INSTITUTO FEDERAL DE EDUCAÇÃO, CIÊNCIA E TECNOLOGIA FLUMINENSE

PROGRAMA DE PÓS-GRADUAÇÃO EM SISTEMAS APLICADOS À ENGENHARIA E GESTÃO

Ariele Lorena Barbosa da Hora

EFICIÊNCIA, DIGITALIZAÇÃO E TRANSIÇÃO ENERGÉTICA DO PORTO DO AÇU

Campos dos Goytacazes/ RJ

Dezembro de 2023

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Milton Erthal Júnior, D.Sc. (Orientador)

Dissertação de Mestrado apresentada ao Programa de Pós-graduação do Instituto Federal de Educação, Ciência e Tecnologia Fluminense, no curso de Mestrado Profissional em Sistemas Aplicados à Engenharia e Gestão (MPSAEG), como parte dos requisitos necessários à obtenção do título de Mestre em Sistemas Aplicados à Engenharia e Gestão.

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Dedico esse trabalho à memória de todos que tiveram suas caminhadas abruptamente interrompidas pela pandemia.

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RESUMO

Contexto: Localizado na região norte do estado do Rio de Janeiro, Brasil, o Porto do Açu é administrado em parceria com o Porto Antuérpia-Bruges, Bélgica. Ele se estende por uma área de 130 quilômetros quadrados e compreende 10 terminais privados de classe mundial. O Porto do Açu entrou em operação em 2014 e, em 2022, movimentou aproximadamente 60 megatoneladas de carga. Como os portos são grandes consumidores de energia e geradores de emissões, a transição para fontes de energia renováveis é considerada a principal alternativa para aliviar seus impactos em mudanças climáticas. Por este motivo, há expectativas de priorização de investimentos em estratégias de transição energética, bem como em soluções. **Objetivo**: Esta pesquisa busca avaliar o empreendimento do Porto do Açu em seu processo de transição energética, por meio de planejamento estratégico e avaliação de eficiência. **Metodologia**: Em primeiro lugar, a Análise Envoltória de Dados (DEA) foi aplicada para medir a eficiência dentre 161 terminais portuários no Brasil. Em segundo lugar, dados organizacionais internos e externos foram coletados por meio de enquete com especialistas e os resultados foram plotados em uma Matriz SWOT. Em terceiro lugar, um software de processamento de texto usando Quadratic Assignment Procedures (QAP) foi aplicado aos relatórios de sustentabilidade mais recentes do Porto do Açu e do Porto de Antuérpia-Bruges, para analisar a questão da transição energética a partir da perspectiva de uma avaliação de contrastes. **Resultados**: Os resultados encontrados sugeriram que número de berços seria a variável mais significativa para impulsionar a eficiência portuária, revelando os portos mais eficientes, e apontaram a proposta de oito estratégias de negócios comprometidas com a digitalização. Por último, os resultados apontaram para uma consonância geral entre a narrativa das autoridades portuárias e as suas publicações sobre sustentabilidade e iniciativas de alívio de impactos ecológicos. **Conclusão**: Por fim, conclui-se que o Porto do Açu, enquanto terminal portuário está a caminho da eficiência, que passa pela digitalização portuária, e que as ações de transição energética estão em curso e alinhadas com as práticas de portos em países economicamente mais desenvolvidos.

Palavras-chaves: Eficiência, Estratégia, Transição Energética, Porto do Açu.

ABSTRACT

Context: Located in the northern region of Rio de Janeiro state, Brazil, Port of Açu is administered in partnership with the Belgian Port of Antwerp-Bruges. It extends for 130 square kilometers in area and comprises 10 world-class private terminals. It has been in operations since 2014 and it moved almost 60 megatons of cargo in 2022. As ports are major consumers of energy and generators of emissions, switching to renewable energy sources is reckoned to be the leading alternative to alleviate their impacts on climate change. Thus, there have been expectations for investing in strategies towards energy transition, as well as innovative solutions for enhancing efficiency in port logistics, infrastructure, and operations. **Objective**: This research seeks to evaluate the enterprise of Port of Açu on its process towards energy transition, via strategic planning and efficiency assessment. **Methodology**: First Data Envelopment Analysis (DEA) was applied to measure efficiency among 161 port terminals in Brazil. Secondly, internal and external organizational data were collected via survey with specialists and the findings were plotted to a SWOT Matrix. Thirdly, a text processor software using Quadratic Assignment Procedures (QAP) was applied to the latest sustainability reports from both Port of Açu and Port of Antwerp-Bruges were used to analyze the issue of energy transition from the perspective of a contrasting assessment. **Results**: Results suggested the number of berths variable as a significant driver of port efficiency, and it revealed the most efficient ports, and a the proposal of eight business strategies committed to digitalization and the fomentation of changes within the organization and to its context. At last, results pointed to an overall consonance between the narrative from port authorities and their publications on sustainability and green alleviation initiatives. **Conclusion**: Finally, it was concluded that Port of Açu, as a port terminal, is on a steady path to increased efficiency through port digitalization, and that actions towards energy transition are ongoing and aligned with the practices of ports located in more economically-developed countries.

Keywords: Efficiency, Strategy, Energy Transition, Port of Acu.

Sumário

1. Presentation

Port of Açu is a reality in the northern region of Rio de Janeiro state, which impacts the local socio-economic context in its entirety, as well as the whole of Rio de Janeiro state, besides contributing to the national dynamics.

As a new venture composed of international capital, Port of Açu is aligned with the Agenda 2030 Sustainable Development Goals (SDGs) of the United Nations (UN), more specifically Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all.

From a world perspective, it is a time of immense challenges to sustainable development, while it is also a time of immense opportunity. Building on the 2000's Millennium Development Goals, the 2030 Agenda for Sustainable Development came into effect on 1 January 2016, seeking to achieve what the MDGs did not, proposing 17 Sustainable Development Goals with 169 associated targets which are integrated and indivisible, via which the United Nations collectively commit to the pursuit of global development (United Nations, 2015).

Within the 2030 Agenda for Sustainable Development, Goal 7 states "Ensure access to affordable, reliable, sustainable and modern energy for all".

With additional impact of COVID-19, closing the investment and research gap in achieving SDG 7 by 2030 also requires good analytical and information support, as well as specific focus on responsible investments (Makarenko et al., 2023). The total conditional effect of energy efficiency on economic growth is robustly positive, but it is much higher in economies with minimal income inequality. Thus, energy efficiency improvements might not lead to a win-win situation in economies with a highly unequal distribution of income (Adom et al., 2021).

Progress has, on average, been positive across the world, with more than 87 per cent of the sample of countries experiencing some degree of progress. However, progress is smaller for the Middle East and North Africa and Sub-Saharan countries and it is negative for most of the countries that exhibit low levels of human development, as measured by the Human Development Index.

The first study analyzes the efficiency of 161 Brazilian port terminals (both maritime and riverside) in 2020, the first year of the COVID-19 pandemic, using data extracted from the governmental registry ANTAQ (National Agency for Waterway Transportation), considering the similarities among the DMUs (decision-making units).

Later, the second study strategically assesses the variables surrounding port digitalization and its context in the Port of Açu complex using the SWOT analysis method. Understanding that organizations exist both within and outside of themselves, the analysis of these environments allows for strategic planning and management practices in a multitude of scenarios.

And lastly, the third study investigates the question of energy transition in the context of a comparison between Port of Açu (in Brazil) and Port of Artwerp-Bruges (in Belgium), where the latest sustainability reports from both entities are contrasted in regards to planning, feasibility, and alignment, via the application of a text processor software, and later a breakdown analysis of the results.

1.2 Objectives

1.2.1 General Objective

The general objective of this research is to evaluate the enterprise of Port of Açu on its process towards energy transition, via strategic planning and efficiency assessment.

1.2.2 Specific Objectives

A total of three studies were taken into account for this research paper. Their objectives are listed below:

- Evaluate the port operations efficiency at Port of Açu;
- Evaluate Port of Açu regarding its port digitalization strategy;
- Verify energy transition strategies at Port of Açu, compared to the Port of Antwerp-Bruges.

2. Research Structure

The first section of this paper introduces the general concept of the problem to be solved by this research. Whereas the second section fulfills the first specific objective, organized in the format of an article. Similarly, the third and fourth sections attain the second and third specific objectives, respectively.

The fifth section relays the final considerations of this research.

2. PORT EFFICIENCY IN BRAZIL – AN APPROACH WITH CLUSTERIZATION AND DATA ENVELOPMENT ANALYSIS

Abstract. The Covid-19 pandemic has brought about unforeseen challenges which add to already pressing foreign trade demands for improved infrastructure and services efficiency of Brazilian ports. This paper considers data from the year 2020 on 161 port terminals in Brazil and uses K-means as a clusterization method to initially divide the data into groups, subsequently applying Data Envelopment Analysis (DEA) to each cluster to measure efficiency. Operation time, Laytime and Number of berths are input variables, while Annual Movement is the output variable. Results suggest the number of berths variable as a significant driver of port efficiency in all clusters, and it reveals the following ports as the most efficient ones: Cluster 1: Santos, Rio de Janeiro, Angra dos Reis and Niterói; Cluster 2: Rio Grande and Recife; Cluster 3: Porto Velho; Cluster 4: Hermasa, Belém and J. F. Oliveira; Cluster 5: Portocel, Vitória, Maceió, São Sebastião. Most of such ports are publicly operated and located in the southeastern and northern regions of the country. The study also recommends specific niches for future research on this subject.

Keywords: Port, Efficiency, Brazil, Clusterization, DEA.

2.1. Introduction

Comprising 175 maritime and riverside ports, the Brazilian network of ports encompasses 20 out of the 26 states of the federation. This research considers the main 161 ports, which in 2020 alone were responsible for moving over one billion tons of goods both within the country and overseas, that being an increase of 4.53% when compared to the cargo moved in the previous year (ANTAQ, 2021).

Brazilian ports have seen a fast-tracked growth on foreign trade demands, especially since the state monopoly on port operations was broken in the mid-1990s. As the public-private partnerships ownership model is embraced, it makes for enhanced financial funding of private ports, which is consistent with the emergent needs for investments in infrastructure to accelerate capacity expansion projects and better aid Brazil's hinterlands (Wanke & Barros, 2015).

From 2006 to 2010, the accumulated throughput (measured in tons/year) in Brazilian ports increased at an average rate of 10% every year (Wanke, 2013). In 2014, foreign trade represented 19% of the country's GDP, revealing that maritime infrastructure investments realized from 2009 to 2012 generated an increase of around 14% for exportation and 11% for importation flows (López-Bermúdez et al., 2019).

Wanke (2013) analyzed the physical infrastructure shipment consolidation efficiency drivers in Brazilian ports using a two-stage network DEA (Data Envelopment Analysis) approach, in which first assets were used to achieve a given shipment frequency per year; and secondly, such movements allowed solid cargo (bulk and containerized) to be handled. Results pointed to a private administration and hinterland size being responsible for positive impacts on efficiency levels.

Andrade et al., (2019), in its case study on port efficiency incorporating service measurement variables, pointed to the drawbacks of traditional DEA models as lacking discriminatory power. A bi-objective multicriteria variation is applied to data from 2010 to 2016 to analyze the efficiency of 20 Brazilian ports. Results exposed a significant disparity among ports, and a clusterization technique verified a robust correlation between port efficiency and cargo throughput.

Beuren et al., (2018) explored the effects of logistics inefficiencies on Brazil's global competitiveness and measured the efficiency of Brazilian ports and their management models using DEA. Results indicated Paranagua Port as being the country's most efficient port and took it as a benchmark. Results also showed that neither the management model nor the nature of the cargo handled were found to skew efficiency rates.

Haddad et al., (2010) attempted to explain the link between trade barriers and regional inequality in their research on regional effects of port infrastructure using a spatial computable general equilibrium (CGE) model integrated to a transport network system. Three scenarios were considered in the simulation: (1) overall port efficiency matching international standards; (2) efficiency gains of decentralized port management; and (3) regionally differentiated increases in port efficiency to reach the national frontier. Results found that gains in efficiency and welfare were optimistic and the largest impacts occurred in scenario 3, suggesting that increases in port efficiency lead to a more competitive and open Brazilian economy.

Hwang et al., (2016) used a reasonably simple methodology to evaluate the returns to scale and convexity in DEA built upon the Bootstrap technique in the case study of Brazilian port terminals. Confidence intervals and bias corrected estimates were used to test for relevant differences on distance functions and returns-to-scale indicators delivered by distinct DEA models. Results demonstrated how the bootstrapping method might be used to unambiguously characterize returns-to-scale under different DEA models.

López-Bermúdez et al., (2019) used data from 2008 to 2017 and a stochastic frontier analysis to measure efficiency and productivity of 20 containerized goods terminals in Brazilian ports. The most prominent results revealed that private terminal operators are more efficient than public ones.

Rubem et al., (2014) applied data envelopment analysis and the Copeland method to evaluate the relative importance of each Brazilian port unit for national trade within the business they operate. The units were first clustered according to the nature of the cargo they handled, then the decision-aid techniques were applied, and the results demonstrated that the Copeland and the composite rankings were comparable for the task.

The prominent relevance of the maritime sector to economic development contributes to making a nation internationally competitive as it forms a vital connection in the global trading chain (Wanke et al., 2011). Thus, the Brazilian port structure affects not only its trade balance, but also other trading partners. Therefore, it is relevant to investigate Brazilian ports' efficiency levels. However, given the complexity of factors affecting port performance such as the Brazilian economical asymmetry, the diversity of ports types and their cargos, and the methodological limitations of data envelopment analysis in search of benchmarking, this paper seizes the research opportunity of segregating the many ports through a clusterization algorithm, prior to assessing their compared efficiencies against one another.

The objective of this work is to analyze the efficiency of 161 Brazilian port terminals (both maritime and riverside) in 2020, the first year of the COVID-19 pandemic, using data extracted from the governmental registry ANTAQ (National Agency for Waterway Transportation), considering the similarities among the DMUs (decision-making units).

2.2. METHODOLOGY

2.2.1. Research Classification

According to Silva and Menezes (2001) this research can be classified as of applied nature with a quantitative approach. Its objectives are descriptive and its procedures of data gathering and case study as per Gil (2002).

2.2.2. Variables Definition and Data Collection

The variables used in this research are selected based on prior research by Pratap et al. (2015) in which a decision support system is applied to data of bulk material handling ports in

India in relation to ship scheduling and discrete berth allocation. Their investigation and model application to input parameters have thus supported the selection of the three input variables used in this present research, namely: (a) operation time, (b) laytime, and (c) number of berths. Annual Movement of cargo moved is the sole output variable.

The data on all input variables refer to the year 2020, from January to December, and are collected in 2021 directly from ANTAQ's website (ANTAQ, 2021), referring to 161 Brazilian ports located either by the ocean or by riverside, of which only 26 are strictly publicly owned and/or operated.

2.2.3 Technical Procedures

First the data are clustered, that is, they are segregated in groups according to their similarities, using k-means algorithm subsequent to the analysis of the ideal k value. Afterwards, the efficiency analysis is done using DEA.

2.2.3.1 K-means Clusterization

K-means is a non-supervised clusterization algorithm which analyzes data based on their features and similarities and then separates them in groups.

In the first moment, the ideal k value is determined mathematically, and that number represents the number of clusters by which all data should be divided. Then the clusters centroids are established, and the distance between the latter and the variables is calculated to relate them by the least value. This calculation is then repeated for as many times as is needed to check if there were changes in the associations between variables and centroids. When no more such changes are found, the process is considered finalized (Roiger, 2017).

There are two methods within K-means for cluster analysis: (i) The Silhouette Method and (ii) The Elbow Method. When choosing the adequate number of groups, both can diminish subjectivity. In this research, The Elbow Method is used, where the variation as a function of the quantities of clusters is plotted graphically and the "point of inflexion" is established as the number of clusters to be used (Salles et al., 2019).

2.2.3.2 Data Envelopment Analysis

Data Envelopment Analysis is a technique based on linear programming, aimed at measuring the efficiency or performance of Decision-Making Units (DMUs) by means of a non-parametric algorithm. Provided the variables are presumed homogeneous, inputs and outputs are compared and each individual DMU is optimized (Rubem et al., 2014).

Representing an alternative to more traditional statistical methods, DEA allows for the estimation of relative efficiency in regard to an efficiency frontier, which means that the points considered the most efficient in a plotted graph are the ones within such frontier, while the inefficient ones are plotted below it (Mariano et al., 2006).

There are two most widely used methods in DEA, which are: (iii) CRS, which assumes constant returns to scale and (iv) VRS, which does not take into account proportionality among inputs/outputs and is based on variable returns to scale (Périco & Ribeiro da Silva, 2020). The Constant Returns to Scale (CRS) model is used in this research.

2.3. Results and Discussion

Out of the over 1.1 billion tons of cargo moved by means of all Brazilian ports in the year 2020, this current research considers the main 161 ports, of which 135 are denominated Private Use Terminal (PUT), spread among 20 out of the 26 states in all five macro regions of the federation.

2.3.1. Clusterization

Initially, the variables being studied were analyzed to find the optimal number of clusters by which all units should be divided, that is, k. Figure 1 shows, in the form of an Elbow Method for K-means, the variance sum distribution for each cluster formed. The ideal k value means that the clusters are furthermost dissimilar from one another while the components within each cluster are the most similar.

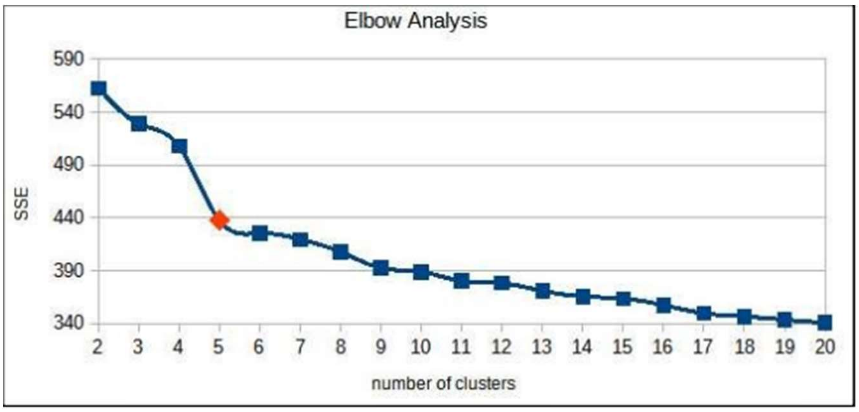

Figure 1: Elbow method for k clusters. Source: Own elaboration.

Using the Elbow analysis, the dataset was divided into 5 clusters. This is clearly exemplified in Figure 1 where the Elbow Method illustrates that the point at which the percent value change in variation between the consecutive data points is less accentuated (point of inflexion) in the plotted line corresponds to value 5 in axis k, that is, number of clusters.

2.3.1.1. Characterization of clusters

Cluster 1 is on the higher end of the output variable accumulated value. Composed of 31 ports, which includes the three largest ports in terms of annual movement tonnage (i.e., Ponta da Madeira, Santos and Angra dos Reis), it accounts for the highest number of berths (38% of the total) as well as the highest total throughput share (63%), thus likely holding good physical infrastructure. Operation time (18% of the total) and laytime (27% of the total) are average. 25 of these ports are located in the southeast, being all in Rio de Janeiro, but two in São Paulo (Santos and Itaguaí). The remaining 6 ports are located in the north (Vila do Conde), south (Paranaguá) and northeast (Ponta da Madeira, Suape, Itaqui, Pacém) regions. In this cluster, 6 ports are publicly owned/operated.

Cluster 2 is composed of 32 ports from all 5 regions in Brazil, being 19 in the south region, while 5 are in the northeast (Salvador, Cotegipe, Recife, Gerdau and Ilhéus), another 5 in the north (Vila do Conde, Murucupi, Jari, Caulim, Itaituba), 1 in the center-west (Porto Murtinho), and 2 in the southeast (Tiplan and Cubatão). This cluster accounts for just 9% of the total throughput share, 25% of the total number of berths, yet the highest times, being 39% of the total operation time and 33% laytime. In this cluster, 8 ports are publicly owned/operated.

Cluster 3 also presents components from all Brazilian regions, consisting of a total of 24 ports, mostly in the north region, being 10 in the state of Rondônia and 5 in Pará. The remaining ones are 1 in the center-west (Gregório Curvo), 1 in the southeast (Dow), 3 in the south (Osório, Poly, Asfalto da Amazônia) and 4 in the northeast (Belmonte, TRBA, Dow Aratu, Braskem). This cluster is the smallest in terms of number of components, and holds the lowest numbers in this analysis, accounting for 4% of the annual movement, 7% of the operation time, 9% of the laytime and 5% of the number of berths. In this cluster, only 1 port is publicly owned/operated.

Cluster 4 comprises 48 ports, being 30 in the north, and the remaining 18 spread among all other regions as follows: 6 in the northeast (Madre de Deus, Areia Branca, Villas Boas

Machado, TMIB, Salina Diamante Branco, Miguel de Oliveira), 3 in the center-west (São Simão, Química Ladário, Caramuru São Simão), 4 in the southeast (World Santos, Pederneiras, CCPN, Base Logística de Dutos) and 5 in the south (São Francisco do Sul, Portonave Navegantes, Itapoá, Itajaí, Barra do Rio). This cluster is the largest in terms of number of components, and accounts for 13% of the total throughput share, 14% of the operation time, 10% of the laytime and 18% of the number of berths. In this cluster, 5 ports are publicly owned/operated.

Cluster 5 is composed of 26 ports, most of them being in the southeast region, mainly in the state of Espírito Santo, except for 1 in Rio de Janeiro (Açu) and 2 in São Paulo (Cutrale, São Sebastião). Of the remaining ports, 8 are located in the northeast (Alumar, Aratu, Fortaleza, Guamaré, Maceiró, Cabedelo, Natal, Aracaju) and 2 in the south (Cattalini, Teporti). This cluster accounts for 12% of the total throughput share, 23% of the total operation time and 22% of the total laytime and 14% of the total number of berths. In this cluster, 6 ports are publicly owned/operated.

2.3.2. DEA analysis

As shown in Table 1 below, Cluster 1 has a total of 4 ports in the efficiency frontier, reaching the 100% mark, namely: Santos, Rio de Janeiro, Angra dos Reis and Niterói. These are all located in the southeast region of Brazil. Amongst them, Santos port holds the second highest annual movement tonnage and the highest number of berths within the cluster. Rio de Janeiro port holds the second highest number of berths, however its annual movement value is 13 times smaller than Santos port.

Paranaguá port scores poorly in this analysis, and that goes against the results found by Beuren et al. (2018) where it was found to be the most efficient port in Brazil and a benchmark in 2014. Certainly, different variables were used in that research and it was mainly focused on ports management models and whether they could affect their outcomes, yet we understand this is a finding worth pointing out.

DMU	Port (Cluster 1)	Annual Movement (t)	Operation Time (min)	Laytime (min)	Number of berths	Type	State	Region	DEA
2	Santos	114,353,735	35.7	35.1	64	Public	São Paulo	Southeast	1.000000
31	Rio de Janeiro	8,265,002	22.5	43.6	61	Public	Rio de Janeiro	Southeast	1.000000
139	Angra dos Reis	15,000	0.2	1	2	PUT	Rio de Janeiro	Southeast	1.000000
140	Niterói	14,316	0.5	130.2	3	PUT	Rio de Janeiro	Southeast	1.000000
9	Suape	25,698,583	23.8	57.8	15	Public	Pernambuco	Northeast	0.226576
7	Itaguaí	46,241,794	40.5	125.5	25	PUT	Rio de Janeiro	Southeast	0.221323
6	Paranaguá	52,087,253	39.6	195.5	21	Public	Paraná	South	0.188735
12	Porto do Açu - Terminal de Minério	23,849,335	27.4	102.9	11	PUT	Rio de Janeiro	Southeast	0.145249
18	Vila do Conde	15,256,767	56.6	142.3	16	Public	Pará	North	0.142092
15	Terminal Aquaviário da Ilha DAgua	18,116,245	16.1	37	5	PUT	Rio de Janeiro	Southeast	0.111479
134	Terminal de Combustíveis Marítimos do Açu - TECMA	31,478	7.5	14	2	PUT	Rio de Janeiro	Southeast	0.094216
157	Terminal Portuário da Nuclep	283	6.5	11	2	PUT	Rio de Janeiro	Southeast	0.090909
16	Terminal Portuário do Pecém	15,894,291	41	83.3	10	PUT	Ceará	Northeast	0.089892
111	Estaleiro Brasfels	167,117	6.8	378.8	3	PUT	Rio de Janeiro	Southeast	0.085107
155	Terminal NOV Flexibles	593	1.6	154	1	PUT	Rio de Janeiro	Southeast	0.062500
10	Itaqui	25,303,708	51.2	206.3	8	Public	Maranhão	Northeast	0.057321
5	Terminal Aquav. de São Sebastião (Almirante Barroso)	52,218,514	25.6	93.1	4	PUT	São Paulo	Southeast	0.054295
32	Ternium BR	8,230,092	88	182.1	3	PUT	Rio de Janeiro	Southeast	0.049389
1	Terminal Marítimo de Ponta da Madeira	191,321,793	36.7	234.8	5	PUT	Maranhão	Northeast	0.042667
148	Intermoor - Base de Apoio Marítimo Intermoor Açú	3,679	16	20	1	PUT	Rio de Janeiro	Southeast	0.036828
144	Flexibrás Açu	11,453	21.2	81	2	PUT	Rio de Janeiro	Southeast	0.034541
3	Terminal Aquaviário de Angra dos Reis	60,250,095	30.9	115.8	3	PUT	Rio de Janeiro	Southeast	0.033837
126	Terminal Ilha do Governador	68,450	16.9	40.2	1	PUT	Rio de Janeiro	Southeast	0.019265
132	Terminal Marítimo Ponte do Thun	37,007	19.6	43	1	PUT	Rio de Janeiro	Southeast	0.017839
94	Terminal Flexível de GNL da Baía da Guanabara	632,404	28.3	71.9	2	PUT	Rio de Janeiro	Southeast	0.015622
156	Mac Laren Estaleiros	286	33	37.8	1	PUT	Rio de Janeiro	Southeast	0.014011
13	Terminal da Ilha Guaíba - TIG	23,743,666	55.1	217	2	PUT	Rio de Janeiro	Southeast	0.013352
8	Terminal de Petróleo Tpet/Toil - Açu	29,611,392	32.1	91.6	1	PUT	Rio de Janeiro	Southeast	0.011258
119	Terminal Aquaviários Ilha Redonda e Ilha Comprida	88,363	44.4	99.5	1	PUT	Rio de Janeiro	Southeast	0.007847
121	Cosan Lubrificantes e Especialidades	84,594	25	135.8	3	PUT	Rio de Janeiro	Southeast	0.004285
123	Terminal Marítimo Braskem	75,170	119.2	162.4	1	PUT	Rio de Janeiro	Southeast	0.004285

Table 1: DEA Port Efficiency Analysis (Cluster 1). Source: Own elaboration.

Table 2 illustrates Cluster 2, where ports Rio Grande and Recife are found to be the most efficient ones. The latter is located in the northeast region and the former is in the south having the highest numbers in the group for annual movement and number of berths.

DMU	Port (Cluster 2)	Annual Movement (t)	Operation Time (min)	Laytime (min)	Number of berths	Type	State	Region	DEA
11	Rio Grande	24,661,138	23.6	59	62	Public	Rio Grande do Sul	South	1.000000
69	Recife	1,281,354	130	142.9	12	Public	Pernambuco	Northeast	1.000000
43	Salvador	5,173,804	18.2	226	12	PUT	Bahia	Northeast	0.862656
84	Porto Alegre	810,893	16.8	61.2	37	Public	Rio Grande do Sul	South	0.838326
98	Bianchini Canoas	559,772	11.9	12.9	1	PUT	Rio Grande do Sul	South	0.737680
58	Terminal Santa Clara	2,244,867	7.8	25.1	4	PUT	Rio Grande do Sul	South	0.663454
53	Yara Brasil Fertilizantes	2,568,314	32.3	52.3	5	PUT	Rio Grande do Sul	South	0.588838
80	Pelotas	925,348	9.6	11.4	6	Public	Rio Grande do Sul	South	0.500849
23	São Francisco do Sul	11,813,145	66.1	123.7	8	Public	Santa Catarina	South	0.239273
60	Terminal Portuário Bunge Alimentos	1,971,675	53.7	92.3	2	PUT	Rio Grande do Sul	South	0.235597
66	CMPC Guaiba	1,677,222	9.8	12.9	1	PUT	Rio Grande do Sul	South	0.209442
41	Terbian - Terminal Bianchini	5,479,724	24.2	78.6	3	PUT	Rio Grande do Sul	South	0.199088
45	Terminal Portuário Cotegipe	4,981,978	77.3	377.2	2	PUT	Bahia	Northeast	0.114484
110	Oleoplan	188,711	8.1	8.5	1	PUT	Rio Grande do Sul	South	0.111954
117	Terminal Privado Copelmi	92,691	8.2	8.5	1	PUT	Rio Grande do Sul	South	0.111954
20	Terminal Integ. Portuário Luiz Antonio Mesquita-Tiplam	12,834,722	71.3	254.3	4	PUT	São Paulo	Southeast	0.110221
40	Imbituba	5,868,241	64.4	138.8	2	Public	Santa Catarina	South	0.106607
61	Terminal Marítimo Luiz Fogliatto - Termasa	1,951,103	71.5	141.2	1	PUT	Rio Grande do Sul	South	0.103604
147	Terminal Hidroviário de Porto Murtinho	4,090	208.8	222	2	PUT	Mato Grosso do Sul	Center West	0.084728
112	Estação Adm Armazéns Gerais	278,489	5.6	193.1	1	PUT	Rio Grande do Sul	South	0.067972
25	Terminal Vila do Conde	10,755,527	56.6	142.3	2	PUT	Pará	North	0.066232
109	Unidade Misturadora de Porto Alegre	315,170	15.5	46.5	2	PUT	Rio Grande do Sul	South	0.049116
129	Terminal Aquaviário de Niterói	53,808	10.2	35.2	1	PUT	Rio Grande do Sul	South	0.037318
142	Terminal de Gás do Sul - Tergasul	13,989	15.2	33	1	PUT	Rio Grande do Sul	South	0.028837
83	Terminal Marítimo Privativo de Cubatão - Tmpc	834,320	126.7	193.4	5	PUT	São Paulo	Southeast	0.024602
108	Ilhéus	322,095	132.7	161.6	4	Public	Bahia	Northeast	0.023555
125	Porto Jari - Terminal Munguba	73,096	78.6	102.5	1	PUT	Pará	North	0.009284
127	Terminal Fluvial Caulim	63,207	77.7	104.7	1	PUT	Pará	North	0.009089
79	Porto Murucupi	934,127	117.1	118.5	1	PUT	Pará	North	0.008030
78	Antonina	938,000	117.1	253.9	2	Public	Paraná	South	0.007496
130	Base de Distribuição Secundária de Itaituba	49,942	279.5	390	1	PUT	Pará	North	0.007074
99	Gerdau Aços Longos	525,286	191.8	205.4	1	PUT	Bahia	Northeast	0.004633

Table 2: DEA Port Efficiency Analysis (Cluster 2). Source: Own elaboration.

Table 3 presents Cluster 3, where again 2 ports reach the 100th efficiency percentile, them being Porto Velho in the north and Gregório Curvo in the center-west region. Both are fairly average in terms of annual moved cargo; however the former has the highest number of berths in the group.

DMU	Port (Cluster 3)	Annual Movement (t)	Operation Time (min)	Laytime (min)	Number of berths	Type	State	Region	DEA
59	Porto Velho	2,097,233	16.7	13.3	10	Public	Rondônia	North	1.000000
67	Porto Gregório Curvo	1,652,104	1.6	47.6	2	PUT	Mato Grosso do Sul	Center West	1.000000
51	Terminal de Expedição de Grãos Portochuelo	3,079,524	1.9	1.9	1	PUT	Rondônia	North	0.872277
122	Passarão	83,242	1.9	4.4	1	PUT	Rondônia	North	0.831395
50	Terfron	3,542,307	3.1	82.6	3	PUT	Pará	North	0.820003
116	Atem PVH	94,861	3.7	23.9	1	PUT	Rondônia	North	0.372186
56	Terfron Itaituba	2,396,231	2.3	71.4	1	PUT	Pará	North	0.347826
90	Bertolini - Belém	667,194	7.7	62	2	PUT	Pará	North	0.340872
104	Aivel	389,350	4.8	8.3	1	PUT	Rondônia	North	0.336140
39	Terminal Ponta da Montanha	5,899,844	10	37.7	2	PUT	Pará	North	0.300444
73	Cargill Agrícola	1,056,847	7.3	91.8	1	PUT	Rondônia	North	0.223622
103	Base Secundária Ipiranga de Porto Velho	432,759	7.4	13.3	1	PUT	Rondônia	North	0.217499
62	Estação Cianport Miritituba	1,919,638	7.1	58.4	1	PUT	Pará	North	0.200418
55	Estação Cujubinzinho	2,459,569	16.6	18.6	2	PUT	Rondônia	North	0.198785
72	TMB - Terminal Marítimo de Belmonte	1,092,766	41.2	57	1	PUT	Bahia	Northeast	0.191920
22	Terminal Aquaviário de Osório	11,982,962	24.1	66.9	2	PUT	Rio Grande do Sul	South	0.128998
133	F. H. de Oliveira Peixoto	35,438	13.4	42.4	1	PUT	Rondônia	North	0.114449
107	Terminal Braskem	329,314	17.2	41.9	1	PUT	Alagoas	Northeast	0.091460
137	Poly Terminais Portuários	22,000	19.5	36.1	1	PUT	Santa Catarina	South	0.082377
101	Terminal Marítimo Dow Aratu - Bahia	473,093	24.5	56.6	1	PUT	Bahia	Northeast	0.064496
93	Terminal Marítimo Dow	640,910	30.7	43.7	1	PUT	São Paulo	Southeast	0.053146
143	Companhia Brasileira de Asfalto da Amazônia	13,257	31	65.7	1	PUT	Santa Catarina	South	0.051321
77	Terminal De Regaiseficação De Gnl Da Bahia - TRBA	939,633	31.6	66.4	1	PUT	Bahia	Northeast	0.050379
106	Belmont	343,242	41.2	57	1	PUT	Rondônia	North	0.039659

Table 3: DEA Port Efficiency Analysis (Cluster 3). Source: Own elaboration.

Table 4 shows Cluster 4 which presents 4 ports as being the most efficient: Hermasa, Belém and J. F. Oliveira, all in the north region. Belém port has the highest number of berths in the group.

DMU	Port (Cluster 4)	Annual Movement (t)	Operation Time (min)	Laytime (min)	Number of berths	Type	State	Region	DEA
28	Terminal Graneleiro Hermasa	9,329,100	5.5	5.8	6	PUT	Amazonas	North	1.000000
52	Belém	3,058,210	1.8	21.6	19	Public	Pará	North	1.000000
81	Terminal J. F. de Oliveira de Belém	863,773	1.8	4.7	7	PUT	Pará	North	1.000000
19	Santarém	14,427,000	17.3	18.8	12	Public	Pará	North	0.674952
95	Norte Log	570,956	1.4	2	2	PUT	Pará	North	0.671429
150	Carinhoso	2,144	1.5	3.5	2	PUT	Amazonas	North	0.614869
68	Santana	1,309,982	4.3	10.6	5	Public	Amapá	North	0.614354
158	Base Logística de Dutos	163	4.9	5.2	3	PUT	São Paulo	Southeast	0.520343
91	ATR Logística - Chibatão	651,597	1.9	4.5	3	PUT	Amazonas	North	0.483858
153	Terminal Navecunha	838	0.4	2	1	PUT	Amazonas	North	0.447616
115	Chibatão Navegação e Comércio	105,634	1.7	4.6	2	PUT	Amazonas	North	0.435348
105	Granel Química Ladário	370,211	3.7	6.2	3	PUT	Mato Grosso do Sul	Center West	0.420833
49	Areia Branca	3,652,929	6.7	15.1	5	Public	Rio Grande do Norte	Northeast	0.371959
100	J. F. de Oliveira - Manaus	476,290	1.9	5.3	2	PUT	Amazonas	North	0.314485
82	Super Terminais Comércio d Indústria	852,941	18.4	4.7	2	PUT	Amazonas	North	0.286823
70	Terminal Aquaviário Solimões - Coari	1,214,825	6.5	15	2	PUT	Amazonas	North	0.264990
38	Itajaí	5,979,919	16.4	28.7	5	Public	Santa Catarina	South	0.196482
120	Amazon Aço Indústria e Comércio Ltda	86,465	4.2	5.5	1	PUT	Amazonas	North	0.173950
63	Terminal de Barcaças Luciano Villas Boas Machado	1,919,638	17.1	26.3	2	PUT	Bahia	Northeast	0.167697
124	Caramuru Alimentos São Simão	73,816	5.2	5.9	1	PUT	Goiás	Center West	0.160510
29	Portonave - Terminais Portuários de Navegantes	9,232,954	8.2	21.7	3	PUT	Santa Catarina	South	0.151939
36	Porto Chibatão	6,661,176	56.4	65.4	6	PUT	Amazonas	North	0.144982
113	Moss	123,698	18.6	20.6	3	PUT	Amazonas	North	0.140037
26	DP World Santos	10,524,034	14.6	35.1	4	PUT	São Paulo	Southeast	0.127140
48	Terminal Aquaviário de Manaus	3,973,765	17.9	71.7	3	PUT	Amazonas	North	0.121516
131	Ronav	47,565	15.5	16.5	2	PUT	Amazonas	North	0.116909
151	Terminal Marítimo Miguel de Oliveira	2,069	6	10	1	PUT	Bahia	Northeast	0.112800
76	LDC Pederneiras	966,525	31.6	6.4	1	PUT	São Paulo	Southeast	0.111008
75	LDC São Simão	967,569	2.8	7.3	1	PUT	Goiás	Center West	0.102698
14	Terminal Aquaviário de Madre de Deus	19,773,916	23.6	56	5	PUT	Bahia	Northeast	0.098991
33	Porto Itapoá Terminais Portuários	8,026,562	11.5	22.9	2	PUT	Santa Catarina	South	0.096859
118	Terminal CCPN	91,067	7.6	13.6	1	PUT	Rio de Janeiro	Southeast	0.074861
138	Terminal de Embarque Marítimo da Salina Diamante Brar	17,274	4.4	14.6	1	PUT	Rio Grande do Norte	Northeast	0.074392
149	Barra do Rio Terminal Portuário	2,352	12	18.7	1	PUT	Santa Catarina	South	0.068435
87	Terminal Marítimo Inácio Barbosa - TMIB	711,438	26.7	30.1	2	PUT	Sergipe	Northeast	0.060988
102	Ibepar	442,020	10.7	57	3	PUT	Amazonas	North	0.057152
161	Terminal Hidroviário Cimbagé	77	9.2	21.2	1	PUT	Amazonas	North	0.049590
97	Bertolini - Santarém	559,851	4.5	22.4	1	PUT	Pará	North	0.045762
154	Itacal- Itacoatiara Calcários Ltda	678	17	20	1	PUT	Amazonas	North	0.044838
44	Hidrovias do Brasil Miritituba	5,007,340	27.5	28.6	1	PUT	Pará	North	0.039591
24	Terminal Aquaviário de São Francisco do Sul	10,767,108	21.7	28	1	PUT	Santa Catarina	South	0.039451
34	Terminal Fluvial de Juruti	7,098,264	25.9	30.8	1	PUT	Pará	North	0.036521
21	Terminal Trombetas	12,449,286	20.6	31.6	1	PUT	Pará	North	0.034918
135	J A Leite Navegação	27,798	10.5	37.8	1	PUT	Amazonas	North	0.028905
86	Atem Manaus	743,059	35.9	43.6	1	PUT	Amazonas	North	0.021645
145	Porto Brasilit	11,175	52.7	55.9	1	PUT	Amazonas	North	0.020196
141	Ocrim	14,010	98.3	138.1	1	PUT	Amazonas	North	0.011489
114	Cimento Vencemos	113,923	67.3	93.3	1	PUT	Amazonas	North	0.010787

Table 4: DEA Port Efficiency Analysis (Cluster 4). Source: Own elaboration.

And finally, Table 5 presents Cluster 5, where Portocel, Vitória, São Sebastião (in the southeast) and Maceió (in the northeast) are found to be the most efficient ones. Vitória port has the highest number of berths in the group.

DMU	Port (Cluster 5)	Annual Movement (t)	Operation Time (min)	Laytime (min)	Number of berths	Type	State	Region	DEA
30	Portocel - Terminal Especializado de Barra do Riacho	8,334,028	36.1	41.3	10	PUT	Espírito Santo	Southeast	1.000000
35	Vitória	6,945,828	40.2	70.3	12	Public	Espírito Santo	Southeast	1.000000
65	Maceió	1,846,572	48.6	91.5	9	Public	Alagoas	Northeast	1.000000
85	São Sebastião	798,265	42.5	93.1	14	Public	São Paulo	Southeast	1.000000
71	Cabedelo	1,126,973	49.2	80	5	Public	Paraíba	Northeast	0.910291
37	Aratu	6,108,057	24.5	133.1	6	Public	Bahia	Northeast	0.820059
159	Terminal Portuário da Glória - TPG	156	5.3	5.4	1	PUT	Espírito Santo	Southeast	0.764815
152	Companhia Portuária Vila Velha - CPVV	1,109	4.6	10.4	1	PUT	Espírito Santo	Southeast	0.727984
46	Fortaleza	4,944,786	42.1	90.2	7	Public	Ceará	Northeast	0.659831
4	Terminal de Tubarão	56,177,117	39.1	247.8	7	PUT	Espírito Santo	Southeast	0.595557
64	Terminal de Barcaças Luciano Villas Boas Machado	1,919,638	17.1	26.3	2	PUT	Espírito Santo	Southeast	0.517501
128	Terminal Aquaviário de Barra do Riacho	55,723	17.9	35.3	2	PUT	Espírito Santo	Southeast	0.368278
74	Terminal Marítimo Ponta Ubu	976,226	40.5	55.7	4	PUT	Espírito Santo	Southeast	0.342236
47	Cattalini Terminais Marítimos	4,081,005	33.1	103.3	2	PUT	Paraná	South	0.235201
92	Terminal Aquaviário de Aracaju	650,173	26.4	101.7	2	PUT	Sergipe	Northeast	0.229978
42	Terminal Marítimo Alf. Privativo Uso Misto Praia Mole	5,437,278	59.7	116.6	3	PUT	Espírito Santo	Southeast	0.218661
17	Terminal Portuário Privativo da Alumar	15,268,027	36.2	120.1	2	PUT	Maranhão	Northeast	0.184827
88	Natal	696,895	66.1	82.7	3	PUT	Rio Grande do Norte	Northeast	0.160731
160	Ipiranga Manaus	102	26.9	26.9	1	PUT	Espírito Santo	Southeast	0.153532
57	Terminal Aquaviário De Guamaré	2,357,351	34	97.1	1	PUT	Rio Grande do Norte	Northeast	0.139041
146	Estaleiro Jurong	5,144	277.4	301.7	3	PUT	Espírito Santo	Southeast	0.119659
89	Porto do Açu - Terminal Tmult e Tcar	671,714	55.5	94.5	2	PUT	Rio de Janeiro	Southeast	0.118158
96	Terminal Aquaviário do Norte Capixaba	562,192	25.7	76.8	1	PUT	Espírito Santo	Southeast	0.118121
54	Sucocítrico Cutrale	2,489,004	67.9	81.1	1	PUT	São Paulo	Southeast	0.114139
136	Teporti	25,330	48.3	71.4	1	PUT	Santa Catarina	South	0.071601
27	Terminal de Praia Mole	10,074,322	91.2	378.9	1	PUT	Espírito Santo	Southeast	0.044552

Table 5: DEA Port Efficiency Analysis (Cluster 5). Source: Own elaboration.

The analysis indicates that the variable number of berths plays a role in the likelihood of a port being considered efficient in the analysis, as in each cluster the port with the highest value for this input variable invariably figured at the 100th efficiency percentile.

Overall, publicly owned/operated ports were found to be more efficient than private ones at a 9 to 6 ratio. And regionally, the most efficient ports were found to be: 7 in the southeast, 5 in the north, 1 in the northeast, 1 in the south and 1 in the center-west.

2.5. Conclusion

The objective of this research has been met, where the data from 161 Brazilian port terminals in the year 2020 were first segregated into k=5 clusters according to their similarities using k-means, and then an efficiency analysis was duly performed in each one of those clusters and the most efficient ports were highlighted.

These results demonstrate that holding the highest values of either input or output variables does not necessarily mean high efficiency in port operations. This suggests that the best use of resources needs to be continuously reassessed in search for improvement, even in everyday activities. Further research on why the efficiency results of the Ponta da Madeira port is suggested, as it has the highest throughput in the country, yet averages at lower scores in the efficiency analysis.

Evidently, there are several other variables that have not been all accounted for in this research but are likely to contribute to lower efficiency numbers even in the more modern and well-equipped ports, such as type of cargo, size of hinterland, proximity to urban areas, digitalization levels, management style, government-dependent infrastructure, regulatory agenda, irregular layouts, among others. Correcher et al. (2019), for instance, goes into how berth allocation poses a prevalent problem in terminal management and complex layouts pose spatial constraints and affected operations times. Thus, we understand that further research could be carried out specifically considering such other variables to better elucidate the results discrepancies found for the most prominent ports.

Also, we are aware that this research being focused on one sole year, which is the first year of the world-wide Covid-19 pandemic, may distort the results found, even though there was a 4.53% increase in total cargo moved via ports in Brazil in relation to the previous year. As the pandemic progresses through time, it would be of academic interest to further look into the effects of such an event on Brazilian port efficiency in the months or years that follows the time frame considered here.

As unambiguously stated by Tongzon and Oum (2021) on the criticality of port performance to the achievement of international gateway logistics, yearly benchmarking of port efficiency is suggested for all world main ports. Therefore, this research sheds a fresh insight on the current state of port efficiency in Brazil and considering that most goods transportation is done by sea, this is of significance to supply chain, economics, and trade instances both national and internationally, serving the purpose of coping with the growing pressure for faster and more dependable port transportation.

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3. PORT DIGITALIZATION AND ITS ASPECTS IN PORT OF ACU , IN NORTHERN RIO DE JANEIRO - BRAZIL

Abstract. The global logistics and transportation sectors have been adopting digital transformation initiatives to enhance business operations, financial efficiency, compliance to safety and sustainability standards. In search of smarter ports, the objective of this article is to review port digitalization, evaluating its aspects in Port of Açu and proposing related business strategies. Internal and external organizational data were collected via survey with specialists, and the findings were plotted to a SWOT Matrix. The brainstorming technique was employed in the and resulted in the proposal of eight business strategies which comprise the digitalization aspect besides the fomentation of changes within the organization and to its context. We surmised that the application of such strategies may transform Port of Açu into a smart port complex and contribute to the sustainable and economic development of northern Rio de Janeiro state in Brazil.

Keywords: Brazilian Seaport; Smart Port; Digitalization; Port of Acu; SWOT.

3.1. Introduction

As the world becomes globalized, ports have a major role in the global supply chain, where 85% of all goods traded worldwide are transported by ship, making maritime the most prominent logistics modal of transportation (EADES; PEPPER, 2019). This is the era of the 'Smart Port', when ports are more aware of the pressing demand for improved data governance as well as the benefits of becoming 'data centric'. Becoming a smart port means combining digitalization with the use of smart technology solutions, automation, artificial intelligence (AI), the Internet of Things (IoT) and Big Data in order to optimize resources and improve cost effectiveness, performance efficiency, security, safety and even monitor environmental impacts (EADES; PEPPER, 2019).

Located in the northern region of Rio de Janeiro state, the logistics and industrial complex of Port of Açu is managed by PRUMO Global Logistics, with a partnership with the Belgian Port of Antwerp. It is a private seaport which has been in operations since 2014, it takes up a 130km2 area, and comprises four distinct terminals: multi-cargo, petroleum, maritime diesel and fuels (SILVA; HORA; ERTHAL, 2018). It attracts businesses from different industrial sectors, leading to a rapid yet robust regional economic transformation in the form of a multi-sectorial productive conglomerate, and consequently playing a significant role in both the logistics and oil and gas sectors of the Brazilian economy (BITENCOURT et al., 2017).

In a frequently unpredictable business environment, smart port carries a more strategic essence to its concept, with focus on the intrinsically hard task of adapting and thriving in tackling changes. A port which is efficiency-oriented in its operational performance, committed to innovation and to meeting safety and environmental standards, can greatly benefit from digitalization, as it aids a port in its endeavors of becoming a green, intelligent and integrated ecosystem (RASTEGARY, 2020). The application of intelligence to port operations mitigates resources and infrastructure limitations, favoring cost-effective and competitive differential feats (FRAZZON et al., 2019). Nonetheless, it is essential that implementation be at the right time and to the appropriate degree, assuring that the effort applied towards digitalization be sufficient, yet not excessive, as not to overly compromise the organization's financial health.

Understanding that organizations exist both within and outside of themselves, the analysis of these environments allows for strategic planning and management practices in a multitude of scenarios. That being stated, the objective of this paper is to strategically study the variables surrounding port digitalization and its context in the Port of Açu complex.

3.2. Theoretical Background

Wiegmans & Geerlings (2010) attempted to answer how modernization could make deepsea ports more sustainable regarding environmental issues, which include concerns with external safety, wildlife, water quality; they concluded that the reduction on vessels emissions, hinterland transportation and transshipment equipment were key to maintainable port enhancement while innovation systems and user requirements were indicated as having the best performance from the point of view of product characteristics. Digitalization is a form of innovation which could positively contribute to the initial economic-efficiency-aimed projects, as data governance develops efficiency, thus avoiding wasteful work trends. Port digitalization, through the concept of smart port, is pushing the maritime industry towards better planning and management both inter and intra seaports. However, seaports are complex ecosystems, so cooperation among stakeholders play a crucial role in digitalization. Regardless of being innovative and largely beneficial, digital transformation may fail if managerial, cultural and financial challenges are not duly addressed. The authors used a game theoretic framework to identify current potentials and barriers, later demonstrating how such framework facilitates the development of strategic decision-making tools and methods for driving the digital transformation in ports, pushing the sector towards new opportunities to enhance productivity, efficiency, and sustainability in logistics (HEILIG; LALLA-RUIZ; VOSS, 2017).

Philipp et al. (2020) draw attention to the increasing global need for digitalization as it facilitates the management of competition and environmental issues with a customer-oriented supply chain focus in different industries. With the intention of determining the digitalization status of small and medium-sized seaports, the authors developed a digital auditing tool, and firmly emphasized that since bigger ports have solidly invested in digital technologies, it is binding that small and medium-sized ports recognize the added value and take immediate action.

Gonzalez et al. (2021), study the digitalization impacts on ports sustainability and maritime transportation, going into the implementation of a port activity information and communication technology (ICT) for improving data exchange applications to ensure effective interoperability between systems of ships and two ports in the Baltic Sea. With the intention of gaining optimal benefits, end to end information should be reliable and readily available. Besides the rational use of resources, the authors found that the use of digitalization and proper data governance were deemed suitable for helping resolve the main information exchange bottlenecks identified, such as obsolete technologies and poor-quality data: unclear, outdated, unshared, manually handled, unreliable or lack thereof.

The absence of a smart port concept could exacerbate infrastructure restrictions along with inefficient synchronization on operations, control and technologies. With that in mind, Frazzon et al. (2019) perform a simulation-based analysis on how the integration between smart port-hinterlands efficiency and reliability could be improved by employing digitalization in the form of technology-based decision-making support systems and technologies that could reduce supply chain disruptions in five major ports in Brazil. Results substantiated that the more data management and intelligence are implemented in logistics and seaport sectors, the greater the ability to increase productivity levels.

In the era of the Internet of Things (IoT), Zhao et al. (2020) consider the integration roles of technology on sustainable smart port development, recognizing the decisive function of the triple bottom line principle in port management, according to which sustainability entails the integration among economic, social and environmental responsibilities. The authors then set out to investigate the measures to improve sustainability specifically in the coal sector in China. The results indicate that when port decision-makers strive towards making full use of the many available digitalization applications and benchmark against world-class ports, collaborating with them to mutually complement advantages, port revenue and throughput are improved, and energy consumption is optimized.

Inkinen, Helminen and Saarikoski (2021) focus on the future prospects of port digitalization in Finland to identify the main drivers and impending technological trajectories for port digitalization. Using both SWOT (Strengths, Weaknesses, Opportunities, Threats) and PESTEL (Political, Economic, Social, Technological, Environmental, Legal) frameworks, three scenarios were identified and classified: digital supremacy, business as usual and digital failure. The results demonstrated that digitalization requires thorough preparation and a proactive mindset from port managers, besides outstanding professional procurement competence for the implementation of standardization protocols.

All authors researched come to the agreement that there are several positive outcomes of port digitalization and technology-based solutions, such as sustainability, increased efficiency and profit margins, which make up competitive business advantages. Nevertheless, attention is drawn to stakeholder's engagement as being indispensable for a successful transition.

3.3. Materials and Methods

This research is classified as applied, with an explanatory objective, using a qualitative approach. Its technical procedures are classified as both a scenario analysis (external data) and primary data collected from port information technology experts working with digitation (internal data) (SILVA; MENEZES, 2005).

The SWOT analysis has been long and extensively used by managers to size up organizations' managerial capabilities and deficiencies, besides their environmental threats and market opportunities. It allows for gathering data to help match the company's resources and competences to the environment in which it operates and competes. SWOT is an acronym that stands for Strengths, Weaknesses, Opportunities and Threats (GÜREL, 2017).

It is paramount that a business be mindful of its strengths and weaknesses, as strategy is built on strengths, and working on weaknesses will lead to improved efficiency. Organizational strengths are advantageous characteristics that add worth to the business, playing an active role in achieving its goals, and making it more efficient and competitive. Organizational weaknesses are unfavorable characteristics that put it at disadvantage as they negatively affect the organization in comparison to its competitors. While any environmental factors that may hinder organizational efficiency are considered threats as they jeopardize the organization's ability to reach its organizational goals, environmental opportunities are conditions in the external environment that allow an organization to benefit from its strengths and overcome organizational weaknesses or counteract environmental threats (GÜREL, 2017).

SWOT is the framework used in this research to perform the strategic analysis on the object of this study, as a way to consider external and internal factors is essential as a means to elucidate the sphere in which the organization operates, supporting it to better forecast and plan for the desired future regarding digitalization. From those, a strategic plan can be drawn by intersecting the internal and external factors, as exemplified in Figure 1 below:

Figure 1: Framework for SWOT Analysis. Source: Own elaboration.

The variables to be identified are precisely the four components of this framework, as seen in Figure 1. A data collection survey and a scenario assessment with specialists are used to identify both organizational variables (strengths and weaknesses), and external environment variables (opportunities and threats). Subsequently, a brainstorming session among IT experts from Port of Açu and the authors is used to discuss the data collected and propose strategies based on the intersection of internal and external factors collected.

3.4 Result and Discussion

Data collected from both the survey and the scenario assessment were sorted according to variable categories, and then listed in a SWOT matrix. The results found are presented on Figure 2.

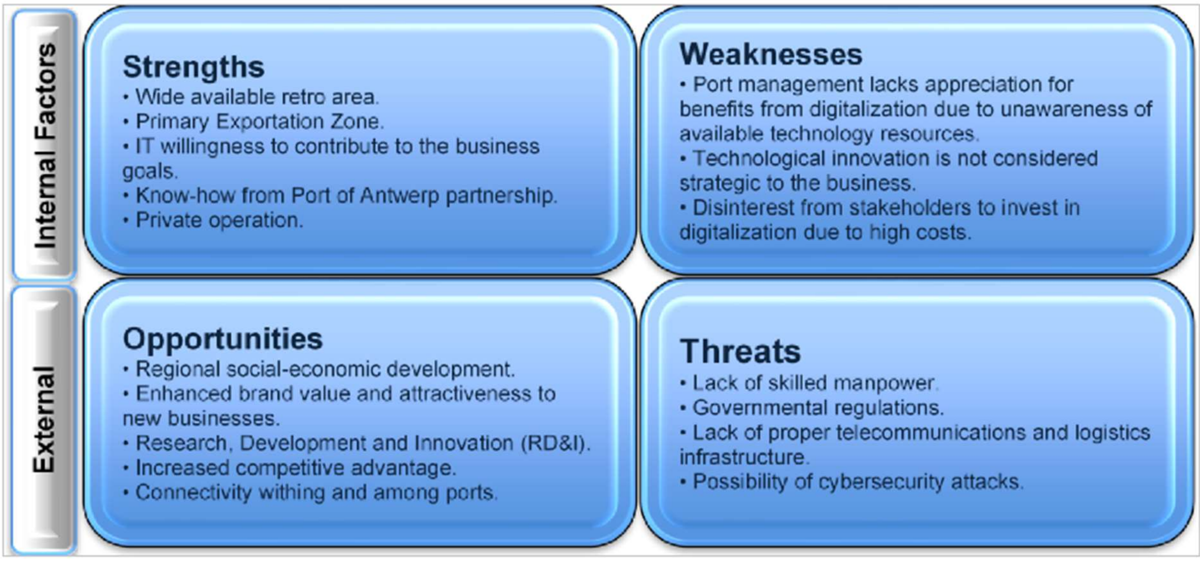

Figure 2*: SWOT Matrix: Results.*

When analyzing the strengths, we can see that besides being solely privately operated, the fact that Port of Açu is a primary exportation zone with a broad available retro area or hinterland indeed sets it apart from most seaports in Brazil. Frazzon et al. (2019) on the main five ports in the country, stressed how them being located in urban areas and under heavy governmental influence may affect strategies in expanding the business, both physically and financially. Another point is that all stakeholders play a crucial role in digitalization (HEILIG; LALLARUIZ; VOSS, 2017), so the willingness of IT experts to contribute to the advancement of the business goals plus the expertise acquired from the partnership with Port of Antwerp are distinctive positive aspects of Port of Açu .

Regarding weaknesses, Heilig, Lalla-Ruiz and Voss (2017) remark on how managerial resistance to collaborate with digital transformation efforts would most likely cause it to fail altogether validates the finding of this research, as port management should be made aware of available technology resources and how they could benefit the organization, e.g. enhanced productivity, efficiency and sustainability. Digitalization is a costly process and it requires a proactive mindset from port managers (INKINEN; HELMINEN; SAARIKOSKI, 2021) therefore it should be considered strategic to the business, so the advantages of it facilitating management of competition and environmental issues (PHILIPP; GERLITZ; MOLDABEKOVA, 2020) outweighs the challenges it poses.

On opportunities, first the respondents indicated regional and social-economic development in addition to the prospects for RD&I as optimistic returns for digitalization, which are supported by both Zhao et al. (2020), who recognize the decisive function of the triple bottom line principle in port management, where economic, social and environmental responsibilities are key to a sustainable smart port; and Wiegmans & Geerlings (2010), who see digitalization as a form of innovation.

Secondly, besides pointing up the value of safety and environmental aspects to the community surrounding a port, Sari & Pamadi (2019) discuss how digital technology adds competitive value to the organization by increasing productivity, efficiency in processes and resources utilization, plus revenue, which is in synch with the opportunity for increased competitive advantage found in this research.

Thirdly, corroborating with the opportunity for connectivity, Gonzalez et al (2021) touch on the role of digitalization for effective data exchange within and between ports and vessels highlighting how this may help treat information bottlenecks and optimize daily operations. Concerning threats, Inkinen et al. (2021) underscore the need for outstanding competence for professionals in the implementation phase of a digitalization process in a seaport. However, on top of that, respondents indicated concern for the lack of skilled manpower also for the subsequent phase of operations, and how this could affect the project success. Moreover, proper telecommunications and logistics infrastructure could make or break a considerably new port such as Port of Açu , likewise the impact of governmental regulations was identified as an issue that could either delay or hinder the accomplishment of the project, as political influence cannot be overlooked in Brazil (MARINHO et al., 2019). Further, strong cybersecurity is seen by IT specialists as vital and unarguable, to which Senarak (2021) fully concurs and points human, infrastructure, and procedure factors as reasons for vulnerability. Surprisingly enough, the means through which Port of Açu could benefit from the many applications of digitalization were not specifically related by the respondents to Health, Safety and Environmental (HSE) concerns. That is not to say that such concerns would not be achieved or even desirable as key results from digitalization, being as profusely indicated in the researches of Chen et al. (2019), Durán et al. (2021), Vanelslander (2016), Dry (2018) and de Andres Gonzalez et al. (2021), indicating that the concept of a green port is crucially dependent on the one of a smart port. Nevertheless, one could make the case that HSE constitutes essential pillars for social improvements and regional development, besides pollution reduction as a result of superior planning in logistics. We surmise that such discrepancy against the available literature on the topic is due to the fact that the main mindset of the consulted specialists was on Industry 4.0 and related IT issues.

3.3.1 Strategies

When considering the organization's existing strengths and how to thoroughly take advantage of the opportunities, a strategy to develop a digitalization masterplan is proposed, this format would give port management both an overview and a sense of feasibility as the project unfolds and materializes. The readiness from the IT professionals to play a more active role in the business strategy, combined with the vast expertise acquired from the partnership with the Port of Antwerp, are expected to positively contribute to the organization's goals, as competitive advantage is a direct outcome of its benefits, such as financial resulting from resources and processes optimization, better logistics scheduling with consequent fuel and pollution reduction, continuous regional social-economic development, connectivity within and with its neighboring ports, and so forth. These are all desirable to any enterprise, so as the brand value is enhanced through digitalization, so is Port of Açu's attractiveness to new businesses.

On that same mark, the organization is encouraged to develop a long-term strategy based on its most advantageous features, for instance: a wide available retro area or hinterland which allows for expansion where needed, and the fact that Port of Açu is privately operated which moderates political interference and time-consuming bureaucracy, besides holding a permit as a Primary Exportation Zone with incurs fiscal benefits.

Regarding the use of existing strengths to reduce the impacts of threats, we propose the development of an ecosystem between port authorities and stakeholders, which includes client businesses and a partnership with local and federal government, in order to prioritize regulatory barriers mitigation and investment/funding canvassing for logistics and telecommunications infrastructures. Likewise, in an endeavor to increase the availability of skilled manpower, another strategy suggests the fomenting of relationships between port stakeholders and institutions such as universities and government to promote academic and professional qualification. Lastly, cyber-attacks and cyber terrorism are a sad reality and must be taken seriously as they can cause massive financial damages, environmental catastrophes, ultimately putting lives at risk. Recognizing the vital importance of collaboration among companies which compose the Açu port complex, we appreciate that a more zealous approach is best, so we strongly advise for a strategy to create a cybersecurity committee to prevent or remediate security threats.

In order to prevent missing out on opportunities due to weaknesses, we propose a strategy to evaluate a digitalization cost/benefit study, as we comprehend that the disinterest from stakeholders to invest in digitalization primarily stems from the lack of appreciation for its benefits plus the considerable costs involved. However, a more sophisticated approach would be to engage port stakeholders in all levels of the organization in the efforts to increase the business' competitive advantage, as positively boosting the brand value in the industry is a solid way of attracting new businesses.

Figure 3 presents all strategies at the intersection of internal and external factors of the SWOT framework, which were discussed above.

Figure 3 – SWOT Matrix: Strategies. Source: Own elaboration.

3.4. Conclusion

The objective of this research was to study the variables surrounding port digitalization and its context in the Port of Açu complex using the SWOT analysis method. First, IT specialists from said port were surveyed on a digitalization scenario assessment to gather information on the internal (strengths and weaknesses) and external (opportunities and threats) variables. Secondly, a SWOT matrix was then elaborated with the results collected and they were discussed. Lastly, a brainstorming session was carried out and strategies for successfully digitalizing the port were proposed.

An extensive research of papers on this subject were studied, which included considerations on how the use of digitalization and technology applications have been used as a strategic edge for business goals, with financial, operational, and usually social and environmental gain. Even though the results on this paper do not ponder on the green aspects of the use of technology applications to improve port operations and results, the extensive available hinterland of Port of Açu and the fact that it is privately operated were found to be significant strengths when compared to other main Brazilian ports. Opportunities especially highlighted enhanced brand value to attract new businesses and increased competitive advantage. The main weaknesses identified were around apparent disengagement of port management towards innovation, due to unawareness on the benefits and high costs. Whereas the lack of proper infrastructure, skilled labor and the possibility of cyber-attacks were found to be threats.

Based on such findings, eight strategies were proposed, as follows:

- Develop a Digitalization Masterplan;
- Develop long-term strategy to attract new businesses;
- Foment relationship between stakeholders and institutions to promote professional qualification;
- Create a Cybersecurity committee;
- Develop ecosystem between port authorities and stakeholders;
- Evaluate a digitalization cost/benefit study;
- Engage stakeholders in all levels of the organization;
- Make digitalization a priority for the organization.

Since digitalization is an unavoidable reality, we suggest prioritizing it as a business strategy and integrating it to the organization's goals so Port of Açu could measure up to other well-established seaports, becoming more competitive. Lastly, all the above would thus enhance the brand value of Port of Açu making it a more attractive option to new businesses when compared to other Brazilian ports.

To complement this research, we suggest an in-depth study of the actual costs of implementation and operationalization to make Açu a smart port, as then the project viability could be contemplated.

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4. ENERGY TRANSITION AT PORTS: A COMPARISON BETWEEN AÇU (BRA) AND ANTWERP-BRUGES (BEL)

ABSTRACT: Renewable energy sources are frequently deemed the foremost and better choice to mitigate the climate change issue. Although transitioning away from the existing energy system in the port industry and transportation networks is of utmost significance, as they represent great consumers of energy and generators of emissions, the green port rhetoric is not always aligned with actions being taken by port authorities. At the core of this concern, ports have been expected to prioritize designing a sustainable strategy for energy transition, while investing in the development of technologies and innovative solutions for more efficient logistics, infrastructure, and operations. The purpose of this paper is to analyze the issue of energy transition from the perspective of a contrasting assessment between two major ports in the international context (i.e. Port of Açu in Brazil, and Port of Antwerp-Bruges in Belgium) using their latest sustainability reports. The results found an overall consonance between the narrative from port authorities and their publications and delved into their considerations surrounding sustainability and green alleviation initiatives. Further research on the role of policies and legislation as well as thorough financial planning is recommended.

Keywords: Energy Transition, Energy, Port, Sustainability, Green Port.

4.1. Introduction

Transition towards clean energy sources requires synergy among multiple factors, such as financing, innovation, and implementation strategies. Although we appreciate that the interactions between utilization and innovation can be strategically pursued in order to benefit society, most of the technical studies to plan for potential cost reduction performed until now treated utilization and innovation strategies separately (Kittner et al., 2017).

The development and deployment of renewable energy sources is vital to resisting the effects of climate change. Earlier studies have demonstrated that it is possible to achieve access and security to better energy quality, via a combination of alternative resources, technologies, and standards. The prompt insertion of fundamental political changes toward synchronized endeavors to integrate global concerns into national policy priorities is required for such an end (Gielen et al., 2019).

Although interdisciplinary research is essential to tackling clean energy transition issues, experience has shown that the shift from fossil-based systems of energy production and consumption to renewable energy sources takes considerable time. Previous energy transitions were pushed by self-determination of individuals, economics, innovation in technology and access to resources. A much faster understanding of critical research end products could enable a more robust integration with regulations that foment market growth and pioneering business models (Gielen et al., 2019).

Located in the municipality of São João da Barra in the northern region of Rio de Janeiro state, Brazil, and sanctioned by the municipal law 035/06, extending for 130 square kilometers in area and comprising 10 world-class private terminals, Port of Açu is a result of 20 billion Brazilian reais in investments and is currently managed with a partnership with the Belgian Port of Antwerp-Bruges and is a privately owned logistics and industrial complex where 20 businesses operate (Hora et al., 2021).

Most Brazilian seaports are located in either capital or main cities, putting the Port of Açu in a unique situation of remoteness, which required investments and sponsorships in infrastructure from both the government and the private sector to cover its main industrial conglomerate as well as its extensive hinterlands (Frazzon et al., 2019).

Given its sheer size and degree of operations (over 57 megatons of cargo moved in 2022), and despite being a fairly new seaport in operations since 2014, it is responsible for nearly 30% of the oil exports in the country, Port of Açu has been aware of its increasing energy consumption demands from both port operations and the enterprises located therein, local energy supply instabilities, Port of Açu has been strategically investing on alternative sources of power to hydroelectricity in two main fronts: First, by building the largest gas-powered thermoelectricity generating plant in Latin America, expected to generate 3 gigawatts of power, and secondly by investing on the development of solar and wind power supply structure as a greener source of power expected to generate 2.4 gigawatts (Porto do Açu, 2021).

Given its ecological impact in the region, incumbents at Port of Açu want to integrate social and environmental projects towards the preservation of regional flora and fauna by keeping an area of 40 square kilometers as the green belt Caruara environmental protection area, which is the largest private reserve of *restinga* ecosystem in Brazil. (Porto do Açu, 2020a). Moreover, efforts in favor of relieving the effects of climate change are in place, through the restoration and protection of both shoreline and maritime ecosystems, besides extensive investments on Research and Development work on biodiversity conservation (Porto do Açu, 2021).

While large energy users are partaking in the global energy transition, a greater sense of urgency is needed to meet the goal of limiting average surface temperature increase. Thus, seaports and transportation systems are likewise urged to engage efforts and capital into efficient resource management for adaptation purposes. The absence of integration in governmental engagement and business efforts could result in unreliable strategies and inefficient use of resources. An all-inclusive approach of climate, energy and water strategies could help resolve some of these research limitations (Gielen et al., 2019).

Energy poverty may be described as the lack of either availability or access to safe, dependable, affordable, appropriate, good-quality, and environmentally friendly energy services to aid both human and economic development (Goldemberg et al., 2000).

Among impoverished populations, energy poverty poses a hurdle to everyday household chores such as lighting, cooking, water purification by boiling, and space heating, typically requiring the use of firewood, animal dung, crop residue, charcoal or even kerosene as fuel. In this scenario, as women and girls are inhaling the air pollution brew of fumes and soot produced by the burning of said fuels indoors, their health is disproportionately more affected, their ability to work productively is diminished and they may also incur in higher medical care expenses (Goldemberg et al., 2000).

Household air pollution from burning solid fuels in confined spaces accounted for 3.5 million deaths in 2010, representing one of the leading risk factors for the global disease burden in developing countries, together with high blood pressure and tobacco smoking and alcohol consumption (Lim et al., 2012). Moreover, these types of fuel are often associated with accidents, house fires, child poisoning, and increased susceptibility to tuberculosis (Cecelski & Matinga, 2014). Thus, poverty-stricken populations are likely to benefit from the economic development slowly, as their limited energy consumption patterns depress their nutrition, health, and productivity (Reddy et al., 2000).

By 2019, nearly 90% of the global population was estimated to have some form of access to electricity, however limited or costly (Lee et al., 2020). Yet at that same point in time, a third of the world's population still used inefficient, unclean, and unsafe cooking systems (The World Bank, 2021).

Nevertheless, a significant increase in cost for residential electricity had previously been estimated in order to allow for renewable electricity production to expand and become accessible, meaning that electrification would not fully address the issue of energy poverty nor would it guarantee significant economic advancement by itself (Lee et al., 2020). Sustainable energy is oftentimes recognized as an effective way to mitigate energy poverty in low potential for electrification places. It is reasonable to suppose that variable renewables will reach a higher degree of penetration in energy systems, especially in regions that have high solar and wind potential. (Arndt et al., 2019)

It is more challenging for underprivileged populations to amass the primary capital needed to invest in more energy-efficient, economical renewable sources of energy and appliances, as they usually pay more for daily energy needs (Reddy et al., 2000). The endeavor to reduce fossil fuel usage solely through financial incentives for private consumers and producers to embrace renewable energy might as well contribute to inequality and have unintended repercussions for individuals who are in a state of energy poverty (Bazilian et al., 2012). That is why the trade-offs between meeting renewable energy targets and relieving energy poverty must be taken into account, especially when strategizing and legislating in favor of ending energy poverty and its implications (Arndt et al., 2019).

Economically, smaller-scale renewable energy solutions are becoming more appealing, potentially very positive news for the world in general and emerging countries in particular, these energy trends provide swift scalability and adaptability to address expanding energy demands (Bhattacharya et al., 2016). There exists a plethora of activities aimed at financing and investment promoting access to modern energy services, and these can serve as sources for funding energy access and interventions to help formulate future actions (Bazilian et al., 2012).

Income inequality fosters power disparities, which play a critical part in the determination of environmentally-related policies, thus the promotion of renewable energy consumption is an imperative goal of climate policy (Awaworyi Churchill et al., 2021). The trade-offs between meeting renewable energy targets and relieving energy poverty must be taken into account, especially when strategizing and legislating in favor of ending energy poverty and its implications (Arndt et al., 2019). That is why policy makers should also ponder on establishing policies that account for reducing social inequality as well as emissions stemming from energy use, which would safeguard the groups of people who are geographically and financially most vulnerable to the perils of energy poverty while simultaneously encouraging the use of renewable energy sources (McGee & Greiner, 2019)

Although legislations may pose barriers for decarbonization efforts, the availability of space in the port area, and the accessibility of investment and human capitals are also key factors that port authorities need to plan out for energy transition towards climate neutrality on vessels as well as port area, as they are recognized as operators, landlords, regulators and community managers (Hendriks & Gooyert, 2023). Moreover, on port sustainability, Armani Aguiar et al. (2023) explore the issue of eco efficiency concluding that the main determining variables on economic, social and environmental issues are centered around pollution, regional development and operational costs, respectively.

Port authorities face a growing demand for energy-efficient transportation systems, port operations and equipment, in line with increasing legislation promoting alternative sources of energy (Oloruntobi et al., 2023). For green port development, key factors are the monitoring of emissions and energy consumption, besides investments on port logistics information systems, and technology innovation towards energy conservation and environmental protection. Nevertheless, the importance of the practical aspects of green port concepts via training and promotional activities should not be ignored, as a means to ensure its concept does not fall under a mere formality (Hua et al., 2020).

From a world perspective, it is a time of immense challenges to sustainable development, while it is also a time of immense opportunity. Building on the 2000's Millennium Development Goals, the 2030 Agenda for Sustainable Development came into effect on 1 January 2016, seeking to achieve what the MDGs did not, proposing 17 Sustainable Development Goals with 169 associated targets which are integrated and indivisible, via which the United Nations collectively commit to the pursuit of global development (United Nations, 2015). Within the 2030 Agenda for Sustainable Development, Goal 7 states "Ensure access to affordable, reliable, sustainable and modern energy for all".

It is made clear that energy transitions offer solutions to certain sustainability-related world problems, extending to efforts linked to climate change, as well as the achievement of environmentally-friendly development (particularly associated with the Sustainable Development Goal 7) by reducing pollution to air and water, besides land contamination (United Nations, 2021).

Located in the municipality of São João da Barra in the northern region of Rio de Janeiro state, Brazil, and sanctioned by the municipal law 035/06, extending for 130 square kilometers in area and comprising 10 world-class private terminals, Port of Açu is a result of 20 billion Brazilian reais in investments and is currently managed with a partnership with the Belgian Port of AntwerpBruges and is a privately owned logistics and industrial complex where 20 businesses operate (Hora et al., 2021).

Given its sheer size and degree of operations (over 57 megatons of cargo moved in 2022), and despite being a fairly new seaport in operations since 2014, it is responsible for nearly 30% of the oil exports in the country. Port of Açu has been aware of its increasing energy consumption demands from both port operations and the enterprises located therein, local energy supply instabilities, Port of Açu has been strategically investing in alternative sources of power to hydroelectricity in two main fronts: First, by building the largest gas-powered thermoelectricity generating plant in Latin America, expected to generate 3 gigawatts of power, and secondly by investing on the development of solar and wind power supply structure as a greener source of power expected to generate 2.4 gigawatts (Porto do Açu, 2021).

Regarding its ecological impact in the region, incumbents at Port of Açu want to integrate social and environmental projects towards the preservation of regional flora and fauna by keeping an area of 40 square kilometers as the green belt Caruara environmental protection area, which is the largest private reserve of restinga ecosystem in Brazil. (Porto do Açu, 2020). Moreover, efforts in favor of relieving the effects of climate change are in place, through the restoration and protection of both shoreline and maritime ecosystems, besides extensive investments in Research and Development work on biodiversity conservation (Porto do Açu, 2021).

The partnership between the Port of Açu and the Port of Antwerp-Bruges, has aggregated the European experience on innovation commitment towards circular economy and energy transition, as the Port of Antwerp-Bruges is striving to limit its impact on the climate, planning to become Europe's leading import hub for green hydrogen and be climate neutral by 2050. Such partnership promotes the exchange of expertise and the placing of Port of Açu as a pioneer on better energy practices in Latin America (Porto do Açu, 2020a).

As nearly 85% of products traded worldwide are transported by ship, maritime transportation plays a major role in the global supply chain modality, whilst still being heavily reliant on fossil fuels (Eades & Pepper, 2019).

Likewise, within its sustainability policy, Port of Açu is ready to increase sustainability and create value for shareholders and society, as the business and global value chains head to maturity. By expanding core capabilities, industries are attracted, and service capabilities are consolidated, which enables low carbon sustainable businesses (Porto do Açu, 2021).

Port of Açu has been employing investments towards sustainability transition via its Açu GreenPort initiative, which is established around three key elements:

(1) Sustainable Energy: efforts aiming at energy transition, gradual and aggregate renewable energy capacity (solar, wind and wave power generation), and the long-term large-scale implementation plan for a green hydrogen plant as the energy vector that could be transported as ammonia or as is by pipeline, trucks or maritime vessels, for which the end users could be power generation, fuel cells (batteries), industrial applications and chemical production (methanol and ammonia production).

(2) Industries of the Future: capture and storage of carbon for industries, low carbon industries, circular and bio-based economy.

(3) Sustainable Shipping: availability of alternative fuel mix for maritime business and logistics for multimodal connectivity, vessel/vehicle conversion to more sustainable types of energy, and the implementation of Environmental Ship Index (also known as ESI which is an initiative developed by means of an international association of ports and harbors committing to promote sustainability mainly via the reduction of greenhouse gasses emissions (Porto do Açu, 2021).

Figure 1 illustrates the expected physical placement of all sustainable programs being undertaken by Port of Açu in its endeavors to become a greenport. Initiatives include: Green ethylene and access to the Brazilian ethanol market, large scale Hydrogen Project, Green Steel hydrogen-based low-carbon steelmaking, Offshore and Onshore wind power development, Green Ammonia, fertilizer manufacturing & agricultural export, onshore solar power Generation, environmental reserve, among others.

Figure 1: Expected Placement of Sustainable Initiatives at Port of Açu (Porto do Açu, 2021).

At the crossroads of innovation, technology, and economics studies lies the issue of shifts in energy systems which has been broadly researched in the field of energy transition, and has never before been more relevant to the maritime transportation industry (Schot et al., 2016). Given the global tendency towards sustainability in seaports, this research is duly justified as Port of Açu is the largest (in area) seaport in Latin America and carries relevance both nationally and internationally.

Be it due to environmental awareness, social pressures, or investment attractivity, ports worldwide have started the structuring and execution for the transition towards more sustainable energy. Following on these lines, the objective of this study is to investigate the question of energy transition in the context of a comparison between Port of Açu (in Brazil) and Port of Artwerp-Bruges (in Belgium), where the latest sustainability reports from both entities are contrasted in regards to planning, feasibility, and alignment, via the application of a text processor software, and later a breakdown analysis of the results.

4.2.1 Energy Transition in Sea Ports

As nearly 85% of products traded worldwide are transported by ship, maritime transportation plays a major role in the global supply chain modality, whilst still being heavily reliant on fossil fuels (Eades & Pepper, 2019). Figure 2 briefly introduces energy transition by transportation method, according to the 2021 United Nations Report on options for haul transport transformation.

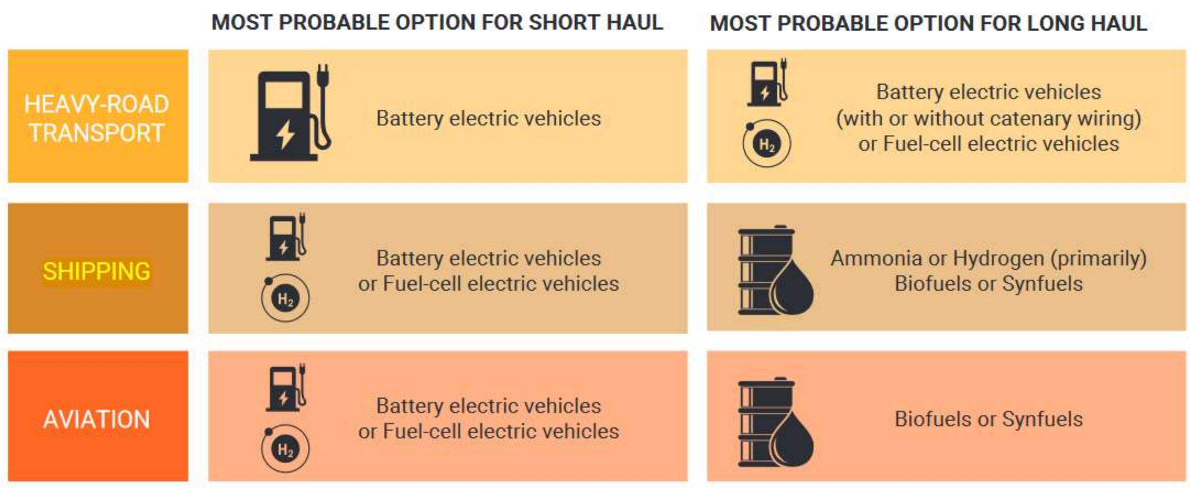

Figure 2: OPTIONS FOR SHORT AND LONG-HAUL TRANSPORT TRANSFORMATION (United Nations, 2021).

It is made clear that energy transitions offer solutions to certain sustainability-related world problems, extending to efforts linked to climate change, as well as the achievement of environmentally-friendly development (particularly associated with the Sustainable Development Goal 7) by reducing pollution to air and water, besides land contamination (United Nations, 2021).

Seaports are encompassed within the maritime method of transportation, as they are nodes of connection for transactions and its location promotes exogenous regional development, and as transformation at such extensive lengths can be costly, it has to be treated as part of the business strategy (Philipp et al., 2020).

Oniszczuk-Jastrząbek et al. (2018) pose that, the concept of ‘Green Port’ has been of noteworthy relevance to the Polish seaports industry in recent years, meaning a port that would take a set of strategic development and financing measures that ensures technical and organizational conditions for its operational goals while also incorporating compliance to economic, societal and environmental aspects. The researchers reached out to Polish sea port authorities to identify actions being taken and the direction towards strategy development, as well as to measure their cognizance on sustainable growth. Results showed that high levels of environmental awareness were found, so port authorities were urged to align it with their business plans for the development of actionable tools. Moreover, the research found that port authorities are progressively more mindful that ports constitute a major source of emissions which could facilitate energy transition, via potentially joining the Eco Ports network. The completion of an assessment of its actual status and strategically planning out of activities with the objective to reduce emissions from port-related activities and businesses within the port.

Seaports constitute an eminent component of the global shipping industry, which faces the challenges posed by environmental degradation and the relentless depletion of natural resources. The concept of 'smart ports' was conceptualized out of the necessity to integrate the adaptability of port technology and infrastructure in the context of increased pressure from market, social-economic and environmental demands. The quantification and reduction of CO_2 emissions; along with planning for energy transition fall into the latter. Nguyen et al. (2022) reviews the recent literature focusing on the analysis of the applications and methodologies of technology in smart port energy management systems. Results revealed that different founding perspectives constitute a pivotal part in technology approaches to establishing a port energy management system including matching demand and energy production, as well as systematically implementing an energy transition plan.

Hentschel et al. (2018) carried out a progressive case study in which stakeholders from several European port authorities were consulted to assess the significance of the renewable energy cooperatives (RECs) for European energy transition, besides serving as a road map to establish and successfully expand a REC at the Port of Rotterdam and aid approach the challenges of making better use of energy-related interaction in an industrial cluster.

The Port of Rotterdam is the largest in Europe and it was specifically targeted by this research because the electricity demand made up from businesses located therein ranges from 10 up to 20% of the total power consumed in The Netherlands. Results found 14 specific features that a REC is expected to embody in order to facilitate the energy transition at said port. Companies whose energy costs are their major cost factor, and those which can benefit from generating or selling energy are expected to become members of the cooperative, as especially in the case of energy, inter-firm cooperation to decrease power procurement related carbon emissions can set in motion a better economic performance of each business involved. Results could also serve as a parameter for stakeholders in other types of industry in driving energy transition through the formation of RECs.

In their descriptive research of three Norwegian ports, Damman and Steen (2021) apply a multi-level perspective to study drivers, barriers, and strategies for the development of zero-emission socio-technical energy hubs. Given their critical role on economic activity, infrastructure systems such as ports, constitute a unique type of incumbent that can take on different roles of being either obstacles or catalysts of major change related to research on energy transition. Although exogenous pressures around ports, such as laws and regulations, are not disregarded by the research, and neither is the influence of their organizational capacity and business models on their commitment to innovation, the study focuses on the spectrum of functions of ports as authorities, society administrators, operators and land proprietors to enable sustainability transition. Results demonstrated that ports are capable of enabling sustainable energy transition in multiple ways, yet the implementation and the synchronization of a comprehensive set of energy solutions pose new challenges for ports, so a continual and gradual shift from few main energy technologies, such as fossil fuels, towards a combination of energy types is expected.

On the transformative role and strategies of actors to advance energy transitions, research can be found on the conceptualization of such roles and how they outline the user's involvement in transition. Schot et al. (2016), however, introduced a typology study on the description and categorization of roles of technology end users in the many stages of transition. Seeking to attain a more complex perspective on the matter, Bjerkan et al. (2020) steers away from the examination of one particular transition or innovation and draws on a case study of actors in and around the Norwegian Port of Oslo and transport systems.

Their research instead explores the variety of actors involved in energy transitions, highlighting the functions intrinsic to their roles, and how role constellations can shape energy transitions, whether said actors are end-users of a specific innovation or not. Results showed that there was potential for accelerating transitions in the port domain, the sea transport domain, and the hinterland transport domain. Nevertheless, as a group, port actors are more capable of structuring energy transitions in ports rather than in the associated transport systems. Results also pointed to the intermediary role as the decisive one to provide direction and reduce risk, thereby promoting the prevalence of other actor roles.

The controversy surrounding fuels and technologies is yet to be resolved, and decision-makers are hesitant to offer direction. The study advised port users to carry on in their endeavors to endorse sustainability issues through international political entities and stakeholders in the search for predictability for the entire maritime sector.

Despite being known for its innovation and high efficiency, the Port of Rotterdam has been under growing pressures to transition in the direction of sustainable and renewable energy sources and away from fossil fuels. Being responsible for a 50% market share for fossil fuel products in North-Western Europe, such a change would entail remarkable effort across society, and the process would require port authorities and management to structure a shift in investments thus impacting the business strategy itself. In their research on the transition management process in the Port of Rotterdam from 2015 to 2017, Bosman et al. (2018) look into the role of port authority in regime destabilization and how they can be reinforced by applying the transition management methodology to large-scale energy-intensive industries as the cutting edge in the energy transition.

Transition management has been established as an innovative approach of controlling environmentally friendly advancement. Results showed that strategy diversification as well as adding transition management to other paths operating at the port have both promoted attitude shift and the unveiling of new opportunities for influence. Likewise, transition management intensifies the destabilization dynamics of a regime setting.

4.2. Methodology

The variables used in this research are the most recent and available sustainability reports from both Port of Açu and Port of Antwerp-Bruges. Such documents report on the operational as well as the economic-financial performance of said ports, while also giving an overview of the businesses' ethics, corporate governance, strategic management performance, safety and security, infrastructure and digitalization. Within the same reports, those points are pondered against topics of sustainability relevance such as environmental and climate change management, conservation of biodiversity, the businesses' commitment to shareholders, environmental externalities, and relationship with communities.

The references for this research were the latest available sustainability reports for Port of Antwerp-Bruges and Port of Açu (Port of Açu, 2021; Port of Antwerp-Bruges, 2019).

In order to assess the similarity between reports, the text processor software WORDij was used. It is a suite of data science programs capable of automating many aspects of natural language processing from a set of unstructured texts. Also, by using an "include list", the opposite of "drop list", one can analyze networks among the included words. The program computes the similarity of pairs of networks from different sets of texts using Quadratic Assignment Procedures (QAP) that produce a correlation coefficient for the comparison of whole networks (Danowski, 2013). The output from WORDij is then processed in Gephi, which is an open-source software for graph and network analysis, that uses a 3D render engine to display large networks in real-time and to speed up the exploration. Gephi generates a pajek-style graph for analysis and visualization of large networks having numerous vertices and varying sizes of nodes (Bastian et al., 2009).

Two separate analyses were performed. First using the full text available, in its entirety, where the frequency of appearance of word or pair was set to no less than 6 times, besides the application of a standard drop list file provided by software default. The second analysis used a list file of word thesauri of terms related to energy transition.

Every single analysis used the setting Porter Stemming Algorithm, which reduces the variations of words to their syntax stems.

The parameters for the analyses are (1) Node size: represented by a circle, which denotes the word frequency; (2) Edge thickness: represented by a link between nodes, which displays how all nodes are related or connected; and (3) Modularity: measures the strength of the network graph's division into clusters.

4.3. Results

Figure 1 presents the analysis from the full text of the sustainability report of Port of Açu in 2021.

Based on the frequency of appearance, represented in the graph by the nodes from large to small, the ten most frequent word stems were: 1) Manag, 2) GRI (Global Reporting Initiative), 3) Oper, 4) Açu, 5) Perform, 6) Corpor, 7) Port, 8) Total, 9) Environment, 10) Commun. Keywords related to energy transition rank between the 20th and 30th places, while the word energy itself ranks at 66th place. Only rarely did the word transition appear in this report.

The most prominent node manag is strongly related to report, açu, corporate, integration, diversity, performance, partnership and people. Its connections to environment, preservation and impact are only slight. GRI, however, is strongly linked to port, environment and strategy.

On modularity, the cluster of scope/emission/GHG (greenhouse gas) is only related to GRI, while the micro cluster of energy/consumption/water/reuse is connected to both the macro nodes operation and GRI.

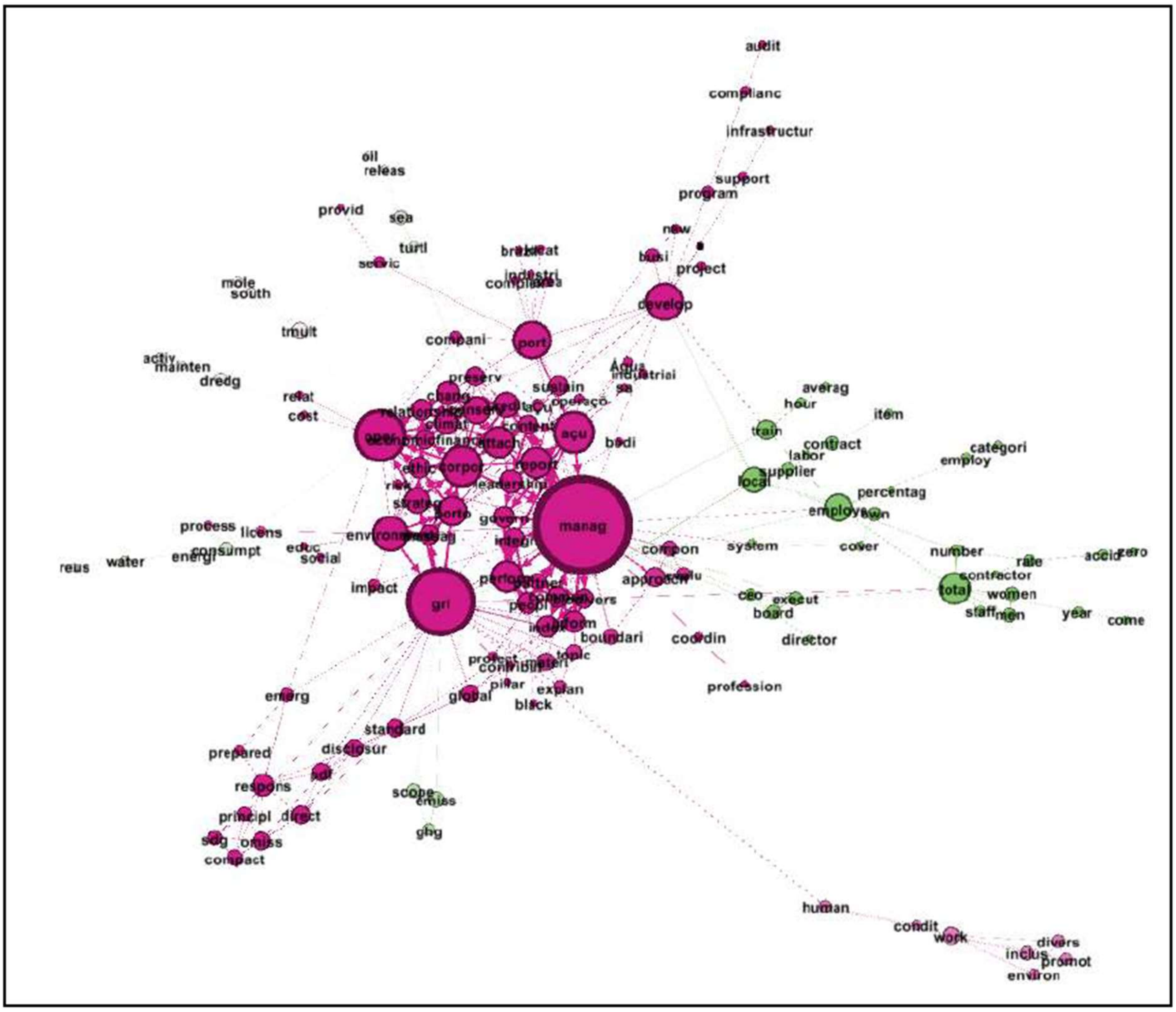

Figure 1 - Full Analysis: Port of Açu 2021. Source: Own elaboration.

Figure 2 shows the analysis from the full text of the sustainability report of Port of AntwerpBruges 2019.

The ten most frequent word stems were, in terms of appearance throughout the report: 1) Port, 2) Antwerp, 3) Sustain, 4) Ship, 5) Transport, 6) Year, 7) Compan, 8) Work, 9) Author, and 10) Develop. The word emissions, water, and waste ranked at the 11th, 14th, and 18th positions, respectively, whilst energy ranked at the 66th. The word transition itself ranked at 125.

As Port is the one node that distinctively surpasses all others, it is related to the most words in the report. Markedly, the strongest connections were to Antwerp, world, work, sustain, year, authority, and company.

On the modularity aspect of the analysis, a cluster of modes of transportation and fuels is directly related to sustainability, which is then connected to the main node.

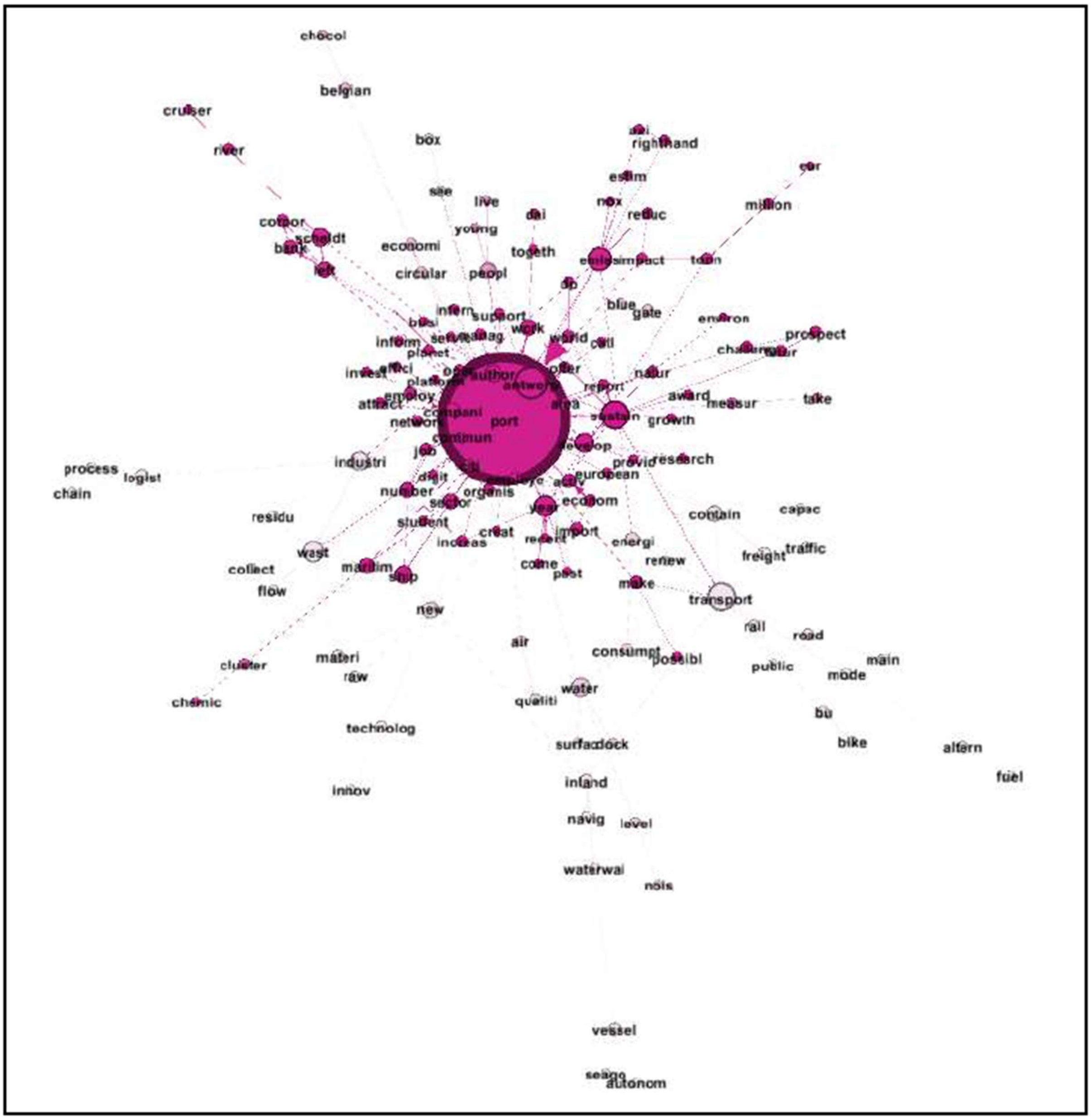

Figure 2 - Full Analysis: Port of Antwerp-Bruges 2019. Source: Own elaboration.

Figure 3 displays the duality of energy transition thesauri analysis against the sustainability reports of both Port of Açu 2021(left) and Port of Antwerp-Bruges 2019 (right).

The visualization of such graphs is more straightforward as the analyses are established in contrast to a defined set of words.

The graph to the left evidences Port of Açu's clear focus on sustainability related to the conservation of biodiversity and the environment, and their connections are noticeably marked.

The energy node is prominent, yet it is only slightly linked to the node transition, and it is weakly or not at all linked to terms such as green, hydrogen, coal, or wind. Action words like recycle, generate, creation and plant are present and linked to the main nodes.

The graph to the right demonstrates the Port of Antwerp-Bruges' obvious emphasis on energy. This main node is most strongly associated with the terms renewable, sustainability, electricity, production, hydrogen, wind and power. Words related to biodiversity, ecosystem, recycling and conservation do appear, but with either weak or no link to the main nodes.

On the modularity aspect of the analyses, Açu's report shows secondary clusters on generation/recycling/production/hydrogen/green, and also nature/power/wind/plant. Meanwhile, Antwerp-Bruges' report presents a secondary cluster on power / wind / solar / nature / conservation / thermal / fuel / biodiversity.

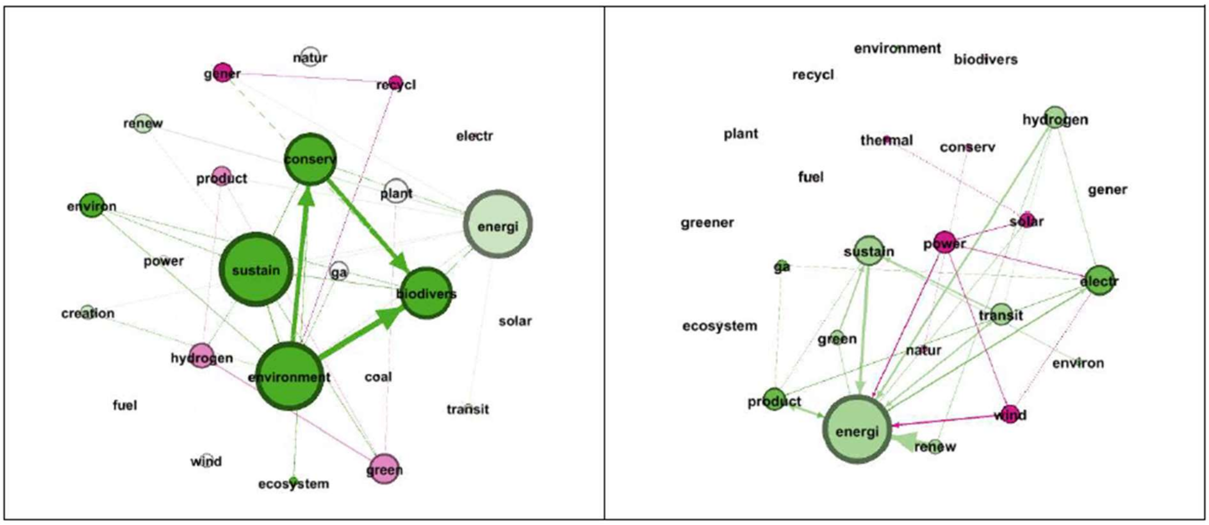

Figure 3 - Energy Transition Thesauri Analysis: Port of Açu 2021(left) and Port of Antwerp-Bruges 2019 (right). Source: Own elaboration.

4.4. Conclusion

The objective of this research was to use the sustainability reports from the Port of Açu (in Brazil) and the Port of Artwerp-Bruges (in Belgium) and explore the issue of energy transition from the perspective of a contrasting assessment between both entities. The results of this research were found to successfully bring insight into the practicality and alignment aspects of the energy transition issue, however, it was not adequately sufficient to touch on the planning portions of the reports, as they are more focused on what is being done, rather than what could be.

The results found were consonant with the overall narrative of the port authorities and their publications. The main nodes on the graphs are concurrent with the topics most strongly regarded by both ports in their concerns around green alleviation initiatives and solutions.

As a comparatively young entity, Port of Açu's focus revolves mostly around the conservation of native fauna and flora, as well as the communities affected by the port installation and operations. The emphasis on the preservation of the biome is backed by their investments in maintaining the Caruara reserve, along with environmentally-sound awareness programs for all levels of stakeholders. However, performance and corporate results are markedly relevant, as this port still needs to justify its business, attract new investors and seek out further capital for future investments. Port of Açu's endeavors towards investing in greener operations and progressively switching to low-carbon energy sources are strong and ongoing. This too is an investment-oriented strategy directed at energy transition.

Conversely, dating back to the 12th century, the Port of Antwerp-Bruges has been long recognized. The results speak to how its impacts on the landscape, society, and logistics are well integrated. The more recent topic of green port initiative and energy transition does transpire in their reports when sustainability is posed as one of the most prominent issues to the entity. At this point, the role of port authority confronts how work performance relates to sustainability, where digitization and automation are also mentioned to help improve port productivity and support fleets' energy transition.

Despite the term energy transition itself not ranking very high, the reports point to the actions already being put in place in the direction of shifting to cleaner energy sources, with the establishment of its green energy hub which already produces much of the renewable energy locally with solar panels and wind farms at land and sea, besides the green energy in use at the port from locally-generated hydrogen. It is important to mention that this know-how is designed to be transferred to Port of Açu in due time, although legislations in each country are at dissimilar levels of alignment and commitment to the global agenda concerning climate change and the environment.

The results found by this research are in line with considerations from Oloruntobi et al. (2023) on their considerations on the relevance of the integration of information and communication technology to moderate the requirements for energy efficiency in transportation systems, where the implementation of lower energy systems benefit future maritime services.

Platias and Spyrou (2023) highlight that mainstreaming ecological goals and sustainability in port operations do affect strategic choices when it comes to energy-related projects eligible for funding, which is corroborated by the findings from this research especially concerning the Port of Antwerp-Bruges. Topics regarding ports as significant energy users and polluters and their part in environmental degradation that led to the concepts of green port, energy conservation, and transition were found in agreement with the discoveries from Hua et al. (2020) on green port policies and the establishment of an effective methodology system.

Although the role of policies and legislations concerning environmental preservation, and governmental financial aid are of central importance, this could not be explored further based on the analyses of the results achieved by this research as this theme was not directly implicated in the reports from either port studied. Further research on this topic is recommended, as these are means to enhance technology innovation and strengthen the development of digitalization, infrastructure, logistics, and operations; all of which are fundamental when considering the mitigation of the impacts caused by energy consumption and pollution emissions, turning the issue of energy transition in ports all the more justified and pressing. It is suggested that financial reports of these same ports be also taken into account in such future research as they might provide supplementary information onto the planning portion that this present research was unable to accomplish with solely the environmentally-focused reports.

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5. Final Considerations

This research delved into three distinct issues associated with the venture of Port of Açu.

In the first article, the issue of port efficiency in Brazil was investigated using DEA, in terms of input and output. The results identified the most efficient ports in the country, besides the variables that most influenced their performance. Port of Açu ranked at the 8th position within cluster 1, with a Decision Making Unit of 12, which is notable, considering its young age. Recommendations were made for specific niches to be explored in future research on this subject.

The second article sought out to investigate quite a relevant item when it comes to port efficiency, namely, digitalization in port operations. By conducting an assessment of the strategic position taken by port authorities, and using the SWOT matrix, eight main business strategies were found to comprise the digitalization aspect besides the fomentation of changes within the organization and to its context. The research surmised that the application of such strategies may transform Port of Açu into a smart port complex and contribute to the sustainable and economic development of northern Rio de Janeiro state in Brazil, so Port of Açu would become more competitive, measuring up to other well-established seaports.

At last, aligned with the UN's Agenda 2030 development goals, besides being directly relevant to Environmental, Social and Governance (ESG) sustainability concepts standards, the third article explored energy transition aspects in both Port of Açu and Port of Antwerp-Bruges, scrutinizing their sustainability and managerial reports. The narrative of these port authorities were found to match their publications. As a still young venture, Port of Açu's focus revolves mainly around conservation, performance results and attracting investors. The issue of transitioning to cleaner, more sustainable sources of energy is evidently marked among its strategic priorities, as efforts along these lines are already being put into motion.