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A Review of Climate Change Impacts to the Crude Oil Sector: Challenges, Prospects and the Way Forward

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Abstract: Since its operations have a profound impact on every productive area of the economy and the population, the oil industry is a crucial component of the global energy sector. Crude oil and oil products continue to be the primary energy source for the production of electricity and the primary source of thermal power, and they have long accounted for the majority of gross inland energy consumption. The oil industry is already being negatively impacted by climate change, which jeopardizes its ability to operate reliably and expand. Climate change and extreme weather phenomena, such as hurricanes, high winds, lightning strikes, storm surges, flooding, etc., represent an additional challenge to the oil supply chain from upstream to downstream because oil infrastructure has multi-decadal lifetime forecasts. This study reviewed frameworks for assessing climate change risk, examined how climate change is affecting oil infrastructure, and identified a knowledge deficit. In a thorough danger threshold matrix, the study provides an overview of the relationships between climate and the design, operational, and service thresholds for the oil sector. The study of existing risk assessment approaches that take into consideration current regulatory frameworks and dependencies with other infrastructures results in recommendations for sector resilience, mitigation, and adaptation.

Keywords: Climate Change, Crude Oil Sector, Hazard, Impacts, Temperature, Flooding.

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1. INTRODUCTION

Since its operations have a significant impact on all the productive areas of the economy and the population, the crude oil business is a crucial component of the global energy sector. Since they continue to be the primary energy source for the production of electricity and the primary source of thermal power, crude oil and oil products have long accounted for the majority of gross inland energy consumption [1,2]. According to the EU-CIRCLE project's findings [3], climate change (CC) is predicted to hasten the aging and deterioration of oil infrastructure processes, from oil extraction and upstream to storage, refining, and distribution processes, resulting in a shorter lifecycle and lower service level as well as the potential for major disasters. Globally, extreme weather events such high winds, hurricanes, droughts, flash floods, storm surges, and forest fires are predicted [4], and they could have serious off-site repercussions like hazardous releases, oil spills, fires, or explosions (Natech incidents) [5-7]. In light of the fact that, according to [8,] CC is the second-most important factor that could make a Natech event more likely. Therefore, steps should be taken to ensure that oil infrastructure is resilient, that oil sector investments are secure, and that people and the environment are safe.

Additionally, given the possible effects on the biosphere and the global economy, climate change is at the top of every nation's agenda [8,9]. Therefore, all national governments and international organizations support a quick decarbonization process [10,11]. However, in the short term, the energy input needed for such a drastic change will have to come from the current energy matrix, which continues to be predominately composed of fossil fuels (approximately 90% of the world's energy consumption in 2019) [12,13]. From this point forward, the energy sector will have to deliver enough net energy for the economy's everyday operations in addition to the additional investments that will be needed in low-carbon technologies and infrastructures [13]. This "overhead" of energy (mostly fossil) translates into an overhead of carbon dioxide (CO_2) emissions, which will determine the bio-physical pay-back time of the energy investment, i.e., the amount of time it will take for alternative energy sources to make up for the additional CO_2 emissions produced by developing and using green infrastructure and technologies [14].

2. Climate Change Tendency

Climate change is recognized to amplify vulnerabilities in coastal and offshore infrastructure [5,7]. In coastal and offshore regions, key drivers of climate change can be classified as air and water temperature, precipitation patterns, extreme storm events, and sea-level rise [7]. The global mean sea level (GMSL) has increased by seven (7) inches since 1880 due to glaciers melting and thermal expansion caused by rising ocean heat content. In 2020, GMSL was 3.6 inches higher than the 1993 average. The rate of rising water levels has accelerated since the 1960s, mainly influenced by sea-level changes in the South Atlantic and Indo-Pacific. The global mean sea level rose from 2.2 mm/year in 1993 to 3.3 mm/year in 2014. Anthropogenic activities contribute to climate change, leading to extreme events such as flooding [14]. Additionally, greenhouse gas emissions can result in long-term committed sea-level rise by trapping the heat from the sun, which is absorbed by oceans and leads to the warming of sea surface temperature.

Moreover, the average global surface temperature anomaly in 2020 (combining land and ocean temperatures) was 0.98 ◦C [17]. Compared to the period of 1850–1900, the mean global surface temperature increased by 0.85 ◦C in 1995–2014 and by 1.09 ◦C in 2011–2020 [17]. The global surface temperature trend from 1850 to 2015 indicates a consistent increase, although there was a "slowdown" observed from 1998 to 2013 [9]. Human activities are considered the primary driver of global warming, with human-induced warming reaching 1.07 ◦C in 2010–2019, while the change caused by natural forcing was only ±0.1 ◦C [17]. Extensive evidence shows that both the hottest and coldest extreme temperatures have changed in most land areas [15]. Additionally, the climate community is consistently interested in exploring the variability of global precipitation under climate warming due to its environmental implications [16]. The mean ocean and land total precipitations were 2.89 and 2.24 mm/day, respectively. Although there was no significant increasing trend in worldwide precipitation during this period, regional precipitation trends were diverse and exhibited spatial heterogeneity.

2.2 Climate Hazards

The possibility of climate-induced risks to infrastructures is estimated using the climate hazards, which also help to identify the operational or structural thresholds. They have been separated into two groups: climate drivers, which are the immediate results of either observational data or various models, and climate hazards, which are the immediate results of climate drivers.

2.3 Overview of the Oil Sector Critical Services

The operations involved in the exploration, extraction, refinement, transportation, and distribution of refined oil products around the globe (from upstream to downstream, as depicted in Figure 1) are included in the oil industry's supply chain. The activities of bringing crude oil to the surface are included in the upstream sector. The most popular routes of transportation (pipelines, rail, oil tankers, and trucks), storage, and wholesale distribution of petroleum products are all included in the midstream sector. The downstream sector also covers the delivery of fuel to other CI, retail and commercial clients, public services, etc., as well as oil refining procedures.

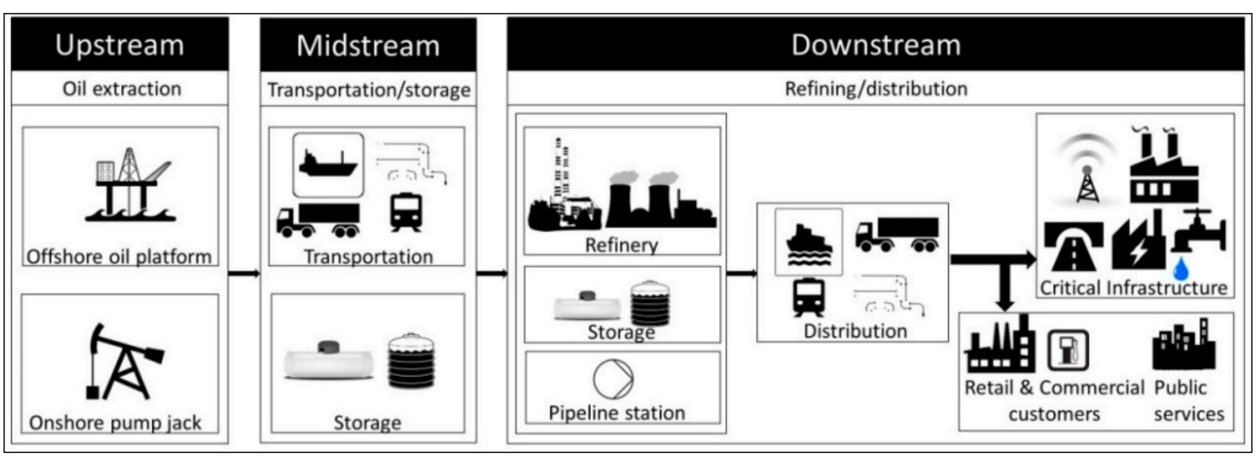

Figure 1: The oil supply chain, from upstream to downstream

2.4 Climate Change Risk and Adaptation Assessment Framework

Climate-related risks are identified by considering asset design thresholds and interconnections, as well as direct and indirect climate impacts, as illustrated in Figure 2. These assessments serve as the foundation for making risk-informed decisions regarding climate change adaptation in the oil industry and enhancing infrastructure resilience [18]. The oil industry is increasingly demonstrating a strong commitment to sustainable and resilient development by integrating extreme weather events into comprehensive risk management frameworks [19]. While most processes and facilities have been designed to withstand climate change risks, extreme events could exceed their design and operational limits. Numerous researchers have highlighted the potential for climate hazards to trigger chemical accidents, leading to the release of toxic, flammable, and explosive materials [20,21]. The combination of complex industrial designs and the projected increase in the frequency and intensity of extreme weather events due to climate change [22] may lead to even more devastating consequences in the future. Safeguarding the crude oil industry is a critical aspect of national security for many countries. For example, the European Program on Critical Infrastructure Protection [23,24] offers a systematic, network-based approach to risk identification and mitigation following the "all-hazards" principle. The SEVESO directive (Directive 82/501/EEC) establishes a comprehensive risk management system (Directive 2012/18/EU), requiring industrial risk management plans for the prevention of oil-related hazards.

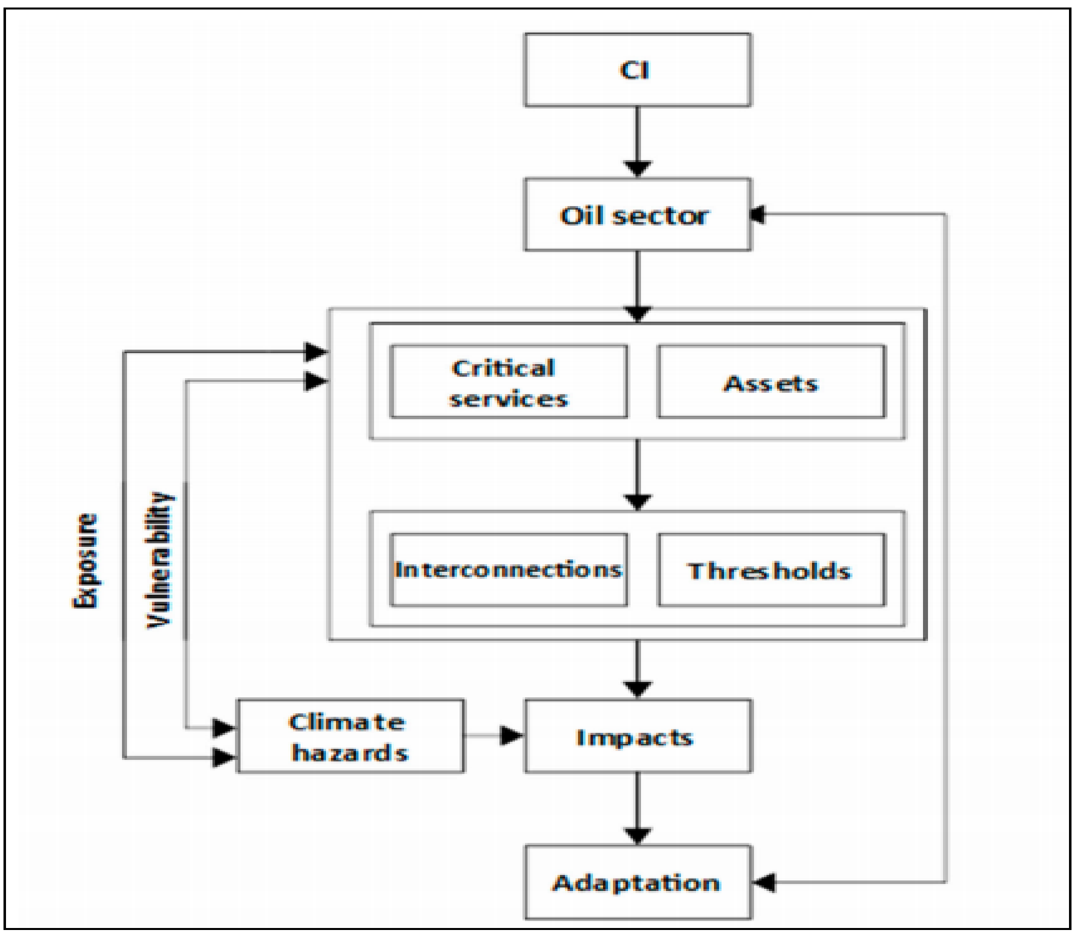

Figure 2: High level description of the oil sector adaptation and the performed analysis

2.5 Oil Sector's Dependencies and Interdependencies with Other Critical Sectors

A CC risk assessment that does not seriously examine CI dependencies and linkages may undervalue and devalue risks, per [25.26]. The increasingly interconnected, interdependent, and dependent character of CI introduces previously unknown dangers, fresh vulnerabilities, and openings for disruption across CI networks [27]. As seen in Figure 3, the transportation and distribution of crude oil, natural gas, electric power, water, telecommunication, industry, etc. are all significantly dependent on the oil sector, as are the aforementioned industries. The transportation and distribution of crude oil and refined products essentially uses every method of transportation available, including trucks, rail, oil tankers, vessels, and shipping containers. As a result, there may be delays and interruptions throughout the entire supply chain as a result of EWE. Electricity and electrical networks are crucial to the oil industry. Although the oil industries produce enough electricity from their integrated combustion engines to suit their needs, a significant amount of electricity is also given by the electric and distribution utilities through the transportation and distribution system. Additionally, water is used in relatively significant quantities at oil refineries, mostly for the cooling system. Despite the fact that the water needs of the oil sector are met by a self-running network and water from the sea or rivers, there is still a significant need for water excess. The water industry does indeed deliver potable water via the drinking water network, wastewater, or even flood water network.

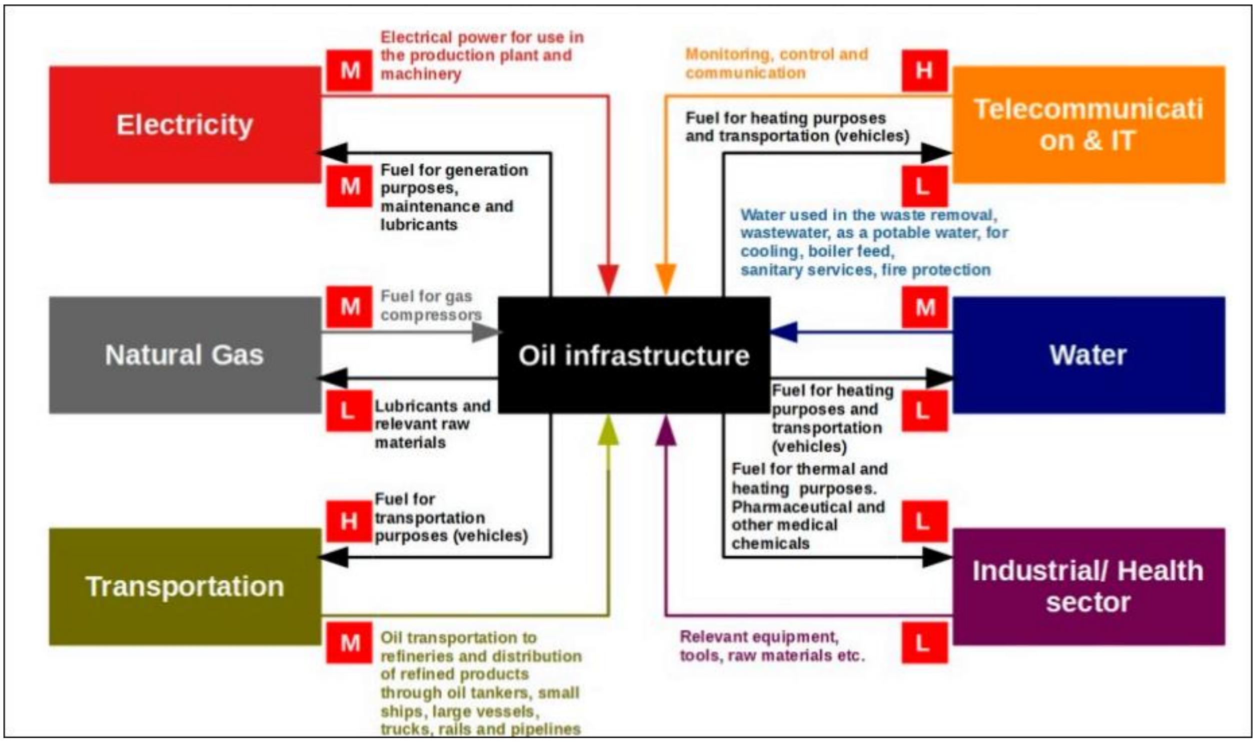

Figure 3: The interdependence of the oil infrastructure [29]

2.6 Climate Change Impacts on Coastal and Offshore Petroleum Infrastructures

An rise in global warming is predicted to cause climate change effects on oil and gas infrastructure in coastal and offshore regions [30]. Over the past few decades, the climate has changed more dramatically. Climate change has a substantial impact on petroleum infrastructure, according to earlier research [31]. The reliability of oil and gas extraction and the associated infrastructures is substantially impacted by the rising temperature. Permafrost thawing could affect how easily people can travel on ice, how stable buildings built on it are, and how much weight they can support [33]. The research of [32] estimated the infrastructure danger zones in the permafrost regions of the Northern Hemisphere by the year 2050. The findings indicate that over 70% of the infrastructure in the permafrost zone is situated in an area at high risk due to ground instability brought on by thawing, which might seriously harm these structures. Additionally, rapid warming makes land-fast ice form later, break up early, and thin the sea ice [28]. Additionally, a US oil company's attempt to start the first oil drilling operation in the Arctic waters was hampered in the Beaufort Sea region of the Arctic because there was insufficient sea ice to allow for the construction of the necessary transportation and extraction equipment. In 2021, permafrost melting caused over 23% of technical failures in Russia, which hampered the country's ability to produce oil and gas. Due to the extremely cold weather that was experienced in 2021, several production activities in oil refineries in Texas, USA, decreased by 2.4 million barrels per day [32]. Extreme temperatures may also exacerbate the degradation of construction materials, which could lead to maintenance issues with facilities such as roads, train lines, and buildings [33]. The severe rain and high humidity, on the other hand, could result in an unanticipated shutdown of the oil refinery process and an overflow of air filters, further harming downstream machinery. They may also cause structures to become weaker and raise the possibility of mold growth [30]. Additionally, there may be a greater chance of equipment electrical damage and structural damage to pipes [25]. Flooding brought on by torrential rain and severe storms also ruins oil refineries and storage tanks, which can lead to the spill of oil and other dangerous contaminants [33]. More than 72% of hydrocarbon output and such reserves are vulnerable to shifting rainfall patterns, flooding, and droughts in the Nigeria delta [33]. Refineries and offshore oil and gas facilities in Louisiana were impacted by floods in August 2021 as a result of Hurricane Ida [44]. The coastal infrastructure, such as tank batteries and ports, may be seriously endangered by the sea level risk [29]. In 2008, an increase in sea level of 61 cm had an impact on 64% of the port facilities in the Gulf of Mexico, according to the "Climate Change Science Program" report [31]. In addition, hurricanes and tropical storms raise the wave heights, which causes coastal infrastructure to erode and submerge. Damage to drilling risers, subsea wells, and production structures are further possible repercussions [25]. Hurricanes also caused damage to offshore pipelines. The coastal oil and gas infrastructure also sustained surface damage as a result of hurricanes. Gasoline supply stations experienced difficulties during Hurricane Rita, including damage to the pumping stations and canopy [32].

Figure 1. An extreme storm impacts on coastal and offshore petroleum infrastructure; (A) offshore platforms were damaged during a hurricane off of Louisiana [34]; (B) oil tanks were carried away by storm surge that caused over 1,750,000 L of oil release [35]); (C, D) before and after operating platform were destroyed during the 2005 hurricane season [36]

3. RECOMMENDATIONS

The major components of how CC is projected to affect the crude oil sector have been outlined in this paper. Comprehensible actions on behalf of the crude oil business are necessary for the most effective response to CC-related concerns. I suggest that you do the following:

i. The crude oil sectors ought to make riskaware choices, such as long-term planning and readiness in the face of significant uncertainty.

i. To increase the body of knowledge for CC research, the crude oil industry should take the initiative in creating local, regional, and/or topical forums.

ii. Future study should focus on creating a universal framework to provide a clear knowledge and assessment of the dependencies, interdependencies, and cascading effects in the oil sector, helping to effectively determine the CC of the oil business.

4. CONCLUSION

This study illustrated the patterns of the changing global climate in terms of temperature, precipitation, floods, severe storms, and sea level. This study also described how the coastal and offshore oil and gas infrastructures are anticipated to be impacted by these climate change factors. Additionally, it included a broad review of the potential effects of CC and associated risks on the petroleum industry, estimating the ability to significantly disrupt the facilities and operations of the oil industry as well as the lifetime and service level. The study also examined asset and service vulnerabilities, the direct and indirect dependencies on other crucial sectors, and the effects of climate conditions on oil CI. Climate change can raise the risk of oil spills in coastal and offshore regions, even though its effects on the frequency of oil spills are still unknown. Therefore, while taking into account the effects of climate change, mitigation and adaptation strategies should necessitate updating facility design standards in order to safeguard and relocate the vital infrastructure. Therefore, it is essential to create thorough risk assessments that can evaluate the dangers brought on by climate change and precisely identify and minimize vulnerabilities in the oil and gas infrastructure in coastal and offshore regions. As a result, climate change poses a severe threat to the coastal and offshore oil and gas infrastructure and increases the likelihood of an oil leak, necessitating the adoption of adequate measures to stop and lessen the consequences.

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