 2nd OPS: 0.82*57=46.74% 3rd OPS: 0.82*15=12.3%	with 1 OPS: 65% with 2 OPS: 94% with 3 OPS: 100%
2030	0 ship: 12% 1 ship: 31% 2 ships: 42% 3 ships: 15%	100%	1.00*27 223.44= 27 223.44MWh	1st OPS: 1.00*88=88.00% 2nd OPS: 1.00*57=57.00% 3rd OPS: 1.00*15=15.00%	with 1 OPS: 65% with 2 OPS: 94% with 3 OPS: 100%

3.4 Assessment of OPS occupancy rates and service levels from 2031 to 2044

Considering the possibility of installing 1, 2, and 3 OPS systems in the SCT, their average annual occupancy rates will be constant from 2031 to 2044, and their values will be the same as in 2030, as already presented in Table 4. Figure 7 shows the predictable utilisation rates of each of the 3 implemented OPS systems throughout the year, if all ships have connections to the OPS system from 2030 onwards. Thus, summarising the values obtained, the average annual utilisation rate of OPS1, OPS2, and OPS3 will be 88%, 57%, and 15%, respectively. These values will be used in the financial evaluation from 2030 to 2044.

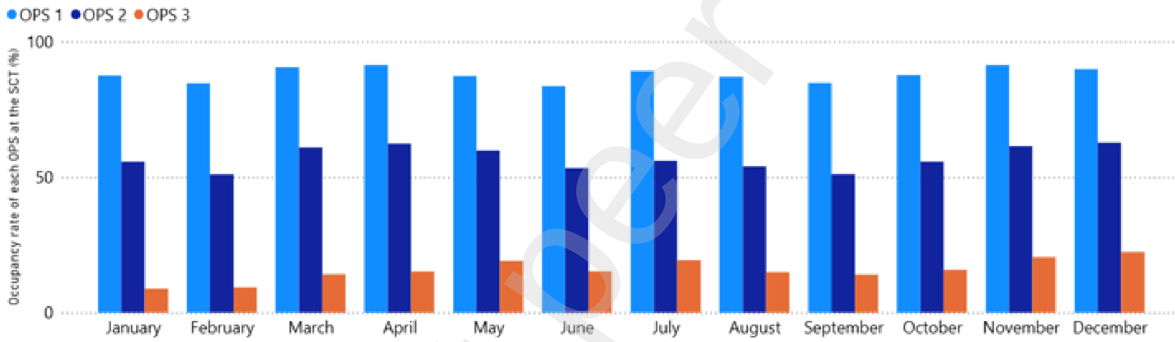

Figure 7 – Projected monthly occupancy rates for OPS1, OPS2, and OPS3 in the SCT, from 2031 to 2044.

Regarding the service level for the period under analysis (2031–2044), this will remain constant and equal to the values established in the preceding period. Specifically, the average service levels with 1, 2, and 3 OPS will be 65%, 94%, and 100%, respectively. These values are independent of the utilisation rates of each OPS system and depend solely on the number of OPS systems deployed at the port.
Summarising the annual average values, the figures to be considered from 2031 to 2044 are those presented in Table 4, which are assumed to remain constant throughout this period. This assumption is justified by the fact that terminal occupancy rates have remained stable in recent years and that total energy demand reflects the maximum potential energy demand, corresponding to the scenario in which all vessels have OPS connection systems installed.

Table 4 – Values for occupancy rates, total energy demand, and service level, from 2031 to 2044.

Year	SCT Occupancy Rates (%)	Ships with OPS connection (%)	Total energy demand (MWh) per year	OPS Occupancy Rates (%)	Service Level (%)
2031…2044	0 ship: 12% 1 ship: 31% 2 ships: 42% 3 ships: 15%	100%	From 2024 till 2030 = constant = 27 223.44MW	1st OPS: 31+42+15=88% 2nd OPS: 42+15=57% 3rd OPS: 15%	with 1 OPS: (31+21+5)*100/88=65% with 2 OPS: 65%+(21+5)*100/88 = 94% with 3 OPS: 65%+29%+5*100/88 = 100%

3.5 Economic Assessment of the Investment as a Function of the Service Level

According to data provided by APDL – Administração dos Portos do Douro, Leixões e Viana do Castelo, S.A., the estimated values associated with the initial investment for the SCT are distributed across the following cost headings:

- Construction of the high-voltage branch line to supply the substation – €4M;
- Construction of the high-voltage substation – €14M;
- Upgrading of the medium-voltage network – €6M;
- Installation of each OPS system with a capacity of 4 MW (average value per vessel) – €2M.

Based on the foregoing figures, the initial investment required for 1, 2, and 3 OPS systems can be determined as follows:

- Initial investment for 1 OPS system = €26,000k;
- Initial investment for 1 OPS systems = €28,000k;
- Initial investment for 1 OPS systems = €30,000k.

In the calculations underpinning the economic assessment of the OPS investment, the following data and assumptions were additionally considered:

- Maximum annual energy demand at the SCT = 27,223.44 MWh, assumed constant throughout the analysis period;
- Initial actual energy demand via OPS = 2,722.34 MWh (corresponding to approximately 10% of vessels with connection systems in 2023), with an annual increase of 15 percentage points in the proportion of vessels equipped with connection systems. These demand values will be applied to Scenario 2;
- Initial energy purchase price per kWh = €0.08, with a projected annual increase of 3%;
- Initial energy selling price per kWh = €0.17, with a projected annual increase of 3%;
- Initial operation and maintenance cost = €121k, €143k, and €166k for 1, 2, and 3 OPS connections, respectively, with an annual increase of 3%;
- No financial support from any governmental body or European programme was assumed.

Based on the foregoing figures, the investment analysis for the period 2025–2044 was conducted for three scenarios. These correspond to the installation of 1, 2, and 3 OPS systems and their respective service levels. The results are shown in Figures 8 a), b) and c), with 1, 2 and 3 OPS systems, respectively.

Growth rates	Scenario with 1 OPS	2025	2026	2027	2028	2029	2030	...	2044
+18% until 2030	Total energy demand at the port (MWh)	2 722.34	7 622.56	12 522.78	17 423.00	22 323.22	27 223.44		27 223.44
-	Percentage of actual demand per 1 OPS	65.00%	65.00%	65.00%	65.00%	65.00%	65.00%		65.00%
3%	Electricity acquisition cost per kWh	0.080 €	0.082 €	0.085 €	0.087 €	0.090 €	0.093 €		0.140 €
3%	Electricity selling price per kWh	0.17 €	0.18 €	0.18 €	0.19 €	0.19 €	0.20 €		0.30 €
-	Total electricity acquisition cost	141 562	408 264	690 842	990 006	1 306 499	1 641 090		2 482 296
-	Annual revenue from electricity sales	304 340	877 717	1 485 223	2 128 390	2 808 810	3 528 139	...	5 336 627
-	Annual gain at the port from eleticity sales	162 778	469 453	794 382	1 138 383	1 502 311	1 887 049		2 854 330
-	Initial investment	26 000 000	0	0	0	0	0		0
3%	Operation and maintenance costs	121 000	124 630	128 369	132 220	136 187	140 272		212 174
-	Cash Flow	41 778	344 823	666 013	1 006 164	1 366 124	1 746 777		2 642 156
-	Accumulated port profitability	-25 958 222	-25 613 399	-24 947 386	-23 941 223	-22 575 099	-20 828 322		9 913 047

a)

Growth rates	Scenario with 2 OPS	2025	2026	2027	2028	2029	2030	...	2044
+18% until 2030	Total energy demand at the port (MWh)	2 722.34	7 622.56	12 522.78	17 423.00	22 323.22	27 223.44		27 223.44
-	Percentage of actual demand per 2 OPS	94.00%	94.00%	94.00%	94.00%	94.00%	94.00%		94.00%
3%	Electricity acquisition cost per kWh	0.08 €	0.082 €	0.085 €	0.087 €	0.090 €	0.093 €		0.140 €
3%	Electricity selling price per kWh	0.17 €	0.18 €	0.18 €	0.19 €	0.19 €	0.20 €		0.30 €
-	Total electricity acquisition cost	204 720	590 413	999 063	1 431 701	1 889 399	2 373 269		3 589 782
-	Annual revenue from electricity sales	440 122	1 269 314	2 147 861	3 077 979	4 061 971	5 102 232	...	7 717 583
-	Annual gain at the port from eleticity sales	235 402	678 901	1 148 798	1 646 278	2 172 572	2 728 963		4 127 801
-	Initial investment	28 000 000	0	0	0	0	0		0
3%	Operation and maintenance costs	143 205	147 501	151 926	156 484	161 178	166 013		251 110
-	Cash Flow	92 198	531 400	996 872	1 489 794	2 011 394	2 562 949		3 876 691
-	Accumulated port profitability	-27 907 802	-27 376 402	-26 379 530	-24 889 736	-22 878 342	-20 315 393		24 789 730

b)

Growth rates	Scenario with 3 OPS	2025	2026	2027	2028	2029	2030	...	2044
+15%	Total energy demand at the port (MW)	2 722.34	7 622.56	12 522.78	17 423.00	22 323.22	27 223.44		27 223.44
-	Percentage of actual demand per 3 OPS	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%		100.00%
3%	Electricity acquisition cost per kWh	0.08 €	0.082 €	0.085 €	0.087 €	0.090 €	0.093 €		0.140 €
3%	Electricity selling price per kWh	0.17 €	0.18 €	0.18 €	0.19 €	0.19 €	0.20 €		0.30 €
-	Total electricity acquisition cost	217 787	628 099	1 062 833	1 523 087	2 009 998	2 524 754		3 818 917
-	Annual revenue from electricity sales	468 215	1 350 334	2 284 959	3 274 446	4 321 245	5 427 906	...	8 210 195
-	Annual gain at the port from eleticity sales	250 428	722 235	1 222 126	1 751 359	2 311 247	2 903 152		4 391 278
-	Initial investment	30 000 000	0	0	0	0	0		0
3%	Operation and maintenance costs	166 880	171 887	177 043	182 354	187 825	193 460		292 625
-	Cash Flow	83 548	550 349	1 045 082	1 569 005	2 123 422	2 709 692		4 098 652
-	Accumulated port profitability	-29 916 452	-29 366 103	-28 321 021	-26 752 016	-24 628 594	-21 918 902		25 768 734

c)

Figure 8 – Economic assessment with 1, 2, and 3 OPS systems, Figures 8a), 8b), and 8c) respectively.

3.6 Discussion of the results

Based on the data in Figure 8, Table 5 presents the three main financial indicators of the investment analysis: the internal rate of return (IRR), the net present value (NPV), and the payback period, for the three scenarios of the case study (OPS 1, 2, and 3), and for each of them with two discount rates: 3% and 5%.

Table 5 – Financial indicators for the investment with 1, 2 and 3 OPS.

Financial Indicators	**Scenario with** 1 OPS (Service level = 65%)	**Scenario with** 2 OPS (Service level = 94%)	**Scenario with** 3 OPS (Service level = 100%)
IRR	2.66%	5.45%	5.32%
NPV (discount rate = 3%) NPV (discount rate = 5%)	-1 009 053€ -6 025 443€	8 757 840€ 1 393 642€	8 821 858 € 1 037 788€
Simple Payback Discounted Payback (3%) Discounted Payback (5%)	16.1 years Not achieved Not achieved	13.0 years 15.9 years 19.0 years	13.2 years 16.1years 19.3years

Considering the IRR, for the Scenario 1 presents an IRR below both discount rates (3% and 5%), indicating that it fails to meet minimum financial attractiveness thresholds. Scenarios 2 and 3 show IRRs slightly above 5%, suggesting moderate but acceptable profitability. Scenario 2 exhibits the highest IRR, meaning it provides the best return relative to invested capital.

For the NPV, at a discount rate of 3%, Scenarios 2 and 3 generate substantial economic value, while Scenario 1 remains slightly unprofitable. This indicates that achieving higher service levels significantly enhances long-term economic benefits. However, with a higher cost of capital, namely at 5% discount rate, all NPVs decrease markedly, confirming strong sensitivity to the discount rate. Scenario 1 becomes clearly unviable, while Scenarios 2 and 3 remain economically acceptable but with reduced margins.

Analysing now the Payback, the data shows that higher service levels significantly accelerate investment recovery. Scenario 2 offers the shortest simple payback, indicating faster liquidity recovery and reduced exposure to long-term uncertainty. When the time value of money is considered, Scenario 1 never recovers the initial investment within 20 years, confirming its economic infeasibility. Conversely, Scenarios 2 and 3 remain viable but show long discounted payback periods, characteristic of infrastructure or long-term strategic investments.

Summary, overall economic analysis points out the following:

1. Scenario 1 is economically unviable due to insufficient service level and persistent negative NPV.
2. Scenario 2 emerges as the optimal economic solution, combining:
    - Highest IRR
    - Strong positive NPV
    - Shortest payback period
3. Scenario 3 maximises service quality and total value creation, but with diminishing financial returns compared to Scenario 2.

Therefore, from a purely economic perspective, Scenario 2 (2 OPS) represents the most efficient investment option, while Scenario 3 may be justified if achieving maximum service level and strategic or societal benefits is a priority.
Based on the analysis above, the answer to the RQ question of this work is yes, the service level of OPS systems influences the economic forecast of the investment. Furthermore, as is shown in this case study, a 100% service level is not necessarily the most attractive investment.

4 Conclusion

This study sets out to answer the research question: Does the service level of OPS systems influence the economic viability of the investment? Based on the case study of the Southern Container Terminal (SCT) of the Port of Leixões, the results clearly demonstrate that the service level has a decisive impact on the financial performance of OPS implementation.
The analysis confirms that the environmental benefits of OPS—namely the reduction of CO_2 emissions, air pollutants, and noise—are unquestionable and aligned with European regulatory requirements and decarbonization objectives. However, from an investment perspective, economic feasibility depends strongly on how installed capacity translates into effective service level and system utilisation.
The financial evaluation of three scenarios (1, 2, and 3 OPS systems corresponding to service levels of 65%, 94%, and 100%) shows markedly different outcomes. The scenario with one OPS (65% service level) is economically unviable under both discount rates analysed (3% and 5%), presenting negative NPVs and an IRR below the cost of capital. This confirms that insufficient service coverage limits revenue generation and prevents cost recovery within the 20-year horizon.
Conversely, the scenarios with two and three OPS systems (94% and 100% service levels) demonstrate positive NPVs at a 3% discount rate and acceptable IRRs slightly above 5%. Among them, the two-OPS scenario emerges as the most economically efficient solution, combining the highest IRR, strong positive NPV, and the shortest payback period. Although the three-OPS scenario maximises service level and overall value creation, the marginal financial gains relative to the additional investment are limited, revealing diminishing returns when moving from 94% to 100% service coverage.
Therefore, the results show that maximising service level does not necessarily maximise economic attractiveness. Instead, there is an optimal balance between installed capacity and demand coverage that enhances financial sustainability while still delivering significant environmental benefits.
This study contributes to the literature by addressing an identified research gap: the explicit relationship between OPS service level and economic viability. Unlike previous case studies, which focus primarily on technical feasibility or aggregate financial results, this work demonstrates how capacity planning decisions directly influence investment outcomes.
From a managerial perspective, port authorities should carefully dimension OPS infrastructure according to realistic demand forecasts, progressive vessel adaptation rates, and regulatory timelines. Oversizing infrastructure may lead to underutilised assets and weakened financial performance, while under-sizing may compromise service quality and strategic positioning.
Finally, although this study did not consider public subsidies or external social cost-benefits, incorporating these factors could significantly improve the economic outlook of OPS investments. Future research should therefore explore hybrid financing models, dynamic pricing strategies, and the integration of social and environmental externalities into economic assessments.
In conclusion, the service level of OPS systems is a critical determinant of investment viability. A balanced and demand-aligned implementation strategy—rather than a purely maximalist approach—offers the most sustainable pathway for ports seeking to reconcile environmental responsibility with financial performance.

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