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Climate change and sustainable economy in multipurpose maritime port concessions, Peru

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The greening of concession ports is relevant for sustainability. This study aims to analyze the nexus between climate change and the sustainable economy of Peru's maritime port concessions. In the period 2011–2023, the cargo in metric tons mobilized by the multipurpose maritime terminals was characterized for the high containerized cargo through the Muelle Norte APMT (Callao), mostly in unloading operations, although by the Salaverry terminal, no containerized cargo was mobilized; the Matarani port terminal increased its shipping operations mainly copper solid bulks, since 2016. Reflective, correlation and regression methods were used; the indicator of climate change included the average sea level. We found a negative correlation between sea level rise and total cargo traffic of the Muelle Norte APMT concession (2011–2023). The regression analysis revealed a significant positive impact of investment on total cargo traffic through multipurpose ports, while also confirming the negative influence of sea level rise on cargo traffic, which is an indicator of a sustainable economy. We conclude that adaptation to climate change requires investment in port infrastructure in the face of sea level rise and conversion to green smart ports that contribute to SDGs 9 and 14 on innovation and infrastructure, and ocean and marine ecosystem conservation.

KEYWORDS

sustainable economy, climate change, adaptation, concessions, multipurpose seaports

1 Introduction

Despite the importance of a comprehensive study of the relevant aspects of terminal concessions in seaports, the number of research articles addressing the issues of concessions in seaports remains reduced and recent (Theys and Notteboom, 2010). Although green ports are an important response to environmental pollution problems and climate change, their development continues to be constrained in developing countries (Le and Nguyen, 2023). The average sea level rise due to climate change affects ports. According to Monios et al. (2024), it is possible to elevate port asset areas, such as the docks themselves, by about 0.5–1.0 meters.

There is a gap in the literature regarding the definition of a sustainable economy within the port concessions sector. There is still no conceptual differentiation between sustainable or green port and sustainable economy. This study contributes to the discussion and the linkage of climate change factors in the sustainable economy of multipurpose marine terminals.

Latin America and the Caribbean have 1,515 terminals in 33 countries (Sánchez and Barleta, 2019), and multipurpose terminals predominate. Geographically, the east and west coasts of South America account for 575 and 390 terminals, respectively, 64% of the regional total. As of 2023, seven maritime port terminal concessions for public use, five

multipurpose, are in operation in Peru, including the concessions of Muelle Norte (Callao) and Salaverry (La Libertad). The Ilo port terminal is publicly operated by Empresa Nacional de Puertos (ENAPU).

The TEU cargo traffic of Peru's maritime port concessions increased by 0.4% between December 2023 and 2022 (Table 1). According to OSITRAN, in the first 10 months of 2023, the total cargo mobilized increased by 3.8% compared to a similar period of 2022. The largest cargo volume was mobilized through the Muelle Norte terminal (14.9 million metric tons). The challenge for port concessions is sustainability and conversion into green ports. In Peru, seaport concessions have recently expanded their cargo capacity, but little effort has been made to reduce polluting emissions.

Globally, port authorities pursue the greening of port management to safeguard their operating license and increase their economic and environmental competitiveness (Notteboom and Lam, 2018). Initiatives aimed at greening concession procedures can reap their full benefits by being integrated into a chain approach to the environment (ship, port, terminal, warehouse, and inland transport). Ports are sensing increased pressure to reduce the negative impact on the environment, and their role in transportation systems is critical to a sustainable economy. Port decision-makers must prioritize tools such as increased data utilization and process understanding (Bjerkan and Hanne Seter, 2019).

According to Pallis et al. (2023), 70% of "global" studies on ports do not present empirical material at all (and 46% do not do so during 1997–2008), despite the international character of port research.

Seaports are responsible for transporting about 90% of the global freight supply chain (Alzahrani et al., 2021). This is exacerbated by the digitization of port infrastructures, including energy systems, and the complex involvement of the value chain.

According to ECLAC, in October 2023, the port of Colon in Panama, which connects the Caribbean Sea with the Pacific Ocean, is the main port in Latin America, handling more than 4,915 thousand TEUs (Twenty-foot Equivalent Unit per container) per year. It is followed in order of importance by the ports of Santos (Brazil) and Manzanillo (Mexico), and Peru's Port of Callao is in sixth place. According to Proinversion, port concessions by Public Private Partnership (PPP) have improved the efficiency of Peruvian ports, reducing costs for users, and access to international markets in optimal time.

The research is justified because seaports contribute to the blue economy due to their key role in mobilizing foreign trade. However, on the one hand, climatic factors affect the operability of port concessions, and on the other hand, these port activities generate pollution and climate change. In the world, the trend is the greening of ports; therefore, it is important that port terminals under concession in Peru move toward a sustainable economy with social and environmental responsibility, contributing to the Sustainable Development Goals (SDGs) 9 on innovation and infrastructure, 13 on climate action, and 14 on the conservation of oceans, and marine ecosystems by 2030.

The objective of the article was to analyze the nexus of climate change and sustainable economy in Peru's multipurpose maritime port concessions, and the specific objective was to examine economic sustainability and explore some adaptation measures for seaports in response to climate change.

2 Literature review

According to sustainability indicators in ports, economic research focuses mainly on port management and investment in the stock market (Lim et al., 2019). Port sustainability refers to business strategies and activities that address both the current and future needs of the port and its stakeholders (Alamoush et al., 2021). Economic sustainability generates financial gains, social sustainability promotes people's wellbeing, and environmental sustainability tends to reduce negative externalities.

One of the impacts induced by climate change in coastal areas is sea level rise (Sierra et al., 2023). Climate change may restrict port operations causing economic losses. Izaguirre et al. (2021) analyze the historical global risk in the operations of 2,013 ports worldwide under an extreme warming scenario, increases in temperatures, sea level rise and coastal flooding contribute to risk amplification. Sustainable port design is a relevant component of adaptation to palliate climate risk (Aita, 2023).

The term "green port" refers to a port with sustainable development, which balances economic and environmental interests and ensures that the socio-economic growth of the port does not exceed the capacity of the corresponding natural system (Abd Elhamed and Mohamed, 2023). In this study, the sustainable economy in port operations signifies economic sustainability, ensuring that the port concessionaire recoups its investment through the total cargo traffic that generates net profits.

Asariotis et al. (2024) compile trends of major climate drivers and risks affecting ports worldwide by 2050 and project that the average sea level rise for ports along the world coasts will range between 0.11–0.21 m and between 0.09–0.29 m in the IPCC moderate and very high emissions scenarios, respectively. Sharaan et al. (2024) examine the perception of Egyptian port authorities to climate risks in the Greater Alexandria Port, which includes the ports of Alexandria and El-Dekheila; it also explores their strategies and adaptation plans, to develop coastal ports respecting the pillars of sustainable development.

Abd Elhamed and Mohamed (2023) argue that the port of Damietta in Egypt experiences several environmental problems that hinder its ability to achieve sustainability because, in the vicinity of the port and navigation channel, pollutants alter the chemical and physical characteristics of the water, which cause the deterioration of marine life. The port terminal area itself, vessel activity, road traffic, cargo handling equipment, bulk material storage, and port-related logistics contribute to local air pollution by generating mainly PM10 concentrations (Ducruet et al., 2024). Bulk solids, such as grain, coal, minerals, and cement, can generate dust during the loading and unloading of vessels.

For the analysis of sustainability in seaports, Hossain et al. (2021) selected 36 ports from North America (NA), Europe (EU), and Asia-Pacific (AP), it turned out that seaports in the EU have made more progress in adopting various sustainability initiatives than those in NA and AP. For port sustainability assessment, Gu et al. (2023) expect ports to assume environmental, social, and governance (ESG) responsibilities and apply this model to the port industry in China, since given the ratification of the Copenhagen Accord in 2010, the port of Shanghai has been transformed from port construction to operations management, promoting environmental protection, energy saving and emission mitigation.

TABLE 1 Cargo traffic in Peruvian seaport terminals for public use, month December 2023/2022 (thousands TEU and MT).

Seaport terminals	Containers			Fractional Cargo (MT)	Solid bulks (MT)	Liquid bulks (MT)	Roll-on/off (MT)	Total MT (Dec-23)	Total TEUs (Dec-22)	Total MT (Dec-22)	Variation TEUs (Dec 2023/2022)	Variation MT (Dec 2023/2022)
	TEUs (Dec-23)	Units (Dec-23)	MT (Dec-23)									
Total	**270**	**159**	**2,549**	**251**	**1,786**	**238**	**34**	**4,859**	**269**	**5,017**	0.4%	−3.2%
Paita - TPE	24	13	178	4	33	0	0	**214**	53	388	−55.5%	−44.9%
Salaverry - STI	0	0	0	2	312	5	0	**319**	0	420	-	−24.0%
Muelle Norte Callao - APMT	92	53	724	174	449	228	32	**1,608**	84	1,644	10.0%	−2.2%
Muelle Sur Callao - DPW	143	86	1,566	0	0	0	0	**1,566**	131	1,337	9.3%	17.1%
Embarque Concentrado Minerales – Transp. Callao	0	0	0	0	253	0	0	**253**	0	266	-	−4.5%
General San Martin - Paracas	11	5	77	12	80	0	2	**171**	1	203	>100%	−15.8%
Matarani - TISUR	0	0	4	55	624	5	0	**688**	0	655	−15.3%	5.1%
Ilo - ENAPU	1	1	2	4	34	0	0	**40**	0	105	-	−61.7%

Source: Autoridad Portuaria Nacional, Peru (2023). Compiled by authors.

Gattuso et al. (2023) evaluate the impacts generated by both the use of green handling units-HUs (hybrid and electric) and automation of operations (driverless vehicles, use of intelligent control systems), making the container port more competitive and sustainable. Panahi et al. (2020) indicate that despite global concern and early alerts, research on port climate adaptation is not a worldwide priority. There are few contributions from researchers in developing countries, and ports are approached as isolated facilities rather than as key components of transportation, supply chain, and urban systems, i.e., research continues to promote the status quo.

In both Southern Europe and South America, port governance has changed significantly (González Laxe et al., 2016), in Latin America, there is a tendency to take the port environment as the only core of governance (with a slight exception in Peru), therefore, it needs port governance adopting a less sectoral and more integral approach to the chain.

The choice of timing and scale of adaptation measures is challenging due to the frequency of disasters and the irreversibility of physical infrastructure investments (Xia and Lindsey, 2021). According to Alamoush et al. (2021), ports can take measures spanning all port-related operations, in addition to transport, to reduce atmospheric emissions and limit dust and odors, including reduction of GHG pollutants and climate adaptation.

The predominant model of terminal concessions consists of port authorities leasing terminals (or port land) to private terminal operators through long-term concession agreements lasting between 25 and 40 years. The investment liability is subject to negotiation of the concession terms, in which port infrastructure such as piers and superstructures such as cranes are identified. In addition, terminal activities have been highly developed in regions with multiple access ports, including cargo-rich hinterlands. Typical examples Rhine-Schelde Delta (Belgium and the Netherlands), the San Pedro Bay area (Los Angeles/Long Beach), the Yangtze River Delta, and the Pearl River Delta in China (Notteboom and Rodrigue, 2023).

Each country could prohibit vessels using fossil fuels from calling at their ports (Monios and Wilmsmeier, 2020). Gupta and Prakash (2022) assessed the 11 major seaports in South Asia to identify the most important environmental sustainability issues. Port operations are vulnerable to the detrimental effects of climate change, which are expected to pose significant challenges to port operators (Devendran et al., 2021). Traditional performance assessment has only considered the economic efficiency of ports, Chen et al. (2024) add carbon emissions to measure the sustainable development of "ship-port" systems.

3 Methods

This research on climate change and economic sustainability of maritime port concessions was applied, non-experimental, correlational, and reflexive. It covers the period from the concession of the Muelle Norte multipurpose terminal of the Callao port, effective in 2011, until 2023. The period 2011–2023 has been selected because the most important multipurpose port concession in Peru (APMT), regarding total cargo traffic, investments, and port revenues, commenced operations in 2011. The universe was determined by the seaport concessions in Peru and the non-probabilistic sample was delimited to three multipurpose seaport terminal concessions

representative of central, northern, and southern Peru: Muelle Norte Callao (APMT), Salaverry terminal of La Libertad and Matarani terminal of Islay-Arequipa (Figure 1). The unit of analysis was the multipurpose port terminal.

The sources of information were statistical documents from ECLAC, Autoridad Portuaria Nacional (APN), OSITRAN, ENAPU, Proinversion, and MTC. The Chucuito station in Callao was chosen for sea level data because the APMT Muelle Norte's location at Callao port.

3.1 Data collection techniques

A mixed-methods approach complemented the quantitative data with a qualitative component. Secondary information obtained from statistical bulletins/annuaries of APN, OSITRAN, Proinversión, and Cepal on the performance of multipurpose maritime port concessions during 2011–2023 was used. The indicator used for the sustainable economy of port activities was the total cargo traffic of the multipurpose terminal, which includes cargo movements (unloading, loading, cabotage, transshipment, and re-stowage) measured in metric tons. Investment, an economic factor, and sea level rise, a climate change factor, were identified as influences on port operations, specifically total cargo traffic. The investment indicator was the cumulative committed investment measured in millions of USD. Data on environmental indicators of climate change such as sea level from the Yearbook of Environmental Statistics (INEI) was used, and the nexus of port operations with sustainable economy from the United Nations Conference on Trade and Development (UNCTAD) was inquired. Sea level rise was measured in average annual meters. A short unstructured interview was also applied to the general manager of the National Port Authority (APN) on the progress in automation and greening of port concessions in Peru on 07.11.2024. The purpose was to complement the secondary information with the point of view of a Peruvian port authority due to the lack of data on GHG pollutants in concessioned ports.

FIGURE 1
Selected concessioned multipurpose ports, Peru. Source: Google Earth Pro.

3.2 Procedure

First, information on multipurpose maritime port concessions was collected, and the literature on the research variables was reviewed. Second, the evolution of total cargo per maritime port terminal concession in Peru was described. The annual cargo mobilization through the multipurpose ports was presented, including containerized cargo measured in TEUs, as well as breakbulk, roll-on/roll-off, and solid and liquid bulk cargo measured in metric tons. Third, climate change was linked to the sustainable economics of multipurpose seaports through a regression model with two factors, one economic and one climatic. The economic factor was port investment, and the climate change factor was sea level rise. The indicator of sustainable economics was total port terminal cargo traffic. Pearson's correlation statistic method and regression analysis were then used for the quantitative analysis. Finally, port adaptation measures to climate change were proposed for the economic sustainability of multipurpose concessioned seaports.

4 Results

In the 2011–2023 period, two maritime port concessions with *multipurpose* designation are in operation in Peru, such as the Muelle Norte terminal- APM Terminals concessioned in 2011 and the Salaverry Terminal Internacional S. A. port terminal concessioned in 2018. In practice, other multipurpose port concessions operate in Peru, such as the port of Matarani, which since 2016 has increased the total mobilized cargo.

In the multipurpose maritime port terminals under concession in Peru (Table 2), the total cargo traffic of the Muelle Norte Callao (APMT) has evolved in container cargo to 1,115 thousand TEUs in 2023 and more than 18,000 thousand MT for breakbulk, roll-on/roll-off, solid and liquid bulk cargo; which is higher than the total cargo traffic of the Matarani and Salaverry terminals that mobilized 7,552 and 3,271 thousand tons, respectively, in 2023. APMT's container traffic in 2023 represents the highest annual historical record of the concession. However, it should be noted that in 2023, in Peru, the DP World concessionaire of the Muelle Sur Callao, which specializes in containers, mobilized 1.6 million TEUs compared to 1.1 million for APMT.

During 2023, the APMT terminal handled a total of 1,458 vessels, mobilizing 637,320 containers, and of the total cargo mobilized, it recorded the highest containerized cargo, followed by solid bulk cargo (Table 2 and Figure 2). In contrast, the Salaverry concessionaire mobilized more solid bulk cargo. On the other hand, the TISUR concessionaire in Matarani handled 497 vessels in 2023, mostly bulk cargo (63.6%); the total mobilized cargo of 7.6 million tons consisted mainly of solid bulk cargo (87.7%).

Figures 3, 4, period 2011–2023 show the total cargo (in MT) mobilized by the multipurpose maritime terminals in both

TABLE 2 Total cargo traffic in multipurpose maritime port concessions, Peru 2011–2023 (thousands TEUs and MT).

Years	Ships attended (units)	Containers			Break bulk	Solid bulk	Liquid bulk	Roll-on/off	Total (MT thousands)
		TEUs (thousands)	Units (thousands)	MT (thousands)					
TNM Callao - APM terminals									
2011	1,131	476	309	3,925	1,645	6,088	1,956	342	13,956
2012	2,184	412	272	4,059	1,797	6,047	2,697	439	15,039
2013	2,419	508	319	4,363	1,807	6,323	3,206	436	16,135
2014	2,137	519	333	5,110	1,825	5,431	2,819	345	15,529
2015	1994	616	396	5,382	1,907	4,451	2,715	342	14,798
2016	1828	916	576	6,831	1,805	4,971	2,981	305	16,894
2017	1901	1,003	624	8,214	1,883	5,831	2,964	348	19,240
2018	1759	1,035	632	8,122	2,314	5,624	2,702	342	19,104
2019	1,664	928	558	8,081	2,230	6,011	2,682	324	19,329
2020	1,494	889	524	7,775	1,924	5,714	2,381	205	17,999
2021	1,481	984	575	8,669	2,804	5,572	2,516	392	19,954
2022	1,468	998	564	7,901	2,479	5,323	2,471	401	18,575
2023	1,458	1,115	637	8,519	1,759	5,272	2,166	339	18,054
TP Matarani - TISUR									
2011	379	22	15	236	225	2,454	395	9	3,319
2012	368	16	12	198	234	2,289	260	9	2,990
2013	403	15	10	165	419	2,700	213	1	3,499
2014	408	21	13	189	401	2,647	156	9	3,402
2015	423	20	14	226	439	2,973	179	2	3,818
2016	499	18	13	207	394	5,681	159	0	6,440
2017	513	18	14	204	378	6,189	176	0	6,947
2018	500	22	15	282	431	6,275	186	1	7,175
2019	518	17	13	239	613	5,791	233	1	6,876
2020	426	15	11	189	590	5,078	211	0	6,068
2021	460	12	8	114	574	5,551	225	0	6,463
2022	472	5	3	66	592	5,508	265	0	6,431
2023	497	7	5	84	640	6,623	205	0	7,552
TP Salaverry - STI									
2011		0	0	0	63	1,968	32	0	2,063
2012		0	0	0	63	2,382	37	0	2,482
2013		0	0	0	122	2,132	40	0	2,295
2014		0	0	2	24	2,590	38	0	2,654
2015		0	0	0	88	2,009	37	0	2,134
2016		0	0	0	99	2,002	31	0	2,132
2017		2	1	0	121	2,522	22	0	2,664
2018[a]	32	0	0	0	92	2,447	30	0	2,568
2019	229	2	1	3	118	2,661	38	0	2,820
2020	183	0	0	0	65	2,530	17	0	2,613
2021	215	0	0	0	96	3,570	4	0	3,669
2022	219	0	0	0	126	3,377	18	0	3,521
2023	216	0	0	0	45	3,202	24	0	3,271

[a]STI operates from 30.10.2018. Source: National Port Authority, Peru (2011–2023). Compiled by authors.

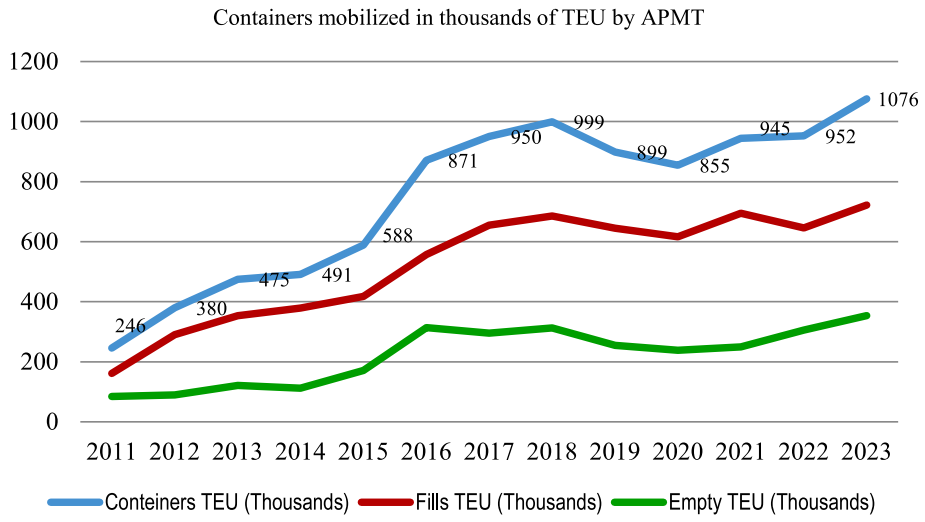

FIGURE 2
Total container traffic in thousands of TEUs mobilized by APMT, Peru 2011–2023. Source: OSITRAN (2024a). Compiled by authors.

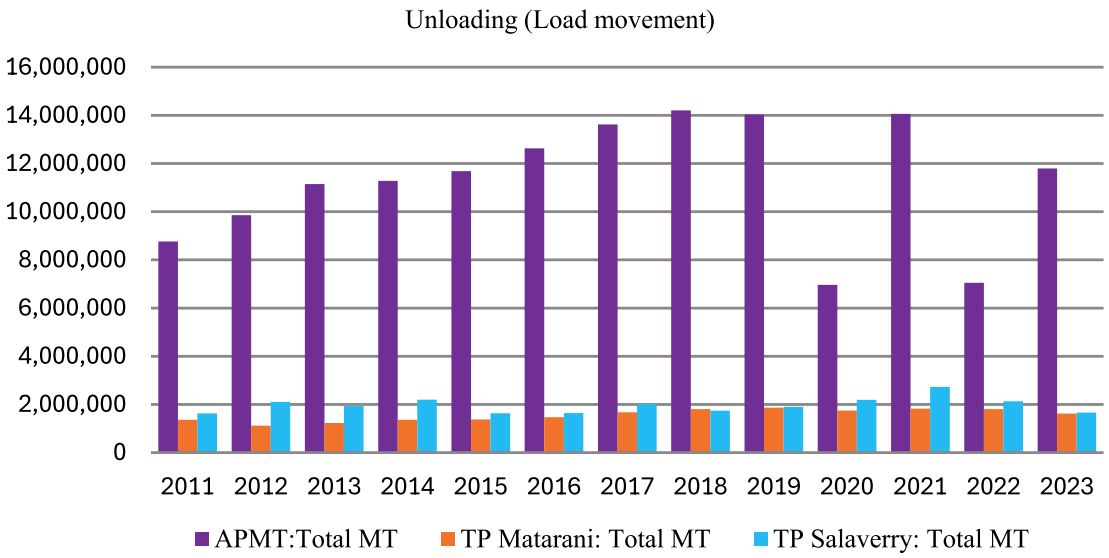

FIGURE 3
Unloading at multipurpose port terminals, Peru 2011–2023.

unloading and loading, with a marked difference mainly due to the high container cargo in addition to the bulk cargo mobilized by APMT, while the Salaverry terminal does not mobilize containerized cargo.

The containerized cargo mobilized by APMT in 2023 was higher in unloading operations, with 40.04% of the total cargo mobilized. In contrast, at the Matarani port terminal, the growth in shipping operations since 2016 stands out (Figure 4), mainly due to the shipment of bulk solids, which accounted for 98.7% of total exports in 2023, and the main product exported was copper concentrate from the copper companies Cerro Verde, Las Bambas, and Antapaccay.

Table 3 provides a comparative description of some of the characteristics of the three seaport concessions studied. Matarani is the oldest Peruvian port, concessioned to Tisur in 1999. The multipurpose terminal Muelle Norte APMT handles the highest cargo traffic, while Salaverry has the lowest total cargo movement.

4.1 The connection between climate change and economic sustainability in multipurpose seaport concessions

The analysis of the relationship between climate change and total cargo traffic as an indicator of economic sustainability indicated that the average annual sea level rise at Chucuito station (Callao) has a weak and negative correlation with total cargo traffic at the Muelle Norte by APMT during the period from 2011 to 2020 (the constraint

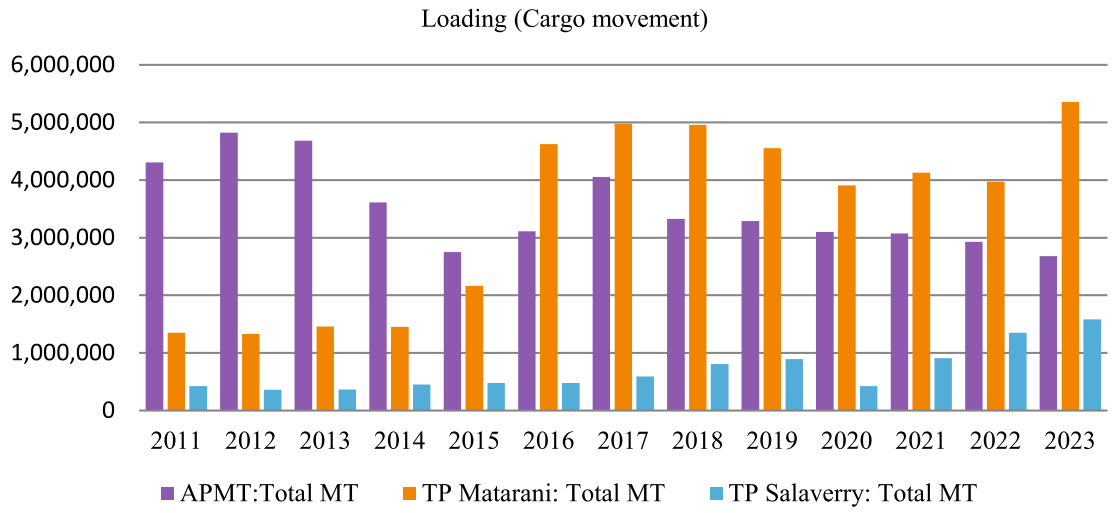

FIGURE 4
Shipments in multipurpose port terminals, Peru 2011–2023.

was sea level rise data records through 2020), as illustrated in Figure 5 ($r = -0.278$). Due to the recent concession of the Salaverry multipurpose port in 2018, there is insufficient data to correlate sea level with total cargo movement.

Tables 4, 5 show the regression results for total cargo traffic, influenced by port investment and sea level rise, for the Muelle Norte- APMT (Callao) and Matarani terminals. The cumulative committed investment in each port has a significant positive impact on total cargo traffic at a 5% significance level. Conversely, sea level rise, viewed as a climate change factor, negatively affects cargo traffic in the analyzed port terminals, with a significance level of approximately 10%. Salaverry, newly concessioned in 2018, has limited data on port investment, so it was not possible to perform a regression analysis to estimate the impact of both port investment and sea level rise on cargo traffic at this terminal.

4.2 Analysis of the contribution of multipurpose port concessions to economic sustainability

Figure 6 shows the positive relationship between the value of investments and total revenues in millions of dollars in the three multipurpose terminals studied (2011–2023). It reinforces the finding that investment is an economic factor that has a relevant impact on the sustainable economy. As investment increases, cargo traffic and, therefore, the port revenues generated also grow.

According to the National Port Authority (Autoridad Portuaria Nacional-APN), as of August 2024, Peruvian seaport concessions have invested around US$ 2,200 million out of an investment commitment of US$ 3,448 million. The DP World Callao concessionaire of the Muelle Sur has built the 1,050 m Bicentennial Pier and invested US$ 714 million in the Container Terminal. In the Muelle Norte Callao, APMT has invested US$ 471 million; in the Mineral Shipping Terminal concession, Transportadora Callao invested US$ 113 million, and the concessionaire of the Salaverry port terminal invested US$ 137 million.

Container loading and unloading are handled by gantry cranes; the Muelle Sur and Muelle Norte multipurpose terminals have 10 and 7 gantry cranes, respectively. APMT's Muelle Norte occupancy rate is 100%. The two main shipping lines served by APMT in 2023 were Maersk (14.6%) and Mediterranean Shipping Company of Peru with 31.8% of total vessel traffic.

The concessionaire of the Salaverry port - STI pays the grantor, which is the National Port Authority (APN), remuneration for the operation of the port of 3% of the monthly income, starting from the beginning of the operation. It also contributes 2% (of the APN remuneration) to Proinversion's Foncepri fund and 1% to the regulator Ositrán. Thus, in 2023, STI paid the State S/. 7.2 million, while APMT, the concessionaire of the Muelle Norte terminal, paid the State USD 28.13 million.

STI's gross profit, the difference between total revenues and total costs, was USD 19.52 million in 2023. In 2023, APMT's standard containerized cargo service invoiced revenues of USD 101.4 million. The total revenue from APMT's port services was USD 259.1 million, with 81.5% coming from regulated services and 16.2% from non-regulated services. APMT's gross profit reached the highest figure of USD 164.4 million in 2022.

The average productivity required for each gantry crane at APMT's Muelle Norte must be at least 25 movements per hour. Ositrán reported that the container throughput per gantry crane operation at the pier during 2023 ranged from 26 to 27 movements /h per crane. APMT throughput for solid bulk cargo generally exceeded the minimum required productivity, ranging from 444 to 559 tons/hour.

Ports can support the sustainable alternative energy transition, decontamination, and low-carbon regulatory measures in the processes of production, storage, bunkering, and transportation of alternative fuels. Adopting a sustainable approach to port infrastructure investments through climate risk adaptation measures would enable more efficient ports that are better integrated with communities (Cepal, 2023).

TABLE 3 Characteristics of multipurpose maritime port concessions, Peru.

Concession	Location and type of concession	Investment/Concession term	Details/Services
T. P Muelle Norte	It is located in the Callao region. A concession contract between the Ministry of Transport and Communications-MTC and APM Terminals Callao S. A. (APMT) for the design, construction, financing, conservation, and operation of the North Dock Terminal of the port of Callao "DBFOT" was signed on May 11, 2011. Self-financed modality. Competition factor: Lower tariff for containerized cargo, including tariffs for standard services and up to 4 days of storage. Higher rate discount for standard service for non-containerized cargo and special regulated services.	Investment USD 1426.0 million (including IGV). Concession term of 30 years. Shareholder composition made up of APM Terminals B. V. (from the Netherlands) (63.75%) and Callao Port Holding B. V. (36.25%) since March 2018. Maritime traffic comes from Lima, Ica, Ancash, and the central part of the country. In the fifth year of operation for Stages 1 and 2, the Regulator conducted the first tariff revision using the "RPI-X" mechanism for standard and special regulated services.	APMT project comprises seven docks: four central docks, one north dock, one hydrocarbon dock, and one-grain dock. Terminal handling containerized cargo and general cargo (metals, grains, fertilizers, chemicals, among others). In detail: Modernization of berths C, D, and the grain pier. Construction of two 300 m long piers, one on the surface of Center Piers No. 1 and No. 2 and the other in space No. 3 and No. 4. Construction of a 314 m pier in front of the berthing area of the North Pier A. Retribution to the State is set at 3% of monthly net income.
T. P Salaverry	It is located in the La Libertad region. The concession contract was signed on October 1, 2018, by the National Port Authority (APN) as grantor and Salaverry Terminal Internacional as the concessionaire, responsible for the design, financing, construction, operation, and transfer. The competition factor was a higher tariff discount.	Investment (excluding IGV): US$ 228.97 million for 30 years. Self-financed Public Private Partnership. Salaverry STI's shareholding consists of Trabajos Marítimos S. A. (99.9%) and Santa Sofía Puertos S. A. (0.1%). The areas of influence include La Libertad, Lambayeque, Ancash, Cajamarca, and San Martín, which supply foreign trade. In the fifth year of operations for Stages 1 and 2, the "RPI-X" regulatory mechanism is implemented.	Mandatory Construction Sites: Stages 1 and 2. Stage 3: Conditioned to a clean bulk traffic target of 1.2 million MT per year in two consecutive annual periods, within the first 20 years of concession. Execution in stages 4 and 5 depends on the goals set for the first 20 years of the concession: 1.8 million MT of mineral concentrate, fertilizer, and/or soybeans, and achieving an average dock occupancy of 65%. 3% of revenues paid to the State- APN.
T. P Matarani	It is located in the Arequipa region, Islay district. Serves cargo from the southern Peruvian regions (Arequipa, Cusco, Puno, and Tacna), as well as from Bolivia and Brazil. Interconnected to the Panamericana Sur, Interoceánica Sur, and Costanera highways, as well as the Southern Railroad. The concession Contract was subscribed on August 17, 1999, between the MTC and Terminal Internacional del Sur S. A. (TISUR) for the construction, maintenance, and operation of the Matarani terminal for 30 years. The competition factor was the higher initial payment to the State.	Investment: USD 6.7 million (including IGV). Shareholders are Santa Sofía Puertos S. A., a subsidiary of Trabajos Marítimos S. A. (owning 99.99999925% of the capital stock), and the remaining shares are held by Calixto Romero Seminario. The Matarani terminal handles containerized cargo and general cargo. Tisur has five tariff revisions that have transferred productivity variations to users. The 2019–2024 applied the productivity factor of 0.05%, and the 2024–2029 of 1.83% to the services regulated by price cap (RPI-X).	TISUR has a 583 m. long, 10 m. deep marginal dock with three berths and a specialized ore loading dock since 2016. Investments: (i) Mandatory improvements from 1999 to August 2004; (ii) Eventual improvements; and (iii) Voluntary improvements, Addendum 2 for expansion of demand and optimization of operations. Main clients 2022–2023: Cerro Verde 30.8%, Las Bambas 16.6%, and Antapaccay 8.1% of the mobilized cargo. Payments to the state: Canon 5% of gross monthly revenues. Special monthly remuneration to the State for 9.85% of gross revenues (Addendum 3) and 1% contribution for regulation to Ositrán.

Source: OSITRAN (2024a, 2024b, 2024c).

4.3 Climate change adaptation measures for the sustainability of Peru's port concessions

Adaptation measures involve altering processes, practices, and structures to reduce potential damage or capitalize on opportunities associated with climate change (UN cited by Cepal, 2023). The following adaptation measures rely on secondary data and a literature review.

1. Conversion to green smart ports

The crucial role of investment in the sustainable economy of ports has been demonstrated. Decarbonization initiatives should involve port infrastructure, shipping lines, and manufacturers. At the terminal level, digitization provides benefits for linking the terminal to external transportation and information systems. Digitalization enhances this connection further. Green ports are characterized by port infrastructures that prioritize environmental conservation and sustainability. They implement eco-friendly practices in dock design and construction, promote energy efficiency and transition, and employ smart waste management strategies.

2. Investment in port infrastructure reinforcement, coastal defenses against sea level rise, abnormal waves, and other extreme weather events.

This study has corroborated that the climatic factor of sea level rise influences port operations. Operational adaptations could involve

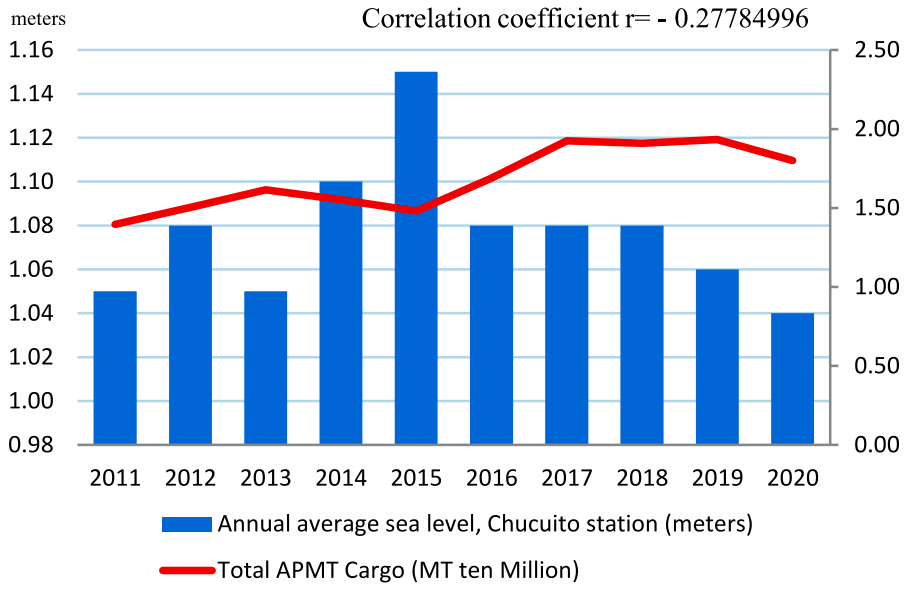

FIGURE 5
The link between total APMT load and sea level (Chucuito-Callao), Peru 2011–2020.

TABLE 4 Impact of investment and sea level rise on cargo traffic, APMT (Callao).

Model	Coefficients		Typified coefficients	*t*	Sig.
	B	Standard error	Beta		
(Constant)	20.068	19.246		1.043	0.332
Cumulative committed investment (millions of USD), APMT	0.031	0.012	0.675	2.471	0.043
Annual average sea level, Chucuito station, Callao (meters)	−27.907	17.366	−0.439	−1.607	0.152

Dependent variable: total Cargo APMT_Muelle Norte (MT Millions), R square = 50.7%.

TABLE 5 Impact of investment and sea level rise on cargo traffic, Matarani port.

Model	Coefficients		Typified coefficients	*t*	Sig.
	B	Standard error	Beta		
(Constant)	36.235	17.546		2.065	0.078
Cumulative committed investment (millions of USD), Tisur	0.014	0.002	1.045	6.564	0.000
Annual average sea level, Matarani station (meters)	−16.295	8.640	−0.300	−1.886	0.101

Dependent variable: Total Cargo Tisur_Matarani (MT Millions), R square = 86.7%.

modifying port procedures to minimize disruptions during extreme weather events or increasing flexibility in commercial networks to reroute cargo when certain ports are inaccessible.

3. Sustainable terminal design

To promote the sustainable development of seaports, from an energy perspective, the possible integration with marine renewable systems is studied, as well as their capacity to meet, even if only partially, the energy demand of seaports (Clemente et al., 2023). At COP 28, APM Terminals and DP World established the Zero Emission Port Alliance (ZEPA) to promote the decarbonization of ports through electrified container handling. Peruvian port terminals should contribute to SDGs 7, 9, and 14 on clean energy, innovation and infrastructure, and conservation of oceans and marine ecosystems, respectively.

4. Investment in clean energy fleet (ships)

Decarbonizing maritime transport requires significant investment (UNCTAD, 2023), and transitioning to cleaner fuels will raise costs.

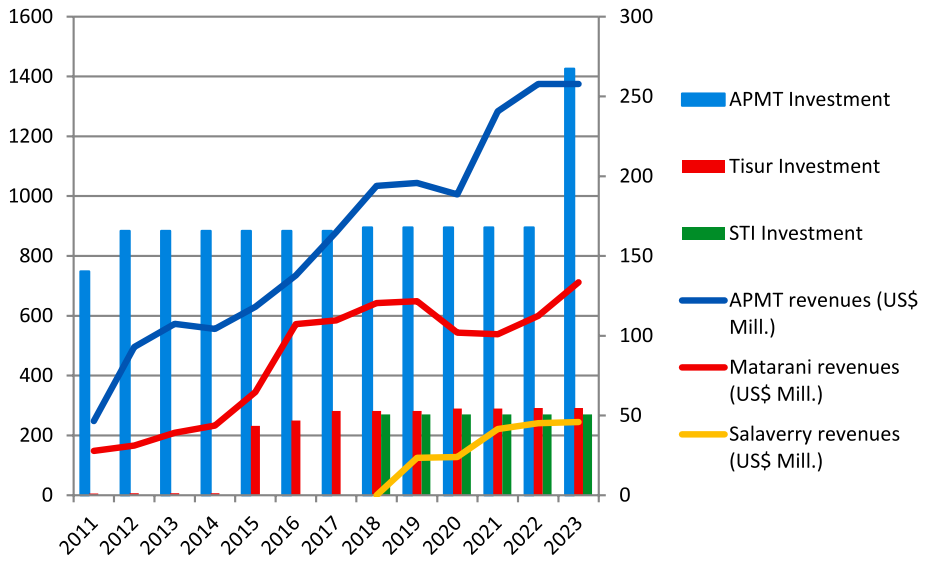

FIGURE 6
Investment and revenues in ports: APMT, Matarani (Tisur) and Salaverry (STI).

5 Discussion

Among the climatic events that would affect port infrastructure or logistics operations are sea level rise, storm surges, and extreme temperatures (Cepal, 2023). Furthermore, Asariotis et al. (2024) highlight the ongoing average sea level rise affecting ports. In our study covering 2011–2023, we observed a negative relationship between total cargo mobilization and sea level rise recorded in their respective stations for the multipurpose ports Muelle Norte Callao and Matarani. Similar to the cases analyzed, many ports worldwide will be increasingly exposed to the consequences of climate variability and change, including extreme sea levels (Asariotis et al., 2024).

For this study in Peru (2011–2023), it was found that the climate change indicator, sea level rise, negatively affects the economic sustainability of ports and is in concordance with Izaguirre et al. (2021). They argue that extreme sea level rise puts port operations at risk. Peruvian concession ports do not have records of local pollution data, nor of greenhouse gas emissions generated in port areas. Coincidentally, Panahi et al. (2020) indicate that research on port adaptation to climate change in developing countries is not yet prioritized.

Policies can promote companies to adopt sustainable practices while also maintaining their competitiveness. Additionally, these policies can encourage local communities to engage in the decision-making processes regarding new port infrastructure projects (Satta et al., 2024). In this study, the general manager of APN was interviewed in November 2024. He mentioned that the infrastructure for the new multipurpose port of Chancay in Peru will be fully automated and operate on an electric power system. Port authorities are investing in advanced technologies to enhance the efficiency of port infrastructure by automating core systems, thereby optimizing the management and handling of goods and people (Clemente et al., 2023). The concessionaire Abu Dhabi Ports Group prepared a comprehensive environmental and social impact assessment (ESIA) as part of its 30-year concession agreement with the Red Sea Ports Authority (RSPA) for the development and operation of a state-of-the-art multipurpose terminal at Safaga Port in Egypt. It incorporates sustainable design in buildings and infrastructure with low-carbon materials, as well as energy- and water-efficient systems.

This research found that investment in port infrastructure positively influences the sustainable economy of concessioned ports. Investment is relevant to the sustainability of ports. Our proposal for adapting to climate change involves converting to green smart ports, which aligns with the adaptation measures being implemented in Colombia's seaport areas. This includes replacing outdated technologies with more efficient ones, such as converting cranes, forklifts, vehicles, and other equipment to electric systems. According to the Container Port Performance Index (CPPI), the port of Cartagena, Colombia, is in third place, and the Callao port is in 26th place in the world performance ranking (World Bank, 2024).

The estimated global investment cost to protect all ports from sea level rise and storm surges projected by 2,100 is $205 billion (RTI International, 2022). When annualized—assuming an interest rate of 3% over a period of 80 years—these costs range from $4 billion to $6.8 billion per year. Policymakers are recommended to implement port management policies aiming at a sustainable economy in the port sector by integrating climate adaptation measures. To address the impacts of climate change, such as sea level rise, port authorities are recommended to invest in infrastructure for the conversion into green and smart ports.

6 Conclusion

Of Peru's multipurpose maritime port concessions, the most important in terms of total cargo mobilization is the Muelle Norte Callao terminal (APMT), which evolved from a total cargo of around 14 million MT at the beginning of the concession in 2011 to more than 18 million MT in 2023. APMT has experienced growth in container

traffic in 2023. However, the total mobilized container cargo of 1.1 million TEUs was surpassed by the specialized container concessionaire Dubai Port World at Callao's Muelle Sur, which mobilized 1.6 million TEUs. On the other hand, the port concessionaires of Matarani and Salaverry reported total cargo mobilization of 7.5 million tons and 3.3 million tons, respectively, in 2023.

From 2011 to 2023, multipurpose maritime terminals handled significant cargo volumes, both in unloading and loading. This period was characterized by a high volume of containerized cargo, particularly at APMT, which also managed bulk cargo. In contrast, the Salaverry terminal did not handle any containerized cargo. The cargo handled by APMT was primarily in the process of being unloaded. Since 2016, the shipping operations from the port of Matarani have notably grown, primarily due to the export of solid bulk copper from the Cerro Verde, Las Bambas, and Antapaccay mines.

A negative relationship was observed between the average sea level and the total cargo handled by the APMT concessionaire. Port investment has a significant positive impact on total cargo traffic, contributing to a sustainable economy. In contrast, sea level rise, considered a climate change factor, negatively affects cargo traffic at the analyzed port terminals. A limitation of this study was the scarce data on investment and revenues of the Salaverry port, newly concessioned in 2018, making a causality analysis impossible.

Adaptation to climate change requires investment in strengthening port infrastructure in the face of rising sea levels and the conversion to green and sustainable smart ports, contributing to the SDGs of innovation and infrastructure (9) and the conservation of oceans and marine ecosystems (14). The most concerning limitation was the lack of climate change data regarding port emissions. The concessioned ports in Peru do not maintain historical records of greenhouse gas (GHG) emissions and other local pollutant emissions in the areas where they operate. Furthermore, the port regulator lacks access to this information as well.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

EC: Conceptualization, Formal analysis, Investigation, Project administration, Writing – original draft, Writing – review & editing. IT: Methodology, Writing – review & editing. YB: Supervision, Writing – review & editing. VR: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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