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PORT AND COASTAL MANAGEMENT AGAINST CLIMATE CHANGE: A CASE STUDY OF TANJUNG EMAS PORT SEMARANG, CENTRAL JAVA, INDONESIA

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ABSTRACT: This study investigates the climate resilience of Tanjung Emas Port, Semarang, Indonesia, a major port facing significant land subsidence and sea-level rise. Through a descriptive qualitative analysis, we examine the port's preparedness strategies and actions in response to climate change impacts. The research aims to provide valuable insights for port managers and decision-makers in developing effective climate adaptation measures. Key findings include the existence of a disaster contingency plan by the port authority, although further identification of disaster-prone port infrastructure is necessary. Based on PIANC standards, Tanjung Emas Port demonstrates a level of climate resilience, but additional research on the resilience of port infrastructure is warranted. Moreover, enhanced synergy among port users, operators, and stakeholders is crucial for building a robust resilience system. This research contributes to the understanding of climate resilience in ports and offers practical recommendations for port managers and policymakers. The findings and insights from this study can inform the development of effective climate adaptation strategies and policies, ultimately promoting the creation of resilient ports in the face of climate change challenges.

Keywords: Climate change, Port resilience, Tanjung Emas Port, Sea-level rise, Land subsidence, Disaster contingency plan, Port infrastructure, Climate adaptation, Stakeholder engagement, PIANC standards.

RESUMO: *Este estudo investiga a resiliência climática do porto de Tanjung Emas, em Semarang, na Indonésia, um importante porto que enfrenta uma significativa subsidência de terras e a subida do nível do mar. Através de uma análise qualitativa descritiva, examinamos as estratégias e acções de preparação do porto em resposta aos impactos das alterações climáticas. A investigação tem como objetivo fornecer informações valiosas aos gestores portuários e aos decisores no desenvolvimento de medidas eficazes de adaptação ao clima. As principais conclusões incluem a existência de um plano de contingência para catástrofes por parte da autoridade portuária, embora seja necessária uma maior identificação das infra-estruturas portuárias propensas a catástrofes. Com base nas normas PIANC, o porto de Tanjung Emas demonstra um nível de resiliência climática, mas é necessária investigação adicional sobre a resiliência das infra-estruturas portuárias. Além disso, uma maior sinergia entre os utilizadores, operadores e partes interessadas do porto é crucial para a construção de um sistema de resiliência robusto. Esta investigação contribui para a compreensão da resiliência climática nos portos e oferece recomendações práticas para os gestores portuários e decisores políticos. As conclusões e os conhecimentos deste estudo podem servir de base ao desenvolvimento de estratégias e políticas de adaptação climática eficazes, promovendo, em última análise, a criação de portos resilientes face aos desafios das alterações climáticas.*

Palavra-chave: *Alterações climáticas, Resiliência portuária, Porto de Tanjung Emas, Subida do nível do mar, Subsidência de terrenos, Plano de contingência para catástrofes, Infra-estruturas portuárias, Adaptação às alterações climáticas, Envolvimento das partes interessadas, Normas PIANC.*

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1. INTRODUCTION

Climate change is the biggest threat facing the planet now, as a consequence of the ever-increasing use of fossil fuels. Melting ice sheets result in rising sea levels (Boukarta & Berezowska-Azzag, 2022). The global hydrological cycle has been altered as a result of the warming of the planet (Oza *et al*., 2022). Extreme weather and other disasters are possible results of climate change. Climate change can cause various kinds of impacts, one of the biggest impacts is the hydrological consequences. The water balance in an area becomes unbalanced, especially due to increased evaporation (Marsz *et al*., 2022).

Additionally, ports are crucial nodes in both regional and international supply chains (León-Mateos *et al*., 2021). Because of its closeness to the ocean, the port is a crucial economic sector at risk from climate-related disasters (Poo *et al*., 2021). Climate change also results in social risks, social risk is one of the impacts that occur from social vulnerability, resilience and adaptive capacity (Lupu, 2019). Rising sea levels, storms, floods, tidal waves, strong winds, heavy rain, and higher average water temperatures are only some of the natural disasters that the changing climate is causing. According to previous studies that confirm this, port flooding due to rising sea levels, violent storms, strong winds, and erosion of coastal areas is the most significant hazard to ports. The devastating effects of climate change necessitate port adaptations. Port authorities and stakeholders can utilize an adaptation framework to assess the impact of climate change on their operations and develop effective responses (da Veiga Lima & de Souza, 2022a; Yang *et al*., 2018).

The melting of ice sheets and thermal expansion of warming seawater contribute to an overall increase in sea levels due to global warming. Half of the sea level rise from 1971 to 2018 was due to thermal expansion, the rest was due to melting ice sheets, and 8% was due to surface water storage. From 2006 to 2018, rising sea levels had a significant contributor in the form of melting ice from the Earth's surface. The present-day sea level rise is as much as 20 centimeters. Depending on future emissions, it will continue to go up (Arias, *et al*., 2022). When sea levels rise, piers, storage areas, and breakwater piers may become inaccessible, rendering port facilities useless and raising expenses for relocation and repairing flooded facilities (da Veiga Lima & de Souza, 2022b).

Subsidence is a common issue in large coastal cities like Semarang. It wreaks havoc on urban infrastructure, such as roads and buildings, and other infrastructure, such as ports (Yastika *et al*., 2019). Semarang City's ports and coastal areas are frequently flooded due to soil subsidence and other factors. Geodetic monitoring, groundwater extraction, and engineering geology are just a few monitoring methods applied to study land subsidence in Semarang.

The rate of land subsidence in Semarang varied spatially between 1 and 10 cm per year between 1980 and 2010, according to geodetic measurements (Sarah & Soebowo, 2018). Overpopulation, Industrialization, and excessive groundwater consumption are to blame (Bott *et al*., 2021). The Tanjung Emas Port is located nearby, and land subsidence has been observed in the surrounding waterways and alluvium sediments (Yastika *et al*., 2019). Coastal areas, including the port area in Semarang, face a severe threat from the combined effects of sea level rise and ground subsidence (Nurhidayah & McIlgorm, 2019). Approximately 6.51 centimeters per year is the average rate of sea level rise in Semarang waters (Salsabila *et al*., 2022).

The effects of climate change have been the subject of extensive study. Despite the issue's urgency, studies of climate change's impact on ports are still scarce (Panahi *et al*., 2020). Therefore, studying ports' preparedness for climate change's effects is appealing. This research looks at how well-prepared ports are to deal with the effects of climate change, using the example of Tanjung Emas Port in Semarang, Indonesia. This study will shed new and vital light on how ports may adapt to climate change. When it comes to sustaining and enhancing port performance in the face of the problems posed by climate change, this study can also help decision-makers and connected parties design effective strategic strategies.

This study exclusively investigates the impacts of climate change on Tanjung Emas Port in Semarang, Indonesia. The hypothesis is that the port is not fully prepared to withstand the growing climate risks, particularly considering the potential for future intensification. By focusing on Tanjung Emas, this research aims to provide valuable insights into the vulnerabilities of ports to climate change and identify necessary adaptation measures. The findings may highlight the urgent need for comprehensive strategies to enhance port resilience and ensure long-term sustainability in the face of climate challenges.

First, a literature review of various literatures is presented, including previous research related to climate change, climate change and its effects on ports, and how resilient ports should be to climate change. Then the second is presented regarding the explanation of the research location. the third is presented regarding the methodology used in this study. The fourth,

this study presents the results of research analysis and field observations as well as the results of FGDs, then also presents on how the actions and potential actions taken by the port of Tanjung Emas in the face of climate change. Finally, a summary and discussion of what the port should do in the face of climate change and what findings are generated from this study are presented. The conclusion drawn from the study is presented at the end of this paper.

2. LITERATURE REVIEW

The maritime sector, essential for global trade and the world economy, is encountering unparalleled difficulties as a consequence of climate change (A. Becker, 2020; Lau *et al*., 2024)

As a reference in dealing with the impact of climate change on ports, this study uses illustrations from the PIANC (Permanent International Association of Navigation Congresses) Guidelines regarding the relationship between climate factors and their effects on port infrastructure from PIANC. It is similarly centered on the port work sector. This study relates to PIANC because Indonesia is a member (Indonesia formally joined PIANC in January 2016).

The World Association for Waterborne Transport Infrastructure, or PIANC, is an international professional organization created in 1885. PIANC is a global organization that provides guidance and technical support to ports, marinas, and waterways on sustainable aquatic transportation infrastructure. PIANC is deeply concerned about sustainable development, climate change, working with nature, and digitization (https://www.pianc.org/about). PIANC is the only global organization involved in maritime affairs. Providing recommendations on sustainable water transportation infrastructure for ports and waterways is one of PIANC's responsibilities Table 1 depicts the link between climate conditions and port infrastructure impacts.

The PIANC paper categorizes ports into eight sections: navigation zone, protective infrastructure, maneuver, and berthing area, loading/unloading area, storage/offices, processing/manufacturing area, and hinterland connection. This study refers to these eight kinds of port areas/port activities. For example, air temperature, water temperature, precipitation intensity, mean

Table 1. Relationship between climate parameters and impacts on port operations/infrastructure.

Work Area in Port	Climate Parameters	Impacts
Navigation Zone	Air Temperature, Water temperature, Precipitation Intensity/distribution, Mean sea level/astronomical tide, Wind conditions/storminess, water chemistry	Ice or Icing, Snow or hail, Fog or visibility, Water depth, Currents, Sediments characteristics, Wind load, Biological change
Protective infrastructure		Ice or icing, Overtopping, Scouring Wave load, Biological change, Corrosion
Manoeuvre and berthing area		Ice or Icing, Fog or visibility, Water depth, Currents, Scouring/accretion, Wave characteristics, Wind Load, Biological change, Corrosion
Loading/Unloading Area	Air temperature, Precipitation intensity/distribution, Mean sea level/astronomical tide, Wind conditions/storminess, Water chemistry	Excess heat/humidity, Ice or icing, Snow or hail, Fog or visibility, Surface water flooding, Overtopping, Water depth, Wave load, Wind load, Biological change, Corrosion,
Port equipment,	Air temperature, Precipitation Intensity/distribution, Wind conditions/storminess	Excess heat/humidity, ice or icing, Snow or hail, Fog or visibility, Surface water flooding, Overtopping, Water depth, Wave load, Wind load, Biological change, Corrosion,
Storage/office		
Processing/manufacturing		
Hinterland connections	Air temperature, Water temperature, Precipitation intensity/distribution, Mean Sea Level/Astronomical Tide, Water chemistry	Excess heat/humidity, Ice or icing, Snow or hail, Fog or visibility, Surface water flooding, Overtopping, Water depth, Currents, Sediment dynamics, Wave characteristics, Groundwater flooding, Legacy contamination, Wind load, Biological change, Corrosion

(Source : (Brooke *et al.*, 2020))

sea level, wind conditions, and water chemical conditions can all be affected by climate characteristics in the navigation area zone. Visibility or fog that interferes with navigation, water depth, changes in currents and sediment dynamics, wave features that interfere with navigation, wind loads, and changes in biological conditions can all have an impact (Brooke *et al*., 2020)

So far, we only have a general idea of how climate change will affect ports. However, several studies have looked at individual ports. Several studies in Asia have concluded that port cities in several Asian countries are at risk from climate change. Adaptation tends to have a negative impact on other ports compared to mitigation. However, in general, adaptation can also improve community welfare more quickly. Mitigation efforts remain essential as a long-term solution to climate change. This research provides insight into how the world's port cities are working together to address the global challenges of climate change while rebuilding their identities as progressive and ecologically responsible urban centers (Blok & Tschötschel, 2016; Jiang *et al*., 2020). Another research about a hybrid statistical-dynamic hybrid framework combining weather generators and meta models can be used to probabilistically evaluate port operations considering climate change influences such as sea level rise (Camus *et al*., 2019). Research conducted on 18 port organizations in China shows that port organizations are generally aware of climate change and agree that more advanced measures must be taken. However, policy support is key to implementing climate change adaptation plans (Lin *et al*., 2020).

A study was done in 2,013 ports worldwide (Toimil *et al*., 2020), analyzing the global risks and effects of high-level warming by looking at atmospheric and ocean materials, setting operational limits for industries, and assessing vulnerabilities. In the year 2100, places in the Pacific Islands, the Caribbean Sea, and the Indian Ocean were found to be in a perilous situation. Ports in the African Mediterranean and the Arabian Peninsula (the Persian Gulf and the Red Sea) are at very high risk. Much research has also been done on how ready and strong the ports in South America and the Caribbean Islands are. The results show that ports need better information and knowledge about setting up a local database of important climatological parameters, permanent scale projections, and temporary risks for port operations. And infrastructure in different climate situations (Mariano & Cascajo, 2020). With case studies of several ports in the United Kingdom, the Climate Change Risks Indicator Framework was made to help lawmakers evaluate ports. This study used Evidence Reasoning (E.R.) to fill in missing data to evaluate climate risk at ports (Poo *et al*., 2021). Still, more research is needed, especially case studies of specific ports in different parts of the world, such as Indonesia, to learn more about the effects of climate change on ports and what can be done to fix them.

Several studies have shown that sea level rise caused by climate change is the leading cause of problems with port facilities. The research was done at Morocco's Tangier Med-Port Port, whose operations will be affected if the High-End Scenario happens in 2090 (Jebbad *et al*., 2022). Another study done at the Port of Mobile, Alabama, showed that if a hurricane like Hurricane Katrina hit in the late 21st century, the damage to the port would be nearly seven times worse than what Hurricane Katrina did on its own (Abdelhafez *et al*., 2021). Researchers who looked at case studies in Indonesia and Japan found that when people face the problem of relative SLRs, they tend to move closer to the sea instead of moving away. This adaptation to face the SLR is an example of maladaptation (Esteban *et al*., 2020). Then, another study that talks about the future effects of SLR is research that looked at how well ports and low-lying areas in Tohoku, Japan (which was hit by the 2011 Tsunami Earthquake) and Jakarta, Indonesia, were able to adjust. The results of this study show that one way to figure out how SLRs will affect transportation systems in the future is to look at how ports in Japan and Indonesia deal with sinking land. At the same time, adaptation will not cost more if a stricter plan for preventing climate change is implemented (Esteban *et al*., 2020). Another research says that one way to adapt to SLRs is to change how harbors and other coastal defense buildings are built ahead of time and the study will look at changes in international maritime trade that align with world temperature rises of 2°C and 4°C, as well as the effects of sea level rise that would come with those temperature rises (Hanson & Nicholls, 2020).

Climate change impacts global shipping networks, requiring the development of a methodology combining climate risk indicators, centrality analysis, and ship routing optimization to identify alternative routes and reduce vulnerabilities (Poo & Yang, 2024). Another research indicates that global ports will increasingly be exposed to significant risks due to climate change, including extreme sea level rise (ESLs), waves, and extreme heat events. By 2050, between 55% and 59% of the 3,630 ports considered may face ESLs exceeding 2 meters above baseline average sea level. By 2100, this figure is projected to rise to between 71% and 83%. Although international and regional policies and legal instruments have been established to support climate change adaptation, resilience building, and disaster risk reduction in ports, further action is required to accelerate the implementation of effective adaptation measures across regions (Asariotis *et al*., 2024).

Another study was done on how ports can adapt to climate change and its effects in Australia. This research found that effective adaptation solutions are not just about the physical layout and engineering projects. However, it must also change how ports are managed and planned (Ng *et al*., 2013). Other studies (Yang *et al*. 2018) say that taking the steps suggested in the literature to adapt to climate change can lower the chance that significant climate change will affect how a port works.

A resilient port can bounce back quickly after natural disasters without suffering severe losses, damage, or a drop in productivity or quality of life, and does so with little to no outside aid. Ports can prepare for climate change in some ways, some of which are: 1. involving the entire network of stakeholders in resilience planning; 2. increasing local climate projections and improving conditions for risk assessment; 3. choosing adaptation strategies, such as renewing storm defenses, elevating buildings based on projected sea level rise, or relocating the harbor as a whole (A. Becker, 2013); and 4. developing an environment that is beneficial to coping with the effects of climate change. The concept of resilience ports system shown in Figure 1.

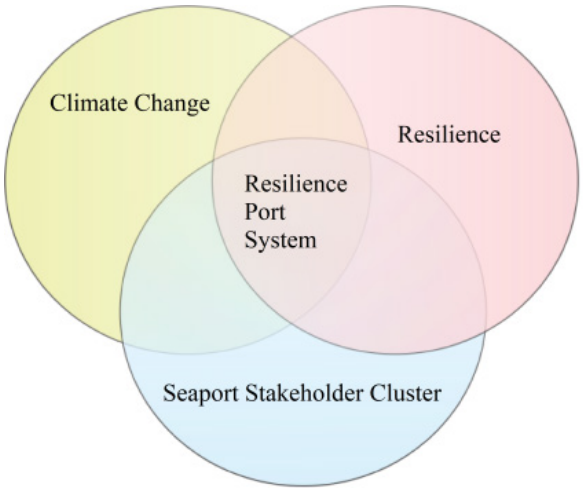

Figure 1. Sea Port Resilience System (Source: (A. H. Becker *et al.*, 2013))

3. MATERIAL

The location of this research is being conducted in Semarang, Central Java, Indonesia. Tanjung Emas is Semarang City's only harbor for both people and freight. Geographically it is located at -6.94S and 110.423E or roughly 5 km from Tugu Muda City Center Semarang.

The port is run by the state-owned company P.T. (Persero) Pelabuhan Indonesia III Tanjung Emas Branch, which is overseen by Kantor Syahbandar dan Otoritas Pelabuhan (KSOP) Class I Tanjung Emas, a Technical Implementation (UPT) under the Ministry of Transportation's Directorate General of Sea Transportation. This port is a class I port on an international scale and is a strategic port supporting sea transportation in Semarang (Ariyono *et al*., 2017). Tanjung Emas Port is an efficient port in western Indonesia (Sutomo & Soemardjito, 2012) based on the criteria of (1) density of transportation infrastructure, (2) port capacity, and (3) speed of commodities flows to the port. Tanjung Emas Port in Semarang serves as a liaison (supply chain logistics), commercial gateway, and a link between sea, land, and rail transit via railroad reactivation. Semarang Tanjung Emas Port offers Roro Terminal, Passenger Terminal (both International and Domestic), Container Terminal (both International and Domestic), Liquid Bulk Terminal, and Dry Bulk Terminal services. Fuel, LNG, LPG, CPO, and asphalt are among the commodities handled at the Liquid Bulk Terminal. Tanjung Emas Port is also expected to be able to support businesses such as textile, food, energy, gas shipping, and other manufacturing. The Location of Tanjung Emas Port in Semarang is seen in Figure 2.

4. METHOD

The method used in this research is descriptive analysis to explain the readiness of Tanjung Emas Port to face climate change. The research flow chart is shown in Figure 3. The primary and secondary sources of data were used for this review. The data used is secondary data obtained from Kantor Syahbandar dan Otoraritas Pelabuhan (KSOP) Class I Tanjung Emas and PT Pelindo Regional III. The data include Tanjung Emas Port Semarang port facilities in 2022.

A group discussion was conducted once among scientists and stakeholders on September 27, 2022. This focus group discussion (FGD) took place to collect information from stakeholder and scientists about how the Tanjung Emas Port is handling the effects of climate change. The discussion aimed to identify strategies that the port can adopt to enhance its resilience. Stakeholders involved in this discussion are BMKG (Badan Meteorologi, Klimatologi, dan Geofisika) or Meteorological, Climatological, and Geophysical Agency; KSOP, PT Pelindo Regional III, and BRIN (Badan Riset dan Inovasi Nasional) or National Research and Inovation Agency.

The selection of FGD participants was based on the significance of their role in managing ports concerning climate change. KSOP

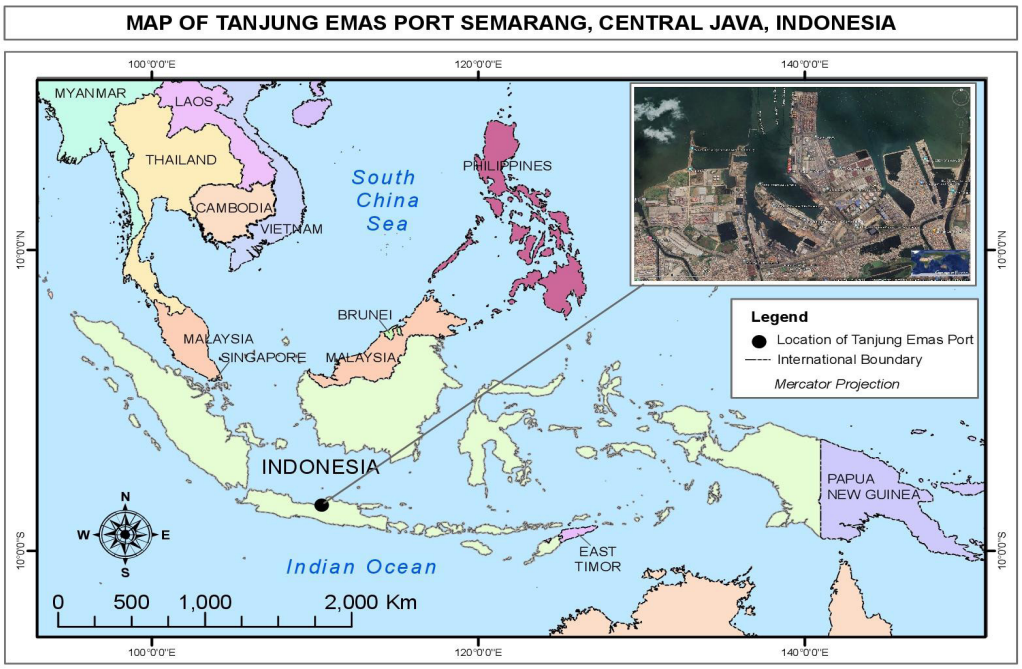

Figure 2. Location of Tanjung Emas Port Semarang (Source: Processed Secondary Data, 2024).

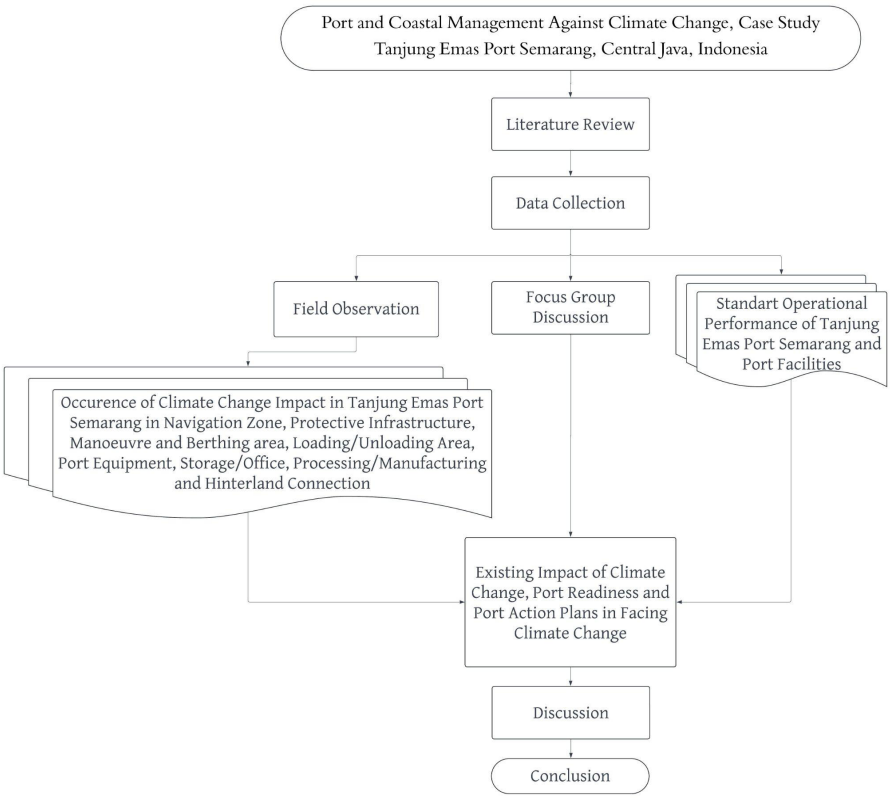

Figure 3. Flow chart of the research.

is active in policymaking and regulation, BMKG is a climate information agency, PT Pelindo Regional III is a port operator or user, and BRIN is also a scientists for hydrometeorological disasters. FGD participants were agency executives, port managers, hydrometeorological disaster professionals and disaster practitioners. In particular, those present in the FGD are senior officers from each institution with the appropriate knowledge, power and skill necessary to design and build climate resilient ports. Figure 4 shows FGD activity.

Researchers also made direct observations in the field to see the impact of climate change occurring at Tanjung Emas Port and to validate the data obtained from the agency. Direct field observations were carried out in each port area as classified according to the PIANC document. The area is divided into eight areas: a navigation zone, protection zone, maneuvering and berthing area, loading and unloading area, port equipment, storage/office area, processing/manufacturing area, and hinterland connection.

Direct observations were carried out to determine the impact of climate change on regional navigation zones, especially the influence of climate parameters such as air temperature, water temperature, rainfall intensity, average sea level/astronomical tides, wind/storm conditions, and water chemistry. Observations are made by observing whether there is ice or ice, snow or hail, fog or visibility, water depth, current sediment dynamics, wave characteristics, wind loads, and biological changes that can disrupt the smooth navigation of ships and other air transport.

Like observations in the navigation area, observations are carried out by observing whether there are impacts arising from climate change, such as ice cover, water overflow, scouring, wave loads, biological changes, and corrosion on the area's protective infrastructure.

Observations in maneuvering and anchoring areas are carried out by observing whether icing occurs, fog or visibility occurs and disrupts the port process, water depth that can interfere with the ship's berthing, currents, scour/accretion, wave characteristics, wind loads, biological changes, and corrosion that occurs in that area. Observations in the loading/unloading area are carried out by observing the processes of excess heat/humidity, ice or layers of ice, snow or hail, visibility of fog that can disturb the area, surface water flooding, runoff, water depth, wave load, wind load, biological changes, and corrosion that occur in that area.

Observations of the port equipment, storage/office, and processing/manufacturing areas are carried out to see if there is excess heat/humidity, ice or layers of ice, snow or sleet, fog or visibility, surface water flooding, water overflow, groundwater flooding, legacy contamination, wind loads, and corrosion. Meanwhile, observations for hinterland area connections

Figure 4. Focus Group Discussion to identify strategies that the Tanjung Emas Port Semarang can adopt to enhance its resilience (Source: Primary Data, 2022).

are carried out by observing whether there is excess heat/ humidity, ice or layers of ice, snow or hail, fog or visibility, surface water flooding, water overflow, water depth, currents, sediment dynamics, wave characteristics, water flooding, legacy contamination, wind loads, biological changes, corrosion occurring, or not.

A systematic search was also conducted to find all articles published in English and other languages related to the subject of the current review from 2012 to 2022 Science Direct and Google Scholar databases. The keywords used for the search are "Port Tanjung Emas, Port Resilience, Climate Change in Port Tanjung Emas, Sea Level Rise, Climate Change in Port, Land Subsidence in Port Tanjung Emas Semarang, Land Subsidence in Semarang." The articles found were then selected according to the scope of the subject of this current review.

Based on the potential application of specific methods or approaches, case studies were selected to explore and estimate the impacts of climate change in a specific context. The search using the keywords yielded the following results: 1 article on a specific topic, 77 articles on another topic, no articles on a third topic, an estimated impact value of 33.046, 41 articles on a fourth topic, no articles on a fifth topic, and seven articles on a sixth topic. The study also placed significant emphasis on research articles related to policies for climate change adaptation in ports. After that, each of the papers main findings was noted along with their research scale, adopted methods, the illustration of concepts, and their limitations.

5. EXISTING IMPACT OF CLIMATE CHANGE IN THE TANJUNG EMAS PORT SEMARANG

Researchers conducted field observations to validate the data and explore the extent to which climate change is affecting the port area. The results of these observations are explained in the points below.

a. Navigation zone
   Because in a tropical country, the ice and snow phenomenon does not occur. For the navigation area, based on observations, it shows that the phenomenon of fog or visibility of water depth, currents, wave characteristics, and wind load occurs. The navigation area is not affected by sediment dynamics and biological change phenomena. Because of this, the conditions in the navigation zone environment of the Semarang Emas Port are relatively safe to carry out work operations by the density of ship traffic that has existed so far. Table 2 shows existing impact of climate change in the Tanjung Emas Port Semarang at the navigation zone.

b. Protective Infrastructre Zone
   At present, the existing condition of the breakwater of Port Tanjung Emas is below sea level, and this is due to sufficient scour at the breakwater and a pretty intense wave loading along the breakwater. Table 3 shows existing impact of climate change at protective infrastructure zone in the Tanjung Emas Port Semarang.

c. Maneuver and Berthing Area
   In the maneuver and berthing port work area, the process of ice or icing does not occur because the Tanjung Emas Port

Table 2. The Curent Impact of Climate Change in the Tanjung Emas Port Semarang at Navigation Zone.

Impact of Climate Change	Explanation	Yes	No
Ice or Icing (N/A)	There is a layer of ice around the navigation zone		√
Snow or hail (N/A)	The occurrence of snow or hail in the navigation area		√
Fog or visibility	There is fog which causes a decrease in visibility in the navigation area	√	
Water depth	The occurrence of silting which disrupts the navigation flow	√	
Currents	The strength and direction of the currents that occur in the navigation channel	√	
Sediments dynamics	The dynamics of sedimentation that occurs in the navigation area		√
Wave characteristic	Wave characteristics in the navigation area	√	
Wind load	The occurrence of strong winds can affect the navigation process	√	

(Source: Processed Primary Data, 2022)

Table 3. The Curent Impact of Climate Change at Protective Infrastructure Zone in the Tanjung Emas Port Semarang

Impact of Climate Change	Explanation	Yes	No
Ice or Icing (N/A)	There is a layer of ice around the protective infrastructure zone		√
Overtopping	Occurrence of overtopping/overflow of seawater in massive breakwater structure		√
Scouring	The occurrence of scouring on the concrete structure of breakwater buildings	√	
Wave load	Intense wave loading on breakwater structures due to big waves	√	
Biological change	Biological changes (marine biota) around the breakwater area		√
Corrosion	Corrosion occurs in breakwater structures		√

(Source: Processed Primary Data, 2022)

in Semarang is located in a tropical country. Ships must maneuver when they are about to sail or arrive at the port and when crossing canals and traffic zones. Maneuver and berthing areas are crucial port work areas because they involve the safety of shipping ships. Therefore, climate change impacts in this area are very influential, such as wave load, overtopping, scouring, and changes in biological conditions. Overtopping, scouring, wave loads, and biological changes in the maneuver and berthing area did not occur at Tanjung Emas Port, Semarang. Table 4 shows existing impact of climate change at protective maneuver and berthing area in the Tanjung Emas Port Semarang.

d. Loading/Unloading Area
Based on the actual conditions, the results of observations in the dock area/loading and unloading area have increased heat/humidity, which is relatively high. Under certain conditions, massive seawater runoff and tidal floods often occur. There was no siltation in this area but quite an intense wave loading in the dock/loading area due to big waves. For wind conditions that do not affect the loading and unloading process, the occurrence of quite massive corrosion on the dock/loading and unloading facilities and infrastructure needs special handling so as not to disturb the loading and unloading process. Table 5 shows existing impact of climate change at loading/unloading area in the Tanjung Emas Port Semarang.

e. Port Equipment Area
In the work area for Port Equipment, the process of ice or icing and snow or hail does not occurs because Tanjung Emas Semarang Port is located in a tropical country. Based on the actual conditions observed in the port equipment work area, climate change impacts such as excess heat/humidity, fog or visibility, surface water flooding, overtopping, groundwater flooding, and legacy contamination do not occur at Tanjung Emas Port. However, corrosion can happen in this port work area. Table 6 shows existing impact of climate change at port equipment area in the Tanjung Emas Port Semarang.

f. Storage Office Area
In the storage office work area, climate change impact that do not occur are ice or icing and snow or hail because Tanjung Emas Port is in a tropical country. Meanwhile, other climate change impacts that occur in the port work area are the occurrence of excess heat/humidity and corrosion. While fog or visibility, surface flooding, overtopping, groundwater flooding, and legacy contamination. Table 7 shows existing impact of climate change impacts at strorage office area in the Tanjung Emas Port Semarang.

g. Procession Manufacturing Area
In the procession manufacturing work area, the climate change impact such as ice or icing and snow or hail do not occur because Tanjung Emas Port is located in the tropics. The climate change impacts such as fog or visibility disturbance, surface water flooding, overtopping, groundwater flooding, and legacy contamination do not appear in the work area of the procession manufacturing port. However, excess heat/humidity affect the procession manufacturing area. Table 8 shows existing impact of climate change change impact at procession manufacturing area in the Tanjung Emas Port Semarang.

h. Hinterland Connection Area
In general, the hinterland connection does not have much impact on climate change. Still, several aspects of field conditions need attention, namely high heat/humidity, seawater runoff under certain conditions, and massive corrosion of infrastructure in the hinterland connection area. Table 9 shows existing impact of climate change impacts at hinterland connection area in the Tanjung Emas Port Semarang.

Table 4. The Curent Impact of Climate Change at the Maneuver and Berthing Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Ice or Icing (N/A)	Icing process or the presence of ice in the maneuver and berthing area		√
Overtopping	Overtopping of seawater in the maneuver and berthing area		√
Scouring	Scouring occurred in the maneuver and berthing area		√
Wave load	Intensive wave load in the maneuver and berthing area		√
Biological change	Biological changes around the maneuver and berthing area		√
Corrosion	Corrosion occurs in the maneuver and berthing area		√

(Source: Processed Primary Data, 2022)

Table 5. The Curent Impact of Climate Change at Loading/Unloading Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	High heat/humidity in the loading and unloading area	√	
Fog or visibility	The occurrence of fog/decreased visibility ability in the loading and unloading area		√
Surface water flooding	Surface Flooding in the loading and unloading area	√	
Overtopping	Massive overtopping occurs in the loading and unloading area	√	
Water depth	The occurrence of silting, which resulted in obstacles during the loading and unloading process		√
Wave load	Intense wave loading on the wharf/loading or unloading area due to big waves	√	
Wind load	The occurrence of a strong wind is quite intense, which affects the process of loading and unloading/port activities at the dock/loading and unloading area		√
Biological change	Biological changes around the loading and unloading area		√
Corrosion	The occurrence of corrosion on the facilities and infrastructure of the loading and unloading area	√	

(Source: Processed Primary Data, 2022)

Table 6. The Curent Impact of Climate Change at Port Equipment Area in the Tanjung Emas Port Semarang

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	Excess heat/humidity, which may affect port equipment		√
Ice or icing (N/A)	The occurrence of icing that can interfere with the port performance		√
Snow or hail (N/A)	The occurrence of snow or hail that can interfere with the port performance		√
Fog or visibility	There is fog which causes a decrease in visibility when operating equipment at the port		√
Surface water flooding	Surface flooding can affect the operation of port equipment		√
Overtopping	Harbor equipment such as protective walls, dikes, sluice gates, drainage systems, and surge gauges can help reduce the risk of seawater runoff into the port area		√
Groundwater flooding	Flooding in the port area affects the performance of port equipment		√
Legacy contamination	The occurrence of continuous pollution can affect the operation of the equipment at the port		√
Corrosion	The occurrence of corrosion that can affect the use of port equipment	√	

(Source: Processed Primary Data, 2022)

Table 7. The Curent Impact of Climate Change at Storage Office Area in the Tanjung Emas Port Semarang

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	There is excess heat/humidity that can affect the storage office area	√	
Ice or icing (N/A)	The icing process occurs in the storage office		√
Snow or hail (N/A)	Snow or hail occurs in the storage office		√
Fog or visibility	Fog or limited visibility occurs, which disrupts visibility in the storage offices area		√
Surface water flooding	Surface flooding occurs in the storage area		√
Overtopping	Massive overtopping occurs in the storage area		√
Groundwater flooding	Flooding in the port area affects the storage office		√
Legacy contamination	The occurrence of continuous pollution can affect the operation of the storage office		√
Corrosion	The occurrence of corrosion that can affect the use of port equipment	√	

(Source: Processed Primary Data, 2022)

Table 8. The Curent Impact of Climate Change at Procession Manufacturing Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	Excess heat/humidity that can affect the procession manufacturing area	√	
Ice or icing (N/A)	The icing process occurs in the storage office		√
Snow or hail (N/A)	Snow or hail occurs in the procession manufacturing area		√
Fog or visibility	Fog or limited visibility occurs, which disrupts visibility in the procession manufacturing area		√
Surface water flooding	Surface flooding occurs in the procession manufacturing area		√
Overtopping	Massive overtopping occurs in the procession manufacturing area		√
Groundwater flooding	Flooding in the port area affects the operation of the procession manufacturing area		√
Legacy contamination	The occurrence of continuous pollution can affect the operation of the procession manufacturing area		√
Corrosion	The occurrence of corrosion that can affect the use of the procession manufacturing area		√

(Source: Processed Primary Data, 2022)

Table 9. The Current Impact of Climate Change at Hinterland Connection Area in the Tanjung Emas Port Semarang.

Impact of Climate Change	Explanation	Yes	No
Excess heat/humidity	There is high heat/humidity in the hinterland connection area	√	
Fog or visibility	The occurrence of fog or decreased visibility in the hinterland connection area		√
Surface water flooding	Surface water flooding occurs in the hinterland connection area	√	
Overtopping	Massive overtopping occurs in the hinterland connection area	√	
Water depth	Siltation occurs in the hinterland connection area		√
Currents	Strong currents that occur in the hinterland connection area		√
Sediment dynamics	There has been pretty massive sedimentation in the hinterland connection area		√
Wave characteristics	Changes in wave characteristics that disrupt activities in the hinterland connections area		√
Groundwater flooding	Groundwater flooding occurred, which disrupted activities in the hinterland connection		√
Legacy contamination	Legacy contamination occurred, which disrupted activities in the hinterland connection area		√
Wind load	The occurrence of strong winds that are pretty intense and disturbing occurs in the hinterland connection area		√
Biological change	Biological changes occur in the hinterland connection area		√
Corrosion	Corrosion in the hinterland connection area	√	

(Source: Processed Primary Data, 2022)

6. TANJUNG EMAS PORT ACTION AGAINST CLIMATE CHANGE

Information gathering regarding mitigating hydrometeorological disasters caused by climate change was carried out on September 27, 2022. Focus Group Discussions (Figure 4) involved stakeholders in the Tanjung Emas Port area, Semarang. Stakeholders involved include PT Pelindo III, Tanjung Emas Port and Class I Port Authority, BMKG, and BRIN. Some of the discussion points include:

a. Port Authority and Class I Tanjung Emas Port :
   - have software to handle hydrometeorological disasters
   - have regulations related to port activities when hydrometeorological and land subsidence disasters occur
   - The port area needs to anticipate tidal disasters and land subsidence
   - The Port of Tanjung Emas Semarang has a Port Master Plan, which contains one concerning the Repair and development of port infrastructure. Improvement and construction of Tanjung Emas Port infrastructure in Semarang as part of the port's adaptation and mitigation of disasters caused by climate change. The Port Master Plan I (2012-2016) of Tanjung Emas Port has been implemented with various infrastructure developments. Meanwhile, the implementation of Port Master Plan II (2017-2021) was constrained by the pandemic, and construction continued on Port Master Plan III (2022-2031). In this Port Master Plan III, several activities have been carried out, such as those carried out in stages in improving the facilities and management of Tanjung Emas Port.
   - Efforts that have been made in addition to the construction and improvement of infrastructure include: calculation of the tides, construction of breakwaters, and use of pumps (when a disaster occurs)
   - KSOP issues a sailing permit
   - Collaborate with BMKG to update data from BMKG in real-time

b. PT Pelindo III as Port Operator at Tanjung Emas Port in Semarang
   - Pelindo III has taken several strategic steps, including dredging shipping lanes and the Tanjung Emas port pool, extending the TPKS Pier, procuring container cranes and RTG
   - The main problems that often occur are tidal flooding and land subsidence
   - Pelindo III has invested in equipment that is planned to come in 2024
   - Have built an embankment as high as 1 meter and always add height periodically (30-40cm)
   - Use of sluice gates to accommodate small vessels
   - Pumps have been installed in the Tanjung Emas port area, Semarang
   - Implementation of a polder system
   - build 3 pump houses, where all the water will be brought to the retention pond and then disposed of to cope with overflow from the sea with a capacity of 800 m3/s
   - Pelindo III already has an emergency response procedure for handling tidal floods at Tanjung Emas Port (Predictive Response Procedure and Emergency Response Procedure).
   - Coordination and communication have been carried out between port operators and Port Authority and Class I Tanjung Emas Port and stakeholders in the Tanjung Emas port area

c. BMKG
   - Submission of weather and climate information is carried out periodically to stakeholders who need weather and climate data at the port
   - BMKG already has a mobile BMKG for early warning
   - Disaster mitigation due to climate change that BMKG has carried out includes outreach to the community, education, field schools, and visits to schools and campuses
   - Release an early warning 1 hour before based on monitoring data 3-6 hours before an early warning is released.
   - determination of limits in managing disasters must be based on impact case.
   - BMKG often gets information from captains who are already docked at the harbor

From the results of the FGD, it was also found that Tanjung Emas Port has several challenges that must be faced, including the implementation of disaster mitigation and anticipation is carried out separately for each stakeholder (due to constraints on their respective duties and functions), requires a high asset and infrastructure maintenance costs, often missing checks

and mitigation and monitoring facilities, there is no massively integrated early warning system in the port area, increased investment for research and application of appropriate technology to deal with the impacts of climate change. From these challenges, various potentials can be developed for the Tanjung Emas Port area, such as creating a comprehensive and integrated early warning system. Apart from that, SOPs can also be set, which involve all parties (stakeholders) in an integrated manner.

In a number of situations, ports must figure out the number of indirect effects on the economy and change to them. As a result of how climate change affects the economic sector, some ports and waterways may see a change in the type, amount, or time of goods and people moving through them. Because of this, the port must also be able to handle different risks linked to weather, water, and ocean processes and parameters. Climate change will affect these factors and make existing risks worse, such as flooding, runoff, and flooding due to high river flow rates, high tides or storm surges, changes in sea conditions (agitation, extreme waves), changes in bathymetry or sediment transport, sedimentation, erosion of river bed or river banks, fog or reduced visibility, changes in wind speed/strength, direction, or duration, extreme heat or humidity (in terms of magnitude, duration, or frequency), and chemical spills.

In this case, the Class I Harbor Master and Port Authority (KSOP) Office of Tanjung Emas Port Authority has done a number of things to deal with the problems caused by climate change, such as the rising sea level and sinking land. Some of the things that can be done are fixing ponds and cleaning, putting in pumps, raising wharves, fixing infrastructure, and moving docks. Table 10 shows what Tanjung Emas Port in Semarang wants to do to deal with climate change.

7. DISCUSSION

This study look at port readiness in the face of climate change, focusing on Tanjung Emas Port in Semarang, Indonesia. Tanjung Emas Port in Semarang is one of Indonesia's ports and a significant port for economic and service activities. Furthermore, the findings of this study demonstrate that numerous efforts and predictions have been made to deal with climate change at the Port of Tanjung Emas.

Port infrastructure development and repair have been carried out by both the authorities and the port operator, including the construction of a breakwater, dredging, dam construction, pump installation, the addition of quay lining, the implementation of a polder system, and the use of sluice gates to accommodate small vessels. Efforts and anticipation of dealing with climate change in terms of Tanjung Emas Port management have been carried out in collaboration between authorities, port management operators, and other stakeholders (for example, BMKG), besides that, the efforts and mitigation of Tanjung Emas Port in Semarang in dealing with climate change are outlined in Port Master Plan I and II but are only limited to physical development and infrastructure. Tanjung Emas Port in Semarang likewise has protocols in place to deal with tidal floodings.

The findings of the study also suggest that numerous factors of climate change are occurring in each location of Tanjung Emas Port in Semarang. Climate aspects that arise and affect port performance, as in the navigation zone area, include fog/visibility, sea depth, currents, wave characteristics, and wind load. Scouring and wave loading occur in the protective infrastructure region, however in the manoeuvre and berthing zones, climate change impacts such as overtopping, scouring, wave load, biological change, and corrosion have no effect. Excess heat/humidity, surface water flooding, overtopping, wave load, and corrosion are climate characteristics in loading and unloading. Corrosion is one of the climate change impacts that happens in the port equipment area. Excess heat/humidity and corrosion occur in the port storage office work area, while excess heat/humidity occurs in the procession manufacturing work area, and extra heat/humidity, surface water flooding, overtopping, and corrosion occur in the hinterland connection work area. If applied to other ports, the climate parameters following the location of the port work area and port circumstances between one port work area and another will be different; the climate parameters in the port will be different.

Table 10 displays the measures and actions taken by the Tanjung Emas port in Semarang. Tanjung Emas Port has responded to climate change by adapting and mitigating its effects. The visible effort is to address climate change by improving and developing infrastructure. According to (A. H. Becker *et al*., 2013), a resilient port is one that can resist natural calamities that can result in large losses, damage, diminished output, or quality of life without much outside assistance. Public. Some of the strategies implemented by the Port of Tanjung Emas Semarang demonstrate that the port is attempting to increase its resilience to climate change, including increasing the resilience of infrastructure and infrastructure development, synergies between stakeholders despite various implementation challenges, increasing climate projections, and creating a

Table 10. Tanjung Emas Port Action Plans Against Climate Change.

No	Port operations as Repoerted by PIANC	Recent Actions of the Port Authority	Potential Actions from Literature	Detailed Potential Actions
1	Navigation zone	Dredging and pond revitalization	· hazard assessment for infrastructure · modify infrastructures, design, operations, and maintenance activities to account for potential hazards.	· investigate climate past records, climatic tendencies, anticipated weather circumtances, start monitoring climate change · Evaluate design parameters to detect threshold, fix maintenance concern, take corrective steps to reduce operational incidents and boost resilience
2	Protective infrastructure	· Pump installation · Improve drainage to overcome rob		· construction of decks, drainholes, increasing aprons and breakwater and also wave bariers to raise vital assets; relocation or increasing elevation of the access road and storage facilities to protect against flooding and wave overtopping · refine or replace outdated infrastructure
3	Maneuver and berthing area	· pier lining elevation · increasing elevation of the pier floor · Harboor and channels maintenance · Pelabuhan Dalam 1 and Pelabuhan Dalam 2 construction and development · Pelabuhan Rakyat Relocation		
4	Loading and unloading	Elevation of the stacking field	· collecting, monitoring and modeling historical and climate data to local level · Adjust infrastructure, design, operation, and maintenance activities in line with possible hazard · Use electric yard tractors, · Use high-tonnage electric forklifts, · Use an electric top handler · Digitization at port · Elevate land	· investigate climate past records, possible climate conditions and climate tendencies · Evaluate design parameters to detect threshold, fix maintenance concern, take corrective steps to reduce operational incidents and boost resilience; · relocation and revitalization infrastructure
5	Port Equipment	Container Terminal Reactivation railroads		
6	Storage/ offices	Storage office relocation		
7	Processing/ Manufacturing	Construction of The Port Associated Industry Zone (planned 2022-2031)		
8	Hinterland Connection	Intermodal development of Tanjung Emas Port and Kendal Terminal I		

Source : Analysis researcher based on data from PIANC; (Margarita Pery *et al.*, 2021), Kantor Syahbandar dan Otoritas (KSOP) Class I Tanjung Emas in 2022; (A. Becker, 2014).; with adjustments made by the researchers.

favourable environment for adaptation investment. According to PIANC (Brooke *et al*., 2020), improving port resilience and adaptation requires more than just reinforcing current physical infrastructure. Depending on the type of risk detected, management or maintenance, operational modifications, or cost savings may be implemented. Institutional reforms, such as finance policies, can be a long-term solution for improving port resilience and climate change resilience.

The findings of this study can be utilized to evaluate and consider managers when making decisions about managing the port area in the face of climate change consequences. This research is crucial because it requires the correct tactics, findings, and policies to assist in the realization of a port that is resilient to climate change disasters.

Climate change adaptation is a continuous process. As a result, conversations with stakeholders and a flexible approach to absorbing new sources of information are critical. As the adaptation planning process proceeds, the objectives are likely

to change. Monitoring results or other additional information, for example, will become available; other organisations may become engaged in the planning and delivery process; or awareness of the potential consequences of climate change will improve. At this stage, first priorities are established to clarify and focus on the climate change adaptation choice. Port and airway operators, as well as other stakeholders, must clarify their roles and duties and take decisive action.

This study contains limitations in terms of source data, information, and references regarding assessing port readiness in Indonesia to face climate change. As a result, more research on establishing port readiness in dealing with the effects of climate change is required. In terms of infrastructure, management, and the environment. Limitations in this research include the limited availability of primary data and previous research so that it can influence the expected results. The data collection method using an FGD scheme could cause personal bias, and a small sample of respondents will influence the formulation of port adaptation strategy recommendations for facing climate change.

Another limitation of this study is the lack of long-term data. Climate change is a long and ongoing process. Therefore, this study is limited if it only uses data over a short period of time. This can lead to a lack of precision and accuracy in predicting long-term trends or in formulating effective strategies for the future in the long term. The lack of social and economic data related to the port in the face of change is also a limitation in this study, so that the resulting analysis cannot be in-depth and does not consider the needs and welfare of the community around the port.

In addition, the difficulty encountered in this research is that there is not much research on port adaptation in the face of climate change both technically and economically in Indonesia, so the references for this research are very limited.

8. CONCLUSIONS

Based on the PIANC standards and the findings of this research, Tanjung Emas Port demonstrates a level of preparedness to address climate change challenges. However, further investigation into the resilience of port infrastructure is necessary to ensure its long-term sustainability. Additionally, fostering synergy among port users, operators, and stakeholders is crucial for building a robust resilience system.

This research offers valuable insights for port managers and decision-makers in developing effective climate adaptation strategies. The findings and recommendations can inform the creation of appropriate policies and actions to promote the realization of resilient ports. A multi-faceted approach, combining various methods and perspectives, is essential for achieving this goal. While port authorities have disaster contingency plans, identifying specific port infrastructure vulnerable to disasters remains a priority for future research. By addressing these gaps, we can enhance the overall resilience of Tanjung Emas Port and serve as a model for other ports facing similar climate challenges.

CONTRIBUTIONS

Destianingrum Ratna Prabawardani : Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Visualisation, Writing (Original Draft), Writing (Reviewing & Editing), Aprijanto: Conceptualization, Supervision, Writing (Review &Editing), Tjahjono Prijambodo:, Resources, Investigation, Ibnu Fauzi: Data Curation, Formal Analysis, Resources, Writing (Review & Editing), Maria Nooza Airawati: Data Curation, Resources, Buddin Al Hakim: Data Curation, Investigation, Danang Ariyanto: Investigation, Validation, Resources, Writing (Review & Editing), Muhammad Alfan Santosa: Supervision, Muhammad Irfani: Supervision , Ridwan Budi Prasetyo: Supervision, Fajar Yulianto: Supervision (Writing), Nofika Cahyani Putri: Visualization, Catur Indra Sukmana: Project Administration, Eny Cholishoh: Project Administration, Cahyarsi Murti Aji:Validation, Eko Kustiyanto: Investigation, Bakti Wibawa: Supervision, Nurkhalis Rahili: Visualization, Joko Sutopo: Funding Acquisition

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