Shipping's Energy Transition:

Strategic Opportunities in Mexico

By Global Maritime Forum
& University College London

For the P4G Getting to Zero Coalition Partnership

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About the Getting to Zero Coalition

The Getting to Zero (GtZ) Coalition, a partnership between the Global Maritime Forum and World Economic Forum, is a community of ambitious stakeholders from across the maritime, energy, infrastructure and financial sectors, and supported by key governments, IGOs and other stakeholders, who are committed to the decarbonization of shipping.

The ambition of the Getting to Zero Coalition is to have commercially viable ZEVs operating along deep-sea trade routes by 2030, supported by the necessary infrastructure for scalable net zero-carbon energy sources including production, distribution, storage, and bunkering, towards full decarbonization by 2050.

About Partnering for Green Growth and the Global Goals 2030

The Partnering for Green Growth and the Global Goals 2030 (P4G) is a global delivery mechanism pioneering green partnerships to build sustainable and resilient economies. The P4G mobilizes a global ecosystem of 12 partner countries and 5 organizational partners to unlock opportunities for more than 66 partnerships working in five SDG areas: food and agriculture, water, energy, cities and circular economy.

About the Global Maritime Forum

The Global Maritime Forum (GMF) is an international not-for-profit organization dedicated to shaping the future of global seaborne trade to increase sustainable long-term economic development and human wellbeing.

About Friends of Ocean Action

Friends of Ocean Action is a unique group of over 55 global leaders from business, international organizations, civil society, science and academia who are fast-tracking scalable solutions to the most pressing challenges facing the ocean. It is hosted by the World Economic Forum in collaboration with the World Resources Institute.

About the World Economic Forum

The World Economic Forum (WEF) is the International Organization for Public-Private Cooperation. The Forum engages the foremost political, business, cultural and other leaders of society to shape global, regional and industry agendas. It was established in 1971 as a not-for-profit foundation and is headquartered in Geneva, Switzerland. It is independent, impartial and not tied to any special interests.

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Environmental Defense Fund Europe is an affiliate of Environmental Defense Fund (EDF), a leading international non-profit organization that creates transformative solutions to the most serious environmental problems. Since 1967, EDF has used science, economics, law and innovative private-sector partnerships to bring a new voice for practical solutions.

About University College London

University College London (UCL) Energy Institute (EI) Shipping Group aims to accelerate the shipping transition to an equitable, globally sustainable energy system through world-class shipping research, education and policy support. The group specializes in multi-disciplinary research anchored in data analytics and advanced modelling of the maritime sector.

About International Association of Ports and Harbours

The International Association of Ports and Harbours (IAPH) was formed in 1955 and over the last sixty years has grown into a global alliance representing over 180 members ports and 140 port-related businesses in 90 countries. The principal aim of IAPH revolves around the promotion of the interests of Ports worldwide, building strong member relationships and sharing best practices among our members.

About UMAS

UMAS delivers consultancy services and undertakes research for a wide range of clients in the public and private sectors using models of the shipping system, shipping big data, and qualitative and social science analysis of the policy and commercial structure of the shipping system. UMAS's work is underpinned by state-of-the-art data supported by rigorous models and research practices, which makes UMAS world-leading on three key areas; using big data to understand drivers of shipping emissions, using models to explore shipping's transition to a zero emissions future and providing interpretation to key decision makers.

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Disclaimer

This report is from the P4G-Getting to Zero Coalition Partnership project, a project between the Global Maritime Forum, the Friends of Ocean Action, the World Economic Forum, University College of London, Environmental Defense Fund, and the International Association of Ports and Harbours. The views expressed are those of the authors alone and do not represent the opinions or views of the partners involved.

Foreword

As the world's maritime fleet transitions towards more sustainable fuels, Mexico's ability to capitalize on the opportunities associated with this transition in the coming years will become increasingly important. As countries around the world explore alternative forms of energy and develop new technologies to run on sustainably sourced fuels, Mexico is in a unique position to leverage its substantial renewable energy potential to benefit from shipping's decarbonization. Acting now would strategically place Mexico at the forefront of this movement, allowing it to become a world leader and advance its emerging green fuel economy.

With access to both the Pacific and Atlantic Oceans, well-established shipping routes and trade relations to multiple continents, Mexico can tap into new markets and establish itself as a global energy hub and provider of green fuels. Realizing this potential can accelerate the transition to cleaner forms of energy across the wider economy, creating several opportunities for the country.

In supporting national efforts towards the production and use of these new fuels, Mexico could, at the same time, address key development goals and achieve wider national ambitions relating to the reduction of air pollution, increased energy security and independence, growth in its green job market, diversifying its value-added export products, building national capacity and skills, and generating new forms of foreign direct investment.

To unlock these opportunities, Mexico could support industry initiatives and public-private collaborations that promote the deployment and scaling of new energy solutions and fuel technologies. Essential to this is a facilitative policy and financial framework capable of effectively motivating and convening key actors across sectors and value chains.

As local stakeholders and members of the Steering Committee, we welcome the findings outlined in this report and call on relevant actors to engage further in order to realize these opportunities for Mexico.

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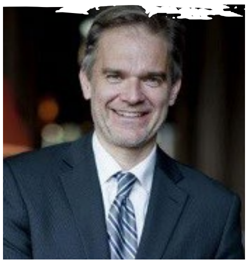

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Executive Summary

Mexico at a crossroads – the chance to become a future powerhouse in Latin America to produce green fuels for international shipping.

Ideally placed between the Pacific and Atlantic Oceans, Mexico enjoys an advantageous geographical position with easy access to key shipping routes, close proximity to large trading partners i.e. the United States and Canada, as well as abundant natural resources. Through strategically leveraging these conditions, Mexico has become Latin America's 2nd largest economy and the 15th largest economy in the world, with over a third of Latin America's total exports stemming from Mexico.

In recent years, the global maritime industry has made significant progress in the development of new innovations and technology to address the challenge of reducing sector emissions by switching to low- and zero-carbon fuels. With this change comes opportunity for countries like Mexico, which is uniquely placed to supply, at scale, green fuels for this energy transition. As the world's 12th largest contributor to greenhouse gas (GHG) emissions in 2015, Mexico could also benefit from reducing its national emissions, of which maritime activities account for about 2.9% of Mexico's 2018 National GHG emissions. Not only would this reduce domestic emissions, but also the country's reliance on the import of natural gas and refined petroleum products from other countries like the United States; thereby increasing Mexico's overall energy security and independence.

New estimates show that Mexico's maritime activities account for 2.9% of its 2018 National GHG emissions.

Figure 1: Maritime activity around Mexico's coastal waters (2018).

Scalable zero emission fuels (SZEF) such as green hydrogen and green ammonia are considered the most promising fuels for the industry's transition. These fuels will require substantial amounts of renewable energy for their production, storage, and distribution.

With Mexico's large amounts of renewable energy in the form of solar, hydropower, and wind, the country is well positioned to supply these fuels. Taking advantage of these resources could see the country producing between 932 – 4,992 Terawatt hours per year (TWh/y) of renewable energy by 2030. This represents more than enough energy to meet domestic electricity demand, decarbonize local industries, as well as contributing to the decarbonization of domestic and international shipping.

Assuming 5% of the global fleet transitions to SZEF by 2030, then the green energy demand for vessels in Mexico would represent about 3.4 TWh/y, which conservative calculations shows is only 0.4% of Mexico's total renewable potential.

Strategic Business Opportunities

The maritime energy transition represents several strategic business opportunities that could bring substantial economic, social, and environmental benefits. Broadly speaking, reducing shipping emissions is an opportunity for Mexico to decrease its overall emissions and fulfill its climate and energy commitments while also driving industrial development and contributing towards other national objectives. Realizing this would have benefits far beyond shipping; improving energy security by harnessing local resources and helping to catalyze a low carbon economy in Mexico by supporting decarbonization of other sectors and helping to boost job creation.

Estimates show that development of green fuel infrastructure to serve Mexico's shipping sector could attract investment up to $37-53 billion MXN ($1.9-2.7 billion USD) in onshore infrastructure by 2030.

By capitalizing on its renewable potential and its existing trade relations, Mexico could establish a competitive advantage in the production of SZEF. Being part of the transition for shipping and investing in itself, Mexico could create new revenue streams from SZEF exports and bunkering, establish green hubs and ports, as well as open possibilities for green corridors along key shipping routes. After extensive consultation with key Mexican stakeholders, three opportunities for Mexico were identified to be the port of Manzanillo, El Bajío industry hub, and the region of Baja California.

Port of Manzanillo

Located in the State of Colima on the West Coast, the port is one of the busiest ports in Mexico and the 3rd largest port in Latin America. It acts as the principal entrance for the handling of internationally traded goods for Mexico's Central and Bajío Zones. Largely handling containership traffic, Manzanillo is Mexico's largest port in terms of maritime energy usage, demanding 11 TWh of fossil fuel energy per year.

Manzanillo was selected due to the type and amount of maritime traffic, its location next to large solar potential, synergies with surrounding hard-to-abate industries, and the existing interest in the port's expansion. Given this, the Port of Manzanillo has the opportunity to contribute to shipping's energy transition through the production, use, bunkering, and export of SZEF.

Leveraging synergies between producing SZEF for containerships and the local mining and cement industries can aggregate demand and increase economies of scale for local green hydrogen and ammonia production. This would enable the port to become a green hydrogen hub for the production and export of SZEF.

El Bajío Industry Hub

Coupling green hydrogen production activities inland to other centrally based industries is a good way to not only decarbonize manufacturing in Mexico but also green logistics and supply chains, thereby reducing scope 2 and 3 emissions. Mexico has multiple initiatives taking place away from coasts that can indirectly support shipping decarbonization.

DH2 Energy is a company focusing on developing green hydrogen projects in Europe and the Americas. The location of these planned green hydrogen activities is adjacent to many automobile producers in Central Mexico. In particular, San Luis Potosí and Guanajuato are strong automotive industry hubs, with key international automobile producers active in the El Bajío region. In addition, these areas also have significant mining and steel industries. These three sectors could act as significant offtakers for locally produced green hydrogen.

DH2 Energy plans to sell green hydrogen to hard-to-abate national industries and is exploring the opportunity of exporting green hydrogen to Europe and Asia, among others. This necessitates connections to port infrastructure capable of exporting these fuels, most likely along both of Mexico's coastlines.

Baja California

Baja California is the 7th largest economy in Mexico, with several unique features that make it a promising regional opportunity, including its energy grid linked to the United States, renewable energy potential, concentration of heavy industries and manufacturing, political will, and existing pilot projects.

The State has the opportunity to produce and operationalize SZEF across multiple sectors, as well as take steps to decarbonize its small boat fleet. With some of Mexico's highest solar and wind potential, green hydrogen and green ammonia can be produced onsite and then transported across the State for domestic and industrial use.

This would reduce imports of natural gas from the United States as well as offer significant cross-sectoral benefits for the decarbonization of local mining, cement, manufacturing, tourism, and fishing. If scaled, Baja could supply green fuels directly to key ports for use onboard international vessels and potentially for export as the demand for SZEF grows.

Recommendations

Currently, the economy of Mexico depends on the production and use of the country's fossil fuel resources. To appropriately leverage these strategic opportunities, there are several key actions that can be taken to advance zero emission shipping in Mexico and globally. These actions can be taken by port actors and authorities, governments, financial institutions, as well as maritime and wider industry players interested in leveraging the renewable energy potential of Mexico. With appropriate incentives and targeted action towards encouraging investments into renewable energy and fuel production, Mexico can gain a competitive advantage in the bunkering and export of SZEF in Latin America.

PORTS

Develop collaborative port plans & strategies that exploit the synergies of addressing both air pollution and decarbonization objectives
Port authorities could develop collaborative plans and strategies in collaboration with national stakeholders, and local communities that explicitly demonstrate engagement with decarbonization, as well as objectives to reduce port pollution.

Increase coordination & guidance between main ports in Mexico
Through improved guidance from the State, sustainable port services and infrastructure in Mexico can become more efficient, competitive, and cost-efficient.

Explore options for port electrification and mitigation of air pollution
Switching port activities wherever possible to rely mainly on electrical energy from renewable sources can reduce local GHG emissions, maintenance, and energy costs.

Prepare to source or produce SZEF for bunkering, port use & export
First movers are already planning to operate ships on SZEF. Preparing to source or produce such fuels can help the country realize strategic opportunities both domestically as well as a possible export product to other countries or regions.

Encourage ports to become green nodes in a multi-sector network
Creating a port ecosystem that acts as a green node for multiple sectors, whereby the port can offer sustainable services using low- to zero-carbon emission energy sources for vessels and land-based transportation alike, will be important for the transition.

POLICY

National

Update policies to reflect climate commitments as part of long-term national planning
Aligning maritime policies, in both national and international settings can increase policy coherence and unlock investment. The maritime sector should be included within the larger decarbonization agenda and explicitly addressed within national policies and plans.

Define a national hydrogen strategy or roadmap
Establishing a National Hydrogen Roadmap with defined targets and actions, planned infrastructure development, transition pathways, coordination between involved parties, governance structures, and business models would likely unlock finance and leverage Mexico's potential as a SZEF producer and exporter.

POLICY

Reduce permitting & administrative hurdles
Through easing or removing barriers that hamper progress, it is possible to further stimulate investments in green energy projects. Government could look to put in place measures that facilitate access to energy infrastructure, especially for the development of hydrogen projects.

Encourage public-private collaborations
Stakeholders argued that Mexican authorities and involved stakeholders (energy producers and industry representatives, system operators, regulators) should seize the global momentum around the prospects of shipping decarbonization and undertake technical and economic cooperation projects.

Prepare labor capacity and skills to handle SZEF and technologies
There is a clear need to foster dedicated training, academic-industry partnerships, and international cooperation in higher education, research, development, and innovation to upskill port employees on the handling of SZEF.

International

Support the development of SZEF safety standards & authorizations
Such standards and labels are required to harmonize technology specifications for the industry and monitor safety of SZEF production, handling, and transport.

Collaboration to secure effective GHG policy at the IMO
Investments and innovation could be increased through enhanced ambition and new policies e.g. fuel standards and market-based measures, developed at the IMO. By working with other ambitious member states to support this, Mexico can better enable shipping's just and equitable transition.

Sign the Clydebank Declaration & develop Mexico's first green corridor
Based on its renewable energy potential, trade relations with other regions, and location along busy shipping routes, Mexico could sign the Clydebank Declaration to signal its interest in international collaboration on early adoption.

FINANCE

Explore national fiscal incentives for first movers
Stakeholders suggested exploring fiscal incentives to support first movers who take higher risks. This would support the creation of an environment that triggers investments in a high renewables-based system.

Boost energy security through private renewable electricity generation
Removing barriers to the private production of large-scale renewable electricity and relaxing the regulatory framework is essential to build Mexico's green energy capacity and scale its potential, including in SZEF production.

Leverage international development finance to prioritize funding of strategic projects
Mexico could leverage its experience in accessing development support, which can be utilized for the benefit of its maritime and land-based industries in scaling SZEF production.

INDUSTRY

Stimulate momentum through lobbying & engagement
Maritime industries can engage with public bodies to expressly show interest in scaling SZEF production and related technologies, as well as help educate government on the multitude of environmental, social, and economic benefits of transitioning towards a low/zero GHG economy and shipping industry.

Target decarbonization activities in strategic locations
Engagement with decarbonization efforts in any sector tends to vary by region and by coast in Mexico. Industry actors could leverage strategic locations within Mexico that have a convergence of favorable factors that would support pilot initiatives.

Aggregate SZEF demand
Maritime industries, though substantial offtakers themselves, could look to coordinate with other sectors across the value chain, especially automotive, mining, manufacturing, and cement producers, in order to aggregate SZEF demand.

Further develop associations focused on SZEF and electrification opportunities to drive market change
Gathering industry actors into non-competitive fora for collaboration can send collective demand signals to fast track decarbonization action. Interested industries could join initiatives like the Mexican Hydrogen Association, which was launched in 2021, and is dedicated to the development of green hydrogen and related business.

Explore alternative business model options
Industry actors could seek new and alternative business models – such as book and claim systems, subscription services, and amending shipping contracts – that reduce high barriers to entry or adoption for SZEF technology.

Building connections to the global maritime energy transition would allow Mexico to establish itself as a global leader in this space through engaging in green fuel production and bunkering. Creating this infrastructure would drive Mexico's ability to leverage this transition and utilize its huge renewable potential to make inroads on several national objectives. Unlocking international finance, easing regulatory hurdles, establishing collaborative partnerships, and investing in renewable energy and climate-proof projects will be fundamental in the years to come.

Shipping's energy transition towards green, alternative fuels is already taking place, with multiple initiatives and new developments announced monthly. Discussions at the international level are already pushing for higher decarbonization targets, making it clear that shipping's reliance on fossil fuels will see an end in the next decades. With such an approaching shift on the horizon, Mexico is faced with a choice to prepare now and reap future gains or risk higher costs to catch up later. As other countries in South America take steps to prepare their own bunker supply chains and engage with the international shipping sector, Mexico should take quick and strategic action if it seeks to position itself as a competitive producer and exporter of SZEF. The actions outlined above could support Mexico in its energy security efforts and becoming a key zero-carbon bunkering hub in Latin America.

Abbreviations

AIS	Automatic Identification System
BC	Black Carbon
CAF	Development Bank of Latin America
CAMIMEX	Mining Chamber of Mexico
CFE	Federal Electricity Commission
CH_4	Methane
CIMARES	Inter-Secretarial Commission for the Sustainable Management of Seas and Coasts
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	CO_2 equivalent
ECA	Emission Control Area
EEZ	Exclusive Economic Zone
EF	Emission Factor
EIB	European Investment Bank
GHG	Greenhouse Gas
GWh/y	Gigawatt hours per year
H_2 MEXICO	Mexican Hydrogen Association
HFO	Heavy fuel Oil
HFO_{eq}	Heavy fuel Oil equivalent
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
IDB	Inter-American Development Bank
IDZ	Industrial Development Zone

IFC	International Finance Corporation
IHS	Information Handling Service
IMO	International Maritime Organization
INECC	National Institute of Ecology and Climate Change
INEGYCEI	National Inventory of Greenhouse Gases and Compounds
IPCC	Intergovernmental Panel on Climate Change
LHV	Low Heating Value
LNG	Liquified Natural Gas
MBM	Market-based measures
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
N_2O	Nitrous Oxide
NADBANK	North American Development Bank
NDC	Nationally Determined Contribution
NMTP	National Maritime Transport Policy
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
PEMEX	Mexican Petroleum Company
PM	Particulate Matter
PNMCM	National Policy of Seas and Coasts of Mexico
PPIAF	Public-Private Infrastructure Advisory Facility
PROFEPA	Federal Attorney for Environmental Protection
QA	Quality Assurance
QC	Quality Control
SCJN	Supreme Court of Justice of the Nation
SEMAR	Secretariat of the Navy
SEMARNAT	Secretariat of Environment and Natural Resources
SENER	Secretariat of Energy

SEZ	Special Economic Zone
SFC	Specific Fuel Consumption
SGM	Shipping Geospatial Model
SOG	Speed Over Ground
SO_x	Sulfur Oxides
SZEF	Scalable Zero Emission Fuels
TWh	Terawatt hours
USMCA	United States-Mexico-Canada Agreement

Section 1

The Need for Maritime Decarbonization

Climate change is the biggest challenge faced by humanity this century. The work of the Intergovernmental Panel on Climate Change (IPCC) has highlighted and evidenced the severe impacts of climate change that are occurring all over the world. These impacts are expected to increase in intensity, frequency, and danger unless an energy transition is implemented across all sectors [1]. The IPCC suggests that avoiding the worst-case scenarios means limiting the rise in global temperature to around 1.5°C. To do so, "Global net human-caused emissions of carbon dioxide (CO_2) would need to fall by about 45% from 2010 levels by 2030, reaching at least 'net zero' around 2050" [2][3]. Multiple countries in Latin America have already committed or pledged to reach net zero or carbon neutrality by 2050, including Argentina, Belize, Brazil, Chile, Colombia, and Ecuador [4].

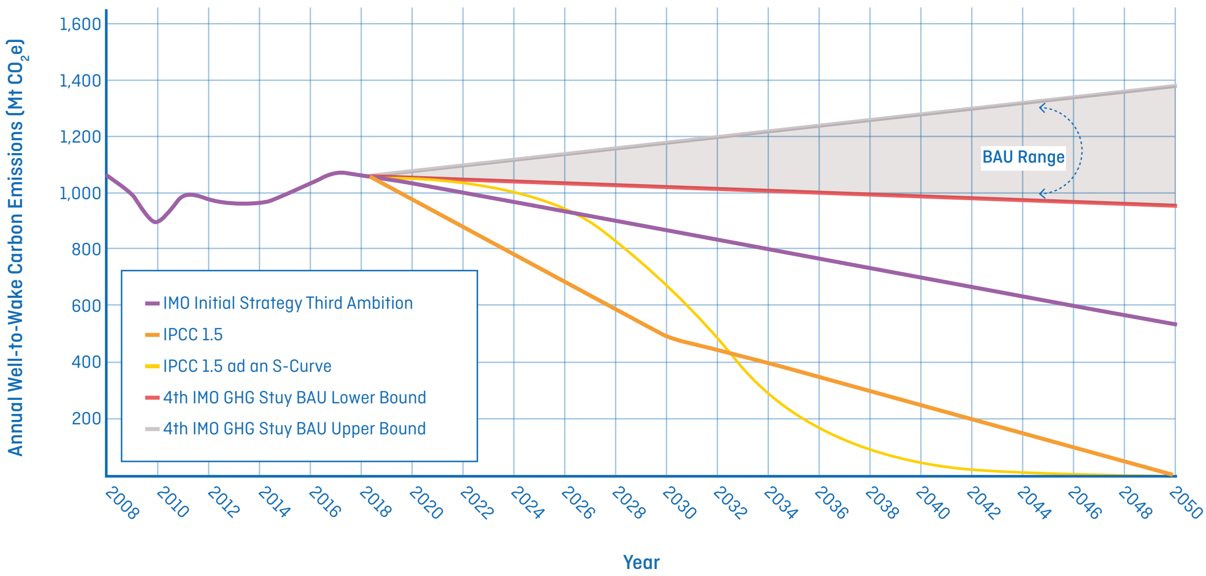
In 2015, the Paris Agreement set the goal to limit global warming to well below 2.0°C and preferably 1.5°C. More recently, at the 2021 United Nations Conference of Parties (COP26), shipping and its contribution to international climate change was highlighted as a key sector to tackle in the coming years. Indeed, the IPCC's most recent work highlights the role of the shipping sector and actions needed to enable its decarbonization [5]. It is clear shipping, as a sector, will need to play its part in the global decarbonization and energy transition if this goal is to be achieved.

Regional and global maritime transport effectively connects economies through the efficient movement of goods, accounting for 80-90% of the world's trade [6][7]. In doing so, the shipping sector emits between 2-3% of the global greenhouse gas (GHG) emissions – and contributes between 12-13% of sulfur and nitrogen oxides emissions to global air pollution [8][9]. Fueling this movement is a $140 billion USD per year energy industry that supplies the shipping sector with 4-5 million barrels of oil every day[1] [10].

Seaborne trade has seen an average annual growth of about 3.2% between 2011 and 2019, meaning that more than 13,000 new commercial ships[2] have entered operation in the past decade with the majority powered by fossil fuels [11]. Recent projections indicate that by 2050, shipping emissions will increase by between 90-130% from 2008 levels (see Figure 1) [9]. With an average lifespan of around 25 to 30 years, ships are considered to be long-life assets. Depending on the type of engine used in these vessels, the cost of retrofitting them to run on alternative fuels could be substantial. To avoid fossil-fueled ships becoming stranded assets, there is an urgent need to implement measures to facilitate shipping's transition and reduce emissions substantially [12]. Actions to support this will be both manufacturing zero emission vessels as well as retrofitting existing assets.

1 Barrel contract price taken on the 17/01/2022 which was $84.20 USD.
2 Above 100 gross tonnage and typically with a length larger than 25 m depending on vessel construction.

Figure 1: Potential maritime Well-To-Wake[3] carbon equivalent emission pathways based on different scenarios, ambitions and climate change objectives. The grey area represent the emission range for the BAU case (based on [9]).



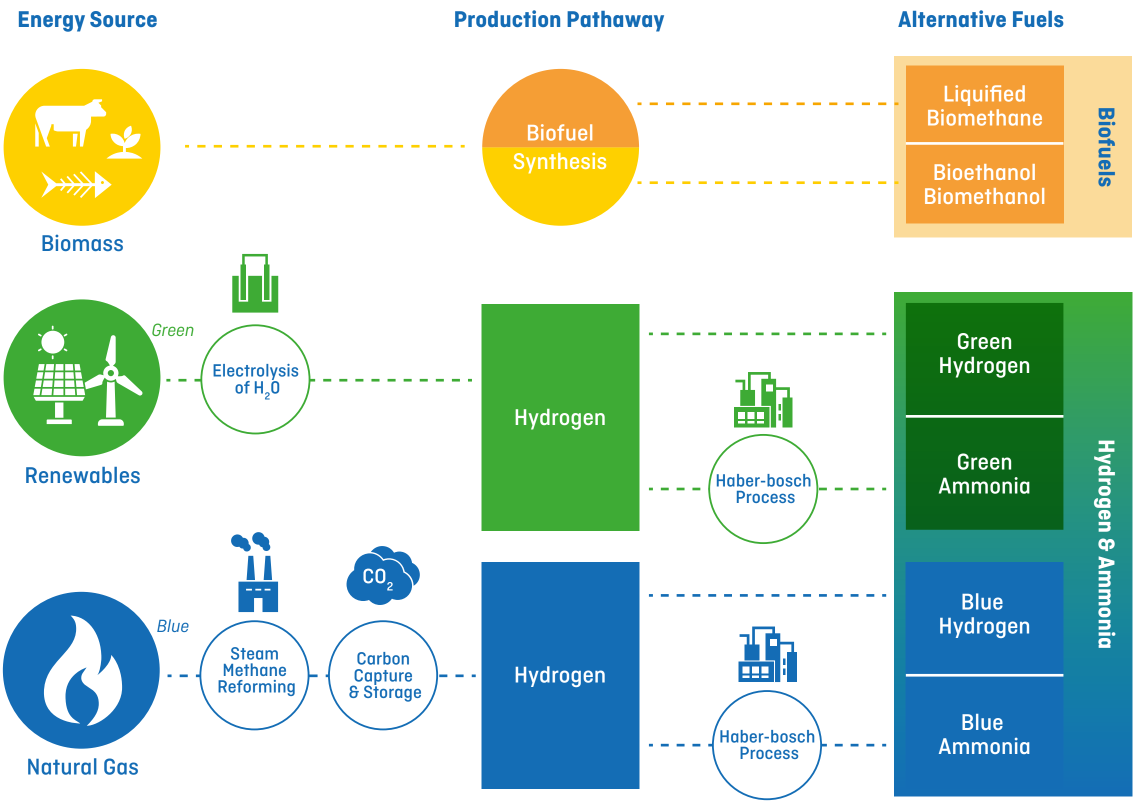
Importantly, increased energy efficiency and natural gas-based fuels alone will be inadequate to meet the Paris climate goals [5]. Thus, the future of international shipping will rely on the production and use of new scalable zero emission fuels (SZEF), a subset of fuels with (i) the potential to have zero GHG emissions on a lifecycle basis, taking into account the emissions from production, transport, storage, and use; and (ii) production processes capable of competitively supplying expected future demand. The scale of demand for such fuels is estimated to be around 200-300 Mt of Heavy Fuel Oil equivalent (HFO_{eq}) energy per year [13].

As shown in Figure 2 below, for larger vessels there are multiple new fuel types with the potential for use in the shipping industry. Though each of these new options come with their own challenges and require changes to the existing fuel and bunkering systems, some are perceived to be more promising than others. Biofuels are unlikely to be the main fuel choice, as they suffer from scalability challenges as well as competitive demand from other sectors. Rather, the most promising long-term options for shipping include green hydrogen and green ammonia for deep-sea going vessels as both can be used in fuel cells or internal combustion engines. Green ammonia, in particular, is thought to be the most suitable long-term option for decarbonizing international shipping though new engines and ship modifications are needed to run on this fuel and its safe handling poses concerns for the industry [14][15][16]. Smaller domestic vessels may also make use of green hydrogen, although other power options such as electrification are attractive.

3 They are the aggregation of upstream (i.e. well-to-tank) and downstream (i.e. tank-to-wake) emissions.

Though not displayed in the figure below, green methanol is also considered a strong contender by some, as methanol requires little to no engine modifications. However, it does require sustainable forms of CO_2 as an input for its production which is both limited in supply and costly. Given the costs linked to CO_2 feedstock, renewable methanol has much higher costs when compared to green ammonia. Significant reduction in costs associated with carbon capture technologies could make green methanol more competitive in the future [16][17].

Figure 2: Alternative fuels and their production pathways



Source: Inspired by World Bank [18]

Clearly a challenge and yet also an opportunity, the fuels transition in shipping can trigger investment, catalyze innovation, and create sustainable growth. This will require the sector to develop and build new vessels, integrate and adopt innovative technology solutions, develop new fuel supply chains and land-based infrastructure while leveraging synergies with other sectors seeking to decarbonize their commercial activities. In such a way, shipping itself can be seen as both a driver and consumer of these new fuels [19].

Steps are already being taken to build, demonstrate, and pilot new SZEF technology and prototypes. Large-scale dual-fuel SZEF marine engines running on green methanol are already in operation, while green hydrogen and ammonia engines are expected to be commercially available by the mid-2020s and large-scale fuel cell arrangements will likely be available later in the decade [20][21][22]. The costs of these new engines and fuel cells will initially be more expensive than the traditional fossil-fuel based ones currently used but will become more competitive over time as economies of scale are leveraged. Zero emission vessels are expected to enter service on a relatively small scale by or before 2030 and will become the mainstream option for new ship orders over the following two decades.

To prepare for this future, action is needed now, especially the expedited creation of SZEF infrastructure [23]. Under this light, it is important to highlight that the maritime energy demand and eventual energy mix in the upcoming decades is still highly uncertain due, inter alia, to technological maturity – for both energy and ship infrastructure, regulatory framework, market-based measures, and their secondary impacts.

«Decarbonizing shipping activities is a big global challenge. It requires working together to innovate, to imagine the pathway to move Mexico's maritime activities towards a zero-emissions future. Policy makers and industry should start conversations to envision how we want our ports, ships, and energy for sea transport to look on a net-zero emissions world.» – Claudia Octaviano Villasana (National Institute of Ecology and Climate Change (INECC))

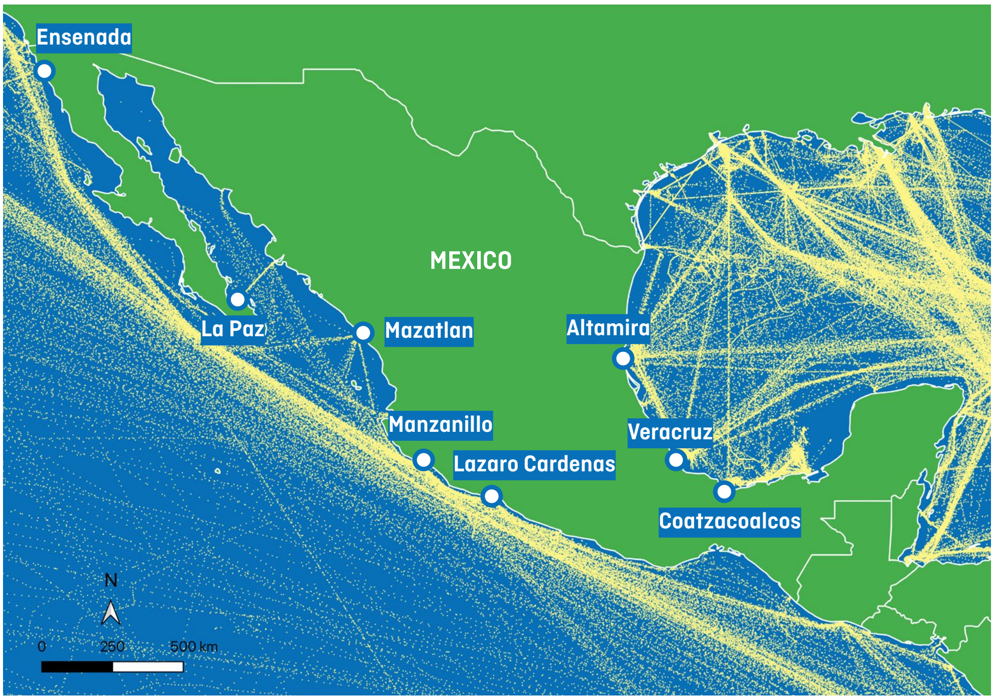
Section 2

Mexico: A Maritime Trading Nation

Mexico has two coastlines along busy domestic and international sea corridors critical to maritime transportation, linking the country to Asian, European, African and North and South American markets. Its geographical location presents a huge opportunity for investing in a diversified maritime market that needs to transition to lower carbon intensity (see Figure 3).

Mexico has 42 major seaports that play an active role in supporting trade [24], industrial activities including oil mining, fishing, and tourism. The national fleet is relatively small, comprised of about 2,697 vessels including fishing vessels, oil tankers, bulk carriers, general cargo, and container ships among others; however, Mexico sees significant maritime traffic from the international fleet [25][26]. In 2021, over 28,775 ships arrived in Mexican ports, the majority of which were bulk cargo vessels for minerals (3,353; 12%), agricultural goods (554; 2%) and other goods (7,664; 27%); followed by ferries (7,988; 28%), containerships (4,237; 15%), and liquid bulk carriers for petroleum products (3,487; 12%) and other liquid bulk (1,492; 5%), with a total of 286,114,290 of gross tons [27].

Figure 3: Maritime activity around Mexico's coastal waters (2018).



The country's key ports are Manzanillo, Lazaro Cardenas, Veracruz, Altamira, and Ensenada. Lazaro Cardenas was listed among the top 25 ports under the Container Port Performance Index for 2020 [28]. In 2019, Mexico saw the movement of 231,146 kt within its top 8 ports and 48,271 kt in cabotage ports [29]. In terms of bilateral connectivity, ships mainly travel to and from the United States, China, Colombia, Panama, The Republic of Korea, Peru, Ecuador, Japan, and Chile [26].

Mexico's container ports saw a significant jump in cargo handling in 2021, up to 7.85 million twenty-foot equivalent units across the country, representing a 21.6% increase from 2020 levels [30]. It should, however, be noted that trucking is the main mode of transport for international trade in Mexico given movement of goods to and from the United States [31]. Trucking mobilizes the majority of Mexico's cargo (57%), followed by shipping (31%), rail (~13%), and air transport (0.1%) [32].

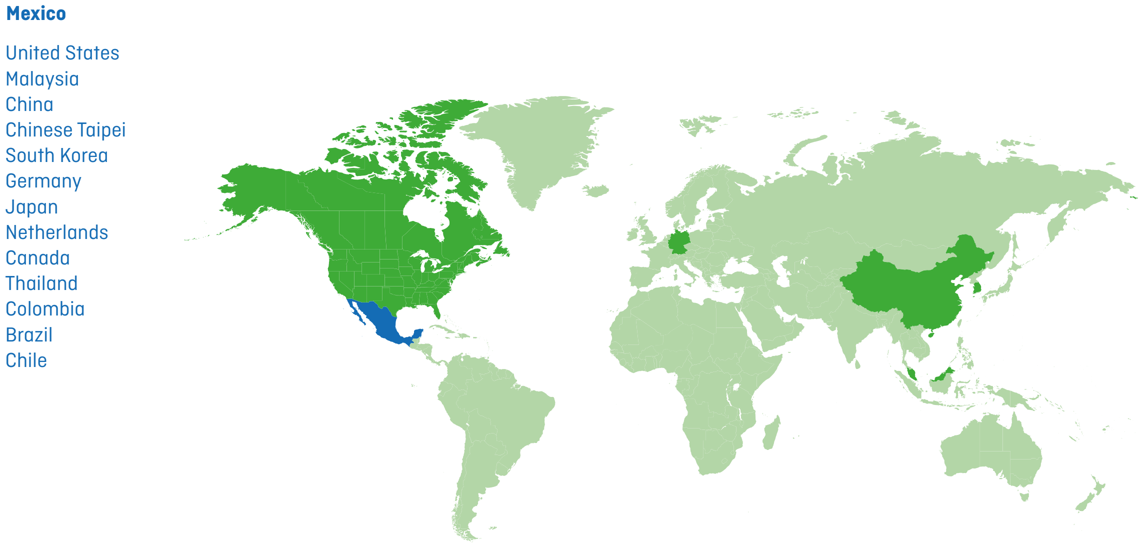
Mexico is considered to be one of the most open economies in the world, with 50 free trade agreements across multiple continents, including the United States - Mexico - Canada Agreement (USMCA). As such, Mexico is Latin America's second largest economy and has the 15th largest economy in the world [33][34]. In 2020, Mexico was ranked 9th among the world's largest exporters with products including cars, computers, vehicle parts, and delivery trucks worth $427 billion USD (see Table 1). Over a third of Latin America's total exports stem from Mexico, mainly destined to partners in the United States, Canada, China, Germany, and South Korea [33][35].

Imports to Mexico were valued at $368 billion USD in 2020 and included products like integrated circuits, vehicle parts, refined petroleum, and office machine parts (see Table 1). The main import origins for Mexico are the United States, China, Germany, South Korea, and Malaysia (see Figure 4) [35].

Table 1: Mexico's key imports and exports [35].

Imports				Exports			
Product	**Value (USD)**	**% of total imports**	**Origin & Value (USD)**	**Product**	**Value (USD)**	**% of total exports**	**Destination & Value (USD)**
Integrated Circuits	28.3 B	7.7%	United States (9.05 B) Malaysia (7.28 B) China (2.91 B) Chinese Taipei (2.22 B) South Korea (1.67B)	Cars	41.6 B	9.7%	United States (29.1 B) Germany (4.92 B) Canada (2.59 B) Colombia (397 M) China (378 M)
Vehicle Parts	21.6 B	5.9%	United States (12.5 B) China (1.99 B) Germany (1.97 B) Japan (1.42 B) South Korea (1.02 B)	Computers	31.5 B	7.4%	United States (28.5 B) Canada (285 M) Netherlands (282 M) Germany (244 M) Japan (199 M)
Refined Petroleum	18.1 B	4.9%	United States (16.8 B) Netherlands (702 M) China (313 M) Canada (47.6 M) South Korea (46.4 M)	Vehicle Parts	27.1 B	6.3%	United States (12.5 B) China (1.99 B) Germany (1.97 B) Japan (1.42 B) South Korea (1.02 B)
Office Machine Parts	14.9 B	4.0%	United States (7.48 B) China (5.18 B) Chinese Taipei (777 M) South Korea (444 M) Thailand (315 M)	Delivery Trucks	23.8 B	5.5%	United States (21.8 B) Canada (1.09 B) Brazil (138 M) Chile (109 M) Colombia (97 M)

Figure 4: Mexico's import and export relationships [35].



Section 3

Maritime Activity and Shipping Emissions

Mexico is located on key shipping routes. As such, there is significant maritime activity within the country's waters. Mexico's shipping activity is dominated by containerships, tankers, and people and vehicle carriers which are mainly on international voyages. Using an activity-based approach[4], Table 2 breaks down the vessels that departed from Mexico's ports in 2018 and shows the energy used by each ship type: large containerships account for 27.3% of the total annual energy demand, while large tankers and large people/vehicle carriers account for 13.7% and 13.2%, respectively.

Table 2: Fossil fuel energy demand from different types of vessels that departed Mexico's ports in 2018 [36].

Vessel category	Fossil fuel energy demand 2018 (GWh/y)	Share of Grand Total (%)
Bulk carriers: Large	1,922	4.9%
Bulk carriers: Small	3,643	9.3%
Tankers: Large	5,370	13.7%
Tankers: Small	3,849	9.8%
Containers: Large	10,708	27.3%
Containers: Small	2,861	7.3%
People & Vehicle Carrier: Large	5,186	13.2%
People & Vehicle Carrier: Small	2,303	5.9%
Offshore and Services	987	2.5%
Fishing	284	0.7%
Small boats: Industrial	1,460	3.7%
Small boats: Fishing / Other Small Boats	720	1.8%
Grand total	39,293	100%

‡ The energy demand presented does not represent fuel sales only the energy expenditure to arrive to any port in Mexico from the previous stop.

§ To convert from GWh to TJ a multiplying factor of 3.6 is used. For HFO_{eq} the Low Heating Value (LHV) used was 40.2 TJ/kt [9].

4 In an activity-based approach, also known as bottom-up approach, ships are aggregated by their design specifications using technical information sourced from ship registry databases such as Clarkson's Shipping Intelligence Network. This is combined with activity data that can be extracted from vessel operator surveys, port authorities, and Automatic Identification Systems.

3.1 Mexico's national GHG emission inventory

In 2018, the government of Mexico submitted its 6th National Communication to the UNFCCC becoming the first developing country to submit six of these reports. Mexico's 6th National Communication included a National GHG Emissions Inventory for the period 1990-2015. The government of Mexico, through the National Institute of Ecology and Climate Change (INECC), prepares the National Inventory of Greenhouse Gases and Compounds (INEGYCEI) in accordance with the 2006 IPCC Guidelines for National Inventories [37][38]. According to the updated National Inventory included in the 6th National Communication, in 2015 Mexico emitted almost 700,000 Mt CO_2e[5] [37]. This amount of GHG emissions put Mexico as the 12th highest emitter in the world in 2015 [39]. In an effort to be transparent and accountable, INECC has publicly shared updated emissions inventories [40].

In order to estimate and contrast shipping emissions, the 2018 maritime emissions, as reported in the INEGYCEI, will be taken so it is aligned with the new maritime emission methodology developed for this report, which uses the shipping activity data for the same year. As such, and relevant to domestic shipping, the country's National GHG Inventory covers its maritime GHG emissions in the *Maritime and Fluvial Navigation* category[6], which accounted for 2,039 kt CO_2e, about 0.3% of the total country's GHG emissions[7] (i.e. 754,100 kt CO_2e) [40]. *International Bunkers* accounted for 5,739 kt CO_2e (0.7% of the national total), while *International Maritime* is blank.

A more detailed presentation of the 2006 IPCC Guidelines for water-borne navigation can be found in Annex I or in Davies et al. [41].

3.2 Shipping Geospatial Model: A new approach for estimating maritime emissions

The Shipping Geospatial Model (SGM) is a new activity-based approach created by the UCL Energy Institute Shipping Group. The approach estimates maritime air pollution and GHG emissions inventories based on the energy demanded by the global fleet and can segregate emissions by ship type and size, operational mode, route or geographical location (e.g. near a port). This versatility allows nuanced analysis of the sector's GHG emissions for any country. Such analysis can illustrate the GHG emissions on specific voyages or in geographical regions or to estimate air pollution and the resulting health impacts in a region.

To study the maritime emissions during 2018 in Mexico through different lenses, the SGM aggregated hourly ship data[8] as follows:

5 Excluding Forestry and Other Land Use.
6 A country only needs to account for domestic maritime emissions in their national inventories, of which fishing activities should be aggregated under the Agriculture/Forestry/Fishing (in Spanish Agropecuario/ silvicultura/ pesca/ piscifactorías) category of the Energy sector. International bunker fuel emissions, comprised of emissions from international aviation and maritime transport, are calculated as part of national GHG inventories, but are excluded from national totals and reported separately [41].
7 Excluding Forestry and Other Land Use.
8 It only accounts for the activity of ships above 100 gross tonnage, the small boat fleet activity and emissions are not considered.

- **Departures:** Shipping activity is aggregated for the complete voyage leg that starts from the country's port (see Figure 5 as an example). The voyage could be either domestic or international.

- **Arrivals:** Shipping activity is aggregated for the complete voyage leg that ends at the country's port. The voyage could be either domestic or international.

- **Geofenced Exclusive Economic Zone (EEZ)**: All shipping activity that occurred within the country's EEZ (i.e. 200 nautical miles from the shore which includes the Territorial Sea) is aggregated. It includes the international and domestic navigation, including domestic fishing. It also captures ships that are passing through the EEZ but not calling at any of the country's ports. The EEZ digital geographical region was taken from Flanders Marine Institute [42].

In general, the SGM approach should be seen as complementary to Mexico's National GHG Inventory. While the latter captures the complex interaction between its economic activities, society, and the environment, the SGM considers in great detail the spatial and technological differences of the maritime sector. The geofencing component of SGM illustrates the environmental, economic and health impacts of emissions from ships transiting to, from, and through Mexican waters and makes the case for decarbonization of shipping, especially considering that not all emissions are resulting from Mexico's imports and exports.

Figure 5: Approaches to the aggregation of vessel ship activity.

The results of the SGM approach show that vessels operating within the EEZ generated the greatest quantities of CO_2e in 2018 at 17,881 kt followed by international arrivals with 11,337 kt CO_2e and international departures 8,632 kt CO_2e[9] (see Table 3). The large difference between the geofenced approach and the international arrivals and departures shows how much GHG emission and air pollution is emitted by international voyages not stopping in Mexico. Roughly 20.4% of the total EEZ air pollution emissions take place within Mexico's territorial waters[10] which negatively and disproportionately affect coastal communities. Under this light, the geofenced EEZ approach can support the study of the benefits of having Mexican emission control areas (ECAs) [43], but also emphasizes the prime position Mexico has to support the maritime transition by supplying SZEF.

Table 3: GHG and air pollutant emissions associated with contrasting inventory methods. Domestic navigation is as well presented.

Pollutant[11]	International Departures	International Arrivals	Domestic Navigation	Domestic Fishing	Geofenced EEZ (200 nm)
GHG (kt)					
CO_2	7,846.56	10,348.60	1,673.64	51.22	16,194.89
CH_4	1.55	2.58	0.03	8.69 $\times 10^{-4}$	2.76
N_2O	0.44	0.58	0.09	2.74 $\times 10^{-3}$	0.90
BC§	0.69	0.85	0.21	5.02 $\times 10^{-3}$	1.52
CO_2e	8,631.92	11,336.87	1,890.81	56.49	17,880.76
Air Pollution (kt)					
SO_x	108.74	149.47	20.37	2.19 $\times 10^{-2}$	240.31
NO_x	189.20	256.97	33.87	1.02	363.47
CO	7.65	10.23	1.45	4.65 $\times 10^{-2}$	14.86
PM_{100}	16.68	22.86	2.97	1.54 $\times 10^{-2}$	35.14
PM_{25}	15.35	21.03	2.74	1.42 $\times 10^{-2}$	32.33
NMVOC	8.09	10.84	1.47	4.39 $\times 10^{-2}$	15.34

‡ To convert CO_2 to Heavy Fuel Oil equivalent (HFO_{eq}) divide the CO_2 emissions by the HFO carbon factor which is 3.114 kt CO_2/kt HFO [9].

§ A value of 900 was used for black carbon 100-year Global Warming Potential [44].

9 The main reasons for the differences between these two approaches are related to the length of voyage leg, ship type and size, fuel usage (i.e. type and quantity), speed profile, ship age and ship cargo loading. Furthermore, the number of arrivals and departures has an impact on the GHG estimations with 6,349 internationally arriving voyages in 2018 and 6,383 international departures.

10 This includes all shipping activity that occurred within the country's territorial seas, up to 12 nm offshore. To estimate this the emissions were captured using the Mexico's 12 nautical mile polygon provided by the Flanders Marine Institute [42] and then divided by the emissions accounted by the EEZ polygon.

11 CO_2: carbon dioxide; CH_4: methane; N_2O: nitrous oxide; BC: black carbon; CO_2e: carbon dioxide equivalent; SO_x: sulfur oxide; NO_x: nitrogen oxides; CO: carbon monoxide; PM: particulate matter; NMVOC: non-methane volatile organic compounds.

Mexico's domestic shipping GHG emissions produced from the 28,842 domestic voyages[12] occurring in 2018 amounted to 1,891 kt CO_2e while for domestic fishing was 56.5 kt CO_2e. The difference with Mexico's 2018 National inventory is about -7.2% or -148 kt CO_2e caused mainly by the fuel consumption database used for the estimation of GHG. Some considerations regarding this are as follows:

- The National Inventory's *Fluvial Navigation fuel consumption* data source comes from Mexico's National Energy Balance which for the maritime sector is based on annual fuel sales of the domestic fleet [45][46].

- The method used in SGM is an activity-based method so it includes emissions from domestic voyages of international ships (e.g. from one Mexican port to another) which would not be captured in the statistics of fuel sales for domestic use. Finding a discrepancy in GHG when calculating with the two methods (i.e. between bottom-up and top-down) is common and has occurred in other countries (e.g. UK) which have since switched to use the activity based method [47].

- Differences between National Inventories data based on fuel sales to international shipping and activity-based methods also have explainable differences. Fuel sales are only recorded if a ship bunkers (takes on fuel) in Mexico. In practice ships calling at Mexico may not need to bunker (some ships have fuel storage for up to three months so they do not refuel for each voyage) and will purchase fuel in Mexico only if it is competitive, and available, to fuel at other port calls they will make. The SGM captures all shipping activity regardless of whether it is associated with a purchase of fuel. The statistics estimated here suggest that only a portion of the fuel associated with Mexico's shipping activity is purchased in Mexico and so the activity-based method is helpful for giving an estimate of the potential bunker sales market - should Mexico want to expand its opportunity, especially for SZEF.

- However, fuel sale databases can capture the fuel being consumed by the small boat fleet which tend not to have onboard tracking systems (e.g. AIS transponder). This is clearly seen from Ferrer et al. [48], where the small fishing boat fleet GHG emission – between 3,000 and 3,700 kt CO_2e – has a relevant and important role in the national maritime emissions. This is a limitation from the SGM but which points to the SGM results on domestic shipping GHG and air pollution to be a conservative estimation.

Looking at the SGM aggregation of all maritime activity in 2018 to, from, and within Mexico, the total GHG emissions amount to 21,916 kt CO_2e – about 7,040 kt HFO_{eq} – which represented about 2.9% of Mexico's 2018 National GHG emissions and 2.0% of the total global shipping GHG emissions in 2018 as reported by the IMO.[13] Employing the SGM clearly shows the important opportunity Mexico has in supporting shipping decarbonization in the decades to come and emphasizes the importance of international collaboration between Mexico and its commercial partners.

Further details on the SGM methodology can be found in Annex I with details of the different root causes between the emission inventories presented in subsection Sensitivity Analysis.

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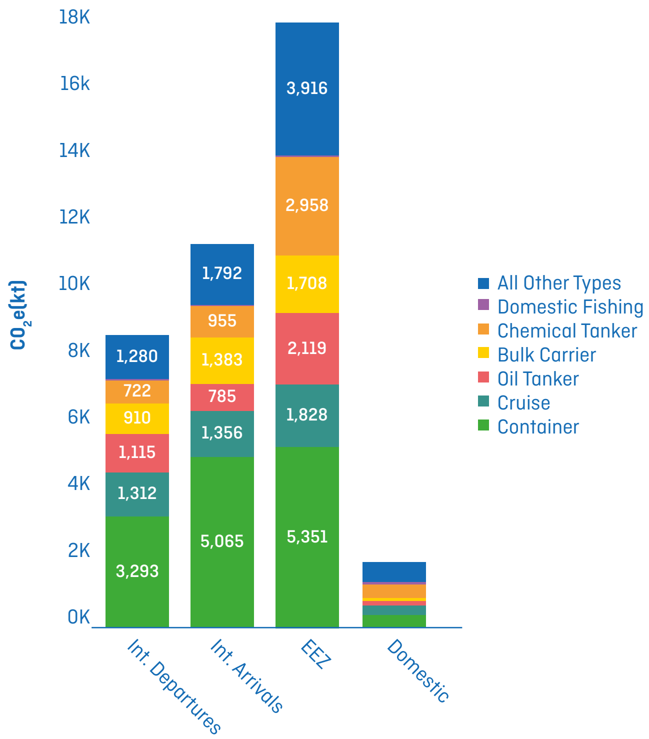
12 The SGM considers a domestic voyage as a voyage that starts and ends in the same country. If it is a multi-stop voyage, it will only consider as domestic the leg that starts and ends in the same country. If there are more than one domestic legs, each one will be treated as independent domestic voyage.

13 The total GHG emissions in 2018 was 1,076,000 kt CO_2e formed by international and domestic shipping and fishing [9].

3.2.1 Analysis by ship type

In this section the SGM analysis is disaggregated by ship type (see in Figure 6). Across the approaches considered, the most pollutant ship types for Mexico are bulk carriers, containerships, cruises and oil tankers emitting on average 71% of the 2018 GHG emissions. This is in line with the level of activity observed in Table 2 where these vessel types demanded about 35,840 GWh/y (i.e. 3,210 kt HFO_{eq}) of fossil fuel energy. However, chemical and oil tankers are the second and third most GHG emitting ship types under the geofenced EEZ approach. Most of these ship types are navigating in Mexico's Gulf of Mexico EEZ waters but not stopping at any of the national ports.

Figure 6: CO_2e inventories by vessel type.

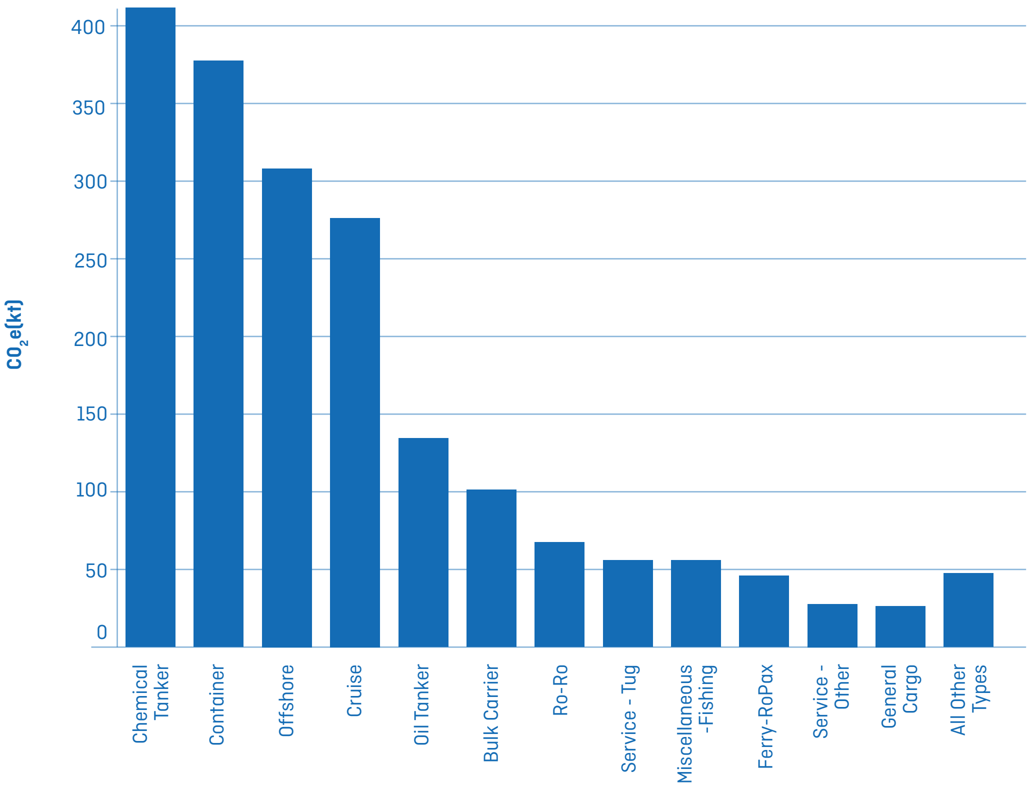


The domestic navigation GHG emissions represented about 21.9% and 16.7% of the total CO_2e generated by international departures and arrivals respectively. Domestic fishing represented about 0.7% of the total GHG emissions from international departures and 0.5% of international arrivals. Domestic fishing emissions appear to be low when compared to Ferrer et al. [48] which estimated 3,000 to 3,900 kt CO_2e from small-scale fishery boats[14] – around 74,000 [49] – that tend not to have an AIS onboard and hence not estimated by the SGM.

A detailed disaggregation of domestic shipping by vessel type is presented in Figure 7 which shows that domestic shipping emissions are dominated by chemical tankers at around 413 kt CO_2e, followed by containerships with about 379 kt CO_2e and offshore support vessels with around 308 kt CO_2e. Therefore, Figure 7 shows that domestic fishing is the 9th greatest source of national shipping GHG emissions with 56 kt CO_2e during 2018, which is not apparent from the IPCC method, simply due to fishing being aggregated into a different category under the Energy sector.

14 Vessels that are below 100 gross tonnage.

Figure 7: Domestic emissions by vessel types. Domestic fishing is added for comparison purposes only.



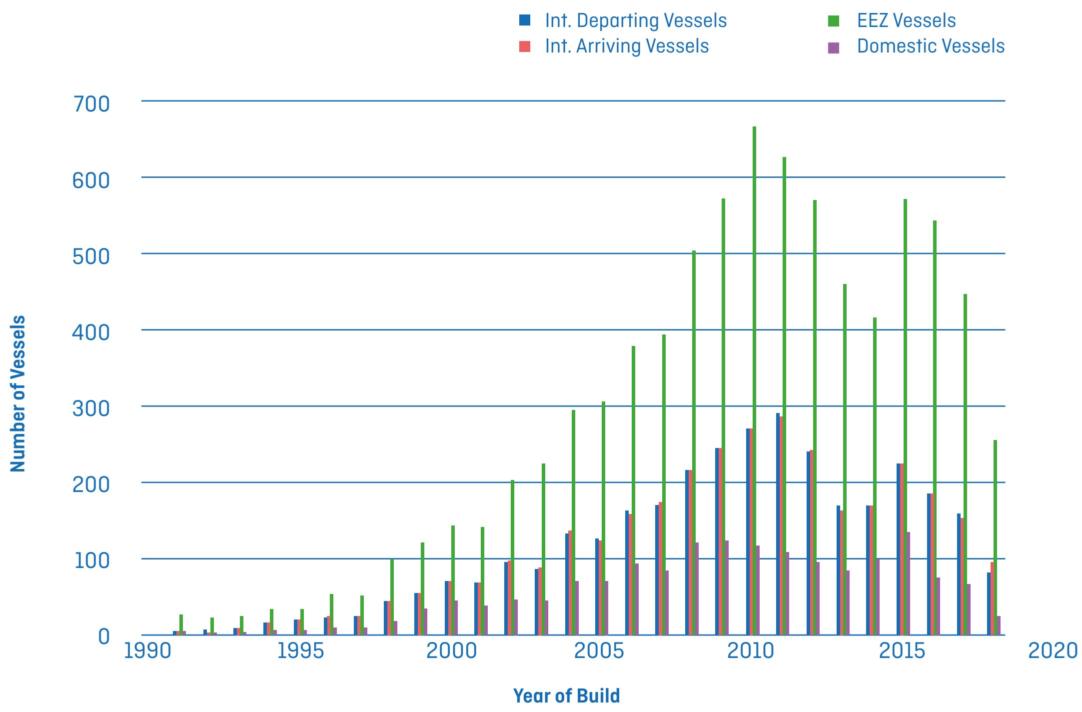
3.2.2 Analysis by age

An important aspect to consider when analyzing shipping emissions is the fleet characteristics; in particular age, which has a strong correlation with fuel efficiency and emissions. Figure 8 presents the spread of build years for vessels navigating Mexico's waters after 1990. The greatest share of vessels operating in 2018 were built between 2010 and 2011. This implies that the largest share of shipping activity occurring in Mexico is coming from relatively new ships, which will tend to have good fuel efficiency and pollution control measures in accordance with IMO regulations.

Of the 3,507 unique vessels to depart Mexico's ports internationally, 3.3% (115) were built before 1988 making them 30 years old or more throughout 2018. This compares with just 3.6% (310) of the 8,554 vessels that traversed Mexico's EEZ during the same year and 7.3% of domestic vessels (131 of 1,805), making the domestic class likely to be most inefficient and polluting due to their old machinery systems.

There is a slight difference in the year of build of each inventory approach. For the EEZ approach, the average build year is 2008, the same as international departures and arrivals. However, domestic ships formed the oldest category with an average build year of 2006. Essentially, under this lens we can see that the international fleet tends to be younger than the domestic fleet, but the average year difference puts them under the same regulatory period for carbon intensity and air pollution from the IMO. This means that future international regulations brought in at the IMO level would likely have a significantly negative effect on the emissions experienced by Mexico, shown in the ship type and geofencing sections. In the short term, the domestic fleet, administered by the Mexican Maritime Authority (i.e. the Secretariat of the Navy) and in cooperation with relevant government departments, would benefit from energy efficiency improvements.

Figure 8: Build years for vessels contained in the 2018 dataset. Domestic fishing is not included.



3.2.3 Analysis by port arrivals and departures

Using the SGM to focus on port-based activity allows a clear picture of emissions which can affect port communities and local populations. Figure 9 presents the breakdown of CO_2e emissions from international voyages departing and arriving at five main Mexican ports, namely Manzanillo, Lazaro Cardenas, Cozumel, Veracruz, and Altamira while simultaneously aggregating the rest of the ports in a single class.

The greatest contribution to the international departures inventory is Manzanillo which, in 2018, generated 27.2% of the total annual emissions from international departures (2,348 kt CO_2e), followed by Lazaro Cardenas with around 11.8% (1,019 kt CO_2e) and Cozumel with around 10.3% (893 kt CO_2e). Ports outside the top five were responsible for 39.0% of emission generation from international departures (i.e. 3,370 kt CO_2e). From the international arrivals point of view, Manzanillo produces the largest amount of CO_2e at 4,009 kt that represented 35.4% of the total in 2018. This is followed by Lazaro Cardenas and Cozumel with a share of 9.7% and 8.7% respectively. The All Other Ports class has a larger share of the total international arrivals with 30.5% or 3,460 kt of CO_2e.

Figure 9: Maritime GHG emissions produced from Mexico's ports international departures and arrivals in 2018.

3.2.4 Geofencing around large port cities

Maritime traffic sampled from 38 Pacific and Gulf-Caribbean Mexican ports contributed 60% of total atmospheric emissions in the Mexican Pacific and 40% of total atmospheric emissions in the Mexican Gulf-Caribbean [50]. Additionally, it has been established that air pollutants can travel hundreds of miles [51]. In an effort to capture the maritime emissions on Mexico's coastal populations, three cities with sizable coastal populations and active ports have been selected for further analysis. Regions of 100 km radius surrounding Mexico's ports of Manzanillo, Playa del Carmen/Cozumel and Veracruz were created to estimate the emissions generated by shipping activity[15] during 2018 (see Figure 10).

Table 4 indicates how maritime activity near the ports[16] contributes to regional GHG emissions and air pollution. Regarding maritime GHG emissions, Manzanillo saw around 519 kt of CO_2e while Playa del Carmen and Cozumel had a total of 449 kt CO_2e, and for Veracruz, shipping activities amounted to 288 kt CO_2e. Updated emission inventories from Mexican coastal cities are difficult to find in the public domain. For example, the last Manzanillo's emission inventory was done in 2013 for the year 2005 which reported about 8,276 kt CO_2e[17] [52]. This will put the share of maritime emissions, if the 2005 Manzanillo's emissions are assumed to stay the same, to about 6.3%. For Cozumel, its latest emission inventory was developed in 2013 for the year 2011 giving 155.1 kt CO_2e [53][54] but for Playa del Carmen it was not publicly available which makes it difficult to contrast the relevance of maritime

15 The emission quantified here only considered the activity performed by the ships present in the regions. This does not account the emissions produced by the port and its systems (e.g. cranes, forklifts).
16 Maritime activity around the ports only considers the ship side activity and are based on the Fourth IMO GHG Study and they are: Normal Cruising, Slow Steaming, Maneuvering, Anchoring and Berthing.
17 Excluding Forestry and Other Land Use.

emissions to both cities. Veracruz is in a similar situation where the GHG emissions are not publicly available. While the GHG emission inventories of coastal cities is not the objective of this work, the previous discussion point highlights the importance of developing updated emission inventories at the city level.

Figure 10: Polygons representing the geofenced areas with a radius of 100 km for the three coastal cities and their shipping activity during 2018.

Table 4: GHG and air pollutant emissions generated within 100 km of the ports of Manzanillo, Playa del Carmen/Cozumel and Veracruz during 2018.

Pollutant	Manzanillo	Playa del Carmen/ Cozumel	Veracruz
GHG (kt)			
CO_2	469.39	384.57	256.92
CH_4	7.77 x10^{-2}	6.59 x10^{-3}	3.24 x10^{-3}
N_2O	2.57 x10^{-2}	2.19 x10^{-2}	1.38 x10^{-2}
BC	4.53 x10^{-2}	6.49 x10^{-2}	3.07 x10^{-2}
CO_2e	519.10	449.01	288.26
Air Pollutants (kt)			
SO_x	7.15	5.63	3.44
NO_x	9.00	7.21	3.89
CO	3.85 x10^{-1}	3.32 x10^{-1}	1.79 x10^{-1}
PM_{100}	9.77 x10^{-1}	7.96 x10^{-1}	4.48 x10^{-1}
PM_{25}	8.99 x10^{-1}	7.32 x10^{-1}	4.12 x10^{-1}
VOC	3.88 x10^{-1}	2.98 x10^{-1}	1.71 x10^{-1}

Regarding air pollution, Manzanillo had the highest exposure with 7 kt SO_x, 9 kt NO_x, 385 t CO, 977 and 899 t PM_{100} and PM_{25} respectively, and 388 t NMVOC, followed by the cities of Playa del Carmen and Cozumel, and Veracruz.

The creation of focused inventories for port cities through the SGM can aid in their efforts to decarbonize regionally and can support the mitigation of air pollution and its health effects on local populations. Furthermore, populations within 5 nautical miles of an air polluting source – in this case a port – possess a 50% higher likelihood of developing cardiovascular issues and cancer because of exposure to these pollutants for extended periods of time [55]. In the particular case of Mexico, the study and mitigation of maritime air pollutants near its ports could help improve the air quality of over 55.3 million people in coastal states [56].

3.3 Implications for Mexico

National GHG inventories present reliable estimates of emissions allowing governments to formulate and implement mitigation measures, taking respective national circumstances and capabilities into account. Mexico's National Inventory, using the widely-accepted IPCC methodology, is presented in Section 3.1 and reports the water-borne domestic navigation emissions under the category *Maritime and Fluvial Navigation*. Although emissions from the international shipping sector are acknowledged, they are not quantified in the national inventory under the IPCC methodology. Given that national inventories drive the government's national strategic aims, objectives and policies, the exclusion of international shipping creates an artificially narrow framing in terms of GHG emission from both a climate change and an air pollution perspective.

To counter this, and to present a more detailed quantification of shipping emissions, this report employed the SGM as a granular activity-based methodology to understand maritime emissions both in Mexico's national waters and at its ports. The SGM complements Mexico's National GHG inventory by presenting domestic and international maritime emissions under a voyage definition and inside geographical regions, all while being able to disaggregate the results by ship types and age. The results from the SGM method show that:

- Domestic emissions and fuel demand, which are more likely driven by national legislation, are a lot smaller than the international arrival/departure emissions and fuel demand. IMO regulation will be key in driving change in the ships that call at Mexican ports (see more in subsection Maritime Policy within Section 5).

- Containerships, tankers, bulk carriers, and cruises are the type of vessels that emit the most GHG and air pollution from maritime activity to, from and within Mexico's ports and national waters. This is seen as well from the port point of view, where Manzanillo, having the largest container activity of any port in Mexico, has the largest amount of maritime GHG emissions in Mexico.

- Despite their relative magnitudes, there is still a significant domestic fleet, hence, significant domestic emissions, providing many opportunities for early adoption that might align with other national strategy/priorities to decarbonize.

- Domestic and international shipping contribute significantly to air pollution including in the proximity of large Mexican centers of population. Decarbonization of shipping, if enabled through SZEF, can be a significant driver of air quality improvement in several important locations.

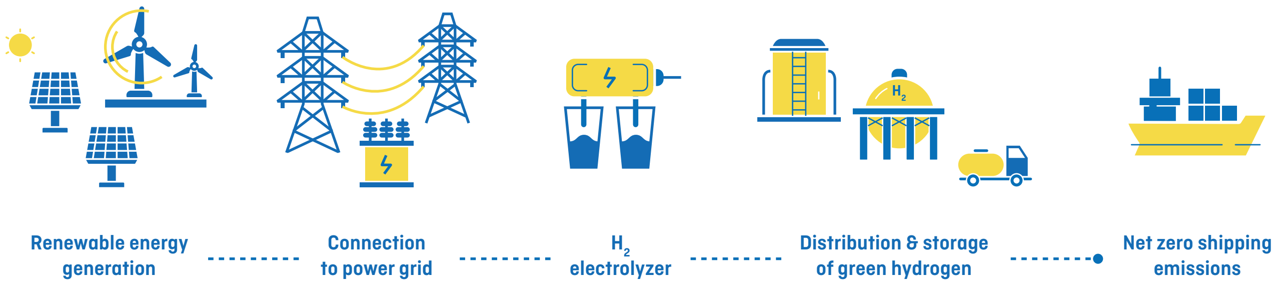
These findings can assist the decision-making process regarding the transition to low- and zero-carbon emissions in the shipping sector and illustrate Mexico's opportunity to participate in shipping's just and equitable transition. Additionally they can support in the creation of strategies, solutions and policies that can reduce the national and regional maritime emissions, air pollution and create green jobs in, and connected with, the oceans economy.

Section 4

Harnessing Mexico's Renewable Potential

Shipping is heavily reliant on fossil fuels, which produce considerable GHG and air pollution. This, in turn, increases the global effects of climate change and negatively impacts the health and socio-economic wellbeing of nearby coastal populations. While energy efficiency and short-term mitigation solutions play a role in the maritime sector's transition, this will not be enough to achieve the Paris Agreement target [5]. The need for green SZEF and the use of clean energy, along with their required infrastructure, is critical to enable maritime decarbonization. Large amounts of renewable energy are needed to produce these fuels and get shipping on track to meet global climate change goals (see Figure 11). Some estimates suggest that the amount of renewable energy to meet shipping needs would need to increase by up to 3,000 TWh [57].

Figure 11: Illustrative production pathway for green hydrogen.

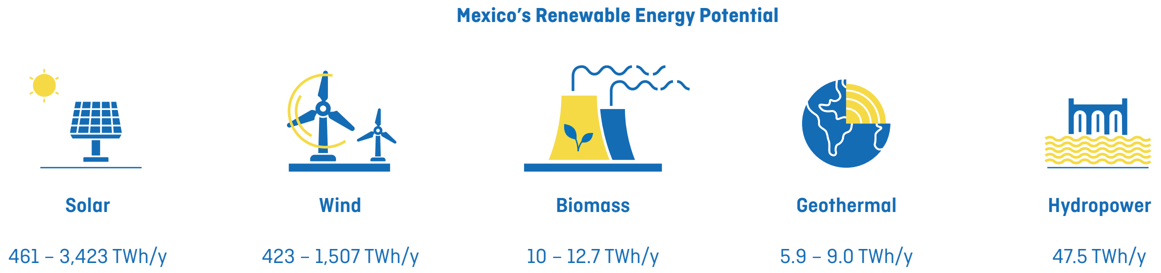


Source: Inspired by Quadrant Smart [58]

In 2020, 19.7% (66.8 TWh) of the country's electricity generation came from renewable sources [59]. Mexico's renewable energy is estimated by its Secretariat of Energy (SENER) in its Program for the Development of the National Electricity Power System (PRODESEN) to expand generation and transmission capacity in the coming years. The most current version covers the time frame 2022 – 2036. For the period 2022 – 2025, Mexico plans a small increase in renewable installed capacity of 897 MW, including 434 MW for hydropower, 420 MW for solar, and 25 MW for geothermal. There is no plan to expand the installed capacity for wind power. Between 2026 – 2035, this amount is planned to substantially increase to over 16,623 MW, including 9,938 MW for solar, 5,259 MW for wind, and 1,426 MW for hydropower [60]. Though this represents a reduction from previous ambitions presented in the PROSEDEN, where it was expected to install an additional 19,000 MW of new clean and replacement generation capacity by 2024. However, the new plan does see a role for hydrogen wherein 4,368 MW is planned to be installed between 2026 – 2035 for combined cycle power plants [60][61].

By 2030, roughly 43% of the country's energy supply is expected to come from clean energy sources [62]. In particular, considering the current technologies available and restrictions regarding land-use, Mexico can reasonably produce by 2030 an additional 865 – 4,925 TWh/y of renewable energy[18]: 447 – 3,409 TWh/y of solar, 402 – 1,487 TWh/y of wind, 7.7 – 10.4 TWh/y of biomass, and 20.7 TWh/y of hydropower 1.2 – 4.5 TWh/y of geothermal [36]. When combined with existing renewable generation capacity, Mexico could produce a total of 932 – 4,992 TWh/y by 2030 (see Figure 12).

Figure 12: Mexico's estimated total renewable energy potential by 2030 (including the current installed capacity).



It is important to note that this figure is only a range estimated using available studies and literature and that Mexico's renewable energy potential could be even greater. Future research is needed to give a more definitive range and to gain greater understanding of likely scenarios and how improving technology could affect this range. Furthermore, as part of a fair and equitable transition, additional renewable energy plants for shipping must be built alongside those estimated by Mexico's PRODESEN to avoid potential negative effects on domestic decarbonization efforts. The building of renewable generation infrastructure must be done responsibly, wherein environmental, and social impacts are considered when planning to leverage Mexico's renewable potential. For example, it is important to investigate potential direct and indirect land use change when building infrastructure in agricultural areas to limit negative environmental and ecological impacts.

Mexico's renewable potential, combined with its maritime traffic, places the country as a potential key player in the shipping transition as a SZEF producer and exporter [36]. Local stakeholders note that shipping decarbonization is relevant for Mexico given the country's abundant renewable energy resources. Assuming 5% of the global fleet transitions to SZEF by 2030 then the green energy demanded would represent about 3.4 TWh/y [36]. Mexico retaining its market share of international bunkering sales is, of course, dependent on the supply and availability of SZEF in Mexico. If either are limited, there could be a market shift for international shipping's bunkering demand to other neighboring countries, for example Panama, that offer SZEF at competitive prices.

Conservative calculations show that 3.4 TWh/y represents only 0.4% of Mexico's total renewable potential, comfortably leaving more renewable energy potential

18 Note that the amount of renewable energy potential is based on an aggregation of various estimates using different methodologies and parameters. More information can be found in Carpenter-Lomax et al. [36].

than needed for both decarbonizing the national grid and vessels stopping at Mexico's ports. This supports local stakeholder perceptions that the country is well-positioned to produce green hydrogen and its derivatives, through which shipping's decarbonization can generate strong synergies with road transportation and other land-based sectors.

Stakeholders also highlighted that if there are solid offtake agreements, wherein a buyer agrees to purchase portions of a supplier's planned production, there is huge potential not only for the production of SZEF, but also the export of these fuels. This is especially the case given that both the EU and Japan have noted that they cannot produce enough SZEF in their own countries and would need to import fuels to meet their energy demands and decarbonization commitments. Indeed, the war in Ukraine has highlighted the need to move away from fossil fuels and import green fuels. Hydrogen export, however, has been limited to grey hydrogen based on fossil fuels, and the growing interest in the export of green hydrogen will require the development of an enabling trade framework.

«Mexico's abundant renewable energy potential makes it an ideal location for the production and potential export of green hydrogen and ammonia, offering a huge opportunity to establish clean energy marine hubs close to its major ports.» – Nelson Mojarro (BRETFIN, U.K.)

Hydrogen Trade

As countries like Mexico consider opportunities to export green hydrogen, it is important to consider how cross-border trade of green hydrogen between production points and demand regions across the globe can be enabled [63]. IRENA reports that more than 30% of hydrogen produced will be traded internationally by 2050 [64]. This will require international and multi-stakeholder cooperation to prevent interruptions in the clean hydrogen supply chain, ensuring products can freely move across borders.

Currently, some aspects of Mexico's regulatory framework mention hydrogen production relating to its value chain and end uses. However, while the production of green hydrogen is not prohibited, it lacks definition as the regulatory framework does not provide clear guidelines to potential producers and interested investors [65].

Standards targeting safety and quality of green hydrogen goods and services are one way to build a resilient global green hydrogen economy and reduce the risk of impeding trade in the future. Questions remain around classifications of hydrogen using color-schemes or levels for example, based on feedstock and whether or not fuels are derived from renewable energy sources. Nevertheless, there are a number of organizations working to get ISO certification for their green hydrogen exports to increase harmonization and address existing fragmentation in the interim.

The Green Hydrogen Organization is one such actor, looking to establish a standard centered around accurate GHG emissions accounting, Environmental, Social, and Governance (ECG) metrics considering broader impacts of hydrogen production, and assessment of hydrogen development with the Sustainable Development Goals in mind [66]. At this early stage, fragmentation from specific arrangements on green hydrogen is a key challenge. To address this, existing models could feed into the development of a common standard in order to avoid further fragmentation and encourage healthy competition.

Bi-lateral and regional trade agreements could also stimulate export of green hydrogen. The United States-Mexico-Canada Agreement (USMCA) is a key trade agreement for Mexico, which specifically includes an environmental section that strongly encourages each country to "prevent the pollution of the marine environment from ships" including vessel-based emissions [66]. Aligned with this, industry cooperation initiatives are also emerging, such as the Mexican Hydrogen Association's signed memorandum of understanding with the Canadian Hydrogen and Fuel Cell Association that seeks to cooperate on the development of zero-emission hydrogen [68]. Tariffs on hydrogen however are very low or non-existent for most key producers and consumers of hydrogen. Rather than having a separate tariff line for green hydrogen, it would make sense to have production and process methods in place that can be certified.

Industry players and governments could also draw on best practices from trade in other relevant green goods and services to create a level playing field, shape an efficient global green hydrogen economy, and work towards full industry decarbonization by 2050. As it is stands, Mexico has not yet adopted a national hydrogen strategy but the national discussion around green hydrogen is starting [65]. Due to this, the legal and regulatory framework around the production of green hydrogen it is still undefined, which in turn does not provide clarity to potential producers and investors.

Section 5

Policy Framework and Climate Ambition

5.1 Climate and energy policy

«The main barrier to realizing the green hydrogen for Mexico is creating a regulatory framework which would give greater certainty to shareholders, helping to align supply and demand, supporting the development of relevant infrastructure and promoting the decarbonization of industry domestically.»
– Israel Hurtado (Mexican Hydrogen Association)

Mexico is highly vulnerable to climate change [69], with the country's total GHG emissions in 2015 amounting to 700 Mt CO_2e, placing Mexico as the 12th largest GHG emitter globally in the same year [39]. This is because, on a national level, oil and gas account for 39% and 46% of the energy mix, respectively [59]. Despite this dependence, the oil and gas industry has experienced continual challenges on several fronts: the decline of oil prices globally, capacity to exploit crude oil reserves, fuel quality, and the financial situation of Petróleos Mexicanos (Pemex), Mexico's state-owned oil company [70][71][72][73].

Mexico's energy resources, especially its fossil fuel resources, are inextricably linked to the country's national identity, especially since the removal of foreign power companies and the nationalization of power production via the creation of Pemex and Comisión Federal de Electricidad (CFE), two state-owned companies for oil extraction and energy generation [74][75]. Since the early 2000s, oil production in Mexico has fallen from its peak, but supporting Pemex and CFE is important for the current administration, which attributes national economic growth to oil extraction and production [76]. In a context where the global demand for zero emission fuels is paired with a demand for low carbon and environmentally sustainable shipping and port services, the current climate and energy policy scenario in Mexico is undoubtedly challenging.

Despite this, the adoption of various climate and energy policies and legislation provide a framework for the reduction of GHGs, which could be further enhanced. Mexico's climate change and energy policy is overseen by the Secretariat of Environment and Natural Resources (SEMARNAT), the National Institute of Ecology and Climate Change (INECC), and by the Intersecretarial Commission on Climate Change, including the Secretariat of Energy (SENER), Secretariat of Finance, Secretariat of Agriculture, among others. Their work is complemented by the Secretariat of Foreign Affairs (SRE) and the Secretariat of Economy (SE).

Relevant policies include:

- **General Law on Climate Change** which provides the institutional foundation to abate GHG emissions from major sectors and to adapt to climate change, positioning Mexico as *"the first large oil-producing emerging economy to adopt climate legislation"* [77][78].

- **Law on Energy Transition**, which set targets for clean energy in the production of electricity: 25% for 2018, 30% for 2021 and 35% for 2024 [79].

- **National Climate Change Strategy** a planning instrument to transition to a sustainable economy with low-carbon emissions consisting of 6 action pillars to mitigate and adapt to climate change [80].

- **Special Climate Change Program** which establishes objectives, strategies, actions and goals to address climate change by defining priorities in terms of adaptation, mitigation and scientific research, as well as the assignment of responsibilities, execution times, coordination of actions and cost estimation for a determined period (i.e. 2014-2018, 2021-2024), in accordance with other national policy instruments [81].

- **Energy Reform Package from 2013** including the Law on Hydrocarbons, Law on the Electricity Industry, Law on Coordinated Regulatory Organs for energy matters, Law on Pemex, Law on CFE, Law on the Agency for National Industry Security and Environment Protection in the Hydrocarbon Sector, Law on Geothermal Energy, Law on Revenues from Hydrocarbons and Law on the Mexican Petrol Fund for Stability and Development [82].

- **Transition Strategy to promote the use of cleaner technologies and fuels** a guiding instrument of national policy in the medium and long terms – fifteen and thirty years, respectively – with respect to clean energy obligations and sustainable use of energy [83].

- **Guidelines for the prevention and comprehensive control of methane emissions from the Hydrocarbons Sector** with actions and mechanisms that regulated parties from the hydrocarbons sector must adopt for the prevention and comprehensive control of methane emissions [84].

- **National Strategy to Reduce Short-Lived Climate Pollutants** with goals to reduce black carbon and methane from major sources by 2030 [85].

The introduction of a bill to the Congress [86] during 2021 by the current administration, which prioritizes power generated by state-owned CFE, including that derived from coal and oil, over cheaper, privately owned wind and solar power in the grid, has drawn criticism from both local governments and proponents of renewable energy [76]. However, the bill was not accepted by Congress [87]. The current administration tried to roll back many of the 2013 reforms, generating criticism and a legal challenge by a minority in the Lower House to the reforms made by the Executive administration to the Electricity Industry Law, which ultimately the Supreme Court of Justice of the Nation ruled to dismiss earlier this year [88].

While a focus on domestic, state-owned energy may seem to offer the advantage of energy security for the country, it risks locking Mexico into a soon-to-be outdated energy infrastructure and means that the social, economic, and environmental opportunity that renewable energy offers remains uncapitalized. Indeed, some stakeholders pointed to the difficulty of obtaining funding for R&D in connection with renewable technologies due to the current political environment and its resulting uncertainty. This is further exemplified in PRODESEN 2022 – 2036, which notably reduced the Secretariat's previous ambitions towards renewable energy capacity. Instead, the program has been criticized for its heavy focus on investing in fossil-based power in the period 2022 – 2025, as well as its conflicts with other climate and energy policies in Mexico [62]. Nevertheless, there are still promising signs of development in renewables and indeed, there are a number of transition-related projects in the country (as shown in Section 6) [89][59].

According to Mexico's first Nationally Determined Contribution (NDC), updated in December 2020, the government signed the Paris Agreement and committed to unconditionally reduce its GHG emissions by 22% and black carbon emissions by 51% below a business-as-usual scenario by 2030 and up to 36% of GHG and 70% of black carbon below business-as-usual, conditional on receiving financial, technical, and capacity-strengthening support. The government's goal is to focus its policies on the eradication of poverty whilst achieving a sustainable development that is balanced and just, centering its climate actions on adaptation to climate change and achievement of the Sustainable Development Goals [90]. The updated NDC was questioned with reference to level of ambition and for raising the baseline against which the GHG emission reduction is measured [91][92][93][94]. In September 2021, a Collegiate Court suspended the NDC presented in 2020, considering that its commitments are regressive. As a result, Mexico's 2015 commitments apply for the 2020-2030 period until a Superior Court rules on the judge's decision [95].

Although no specific reference to the abatement of GHG emissions from the maritime transport was made in the updated NDC, the Mexican government informed its decision to strengthen policy instruments and implement actions for the conservation of biodiversity and restoration of marine, coastal and freshwater ecosystems, as well as to promote the increase and permanence of carbon reservoirs, particularly, blue carbon [90]. Building on this national priority, at COP26 held in November 2021, Mexico took part in the High-Level Panel for a Sustainable Oceanic Economy – of which Mexico is a founding member – and noted the feasibility to sustainably manage 100% of the national waters under North America's national jurisdiction with the recent adherence of the United States to this Panel [96]. Under its membership to this Panel, the government of Mexico developed an Instrumentation Strategy for a Sustainable Ocean Economy for the 2021-2024 period and plans to sustainably manage 100% of its EEZ by 2025 [97].

Mexico has a robust institutional architecture for climate and energy and a mature ecosystem of public, private, and social actors interested in transitioning to low-emission pathways. Additionally, with the exception of recent years, Mexico has a strong legacy of proactivity around climate change policy being one of the first countries to adopt a voluntary mitigation target in 2008, the first Latin American country to introduce a fuel economy standard for light duty vehicles in road transport during 2013 [98], the first "developing country" to submit its NDC in the lead-up to the Paris Agreement in 2015, and one of the first nations to submit a long-term climate strategy after the adoption of the Paris Agreement in 2016. It has also been recognized for its leadership in international climate negotiations, hosting a successful COP16, for which its effectiveness was praised [99]. Mexico's position within the OECD has allowed it to play a 'bridging role' in climate negotiations between developed and emerging economies [100]. This legacy of international leadership, combined with renewable energy potential and a strong, export-based economy would make Mexico a significant actor in the production and use of SZEF if its policy framework was geared to open up domestic energy production and investment opportunities.

The current presidential administration's focus on exploring oil and gas reserves [76][101] represents a significant challenge for transition activities and investments towards the realization of Mexico's potential. In this regard, Mexico would benefit from the development of a national strategy and associated new or amended regulatory and economic instruments that support the energy transition and enable innovation and capacity building [5]. In summary, while the current political environment and policies may not be fully conducive to leveraging transition opportunities through production of renewable energy, a shift in political will could tip the scales regarding Mexico's role in the global energy transition.

5.2 Maritime policy

Since 2020 maritime and port affairs are overseen by the Secretariat of the Navy (SEMAR), which exerts the National Maritime Authority in national marine areas.[19] Previously, ports' activities and services were managed and coordinated by the Secretariat of Infrastructure, Communications and Transports (SICT). In 2018 the National Policy of Seas and Coasts of Mexico (PNMCM) was issued for the first time, prepared by the Inter-Secretarial Commission for the sustainable management of Seas and Coasts (CIMARES), addressing the need for a comprehensive management mechanism that strengthens the maritime and port sectors [103]. At present, the PNMCM is under revision. Similarly, for the past few years the Government of Mexico has been developing and formulating its National Maritime Transport Policy (NMTP), a voluntary articulation of guidelines under the International Maritime Organization (IMO) for safe, secure, and efficient maritime and port sectors.

Presently, shipping decarbonization is not a top priority for the current administration; however, the government of Mexico has undertaken some efforts toward the decarbonization of ocean industries. Notably, the potential transformation of the decarbonization of the national maritime and port sector is underpinned by the respective authority of the federal government agencies listed in this report (i.e. SEMAR, SEMARNAT, and SENER), making such process considerably constrained. Nevertheless, stakeholders commented that there is an opportunity to include maritime and port decarbonization in the objectives of the revised PNMCM.

Time, capacities, and resources will be required for SEMAR to start developing and implementing domestic policies and strategies to address GHG emissions from the maritime and port sectors. Well-structured and implemented policy instruments in Mexico, which include objectives to decarbonize the maritime and port sectors, will allow the Mexican Maritime Authority (i.e. Secretariat of the Navy) to provide modern, secure and environmentally sustainable services within ports and related facilities. This will potentially catalyze action and investment from the public and private sector, contributing to national economic growth as well as compliance with the UN 2030 Sustainable Development Agenda.

19 i.e. in coasts, ports, port areas, terminals, marinas and national port facilities concerning marine pollution prevention, maritime and port security, maritime communications and transport, coordination of maritime and port services, and management of centralized ports and coordination of parastatal ports, among other areas [102].

«In the process of transition of our country towards maritime transport without greenhouse gas emissions, the participation of the National Maritime Administration will be essential, both for its function to supervise compliance with the provisions established in the international standards of OMI Instruments, as well as for its role organizing the participation of different stakeholders and catalyzing their work to get relevant projects off the ground.» – Gildardo Alarcón Daowz (Maritime Authority of Mexico (UNICAPAM-SEMAR)

In the international shipping context Mexico is a member of the IMO, a United Nations agency with over 170 member states that regulates the international shipping industry. The IMO sets global standards for maritime safety, security, and environmental performance. Mexico has adopted, accessed and/or ratified multiple global instruments and conventions pertaining to climate change, marine environmental protection, and a transition to a low-emission maritime sector (see Table 5). In 2016, the Mexican Senate unanimously ratified the Paris Agreement [104] and in 2018 the Senate approved reforms to the General Law on Climate Change through which the national legal framework was updated and harmonized with the commitments established in the Paris Agreement [105]. However, Mexico has not yet ratified MARPOL Annex VI, first adopted in 1997, and its ratification represents an area of opportunity to address air pollution from ships and to eventually achieve the benefits of an ECA, which would also be consistent with the scope of the USMCA free trade agreement.

Table 5: Mexico's commitment to international maritime policies.

United Nations Convention on the Law of the Sea (UNCLOS Convention) (1984)
International Convention for the Prevention of Pollution from Ships (MARPOL Convention), particularly its Annexes I, II and V
Initial IMO Strategy on Reduction of GHG Emissions from Ships (2018)

The IMO has successfully adopted multiple instruments and policies aimed at reducing GHG emissions from ships.[20] The IMO's Initial GHG Strategy sets a minimum target of reducing emissions by at least 50% by 2050 compared to the 2008 baseline year, while generally pursuing the reduction of GHG emissions as a matter of urgency, consistent with the Paris Agreement temperature goal. In addition to its reduction target, the strategy sets out a timeline for consideration and selection of different short-, mid- and long-term policy measures [106]. Short-term measures focus primarily on energy efficiency improvements for the global fleet with current discussions of potential mid-term measures centering on the possibility of a basket of measures combining a fuel standard and market-based measures (MBM). There is also a growing realization among Member States of the need to enable a just, fair, and equitable transition.

20 Including the Energy Efficiency Design Index (EEDI), the Ship Energy Efficiency Management Plan (SEEMP), the Data Collection System for fuel oil consumption of ships, the Energy Efficiency Existing Ship Index (EEXI), and Carbon Intensity Indicator (CII).

Furthermore, momentum has been building for a higher level of ambition, as part of the IMO Strategy Revision, with over 240 signatories from the maritime value chain calling on the IMO to set a target of full decarbonization by 2050 [107].

The forthcoming year of IMO climate negotiations will be crucial. In upcoming meetings, the revision of the Initial GHG Strategy will be addressed with a large focus likely to be setting a new ambition level that is aligned with a 1.5°C temperature goal and potentially the inclusion of interim milestones. The revised IMO GHG Strategy is scheduled to be adopted at MEPC80 which should take place in summer 2023. Additionally, further discussion of the tabled mid-term measures proposals will take place both in meetings scheduled for December 2022, Spring 2023 and Summer 2023.

Within the agenda item 'Reduction of GHG emissions from ships' there is a line of discussion around how working arrangements at IMO could be structured to support the workload under this agenda item. At a recent Intersessional Working Group in May 2022, Mexico co-sponsored a submission [ISWG-GHG 7/2/10] on calling for a Correspondence group to develop options for long-term working arrangements to support the IMO's work to reduce GHG emissions from ships. This, in itself, demonstrates commitment by Mexico to progress the policy work associated with shipping's transition. At MEPC78, which followed in June 2022, Mexico positioned itself among those in support of a high ambition level and echoed calls for a fair and just transition. Additionally, in the past, Mexico co-sponsored submission ISWG-GHG 7/2/10 on defining the needs for Pacific SIDS in the context of implementation of the Initial Strategy and the *Roadmap for developing a comprehensive IMO strategy on reduction of GHG emissions from ships*.

In relation to future global policy measures, multiple proposals for MBMs have been submitted for consideration and will likely be refined further for continued discussion at the upcoming meetings. How these proposals proceed and how a revenue generating measure is designed will have significant bearing on the shape of the transition. Funding generated from a price on GHG emissions could be used in a variety of ways, inter alia:

- Enabling an internationally equitable and socially just transition by supporting the most climate vulnerable States,
- Closing the competitiveness gap[21] between new alternative fuels and incumbent fossil fuels through revenue recycling,
- Addressing disproportionately negative impacts on States,
- Capacity development and technology transfer,
- Climate finance, and
- Training and education for seafarers and workers in the shipping industry [108].

Work by the World Bank finds political viability in a scenario where a portion of revenue is allocated for out-of-sector use [109][110]. However, revenue generation, collection and deployment are dependent on the policy design and therefore uncertain as yet. Nevertheless, given the recent IPCC reports on climate change impacts, adaption and vulnerability [1], some Members emphasize the need for a significant portion of revenue to support the most climate vulnerable [111].

The upcoming regulatory discussions at the IMO may set the shape of the transition for years to come. It is imperative that policy objectives for any country at the IMO level should be as ambitious as possible, aligned with IPCC climate science and

21 Estimates suggest that across the 2030s and 2040s SZEF may be approximately double the price of conventional fossil fuels [23].

geared to send strong policy signals in order to drive long-term investment in the production and provision of alternative fuels that emit zero-GHGs on a life-cycle basis and to enable an equitable transition for all.

«A global carbon pricing mechanism, established through the IMO would send the market a clear signal, helping to close the competitiveness gap between traditional and zero emission marine fuels. This would strongly drive the uptake of these fuels, creating a huge opportunity for countries with abundant access to renewables, like Mexico, to supply them.» – Abel Lopez Dodero (World Bank)

The currently adopted IMO measures have yet to achieve sufficient emissions reductions to put the sector on a trajectory that is compatible with the 1.5°C temperature goal of the Paris Agreement. Although strong policy signals can be sent at upcoming meetings, it will be some years before new measures have been agreed and implemented. As a result, national action and public-private collaboration have a key role to play at this moment to facilitate shipping's transition [13]. Examples of such activity in the international maritime space can be seen in Figure 13.

Figure 13: International maritime collaborations and Initiatives to support decarbonization.

Getting to Zero Coalition Call to Action

More than 240 signatories have urged governments to:

1. Commit to decarbonizing international shipping by 2050
2. Support industrial scale zero emission shipping projects through national action
3. Deliver policy measures that will make zero emission shipping the default choice by 2030

Find out more

Uptake MOUs

Memorandums of Understanding (MoU) or partnership agreements can be signed by parties interested in exploring the establishment of large-scale green fuel production and accelerating the supply of green fuels for shipping. These agreements facilitate investments by ensuring uptake demand.

Example MoU signed in 2022

Clydebank Declaration for green shipping corridors

Launched at COP26, currently 24 countries have pledged to:

- facilitate the establishment of partnerships, with participation from ports, operators and others along the value chain, to accelerate the decarbonization of the shipping sector and its fuel supply through green shipping corridor projects
- identify and explore actions to address barriers to the formation of green corridors. This could cover, for example, regulatory frameworks, incentives, information sharing or infrastructure
- consider the inclusion of provisions for green corridors in the development or review of National Action Plans
- work to ensure that wider consideration is taken for environmental impacts and sustainability when pursuing green shipping corridors.

Mission Statement:

'....to support the establishment of green shipping corridors – zero-emission maritime routes between 2 (or more) ports. It is our collective aim to support the establishment of at least 6 green corridors by the middle of this decade, while aiming to scale activity up in the following years...'

Find out More

An MBM adopted at IMO may offer in-sector financial support at some stage, however in this initial phase, collective action by the maritime industry, the energy sector, financial institutions, and governments/intergovernmental organizations need to provide significant funding in the form of private sector investment and public-private partnerships. Indeed, in consideration of the competitiveness gap between fossil fuels and alternative SZEF [108], it has been highlighted that the production costs for the new fuels will influence the magnitude of the price gap, which is an argument in favor of future fuel production investments being focused on competitive locations such as Mexico [112].

On a more specific level, there may be an opportunity for Mexico to develop policy which would reduce coastal air pollution and incentivize the use of less polluting fuels in the short-term, and the energy transition of international ship traffic transiting in Mexico's EEZ in the longer term. This would involve the establishment of an Emission Control Area off the Western Coast overseen by the federal government. Due to the United States' Emission Control Area (ECA)[22], which starts at the Northern border of Mexico's EEZ, some ship operators wait outside the ECA for their port call to the United States. This allows ship operators to consume cheaper but higher sulfur content fuels [113], which can cause serious adverse health and economic effects to the coastal population [51][114]. Future environmental policies from California could worsen/exacerbate this phenomenon, for example, the ports of Los Angeles and Long Beach have pledged to reach zero port emissions by 2030, with two other ports potentially following this lead [115][116].

Green corridors have been suggested between Los Angeles and Shanghai to reduce the carbon footprint of commercial goods traded by the two nations [117]. These moves could position Mexican ports, specifically ports in Baja California, as the nearest fossil fuel bunkering hub for Transpacific navigation and thereby subject to visits from 'dirty' ships that have yet to transition to zero emission fuels. This scenario illustrates the importance of the geofencing method, presented in Section 3, for creating shipping emissions inventories that capture high density international ship traffic in EEZ. It also highlights the opportunity for Mexico to develop its own ECA, thereby increasing protection from harmful pollutants to both its coastal communities and its biodiversity.

In the evolving policy landscape, combining a focus on domestic ambitions that align renewable energy production and GHG emissions mitigation with an international commitment to engage in global policy development, provides a promising outlook for Mexico's role in the transition.

22 Areas created to limit the emission of air pollutants, in particular SO_x and NO_x.

Section 6

Strategic Business Opportunities in Mexico

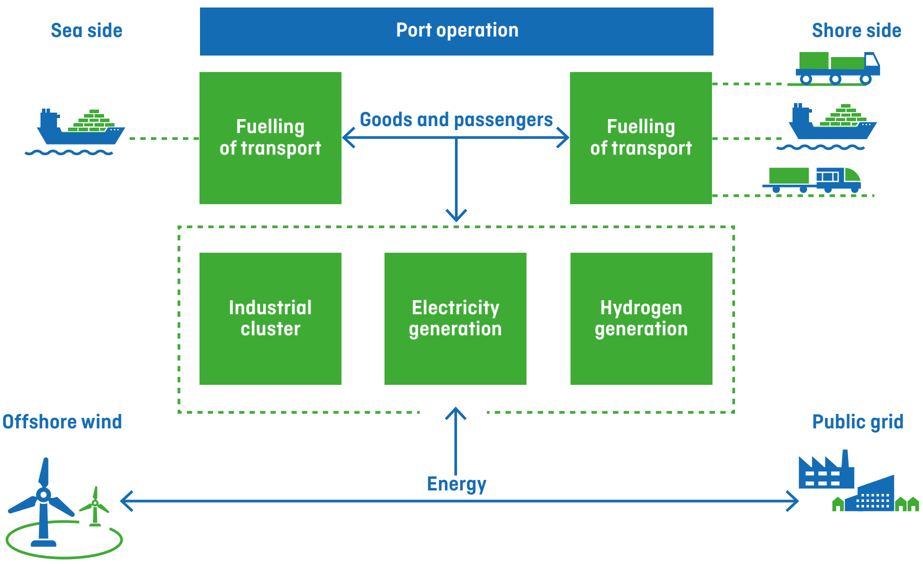
6.1 Ports as opportunities

Ports play an important role in connecting shipping to the hinterlands of various countries, acting as both gateways and refueling stations for the international movement of goods and commodities. As the maritime industry transitions to SZEF, it is apparent that new infrastructure will be needed to produce, store, and provide these fuels to the industry. Ports, in particular, will require significant infrastructure, investment and land availability to meet the bunkering needs of new or retrofitted ships running on alternative fuels. To that end, ports can be both suppliers of these new alternative fuels as well as offtakers to decarbonize their own activities.

Port operations produce substantial emissions and pose a number of environmental issues stemming from port activities, marine vessels calling at ports, and intermodal transport networks serving the port hinterland [118]. Ships operating near a port burning fossil fuels emit significant air pollution – as seen in Section 3 of this report – that affects coastal populations as well as communities living hundreds of miles inland [51]. Given the proximity of the human population to marine and port-related emissions, reduction of pollution emissions from ports and maritime sources will, in the first instance, greatly improve the air quality for millions of people [56]. Having estimates of levels of air pollutants and GHG emissions in ports propel the design of policies and consequent business and investment decisions.

Decarbonization of ports can have several benefits; for instance, it can promote the creation of green jobs in the production of alternative energies, bunkering and storage, and for the provision of green port services. Capitalizing on their established hinterland connections, ports can act as nodes to facilitate decarbonization synergies between the energy sector and the transport sector (see Figure 14). This would harness the local deployment of renewable energies at a large scale for electricity and alternative fuel production used in port bunkering.

Figure 14: Ports as nexus between land & sea [119].



Manzanillo

The Port of Manzanillo, located on the West Coast, is one of the busiest ports in Mexico and the 3rd largest Port in Latin America [120], making it an active emitter of maritime GHGs (see Figure 9). Situated in the State of Colima, it is the principal entrance for containership imports and, hence, attracts significant private, national, and foreign investment [121]. Due to port expansion projects, Manzanillo handles increasingly large amounts of general and consumer goods for import/export. In 2018, a $50 million USD project expanded the port capacity by 17% to 2.1 million TEU. In 2019, the General Coordination of Ports and Merchant Marine[23] put together a $1.2 billion USD plan to expand Manzanillo, upgrading the handling capacity of the port by 33% and including the construction of a new container terminal. This is part of a $2.6 million USD, 5-year public and private investment project proposed by the government to invest in three ports, Manzanillo, Veracruz, and Progreso [122].

Manzanillo currently occupies an area of 437 hectares, which includes water areas, docks, and storage with 19 berthing positions (14 commercial, 3 for hydrocarbons, and 2 for cruise ships). As a major port, Manzanillo has 6.20 km of internal roads and 24.70 km of railways, enabling the port to position itself as the main entrance for the handling of internationally traded goods for Mexico's Central and Bajío Zones [121][123]. Manzanillo handles 46% of container traffic in Mexico, serves more than 17 States representing 55% of the national population and accounts for more than 67% of the country's GDP (see Figure 15) [121]. Consequently, Manzanillo is Mexico's largest port in terms of maritime energy usage, demanding 11 TWh of fossil fuel energy per year [36]. Per Section 3, the maritime activity Manzanillo from the geofenced approach represented about 520 kt CO_2e, while from the international arrivals and departures represented 4,000 kt CO_2e and 2,350 kt CO_2e, respectively. Regarding air pollution emissions using the geofenced approach, the maritime activity around Manzanillo in 2018 was built from 7.15 kt SO_x, 9.00 kt NO_x, 0.39 kt CO, 0.98 kt PM_{100}, 0.89 kt PM_{25} and 0.39 kt VOC.

23 A department within SEMAR that oversees ports.

Figure 15: National influence of the port of Manzanillo [121].

The port is located next to an area of significant solar potential amounting to ~1,750 kWh/kWp, which could be leveraged to both electrify the port as well as produce green fuels [36]. Given this, as well its handling of much of the country's container shipping traffic, the Port of Manzanillo is seen as a significant opportunity to contribute to the energy transition in both the production, use, and bunkering of SZEF. Indeed, local stakeholders believe that the port could offer sustainable services using zero-carbon energy sources and be a renewable energy provider.

Manzanillo has strong ties to large industries that could also act as SZEF offtakers, mainly from mining and cement. The port is very near Mexico's biggest iron deposit, Peña Colorada, mined by ArcelorMittal which has an agreement with the port to use its specialized docks to transport pellet and iron ore concentrate [124][125]. Furthermore, Cementos Mexicanos (Cemex), one of the world's largest cement companies, has a 1.3 hectare terminal for handling and storing clinker and bulk cement alongside Cementos Apasco's 1.7 hectare bulk cement warehouse. Cementos Apasco operates the most productive cement plant in Tecoman, producing about 2.5 Mt per year [126]. As these industries seek to reduce their scope 2 and 3 GHG emissions, the Port of Manzanillo could secure offtake agreements with these companies to supply them with SZEF produced in or nearby the port; thereby increasing the local demand for these fuels and leveraging economies of scale to reduce production price. Research has already estimated that in Mexico the cumulative demand for green hydrogen for multiple sectors, including hard-to-abate mining and cement industries, could create a market of $700 million USD per year by 2050 [127].

Regarding the export of green fuels, the Port of Manzanillo has connections to 74 international ports in Asia, Eastern Europe, Australia, North America, and South America, which could become targets for exporting locally produced SZEF. The production, storage, and export of renewable energies such as green hydrogen and ammonia could become a strategic strength of the Port of Manzanillo. Options to explore a green corridor from Manzanillo were highlighted by stakeholders and could be based on the decarbonization of local industries, similar to the recently announced Australia-East Asia iron ore green corridor, which brings together mining, energy, and shipping companies interested in decarbonizing the iron ore value chain [128].

To realize the bunkering opportunity that the Port of Manzanillo represents, the port would need to prepare to bunker SZEF for use on ships. Infrastructure such as storage for SZEF would be required in addition to upskilling and training port employees to handle SZEF once safety protocols for new fuels are developed. Stakeholders felt that an assessment of the port's capability to produce, use, bunker, and export SZEF would be useful and serve as the basis for a work plan. This plan could phase the transition for the port into key stages, for example, become a green port, produce SZEF, offer export and bunkering services for SZEF in the port, in addition to incorporating a training plan for port employees.

Overall, this opportunity is very aligned with the precedent set by the port, in which Manzanillo was awarded a 'clean port' certification in 2016 by Mexico's Federal Attorney for Environmental Protection (PROFEPA) [129]. Being the first to receive this certification designates Manzanillo as one of the more progressive ports in Mexico. Leveraging this opportunity would complement local and regional decarbonization efforts for the maritime and port sectors, as well as contribute to fulfilling local policies and strategies and the environmental, social, and corporate governance (ESG) agendas of private-owned port terminals. Though the port currently lacks a publicly available environmental strategy or plan, future efforts could scope SZEF production and handling into the planned expansion of the port and look to reduce its reliance on traditional fossil fuels.

«WWF Mexico is working with federal and local authorities as well as industry and local communities on the development of capacities and recommendations to decarbonize national ports and maritime fleet. Our collaborative work seeks to explore how the ports, with Manzanillo as a pilot case, and the maritime fleet can reduce its GHG emissions and contribute to national decarbonization goals.» – Salomón Diaz (WWF Mexico)

6.2 Inter-industry synergies through energy production

An alternative to focusing on port development as a catalyst for shipping decarbonization is to take a sectoral approach in generating momentum towards SZEF production. Though the global maritime industry can act as a significant offtaker for new zero emission fuels, the combination of factors needed, i.e. to have a major commercial port with nearby renewable energy resources, high volumes of large vessel traffic, and space for development, is not always feasible. Indeed, finding land close to large Mexican ports would increase the attractiveness and versatility of any green hydrogen project. However, developable land near ports is not always available, and many ports face space constraints that limit their expansion and ability to have nearby SZEF production sites. In this case production further inland is necessary.

Rather than looking at shipping within a sectoral silo, a more holistic perspective can be taken wherein shipping is only one offtaker for these new fuels and acts as a complement to other industries with additional sectoral demands for green energy.

Such thinking is echoed in industry roadmaps that encourage international and national cooperation across sectors in order to reach global climate goals [130][131][119].

As seen with the Port of Manzanillo above, combining maritime energy needs with other hard-to-abate sectors such as mining, cement, fertilizer production, steel production, chemical manufacturing, etc. can provide the support needed to invest in green fuel production. Importantly, aggregating sectoral demand – both within and outside the maritime field – strengthens the business case for SZEF producers by lowering their investment risks and diversifying target markets [132]. Importantly, aggregating cross-sector demand – the majority of which comes from inland industries – enables large-scale and long-term investment that is needed to capitalize economies of scale and reduce the overall cost of SZEF production. This, in turn, will support the adoption and uptake of SZEF by multiple industries as they become more cost competitive if not cheaper than traditional fossil fuels. Stakeholders also indicated further benefits of creating inter-industrial synergies such as the strengthening of the government-private sector relationship to develop transitional energy sources and the deployment of acquired expertise when developing the infrastructure needed for green hydrogen. On the latter, there are countries with National Hydrogen Strategies, such as Canada, that see a business opportunity in exporting their expertise to other countries [133].

The government's Energy Reform Package (2013) attracted interest from the private sector to invest and participate in the Mexican energy market. Ever since, Mexico's government received several applications and environmental impact assessments for innovative projects focused on the production of renewable energy coupled with the capability to produce green hydrogen [134]. To date, there are multiple renewable electricity and green hydrogen projects that are being pursued in the country. Some of the more advanced ones include Tarafert, which has two projects in Durango focusing on blue ammonia and urea, scheduled for commercial operations in 2026; and Tarafert-2, a production facility for zero-carbon green hydrogen from solar energy. Baja California also has a project by HDF energy (more detail in the following Baja California subsection). Most of these projects are led by internationally backed companies, though local companies such as Grupo Infra, Protexa, Solensa, and Énestas Raw Materials & Fuels, which are seriously looking into green hydrogen as well [135].

El Bajìo Industry Hub

One important key stakeholder in the planning and future production of green hydrogen is DH2 Energy. DH2 Energy is a company focusing on developing green hydrogen projects in Europe and the Americas with important projects such as Hydeal and Hysencia [136]. They also focus on the construction of consortiums ensuring that hydrogen's demand and supply are matched. At the moment, DH2 Energy is planning to develop several renewable hydrogen projects in Mexico, such as a generation park of photovoltaic solar energy capable of producing up to 130 MW peak of electricity and coupled to a 100 MW electrolyzer plant capable of producing up to 5,700 t of green hydrogen per year [137]. Stakeholders from this project indicated the benefits of having considerable expertise on the generation of renewable energy on the manufacturing of SZEF. To that end, DH2 Energy can leverage the expertise of its sister company, Dhamma Energy Mexico, which has fully developed a total 470 MW of installed capacity in the past years in several Mexican states and has an extra 2 GW in solar capacity pipeline in development.

The location of DH2 Energy planned green hydrogen activities are adjacent to many automobile producers in the El Bajío region (see Figure 18). In San Luis Potosí, the automotive industry is one of the largest industries, with the presence of key companies such as General Motors, Mabe, Draexlmaier, Robert Bosch, Cummins, and BMW, among others [138]. In Guanajuato important car manufacturers are General Motors, Honda, Mazda, Toyota, and VW among others (see Figure 16) [139]. In particular, BMW's automotive plant in San Luis Potosí uses, among others, the surrounding ports of Veracruz, Lázaro Cárdenas, and Manzanillo. The automotive industry is a large part of Mexico's economy, with much activity taking place in central Mexico away from coastal states. Coupling green energy production inland to other centrally based industries is a good way to not only decarbonize manufacturing in Mexico, but also green logistics and supply chains, thereby reducing company scope 2 and 3 emissions, respectively. This is especially relevant to companies that serve markets in Europe and North America, which have higher consumer pressure relating to sustainability performance. BMW has indicated general interest in using alternative fuels such as green hydrogen on-site in their Mexican facilities, especially given that they already use such fuels in some European facilities to reduce CO_2 emissions.

Figure 16: Industry Hub in El Bajío, Mexico [140].

San Luis Potosí also has significant mining and steel industries that could act as offtakers for locally produced green hydrogen. Indeed, leading mining companies and members of the International Council on Mining & Metals have set targets to their reduce scope 1 and 2 emissions, and will set targets to address scope 3 emissions no later than 2023 [141]. Though Mexico's mining companies did not sign this commitment, Cámara Minera de México (Camimex) is an associated member of the Council and therefore in tune with new pressures and drivers of the industry to become more sustainable [142]. The state has an important national mining contribution on the extraction of Copper (3rd national extractor), Gold (9th national extractor), Cadmium (2nd national extractor), and Antimony (1st national extractor) [143]. The state had 643 active concessions in 2019 covering about 641,000 hectares. The main metallic mining stakeholders in the state are Minera San Xavier, Industrial Minera Mexico, Negociación Minera Santa Maria de la Paz, Compañía Impulsora Minera Santa Cruz, and Compañía Minera Huajicori. These companies have the capability of extracting about 19,000 t per day of different metals [144]. For the non-metallic activities, the main stakeholders are Cemex, Cementos Moctezuma, Vitromex and Hermes Betancourt.

Furthermore, Mexico's steel industry is another option to aggregate green fuel demand. Mexico and Brazil produced more than 80% of Latin America's steel in 2019. The iron and steel industry uses grey hydrogen for direct iron reduction, and represents the 2nd largest consuming sector in the country for grey hydrogen besides the oil and gas sector [145]. In the State of San Luis Potosí, there are six steel producers that cumulatively produced around 1.22 Mt of steel in 2020, making San Luis Potosí the 5th largest steel producer in Mexico [146].

DH2 experts recognized that shipping activities in Mexico could play an important role on the demand aggregation of green hydrogen through the production and distribution of green ammonia as maritime fuel. At present, however, Mexico's political landscape and government's approval are vital to build green hydrogen stakeholders' confidence about hydrogen's potential market. One of the main challenges that DH2 Energy has identified is the hydrogen infrastructure needed for its storage and transport (e.g. pipeline network), which has to be seen as a key area of development if Mexico is going to take advantage of its green hydrogen potential. After enforcing strategies to mitigate these risks, the company plans to sell green hydrogen to hard-to-abate national industries – such as steel, cement, and fertilizer industries, whilst exploring the opportunity of exporting green hydrogen to Europe and Asia, among others.

«Mexico has substantial solar potential. Capturing this potential and converting it into new products such as competitive green hydrogen, ammonia and e-fuels represents a significant opportunity for the country with multiple spillover benefits to the national economy and local industries.» – Philippe Esposito (DH2 Energy)

6.3 Regional opportunity

Shipping's energy transition is increasingly understood as a cross-sectoral, multi-stakeholder endeavor to move towards a zero-carbon and sustainable economy. Certain regions have significant renewable potential and multi-sector industrial activity which creates a conducive environment for the deployment of decarbonization projects.

Crucially, leveraging regional opportunities can:

- Aggregate demand from different industries, thereby incentivizing investment in pilot projects
- Create inter-sector synergies, particularly between production and transport sectors, which in turn create green supply chains
- Encompass social-facing industries, such as tourism and fishing, which can be used for pilot projects making decarbonization more visible to communities
- Create green jobs and decrease air pollution associated with industrial activities, thereby contributing to the realization of sustainable development goals
- Overcome unique challenges within the region and fulfill State/regional strategic objectives

In other words, regional transition opportunities offer an abundance of spillover, cross-sectoral and co-benefits. The following section presents the regional opportunity of Baja California.

Baja California

Baja California is the 7th largest economy in Mexico representing 3.7% of Mexico GDP (about $39.97 billion USD) in 2020. It has several unique features that make the State a promising regional opportunity, including its energy infrastructure, renewable energy potential, concentration of heavy industries and manufacturing, political will and its proximity to the United States. From a shipping perspective, Baja is also a hub for maritime activity, which lends itself to engaging in the energy transition of the international shipping industry [147]. Despite having a landmass that represents only 3.6% of Mexico's national territory, Baja's coastline accounts for 11.6% of Mexico's coastline with maritime trade representing about 15.5% of the national trade during January 2021 [148][149]. In combination, these characteristics create a unique opportunity to produce and operationalize SZEF across the energy sector, heavy industries, manufacturing, and shipping sectors. Thus, Baja was highlighted by a number of stakeholders as a key case study, the details of which are laid out below.

Both the environmental and social geography of Baja California lends itself to the production of renewable energy and green fuels. Baja has significant renewable energy potential with some of Mexico's highest solar and wind resources in the mid- and southern part of the state [150]. Other alternative renewable energies include wave and tidal energy, located in the northern part of the state's Gulf of California [151], and the expansion of geothermal capacity of the current Cerro Prieto power plant [150].

Despite Baja having the largest protected[24] area in Mexico, representing 36% of the State land [152], there is land that would be ideal for the decentralized production

24 The Government of Mexico does not allow any development or significant human activity on protected natural land unless they fall within the allowed and limited development and activity set for each protected natural area [153].

of green fuels, for example South of Mexicali, between the current geothermal plant and Cerro Prieto Corridors. This land is relatively near the electrical grid, as well as established LNG and electricity cross-border supply sites and, therefore, also offers exportation opportunities to United States and Asian markets or as bunker fuel, leveraging the LNG infrastructure available in the State.[25] In conversations, stakeholders also mentioned exploring production opportunities in other areas on the north Pacific side of Baja.

Nevertheless, production of green fuels can be undertaken in any area of high renewable potential, regardless of proximity to the main electricity grid. Green fuels, such as green hydrogen and green ammonia, can be produced onsite and then transported[26] across the State for domestic and industrial use. Cases exist whereby excess renewable electricity, which would otherwise be lost as grid surplus, is converted to green fuels, e.g. green hydrogen, or for seasonal storage [154][155]. Indeed, there is a project in Baja which aims to store hydrogen to generate electricity, developed by HDF [135]. For Baja in particular, the transportation infrastructure is ideal for moving SZEF, with a modern network of highways connecting the cities where 92% of the population reside and a highly developed railroad freight service between Mexicali and Calexico, California and Tijuana and Tecate [156]. With the potential significance of production and transportation of SZEF for Baja established, there are multiple current and future demand points for the use of SZEF.

One option for SZEF is domestic use. The region's electrical grid is isolated and independent from Mexico's main national grid and is, instead, connected to California's grid in the United States via Tijuana and La Rosita[27] (see Figure 17). Baja's installed capacity for its own consumption was about 2,950 MW in 2019, which is insufficient to meet peak loads and the projected domestic growth in the coming years [158]. Instantaneous power demand peaks due to air conditioning usage in the summer months mean that extra capacity, up to 600 MW, is imported from California [157]. In addition to this, import of electricity, natural gas is provided by the United States to supply Baja's electrical demands [150]. CFE has taken the first steps to operate a green hydrogen pilot project from future solar power plants in Baja California.[28] The green H_2 pilot plant aims to minimize natural gas dependence, increase energy security in the region, and reduce GHG emissions which in turn will support Mexico's efforts to fulfil its commitment towards the Paris Agreement [159][160][161]. The project comprises the construction of a 350 MW photovoltaic park in Cerro Prieto with a view to start operations to produce green hydrogen between 2023 and 2024 [159][162][163]. Producing renewable energy and SZEF could address this challenge and would give Baja a domestic supply of environmentally sustainable energy, reducing its dependence on the United States and decreasing its susceptibility to geopolitical energy issues and resulting price fluctuations. Producing green fuels through renewable energy also offers significant cross-sectoral benefits for the decarbonization of heavy industry and manufacturing. Hydrogen from renewable power is technically viable today and is quickly approaching economic

25 The use of existing LNG infrastructure to either mix fuels or use solely for hydrogen transportation has been studied, suggesting that minor modifications are needed if a small percentage (about 15%) of the flow is made of hydrogen. Larger shares of hydrogen will require larger and more expensive modifications and challenges.

26 Ideally using green transportation, which is also powered by renewable energy, for example Heavy Duty Vehicles (HDV) operating on zero emission fuels or battery electric.

27 As of 2018, there was an agreement of understanding to connect Baja California system to the state of Arizona through San Luis Rio Colorado interconnection [157], however for the next "Programa de Ampliación y Modernización de la RNT y de la RGD" (PAMRNT) reports this agreement is not mentioned and the interconnection has not happened [158].

28 As well there is plans to develop capabilities in the state of Sonora the construction of a photovoltaic park in Puerto Peñasco with an installed capacity of 1,000 MW.

competitiveness, with experts emphasizing the need to explore legislative frameworks that facilitate hydrogen-based sector coupling [155]. Baja is well-positioned for sector coupling which aggregates demand and secures multiple industries a supply of SZEF. Many of the stakeholders identified industries which are already transitioning their operations to reduce carbon emissions, including mining, cement, and manufacturing, as possible sectors to couple SZEF use with shipping for a greener supply chain. For details on different industry sectors in Baja, see the infographic in Figure 17.

Figure 17: Baja California's key industries, cities, ports, electrical grid, gas pipelines and their crossing to the United States.[29]

CEMENT & STEEL

Cement plant in Ensenada, owned by CEMEX which is one of the world's biggest cement firms.

In 2020, Baja California produced about 230 kt of steel which represented about 1.03 TWh per year and about 290 kt CO_2.

MANUFACTURING

>1,400 production-based companies, representing about 38.9% of Mexico's manufacturing sector and 20% of the State's GDP.

This includes aerospace, automobile, defense-related manufacturing, medical device industry, and electrical products.

MINING

> 520 active mining concessions in the state of Baja California. Main commodities are Gold, Lithium, Tungsten & Copper.

Accounts for over $27.72 billion MXN (about $1.39 billion USD) or about 3.5% of the state GDP in 2019.

TOURISM & FISHING

In 2019, Baja welcomed 27.9 million visitors and generated $119 billion USD in annual visitor spending.Post COVID, many visitors now seek adventure or nature tourism in the region.

Baja produces nearly 50% of the total national fisheries product.

29 Sources: Canacero, 2021; Tecma, 2014, 2015; GeoComunes, 2021; The Diggins, 2022; TAW, 2022; and Cota-Nieto, 2016.

Stakeholders pointed out that the pressure to decarbonize shipping will come from downstream as many companies begin to consider reducing their scope 3 emissions[30] which makes supplying green fuels to both the land-based and sea-based transport a key strategic opportunity for any export-driven region, such as Baja. The main commercial partners for the State are the United States, Canada, China, South Korea, Japan, Vietnam and the EU [165].[31] In 2020, Baja's total international sales were $42.4 billion USD with significant drivers being the manufacture and export of monitors and motor vehicles. Several stakeholders emphasized the importance of decarbonization when exporting materials and goods specifically to developed countries. In terms of manufacturing, one stakeholder felt that Western companies with production facilities located in Mexico, or simply with supply chain connections, could be '*good anchors to push for change*'.

As seen in Figure 17, Baja has three key ports: Islas Cedros, Ensenada, and Rosarito. Ensenada Port, connects to 28 different countries through more than 60 international ports, mostly through container transit linked to the manufacturing relationship with Asia, Europe and South America [166]. Bahia Colonet, South of Ensenada, has been proposed as the next generation of ports in the region and has the support of the current State and Federal Governments and it is in the process of receiving funding to start its construction [167][168]. The State sees considerable maritime activity on the Pacific side, primarily large commercial ships, LNG carriers, fishing, and cruise ships.[32] With its heavy focus on manufacturing and export of raw bulk, and its renewable energy potential, Baja could supply green fuels directly to key ports for use onboard international vessels. There will also be increasing opportunities for exportation of green fuels as international demand for SZEF grows. Production of green fuels could also be viable for international exportation which would open up new economic opportunities for the State by leveraging existing and potential trading relationships.

On the Eastern side of Baja, the Gulf of California offers potential maritime electrification projects for the region. This area has substantial small boat traffic associated with tourism, fishing, and ferries. For each of these sectors, electrification of vessels offers a promising transition option which, in turn, would decrease air pollution and protect the biodiverse environment in this area.

Leveraging Baja's potential not only aligns with the aim of the Paris Agreement, but also with the protection of the State's biodiversity and would fulfil multiple Sustainable Development Goals. Furthermore, Baja was also highlighted as a prime regional opportunity by stakeholders due to the political environment in the State, which is relatively progressive and therefore facilitative to green transition initiatives and investments. Additionally, stakeholders in the United States have shown interest in engaging with the Baja California government and Mexican policy makers to create synergies that can mitigate the sales of American fossil fuels through the Pacific coast.

30 Scope 3 emissions include (among others) emissions from transportation and distribution up- and downstream [164].

31 These trade connections are evidenced by Mexico's international trade agreements such as the United States-Mexico-Canada Agreement (USMCA), Trans-Pacific Partnership (TPP) and EU-Mexico Trade Agreement. Mexico's international trade agreements such as the United States-Mexico-Canada Agreement (USMCA), Trans-Pacific Partnership (TPP), and EU-Mexico Trade Agreement.

32 By comparison, the Gulf of California sees small-scale fishing as the dominant shipping activity, sustaining the livelihood of several coastal populations.

The social, environmental and economic case for leveraging Baja's advantages as part of an energy transition is clear however significant investment would be needed to operationalize this opportunity. Although general finance opportunities for Mexico are presented in Section 7 of this report, it is worth noting that in January and September of 2021, Baja California received $1.92 billion USD in Foreign Direct Investment, the largest recorded in the last 20 years and the highest of any state in Mexico [169][165]. Additionally, one stakeholder suggested that funding to develop pilot projects in Baja California, and especially projects to understand the viability and implication of electrifying ships, might be sourced from the North American Development Bank. The bank provides loan programs, community assistance programs and technical assistance programs which cover project development, sector studies, and capacity building in which assistance and funding cover the United States-Mexican border area. Financing opportunities are discussed further in the following finance section.

«Sitting between important Asian and American trade routes and blessed with rich renewable energy resources such as geothermal, solar, wind, and tidal, Baja California can develop and expand existing industrial port facilities and huge green energy farms to become a key player in global decarbonization efforts.» – Daniel Gutierrez-Topete (Energy Cluster of Baja California)

«We wholeheartedly welcome the joint efforts of the Getting to Zero Coalition, the Cluster de Innovación Energética de Baja California, A.C., and the University College London, a world-class research institution keenly interested in the development of our State. Our Governor, Marina del Pilar Ávila Olmeda, is enthusiastically committed to sustainable transformation of our industries, driving the use of clean energy sources, as initially suggested in this ground-breaking study that we consider can provide benefit of our peoples and our country.»

BAJA CALIFORNIA
GOBIERNO DEL ESTADO

Kurt Honold Morales
Secretary of Economy and Innovation,
Baja California State Government

Section 7

Finance and Investment Requirements

As a result of the price gap between fossil fuels and SZEF, the market may need to be supported by regulation – either a mandate to use SZEF, or a market-based measure (MBM) (e.g. GHG pricing) that increases the price of fossil fuels or reduces the price of SZEF. In terms of financial investment to achieve this transition and ensure SZEF scale up to meet the regulatory-driven demand, a significant amount of funding is needed.

Investment requirements for SZEF and funding for key opportunities such as those discussed in Section 6 provide a strong basis to kickstart shipping's energy transition in Mexico. However, by no means is this the only avenue that needs investment, since energy-efficient measures and wind propulsion will have an important role in reducing shipping carbon intensity and operational costs. In the long run, however, new alternative fuels are seen as key to achieving global climate goals [5]. SZEF will require, inter alia, the development of new bunkering infrastructure, deployment support, production scale-up, a decrease in renewable electricity prices, and the development of new regulatory safety measures [23]. In other words, the fuels transition in shipping is linked to the evolution of global energy systems and renewable capacity, which must increase to drive down the price of renewable energy [12].

Currently, and in the near term, there exists a competitiveness gap between incumbent fossil fuels and zero emissions alternatives. This competitiveness gap is driven by a number of factors, including production costs, capital expenditure and infrastructure requirements, availability issues, lack of information, and other market barriers [108]. Developing zero emission-ready ships will demand higher CAPEX costs, relating to the ship's design and engine requirements; however, the major of additional costs will be operational, driven by the more expensive zero-carbon fuels [170]. Estimates suggest that across the 2030s and 2040s SZEF may be approximately double the price of conventional fossil fuels [23].

Estimates suggest that $1.4-1.9 trillion USD of capital investment will be needed globally to fully decarbonize by 2050, with the majority of funds (87%) needed for land-based infrastructure [171]. While it is suggested that some portion of this investment needed could come from a global MBM for shipping, it is also understood that in the initial stages of the project, private sector investment as well as public-private partnerships and deliberate collective action by the maritime industry, the energy sector, financial institutions, and governments/ intergovernmental organizations across the globe can provide significant funding [108][109].

Mexico could attract investment of between $37-53 billion MXN ($1.9-2.7 billion USD) to build the infrastructure required by 2030 to provide renewable electricity and zero-carbon fuels to decarbonize 5% of the vessels visiting Mexico's ports. Of these $24-36 billion MXN ($1.2-1.8 billion USD) would be for solar and wind farms, with the balance required for green hydrogen and green ammonia plants as well as related infrastructure [36].

There is a need to identify sources of finance and instruments which are capable of de-risking private sector investments into land-based infrastructure and zero emission vessels. This will ultimately require leveraging different types of blended finance, through a combination of concessional and private funding. In general, Mexico, as an upper-middle income country, is unable to access large amounts of grant-based development funding [172], particularly through larger financial institutions. This means that most available international finance will come in the form of low interest loans, with some scope for accessing grant financing where certain conditions are met.

From an international perspective, Mexico already attracts a sizeable amount of funding through several multi-lateral development banks, which offer the opportunity to secure large awards of funding to projects or programs. Through these banks, Mexico can receive large loans, such as from the Inter-American Development Bank (IDB), World Bank, Development Bank of Latin America (CAF), and the European Investment Bank (EIB) [173][174][175][176].

The Inter-American Development Bank, as a regional development bank, supports transport decarbonization in various ways through working with the public sector in Latin America and the Caribbean. Specifically, the IDB offers non-reimbursable technical cooperation to government entities for technical assessments as well as policy and regulation development. It can also provide loans, credit enhancements, and assist governments in accessing green financing (concessional financing terms and/or grants, e.g. NAMA Facility, GEF, GCF). IDB Invest [177] is the private sector arm that supports developing key projects in the region, and the IDB Lab [178] acts as an innovation laboratory that provides seed funding to develop innovative technologies and projects to improve their scalability and proof of concepts. The World Bank also offers loans from the International Bank for Reconstruction and Development [179] at market rates of interest or the International Development Association [180] at concessional rates for eligible countries. It can also assist private entities in securing loans, loan guarantees, and equity financing through the International Finance Corporation [181]. Lastly, grants are possible for direct feasibility and technical support funding from, for example, the Public-Private Infrastructure Advisory Facility [182].

The possibility of having access to grant funding is an important factor in reducing the price of entry for subsequent sources of capital interested in financing a given project. This can be used to lay groundwork in terms of scoping a given opportunity and assisting with permits, certifications, and permissions needed to unlock further investments. Additionally, through providing technical cooperation, these banks can also further provide pre-project assistance for studies and development of policies and standards that take advantage of best practice. Multilateral development banks can also work with regional organizations and others to raise attention on these topics for government consideration.

Other streams of international grant finance can be sought that specifically target climate impact and other philanthropic causes. Examples of relevant institutions include ClimateWorks Foundation [183] and Climate Investment Funds [184]. For these types of funds and in general, Mexico's demonstration of climate action and alignment through international commitments and collaboration can hugely support its ability to attract funding.

Mexico could also seek to leverage its relationships with other countries under existing bilateral partnership arrangements. Examples of this include Partnerships with the United States, Germany, United Kingdom, and the European Union [185][186][187][188]. One particularly relevant fund is the North American Development Bank

[189], established between the US and Mexico, which seeks to invest into projects along the US-Mexico border. This is particularly relevant for opportunities like Baja California (see Section 6), which could leverage its proximity to the US both to secure funding and a potential market capable of de-risking relevant projects.

From a national perspective, a large amount of the objectives and volumes of funding awarded through national institutions are strongly influenced by the Federal Expenditure Budget (PEF). This sets the national budget and objectives that influence the provision of funding nationally. In terms of specific national funds, Mexico has a strong infrastructure for development and project finance through, for example, BANOBRAS, BANCOMEXT, NAFIN, and FONADIN [190]. These funds can provide large awards towards projects across a range of areas, including large energy and infrastructure projects.

For private sources of finance, Mexico also has mature capital markets, with several investment vehicles capable of providing early sources of funding for relevant projects. Examples of this include Mexico's hedge funds and pension funds, which are sources of finance more capable of taking on the long-term risk necessary to get these projects off the ground. For infrastructure projects, the federal government also plays a strong role in coordinating capital markets, in particular through the Fibra-E [191] investment vehicle, which helps to coordinate investment across the private sector into energy infrastructure projects.

Globally speaking, Mexico already attracts a huge amount of international investment in the form of development finance. However, the current lack of governmental support for decarbonization in general and maritime decarbonization specifically is a key barrier to attracting finance towards the opportunities outlined in this report. To better leverage its potential to develop green fuels and gain additional access to financing, Mexico could seek to showcase increased support for these objectives to unlock opportunities and de-risk the investment case for international and Mexican stakeholders.

Section 8

Recommendations

Mexico's strategic geographic position next to key shipping routes and its potential to generate substantial amounts of renewable energy, places the country as a possible leader to drive decarbonization of the maritime and port sectors as well as other connected industries. The country's air pollution due to human activity, in addition to emissions from transiting vessels, not only affects coastal and inland populations but also the country's marine environment and attractive biodiversity. As shown in previous sections, the country's vast renewable energy potential has the capacity to not only supply its electrical demand but also produce zero-carbon fuels to cover shipping's energy needs through its ports as well as support decarbonization of other land-based sectors.

The government of Mexico and its ministries are in a prime position to take advantage of the key benefits these new fuels can bring, especially with regards to potential export and bunkering, as well as increasing international demand by foreign industries with manufacturing presence in Mexico to reduce supply chain emissions all while enhancing the country's energy security. Through the production and use of SZEF, Mexico has the opportunity to leverage its renewable resources to create a new revenue stream, retain presence of key manufacturing and production industries, and meet its sustainable development goals. To get there, political recognition and establishment of appropriate incentives and targeted action is needed.

The suggested recommendations below represent a culmination of the work for this project and stem from the evidence base reported in preceding sections, multiple stakeholder interviews, scoping exercises, a collaborative workshop, and a roundtable with the project's National Committee for Mexico. Where appropriate, the synthesis produced from these inputs is also supported by additional references from literature. These recommendations are by no means prescriptive nor exhaustive, but present starting points for key actions to be taken in the coming years to support the country's engagement in shipping's decarbonization.

«Mexico, as one of the strongest economies in Latin America is, at the same time, a nation with enormous maritime potential. Mexico has the opportunity to not only benefit massively from the global energy transition by incorporating itself more closely into global value chains, but also become a first mover driving the uptake of green fuels regionally.» Ricardo Sanchez (United Nations Economic Commission for Latin America and the Caribbean (ECLAC))

Ports

In June 2021, the Secretariat of the Navy (Secretaría de Marina), took over the responsibility of administrating and directing the operation of Mexico's national ports as well as the merchant fleet. This is causing important changes in port development and is affecting the prioritization of opportunities and environmental ambitions. It will therefore take some time to understand how ports will engage with shipping decarbonization if the current political focus of the present government towards the use of fossil fuels remains constant.

As part of this engagement, ports could consider how planned upgrades align with the future of the maritime industry. It would be prudent to build port facilities that are climate change proof and support GHG emission reduction goals. Stakeholders raised the potential co-benefits of decarbonization; for example, decarbonizing shipping would lead to a reduction in air pollution in ports and port cities. Indeed, the United States-Mexico-Canada Agreement (USMCA) now includes an article on the environment and an obligation to improve air quality [67].

Nevertheless, locals are quick to highlight the importance of ports for the energy transition, both as suppliers of these new fuels as well as offtakers to decarbonize their own activities. In scoping interviews and consultations, the importance of ports as key links in a chain of sustainability was emphasized by multiple stakeholders. In particular, Port Authorities were seen as key players in enabling the integration of green fuel infrastructure with Mexico's shipping activity. Stakeholders felt that Mexican ports must be ready to engage with the wider shipping sector as it prepares to undertake its fuel transition.

Suggested actions

Develop collaborative port plans & strategies that exploit the synergies of addressing both air pollution and decarbonization objectives

As discussed in Section 3, areas of Mexico suffer from GHG emissions and subsequent air pollution from vessels that both call on national ports as well as transiting in Mexico's waters. This has a significant impact on local climate and air quality. Sections 5 & 6 show that ports can play a large role in not only reducing shipping emissions through the provision of SZEF, but also grounding initiatives that combine multiple supply chain actors and sectors. Port authorities could develop collaborative port plans and strategies with national stakeholders, such as the Secretariat of the Navy, and local communities that explicitly state port interest in decarbonization as well as objectives to reduce port emissions. Ports could then align their expansion and development plans with these decarbonization goals in mind, ensuring compatibility with stated objectives and avoiding costly retrofits in the future. These strategies would also send needed signals to private actors interested in collaboration on decarbonization initiatives.

Increase coordination & guidance between main ports in Mexico

Stakeholders also noted the need for increased coordination of Mexico's key ports: Manzanillo, Altamira, and Lazaro Cardenas. Furthermore, highly active ports detected in Section 3.2.3 that could benefit from enhanced coordination would be Cozumel and Veracruz. Through improved guidance from the State, sustainable port services and infrastructure in Mexico can become more efficient, competitive, and cost-efficient. In particular, harmonization of official procedures and control mechanisms [192], as well as enhancement of communication and coordination within the port community [193] can improve cargo handling and port performance. This falls in line with international recommendations, which argue for climate-proof maritime infrastructure and services to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change [28].

Explore options for port electrification and mitigation of air pollution

Electrification of existing fossil fuel use of ports is an immediate step towards maritime decarbonization, wherever this change is possible. Switching port activities to rely mainly on electrical energy from renewable sources can reduce GHG emissions. Electrification can also reduce local air pollution emissions and maintenance and energy costs. Options for switching to electrification include electrifying docks for cold ironing; installing charging infrastructure to power logistics and freight handling with cranes and logistical onshore vehicles; cold storage; service vessels, such as harbor tugs and pilot vessels; and offices and buildings [28][119].

Prepare to source or produce SZEF for bunkering, port use & export

As evidenced in Section 1, shipping will need to rapidly transition away from fossil fuels, particularly during the 2030's. Due to the large quantity of international ships calling and passing, evidenced in Sections 2 and 3, Mexico has large amounts of maritime-based GHG emissions that the country does not benefit from (either in bunker sales or through port fees). Rather than import refined petroleum, Section 4 shows that Mexico has enough renewable energy to generate domestic SZEF production, thereby reducing air pollution from passing vessels and generating new revenues. As SZEF move to implementation, all aspects of ports need to be prepared to switch – opportunities exist both as a bunker fuel, for use in port (e.g. new vessel designs such as the Port of Antwerp's 'Hydrotug' which is powered via a dual-fuel combustion engine that burns hydrogen in combination with diesel [194]), as well as for export.

Encourage ports as green nodes in a multi-sector network

Ports are focal points for multiple sources of pollution, from arriving and departing vessels, onshore trucks and rail, as well as their own operations (see Section 3). To handle SZEF, local stakeholders saw the need for investment in port infrastructure and port equipment that is in tune with associated railway and terrestrial infrastructure. Creating a port ecosystem that acts as a green node for multiple sectors is seen as important in the coming years, wherein the port can offer sustainable services using zero-carbon energy sources for vessels and land-based transportation alike. Economies of scale can be leveraged by powering other industries nearby ports, such as chemical plants, fertilizer producers, etc. Adoption of port technology solutions that can provide renewable-based energy to these connected sectors, such as electric charging stations or green hydrogen refueling options, is one step towards decarbonizing supply chains.

Policy

To realize shipping's energy transition in Mexico, both a top-down and a bottom-up approach is needed – manifesting as a multilateral push from the government, companies, civil society, and academia. Intrinsic to this process is decarbonization and the push for increased capitalization of renewable energy sources [135].

Currently, the Mexican government has communicated its efforts to restructure the national energy policy to alleviate poverty and to reduce inequalities while also aiming to conserve and restore blue carbon ecosystems, seas, and oceans. However, research and multiple stakeholders have noted that Mexico's regulatory and policy framework will be insufficient to meet its international climate commitments [127]. Therefore, turning to unexplored mitigation actions such as greening maritime operations could enhance climate action and facilitate meeting international climate commitments.

Mexico has significant potential to produce and promote new fuels and renewable energies, which can contribute to the decarbonization of shipping and create co-benefits for the country and its communities. A more resolute direction and policy stance towards the production and distribution of SZEF could contribute to cover shipping's energy needs and supply the country's domestic electrical demand, whilst improving air quality, reducing GHG emissions, and creating green jobs.

The hydrogen economy in Mexico is projected to develop up to 3.2 million jobs, bring $46 billion USD to Mexico's GDP and reduce around 53 Mt CO_2 of Mexico's carbon footprint by 2050 [65]. As Latin American consumption of hydrogen in 2020 accounted for 3.5 Mt, the government of Mexico has an opportunity to generate economic growth and enhance energy security by developing its hydrogen economy. The race to establish a competitive advantage in this field has already started, with the likes of Chile, Colombia, Panama, Paraguay, Trinidad and Tobago, and Uruguay have developed or developing their national hydrogen strategies and roadmaps [195]. Including shipping in such plans and strategies directly connects the need for sustainable shipping into the larger decarbonization agenda and climate actions, which is necessary in the coming years.

Suggested actions

National

Update policies to reflect climate commitments as part of long-term national planning

As shown in Section 5, the current focus of the Mexican federal government is directed towards production and consumption of incumbent fossil fuels, which is seen by many stakeholders as a barrier or challenge to their engagement with SZEF. Indeed, examples were given where renewable energy projects had been halted in the face of the current political agenda. Sections 3 and 4 illustrate that GHG maritime emissions are vastly underestimated when taking into account transiting vessels, but Mexico's renewable energy resources could be leveraged to reduce these emissions as well as develop a green hydrogen economy that is attractive to both maritime and land-based industries.
To enable this, local stakeholders called to mainstream shipping and port decarbonization into national strategies and other policy instruments. This requires raising environmental awareness among politicians to update climate policies with a perspective towards long-term planning, especially as changes of administration are often disruptive, introducing uncertainty in the market and disincentivizing potential investors. Ratifying MARPOL Annex VI, submitting a voluntary National Action Plan to address GHG emissions from ships to the IMO, and SEMAR's revision of the National Policy of Seas and Coasts in Mexico present such opportunities to emphasize national commitment to shipping and port decarbonization.

Define a national hydrogen strategy or roadmap

Currently, Mexico does not have an official national policy or roadmap for the development and application of green hydrogen [127]. Given this gap, the private industry led by the H_2 Mexico has stepped up to provide guidance in their own work [65]. Though commendable, government adoption and support for such an initiative is required for legitimacy [135]. Creating a National Hydrogen Roadmap that integrates shipping's energy needs with defined targets and actions, planned infrastructure development, transition pathways, coordination between involved parties, governance structures, and business models is needed to unlock further finance and leverage Mexico's potential as a SZEF producer and exporter (see Section 7) [127].

Reduce permitting & administrative hurdles

Legal and administrative barriers can present significant bottlenecks in the advancement of renewable energy technologies and projects. Stakeholders pointed out that the future of SZEF in Mexico could be strengthened by government support, in terms of easing the process of obtaining permits and approvals. They highlighted, for example, the difficulty in obtaining permits for projects and land ownership laws and caps (in certain States) on the amount of renewable energy that can be generated without a specific permit. Easing or removing such barriers that hamper progress can stimulate investments in green energy projects. Government could look to put in place measures that facilitate access to energy infrastructure, especially for the development of hydrogen projects [127]. Such actions should not compromise or reduce effectiveness of existing requirements to undertake environmental and social impact assessments, and should involve consulting with local communities to ensure acceptance of proposed projects, where appropriate.

Encourage public-private collaborations

Many stakeholders identified private initiatives around renewable energies but were not able to cite any public-private arrangements. Some argued that Mexican authorities and involved stakeholders (energy producers and industry representatives, system operators, regulators) should seize the global momentum around the prospects of shipping decarbonization and undertake technical and economic cooperation projects. This would require collaboration between multiple Secretaries (Ministries), specialized hydrogen companies and national energy companies (such as PEMEX and CFE), as well as other interested parties. International collaborations could be in the form of learning missions or partnerships that include knowledge transfer programs [127]. As a first step, however, clarity is needed as to whether it is possible to establish such partnerships in the context of Mexico; wherein an assessment of the current regulatory framework is needed to determine if it facilitates an enabling environment.

Prepare labor capacity and skills to handle SZEF and technologies

The development of new sustainable fuels and their associated technologies in turn will require new skills and knowledge on behalf of the maritime workforce. Research calls for Mexico to create a strategy to develop qualified talent for a green hydrogen economy. This can be done by fostering dedicated training, academic-industry partnerships, and international cooperation in higher education, research, development, and innovation [127]. More practically, upskilling and training port employees on the handling of these SZEF, adapting safe and efficient bunkering procedures, and preparing and loading vessels for SZEF export. Shipyards and ports were mentioned as possible places for education, wherein Mexico could build strategic knowledge hubs that focus on human capacity building and training, offering green scholarships to increase national competence around SZEF in preparation of servicing zero emission vessels in a green hydrogen economy.

International

Support the development of SZEF safety standards & authorizations

Supporting environmental authorizations and setting standards for new bunkering facilities and processes will be crucial in the near future. Mexico's authorities would do well to get involved or closely follow advancements in this space, such as the work by Korea Shipbuilding & Offshore Engineering and the classification society Korean Register, who are working on developing hydrogen ship standards [196]. Stakeholders have stated that safety issues need to be prioritized, particularly safety protocols for handling of new alternative fuels such as green hydrogen and ammonia.

Collaboration to secure effective GHG policy at the IMO

The market for SZEF, and therefore the business case to unlock significant investment, can be most strongly enabled by the timely adoption of effective policy at the IMO. International policy measures such as a potential MBM need to be developed to support investment and jobs in Mexican SZEF. Mexico can advance investment by supporting the IMO to work towards a high ambition strategy and on the design and adoption of policy measures to achieve a just and equitable transition. Supporting an international climate target for shipping that is aligned with the Paris Agreement and signing the Declaration on Zero Emission Shipping by 2050 would be one step towards this goal [197].

Sign the Clydebank Declaration & develop Mexico's first green corridor

Green corridors are signaled as an innovative method to initiate early action along a specific international shipping route between two major port hubs and can be leveraged to serve national interests in the transition to zero emission shipping [23]. Based on its renewable energy potential, trade relations with other regions, and location along busy shipping routes, Mexico could sign the Clydebank Declaration to signal its interest in international collaboration on this front. First movers from Latin American are already making their mark, as seen in the recent announcement that Chilean Ministries of Energy, Transport and Telecommunications, and Foreign Affairs have teamed up with the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping to establish a Chilean Green Corridors Network [198].

Finance

In addition to the political challenges faced, many stakeholders in Mexico raised the financial challenge of decarbonization, citing the vast amounts of investment needed for research and development, pilot and scaling projects, infrastructural adaptations, and new infrastructure installations. To enable the energy transition towards a low carbon economy, significant amounts of financial resources are needed to switch to more sustainable forms of energy. However, despite this clear financial need, many believe that the current governmental agenda in Mexico does not encourage either public or private investment and development of alternative energies [127]. Nevertheless, the Mexican Hydrogen Association has seen a significant increase in interest towards green hydrogen recently, with around $1.35 billion USD of scheduled investments geared towards such projects [199].

Finance frameworks play a large role in facilitating markets and enabling the emergence of innovative clusters. International funding is limited due to the nascent business cases for SZEF; hence, available financing could prioritize reducing investment risks, improving business cases, and supporting national energy independence through funding strategic projects. Though the wider maritime industry and local stakeholders have confirmed their commitment to investing in new infrastructure and R&D, they highlighted the need for a funding framework that supports them in gaining technical assistance and undertaking demonstration projects and pilots.

As for the cons, the subject is not well known and the costs are fairly high. To solve this problem, incentives such as green premiums could be given. This was the case in Mexico with solar energy: installing 1 MW in 2013 came with economic incentives in the form of accelerated depreciation, which allowed companies and individuals to depreciate 100% of expenses on renewable energy equipment on one fiscal period. This contributed, in part, to reducing costs of solar panels by 80% in the last seven years and every day more and more users are betting on this source of energy [135] [200].

Suggested actions

Explore national fiscal incentives for first movers

Infrastructure upgrades are costly and lengthy procedures, which often demands the mobilization of significant private capital. Stakeholders suggest exploring fiscal incentives to support first movers who take higher risks. This would support the creation of an environment that triggers investments in a high renewables-based system. Similar to the development of wind and solar technologies, new SZEF technology will need financial support and structures to ease their adoption. Incentives such as green premiums are one such option. This was previously the case in Mexico for solar power in 2013, providing an incentive for the installation of 1 MW, and contributing to reductions in solar panel costs [135]. Contracts for difference[33], buy-back arrangements, public credit guarantees, and green bonds are also alternative options that could be used [28].

Boost energy security through private renewable electricity generation

Stakeholders have noted difficulties in incentivizing private sector investment, especially as renewable energy production is mostly stated-owned. Removing barriers to the production of large-scale renewable electricity and relaxing the regulatory framework to allow for more privately renewable electricity generation is essential to build Mexico's green energy capacity and scale its potential, including in SZEF production. However, the private sector perceives Mexico to have an ecosystem unsuitable for investment in innovation [127]. Spending on renewable energy infrastructure could focus on building a smart, reinforced distribution grid that integrates both public and private sources of renewable energy, which can help manage local congestions and support grid resilience [28].

Leverage international development finance to prioritize funding of strategic projects

As seen in Section 7, Mexico has experience in accessing development bank assistance, which can be for the benefit of its maritime and land-based industries in scaling SZEF production. Financial investments into SZEF infrastructure are difficult to justify based on current business models; however, development finance could be used to de-risk early action through direct grants, technical assistance, and pre-feasibility funding to strengthen key business opportunities. Funding provided by various organizations and institutions, such as the North American Development Bank, Inter-American Development Bank, World Bank, and bilateral country funding (e.g., Japan-Mexico Joint Crediting Mechanism) are all relevant options [127][201]. MDBs can also assist in seeking green financing sources (concessional and/or grants) to lower the average weighted cost of financing. Exploring project financing through blue bonds, such as the one for Latin America and the Caribbean provided by IDB Invest [202], and potential revenue from a global MBM or carbon price were also highlighted by stakeholders as avenues to pursue.

33 'Contracts for difference' can be used by financial institutions to bridge the gap between using more expensive but sustainable sources of energy generation compared to cheaper but less sustainable fossil fuel options. Renewable suppliers are therefore ensured a steady revenue stream that supports their deployment at scale and improves their project's bankability.

Industry

Despite the lack of political focus on shipping decarbonization, there are many Mexican industries and regional actors that support the development and use of SZEF. This is exemplified in the strategic opportunities described in Section 6 and has been echoed by stakeholders through numerous engagements. The maritime industry has expressed their commitment and interest in pursuing a greener agenda, as seen in the Call to Action for Shipping Decarbonization. Launched in September 2021, the Call to Action has over 240 industry actors publicly calling on governments and international regulators to take decisive action in support of making zero emission shipping the default choice by 2030 [107].

As part of this call, companies volunteered information about their own actions, targets, and plans towards shipping's decarbonization. Industry actions to date include investments into RD&D and pilot projects, ordering and building zero emission ready vessels, purchasing zero emission shipping services, investments into SZEF production and port and bunkering infrastructure, among other actions [203]. Continued efforts by industry actors, both within the maritime sector and in other areas such as transport and energy, will be essential in the coming years.

Suggested actions

Stimulate momentum through lobbying & engagement

The need for higher ambition from public bodies to increase national support for shipping's decarbonization was clearly emphasized by local stakeholders. Maritime industries can engage with public bodies to expressly show interest in scaling SZEF production and related technologies, as well as help educate government on the multitude of environmental, social, and economic benefits of transitioning towards a low carbon economy and shipping industry. Industry voices need to communicate the message that decarbonization is not only a pressing matter for the maritime community but also presents a significant opportunity for Mexico to capitalize on its existing renewable resources. Lobbying the public sector to raise this topic on the political agenda could not only help to address some of the political challenges previously expressed but also set a stage to collaboratively work on closing knowledge gaps, releasing national funds to derisk early-stage projects, and developing suitable standards and regulation.

Target decarbonization activities in strategic locations

Stakeholder discussions revealed that engagement with decarbonization efforts in any sector (not limited to shipping) tends to vary by region and by coast. Indeed, the age, size, and standard of ships in operation differs by coast, especially given a vessel's proclivity for bunkering in the US. Mexico's maritime borders with US abuts the latter's special emissions areas. Hence, Mexican ships that have to port in the US need to comply with the higher standards of US ports regulation and MARPOL Annex VI, making these vessel's more environmentally friendly, with modern upgrades and cleaner fuel use. In addition, some progressive States like Baja California and regions with links to the Caribbean where tourism is a significant economic driver are more advanced in their activities with regards to the production and use of renewable energy. Industry actors interested in developing concrete projects to produce SZEF and pilot associated technologies could leverage strategic locations within Mexico that have a convergence of favorable factors.

Aggregate SZEF demand

As seen in Section 6, maritime industries can act as substantial offtakers by themselves, but industry actors could look to aggregate SZEF demand across the value chain as well as from other sectors. Cross-sectoral collaboration can generate effective synergies between shipping, mining, other transport sectors, and energy. Key industries in Mexico that can aggregate their demand for green hydrogen and its derivatives include automobile, mining, manufacturing, and cement producers, among others. Increasing the volume of demand for new zero-carbon fuels, supported through offtake agreements, strengthens business cases for investors and capitalizes economies of scale to reduce overall cost of production. This is especially important when it comes to extending the asset life of existing infrastructure, such as natural gas pipelines which can be repurposed for power to gas and hydrogen transport and storage [17]. Hydrogen Valleys or Hydrogen Hubs offer a means to aggregate demand and kickstart local hydrogen economies [204].

Further develop associations focused on SZEF and electrification opportunities to drive market change

No single maritime actor has sufficient market influence to enable shipping decarbonization alone. Gathering industry actors into a non-competitive fora for collaboration can send a collective demand signal to fast track decarbonization action [17]. Interested industries could join initiatives like the Mexican Hydrogen Association, which is dedicated to the development of green hydrogen and related business opportunities. This association is already having an impact in Mexico through the development of its Hydrogen Roadmap [65] and its facilitation role in connecting interested actors in pursuing green hydrogen projects. It also acts as a neutral forum for industry to engage in Mexico's growing hydrogen ecosystem and connect to State and government representatives to develop projects and demonstrate pilots.

Explore alternative business model options

Industry actors could seek new and alternative business models that, while regulatory drivers of the business case for SZEF use develop, can help reduce some of the barriers to entry or adoption for SZEF technology, both for onboard vessels as well as shoreside [17][205]. Book and claim[34] systems, subscription services, wholesale power purchase agreements, leasing models, and reverse auctions can act as new ways the maritime and energy sectors do business [207].

34 "Book and Claim" models decouple a sustainability claim from the physical traceability of a product or good. Green electricity is an example where it cannot be tracked in the grid, thus an accounting system is used to charge the customer paying a premium for green electricity who then "claims" this via a verifiable certificate. Such a system is not implemented in the maritime space, but is being discussed within the wider area of transport and logistics [206].

In conclusion, Mexico has strong potential to power the global shipping fleet through national production, bunkering, and export of SZEF. Its large reserves of renewable energy potential, location with coasts along both Atlantic and Pacific oceans, as well as established maritime trade with key countries places Mexico in a unique position to capitalize on the maritime industry's transition to zero emission shipping.

Investing in key renewable energy and SZEF infrastructure would have significant benefits for the country's economy and society, providing energy security, improving air and water quality, creating new supply chains, and tapping into a new export market. Furthermore, Mexico has the chance to leverage its own sustainable development goals as it adapts to meet the future demands of the maritime industry.

To leverage existing and emerging opportunities within the country, the Mexican government and its private industry actors will need to take targeted and decisive action to ensure the country moves ahead of the curve. It is clear that global momentum towards zero emission shipping is increasing in intensity, with new alliances, initiatives, demonstrations, and pilots taking place all over the world. The actions outlined above and information given throughout this report could support Mexico in decarbonizing and becoming a zero-carbon bunkering and export hub.

«We are permanently committed in promoting new actions to further expand the climate ambitions of our members, as well as in expanding our avenues of cooperation with all the stakeholders, locally and abroad, for the decarbonization and greening of our maritime and port industries. We are also thrilled about the possibility to continue exploring new scalable zero emissions fuels for our industrial sectors in the years to come.»
– Eric Serratos (The Mexican Chamber of the Maritime Transport Industry (CAMEINTRAM)

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Annex I

SHIPPING GEOSPATIAL MODEL: Technical Information

This annex presents supplementary information to Chapter 3 on Mexico's Shipping Activity and its Maritime Emissions. It provides a more detailed look at the methodology employed in this report to generate Shipping Geospatial Model (SGM) for Mexico, including the assumptions and limitations of the approach.

It is structured in three sections:

1. Shipping Geospatial Model for Mexico
2. Mexico's National GHG Inventory
3. Comparison between this report's SGM and Mexico's National GHG Inventory

Shipping geospatial model

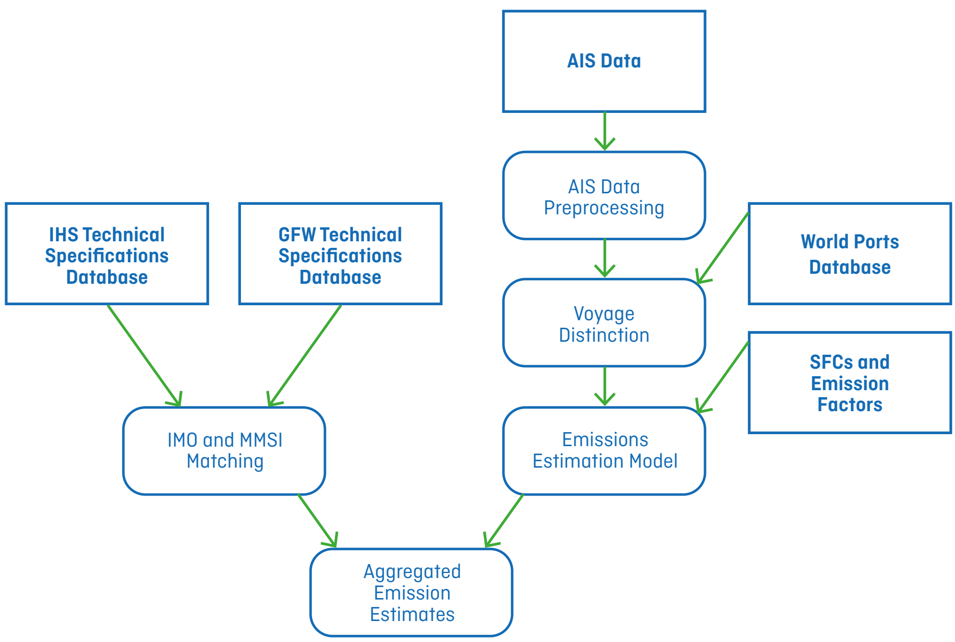
This report provides an estimation of GHG emissions and air pollutants from shipping in Mexico using an activity-based approach.

The SGM for Mexico were estimated from a two-step methodology that allows for the aggregation of data at different levels. The first step is based on the Fourth IMO GHG Study methodology, focusing on the shipping activity in Mexico. The second converts the first-step results into discrete voyages and their geographical location thanks to the ship's Automatic Identification System (AIS) granular data. In this case the AIS data used refers to the ship's hourly records for the whole global fleet operating in 2018. The latter step aims to provide a fair and representative reflection of the emissions associated with Mexico's maritime economic activity.

Step I: Building from the fourth IMO GHG Study

The Fourth IMO GHG Study [9] provides an inventory of GHG emissions from international shipping between 2012 and 2018. While the study provides two different approaches (i.e. top-down and bottom-up) to estimate shipping emissions, this report utilized the bottom-up approach, also known as activity-based (seen in Figure 18).

Figure 18: Flow diagram representing the Fourth IMO GHG Study methodology with the dataset used.



In the bottom-up approach, operational information captured by AIS data is matched with static technical information contained in Markit's Information Handling Service (IHS) and Global Fishing Watch (GFW) databases [208][209]. The design specifications contained in the datasets are used in the calculation of fuel consumption and emission factors over an hourly, per-vessel basis. Consistent with *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (2006 IPCC Guidelines), the Fourth IMO GHG Study builds on the methodology presented in the Third IMO GHG Study [210] to incorporate the identification of port calls from which an allocation of discrete voyages can be made, and a distinction drawn between international and domestic shipping.

The strong advantage of using the IMO methodology is that it contains the latest GHG and air pollution research for domestic and international shipping above 100 gross tonnage [9]. It contains the state-of-the-art technical detailing, fuels and emission factors that allows for the estimation of the country's maritime sector GHG and air pollution.

IHS, IMO and MMSI matching

Raw AIS data from terrestrial and satellite sources were obtained from the provider exactEarth and individual vessel data taken from the IHS dataset [208]. The datasets were combined based on each ship's IMO identification number and Maritime Mobile Service Identity (MMSI). Resampling of the data into hourly time intervals allows for the extrapolation of the activity data for the entire year. This step ensures that the increasing coverage and number of AIS data points generated year on year does not result in an associated artificial growth in estimated emissions. The resampling step also serves to remove or correct invalid and spurious data points, while assessing the quality of AIS datasets for each IMO number in the process.

Following the Fourth IMO GHG Study methodology, this report considered 19 different vessel types – 70 when considering the ship sizes; 13 different propulsive systems with three different generations – based on the ship year of build; auxiliary engines and boilers; four fossil fuels[35]; 10 different GHG and air pollutants and two fugitive emissions (i.e. refrigerants and Non-Methane Volatile Organic Compounds).

AIS data pre-processing

Linear interpolation is applied to the vessel GPS coordinates to account for Earth's spherical curvature and the accurate application of location dependent emission factors such as Emission Control Areas (ECAs). Anomalies can be generated by the linear interpolation method and their numbers are known to correlate with the number of contiguous hours where no GPS data was observed. However, anomalies were found to decrease substantially over the years of the study as a result of increasing AIS coverage. Each hour where an activity report exists is allocated as port phase (operating at less than three knots and near the geographical location of a port), voyage phase or transition phase. Port activities are used to split vessel activity datasets, thereby generating a sequence of individual voyages. Where contiguous missing periods are determined greater than a missing period threshold, that voyage is removed and replaced using backward and forward infilling.

35 Fully-electric, coal, non-propelled and nuclear-powered vessels were removed.

Distinction between international and domestic voyages

Building on the methodology employed in the Third IMO GHG Study for generating bottom-up fuel estimates based on vessel type and size, the Fourth IMO GHG Study applies a new approach to discretizing voyages from continuous data using the geospatial and temporal information contained in AIS data. Central to the Fourth IMO GHG Study is a port database containing the name, coordinates, and country of close to 13,000 ports around the world. Individual port calls are identified using reported Speed Over Ground (SOG) values and a spatial nearest neighbor algorithm to compute the distance of vessels to their closest port. AIS data points with average SOG values of below one knot are grouped into clusters representing potential stops. The clusters are assigned as port stops if the distance to nearest port is sufficiently small, time at port is sufficiently large and the distance between the cluster and any neighboring clusters is sufficiently large. Consecutive clusters located close to one another whilst assigned to the same port are merged into one, however for those with different port assignments one of the clusters is removed. For vessels where AIS coverage is particularly poor, a second stop identification method is employed relying on proximity to port and eliminating the dependence of the stop identification algorithm on accurate SOG records alone. Using the definition of international shipping as that which takes place between ports of different countries, emissions may then be allocated to international or domestic categories in line with IPCC definitions. This distinction enables quantification of the voyage-based inventories presented in the main body of this report.

Fuel consumption, emissions and energy estimation

The hourly main engine power demand of any given vessel is established by using Admiralty formula where the AIS speed and draught reported is combined with the ship design characteristics taken from IHS data. The formula was complemented with speed, fouling and weather factors. For the auxiliary machinery power demand was established depending on the ship type, size and operational mode occurring at each hourly observation.

To transform from power demanded of the main engine to hourly fuel consumption, the power demanded was matched to a specific fuel consumption (SFC) curve which used the engine, fuel type baseline SFC and the engine loading (i.e. how much power is being demanded against the maximum installed power) as independent variables. The multiplication of estimated SFC and main engine power demand yields the hourly fuel consumption. For the auxiliary machinery, the SFC were given as constant and their hourly fuel consumption was obtained by multiplying the power demanded and the SFC. The vessel total hourly consumption was the aggregation of the fuel consumed by the main engine and auxiliary machinery.

The estimation of hourly GHG and air pollution emissions is dependent on how much fuel is being consumed, fuel type, fuel sulfur content, main engine loading and power output, main engine type, machinery (i.e. auxiliary engine or boiler) and geographical location (i.e. if navigating inside or outside an Emission Control Area). As in the Fourth IMO GHG Study's activity-based methodology, two different approaches to emission factors (EF)[36] were used: energy-based and mass-based. The energy-based EF are given as mass of air pollutants by energy demand –

36 The EF are given as tank-to-wake emissions. This means that it quantifies the emissions produced by the onboard systems. It does not consider the upstream emissions produced due to the extraction, production, and distribution of the fuel.

normally given as g pollutant/kWh. The mass-based EF is given as mass of pollutant per mass of fuel – normally given as g pollutant/g fuel. The hourly emissions were obtained by multiplying energy-based EF by hourly energy demanded for each onboard machinery type. For the GHG and air pollutants using fuel-based EF the hourly fuel consumption was multiplied by the EF.[37] To convert GHG emissions into CO_2 equivalent (CO_2e), the Global Warming Potential over a 100-year period (GWP_{100}) of each compound is used. As reference, the GWP_{100} are taken from 2006 IPCC guidelines.[38]

To convert annual fuel consumption to energy demand, the hourly fuel consumption was converted to a common fuel equivalent unit (Heavy Fuel Oil equivalent, HFO_{eq}, in the Fourth IMO GHG Study). This conversion is achieved by using the IMO Heavy Fuel Oil (HFO) Low Heating Value (LHV) of 40,200 kJ/kg and the fuel being consumed (e.g. Marine Diesel Oil (MDO) which has a LHV of 42,700 kJ/kg). However, we present shipping energy demand in MWh. To achieve this, the HFO_{eq} unit needs to be converted to kJ using the HFO LHV to then convert the hourly energy demanded to MWh.[39]

The annual fuel consumption, energy demand and emissions by ship type and size (or shipping as a whole) is the aggregation of each hourly observation within the observed year (i.e. 2018 for this report).

Quality assurance and control

Comprehensive quality assurance (QA) and quality control (QC) efforts were undertaken to ensure accuracy in the inputs, method, and results of the bottom-up study. State-of-the-art Monte Carlo uncertainty analysis applied in the Third IMO GHG Study is replicated in the Fourth Study and used to show that uncertainty has dropped from close to a third in 2012 to <10% in 2018, with ongoing uncertainty reductions expected as overall coverage of AIS data increases. Overall, difference in total fuel consumption figures of 2012 deviated just 3% away from the Third IMO GHG Study, indicating the quality and coherency of methodologies contained in both. Of three vessel types responsible for close to two-thirds of the total international CO_2 emission for 2018, there was a maximum deviation of 6% between CO_2 emissions estimated in the Fourth IMO GHG Study and those presented in the EU's MRV scheme [211]. Further, continuous monitoring data was used to validate the model's speed, main and auxiliary engine models with a good correlation on speed, draughts, main engine power and fuel consumption with the largest uncertainty on the auxiliary engine model due to the assumption of a constant power generation for the different operational modes for all ship types.

37 A more specific explanation of the EF can be found in the Fourth IMO GHG Study subsection Emission Factors or Appendix B and M.
38 For CH_4 is 28 and N_2O is 265.
39 Conversion factor: 1 kJ equals 2.78×10^{-7} MWh.

Step II: Voyages and their geographical location

The addition of the stop identification process enables continuous AIS data representing vessel activity as discrete voyages. Emission data with timestamps falling between the start and end times of a given voyage is pulled by the algorithm. Emission data associated with voyages where vessels depart from a Mexican port and arrive in international destination ports is used to formulate the international departures inventory. Where a voyage originates in the port of another country and arrives into a Mexican port, emissions associated with this journey are added to the international arrivals inventory. Where source and destination ports are both Mexican, voyage emissions are allocated to the domestic inventory, whilst the emissions of voyages that feature no interaction with Mexico's ports remain unused on the voyage approach.

When adding up international departures and arrivals with domestic activities there are two important caveats:

- Not all ships arriving or departing Mexico are fully unloaded or loaded, meaning that part of the cargo contained in any given vessel – and the main reason for the ship to navigate – does not have Mexico as its final or origin destination.
- Taking the first or last voyage leg does not mean that the cargo coming or going from Mexico is fully loaded in the last port before arriving to Mexico or fully unloaded at the first port of call after leaving Mexico. Indeed, different ship types tend to have multiport call voyages.

However, the aggregation of these different approaches allows for a fuller picture of how shipping activities from, to and within Mexico occur and shows the important role that Mexico has on the transition of this transport sector.

For the geofenced emission inventory approach, the geographical location of all the activities for all 72,000 vessels contained in the 2018 dataset is checked for its position with respect to the national Exclusive Economic Zone (EEZ) and radius around port cities. Using the shapefiles provided by the Flanders Marine Institute [42] for the EEZ approach, activity-related emission data that falls within the region is pooled to form the geofenced inventory whilst outlying data is left out (see Figure 19). A similar method has been applied within the localized emission analysis of port regions whereby geographical coordinates of each port are used to generate a surrounding area of 100 km radius from the port centroid using a Geographical Information System software. Aggregating the hourly activity data that occurs in the immediate area surrounding each port, an indication of the exposure of local populations to pollutants arising from vessel activity can be generated. The method results are summarized in Figure 10, whereby only the activities of vessels captured within 100 km of each port are used.

Figure 19: Polygon representing Mexico's EEZ and the shipping activity inside it during 2018.

Quality assurance and control

After obtaining complete results using the Fourth IMO GHG Study activity-based methodology to calculate emissions, remaining sources of error are limited to the methods of data extraction used to access the study's results and aggregations as explained before. These are summarized in Table 6 with their QA and QC to minimize their impact.

Table 6: Potential sources of error in the SGM for Mexico.

Inventory Method	Potential Issue Identified	QA/QC Procedure
Voyage-based	Inaccuracy in copying data from the Fourth IMO GHG Study	Select 10 rows at random and validate data selected
Voyage-based	Inclusion of data lying outside voyage time windows	Select 10 voyages at random and validate voyage
Geofenced	Inaccuracy in copying Fourth IMO GHG Study data	Plot sample of 10,000 hourly events location against the geographic polygons
Geofenced	Inclusion of data lying outside EEZ	Take sample of 10, 000 hourly events location against the geographic polygons

All checks were completed with no errors detected indicating reliability in the SGM for Mexico presented in the main body of the report.

Mexico's national GHG inventory

At national scales, a wide range of methods exist to generate national inventories of maritime emissions. Current international guidelines focus on combining established emission factors with fuel consumption figures to derive estimates for the emission of GHG and air pollutants. In the absence of a concrete IMO framework for assigning national emissions, the International Panel on Climate Change (IPCC) Reference Approach offers one such method that makes use of readily available energy supply data.

Mexico's National Institute of Ecology and Climate Change (INECC), produces its emissions through the preparation of a National Inventory of Greenhouse Gases and Compounds (INEGYCEI) coordinated and compiled the country's National GHG Inventory for 2015. The inventory follows the 2006 IPCC Guidelines. It should be noted that the INECC has been estimating the Mexican annual emissions through its INEGYCEI. The information provided in each of the following subsections is based in the information provided in Mexico's National GHG Inventory for the period 1990-2019 [40].

More information on the 2006 IPCC Guidelines that the Mexican government followed to prepare its inventory will be presented below.

2006 IPCC Guidelines: A brief overview

Intergovernmental Panel on Climate Change in its 2006 IPCC Guidelines for National GHG Inventories for the Energy sector and in Chapter 3 sets out a framework of good practice for the quantification of GHG emissions and air pollutants resulting from mobile combustion. Guidelines for water-borne navigation are included, encompassing emissions generated from all forms of water-borne transport (international and domestic), fishing, military and multilateral operations [41]. For shipping the GHG accounted for are CO_2, CH_4 and N_2O.

Methods

There are two tiers (1 and 2) for the evaluation of GHG emissions for the water-borne navigation where both tiers apply emission factors to fuel consumption figures independently across all fuel and transport vessel types.

Tier 1 is the simplest approach which can use default or country-specific values. The EF are fuel-type specific for the data the country has. To estimate the annual GHG emissions it is required to multiply the fuel data – by fuel type – by the corresponding EF.

The difference with the Tier 2 approach is that the annual GHG emissions need of more specificity by adding classification modes (e.g. ocean-going ships) and, if available, engine type. Further, if the country has availability to access ship movement data it is recommended that the guidelines from the EMEP/CORINAIR emission inventory guidebook are followed [212]. This reference is recommended to estimate EF for NO_x, CO and NMVOC in both approaches.

For both tiers the shipping category is divided in four distinct classes:

1. *Water-borne Navigation*. This can be further subdivided by domestic and international navigation on the basis of the port departure and arrival.
2. *Fishing*. In this category all emissions from fishing vessels that have refueled in the country need to be considered.
3. *Mobile*. All remaining emission from shipping not covered above (e.g. military).
4. *Multilateral Operations*. Emissions produced in multilateral operations (e.g. fuel delivered to the military in the country and delivered to the military of another country).

Fugitive emissions from transport are declared under the category "Fugitive emissions" but they are assumed to be negligible when the ship is navigating.

Mexico GHG inventory report for its water-borne emission estimation of CO_2 is based on T2 while for CH_4 and N_2O used a Tier 1 approach.

Emission factors

The guidelines give for CO_2 EF a range of acceptable values depending on the type of fuel based. The guidelines recognize 10 different fuels for the water-borne transport. However, since Mexico used a Tier 2 approach the EF is based on the results from INECC (2014) [213].

For CH_4 and N_2O EF under a Tier 1 method the values are given as 7 kg/TJ and 2 kg/TJ respectively. However, these factors are taken from HFO being consumed in diesel engines (no engine speed is stated) and for that reason have a large recommended variation (i.e. +50% for CH4 and from -40% to 140% for N_2O).

For a Tier 2 approach the EF should be based, if possible, by the country's testing of fuel and combustion engines and this should be recorded in accordance with EMEP/CORINAIR emission inventory guidebook.

In the case of the water-borne transport EF, Mexico used the INECC values for CO_2 and the default values recommended by IPCC for CH_4 and N_2O.

Activity data selection

The IPCC guidelines offer a wide range of source data to obtain an estimation of the fuel being used for water-borne activity and for what purpose is being used (e.g. domestic or international navigation). However, the selection of the datasets is up to the country and its own circumstances which is recognized to produce results with different levels of accuracy. The IPCC list suggests National energy statistics, surveys of fuel suppliers (i.e. fuel sales), marine authorities and fishing companies to the IMO databases and Lloyd's Register ship movement data, among others. The guidelines recognize that to get a better data resolution of the fuel being used the inventories will need a combination of the recommended databases.

The guidelines recognizes that there are different engine types and fuels being used onboard any given vessel but states that this level of granularity is difficult to obtain. To solve this the guidelines give general statistics of average fuel consumption in percentage per engine type (i.e. main or auxiliary engines) and ship type. As well, the chapter gives average daily fuel consumption and linear regressions to estimate fuel consumption at full power (i.e. 100% the Maximum Continuous Rating (MCR) of an engine) against the ship's Gross Tonnage. This is given for 13 different ship types.

The Mexican domestic maritime emission category data is provided by the 2017 Mexican Energy Balance report [46]. The report uses the sale of fuel during 2017 to establish the energy demand of the sector. The national fuel sales were aggregated from commercial fleet, SEMAR, fishing companies, and general boats.

Completeness and uncertainty

The guidelines depend on the country capacity of accounting for fuel being consumed by shipping. The sources of potential incomplete estimation of fuel used and emissions are:

- Misallocation of navigation emission into another source category.
- When military data is confidential.
- Misallocation between domestic and international voyages.

The guidelines present the difficulty of distinguishing between domestic and international navigation as the highest source of uncertainty in building the water-borne emission inventories. For complete survey data the estimated uncertainty is assumed to be +5% while for incomplete ones it could be as high as +50%. Still, it is recognized that uncertainty could be much larger from country to country. However, as data availability improves, such as in the case of AIS data, the uncertainty levels for this sector will reduce.

Mexico's 2015 National GHG Inventory Report [40] recounted that the estimated uncertainty for the domestic navigation with an uncertainty of +4.98% for CO_2, +48.83% for CH_4 and +87.59% for N_2O. These uncertainties on the maritime GHG contribute to 0.03% of the total annual GHG inventory while the activity data uncertainty is given as 0.00%.

Quality assurance and control

The guidelines recommend four different approaches to assure the QA and QC of the water-borne emission inventories, but this will depend on the country's capacity to take these steps:

1. Compare emissions using alternative approaches.
2. Review of EF.
3. QA and QC of activity data on fuel usage.
4. External review.

For the case of the Mexico's emission inventories the QA and QC is extensively explained in the inventories quality policies report [45]. The report set the guidelines to revise the quality of the data estimated, reports produced and communication to the general public and specialized audiences.

Reporting

Water-borne emissions are reported in different categories depending on the activity that the ship is doing:

1. *Water-borne Navigation*. Domestic navigation is reported and counts towards the national GHG inventory. International navigation is reported separately and does not count towards the national GHG inventory
2. *Fishing*. It is reported under the *Agriculture/Forestry/Fishing* category in the Energy class.
3. *Mobile*. In particular to military should be presented for transparency purposes.
4. *Multilateral Operations*. They are not mentioned how to be reported.

The IPCC guidelines recommend as good practice to present the source of the fuel and other data used, method to differentiate domestic and international navigation, emission factors used, and their associated references and the uncertainty or sensitivity analysis of the data and assumptions taken.

Emission inventories comparisons

Estimation of GHG emissions per sector support policy processes and decision-making for viable mitigation responses from governments that are in consonance with UNFCCC and its Kyoto Protocol and Paris Agreement's goals. The IPCC Guidelines, assist countries in producing transparent, complete, comparable, and consistent over time inventories that do not overestimate or underestimate national GHG emissions.

The SGM developed in this report provides a novel approach to estimate, in a comprehensive matter, the maritime GHG and air pollution emissions of any country. In general, the SGM for Mexico and Mexico's National GHG Inventory need to be seen as complementary. Mexico's National GHG Inventory captures the complex interaction between its economic activities, society, and the environment. Balancing the level of granularity between categories due to data availability, modeling, capacity, and statistic access is a complex endeavor that has the aim of establishing the country's full picture in a transparent way. On the other hand, the emission inventory provided in this report based on the Fourth IMO GHG Study considers in great detail the spatial and technological differences of the maritime sector during 2018. Further, this report proposed four different methodologies of aggregating the data relevant to Mexico with the purpose of exploring the implications of shipping to, from and within the country and establish their opportunity in the transition of the maritime sector.

The differences between the estimation of GHG come from the way they are reported; the granularity of the fuel used databases; how data is aggregated; assumptions taken; and that the Fourth IMO GHG did not consider ships below 100 gross tonnage, leaving outside the small boat fleet[40], which tend to be activity within the national waters.

Still, some of the elements between the general inventory approaches can be compared to understand the main causes between both inventories' differences which for the water-borne domestic navigation – without accounting for fishing activity – stood at -7.28% or -149 kt CO_2e.

Emission factors

As reported by Mexico's National GHG Inventory for water-borne transport, Tier 2 EF were used for CO_2 and default Tier 1 EF for CH4 and N_2O were used. It is important to mention that methanol EF are not presented in this subsection since it is a fuel not considered by the IPCC 2006 Guidelines for water-borne navigation.

CARBON DIOXIDE

Table 7 presents the CO_2 EF used in Mexico's National GHG Inventory and the ones used in the SGM which are taken from the Fourth IMO GHG Study. After division by the low heating value and conversion to the same unit, the percentage difference between CO_2 EF presented in the two documents has been evaluated with a difference of 2.57% for HFO, -3.02% for MDO and 4.77% for LNG. Use of similar emission factors are important to the accurate quantification of GHG generation and give confidence that the results derived in the SGM to generate the emission inventories presented are reliable and representative.

40 Typically, with a length not larger than 25 m depending on vessel construction.

Table 7: Comparison of CO_2 emission factors used in the SGM and the 2014 INECC average values.

Fuel	IMO Default EF (kg CO_2/kg fuel)	Converted IMO EF in IPCC-aligned units (kg CO_2/TJ)	IPCC 2006 Default EF (kg CO_2/TJ)	Difference (%)
HFO	3.114	77,463	79,450	2.57
MDO	3.206	75,082	72,881	-3.02
LNG	2.750	55,000	57,756	4.77

Methane

The Fourth IMO GHG, and hence the SGM, recognizes that methane emissions are different under different fuels, engine technologies and engine loading giving a wide range of values. For the 2006 IPCC Guidelines the methane EF is given as a range but smaller to the SGM. For that reason, the methane EFs will be given in a range to consider all the methane EF (see Table 8).

Table 8: Comparison of CH_4 emission factors contained in the SGM and the 2006 IPCC Guidelines for National GHG Inventories. It is important to mention that the SGM CH_4 EF are given for design engine loads (i.E. 75% Of the MCR).

Fourth IMO GHG Study EF (g CH_4/kWh)	Converted IMO EF in IPCC-aligned units (kg CH_4/TJ)	IPCC 2006 Default EF (kg CH_4/TJ)
0.002 - 5.500	0.560 - 1,527.780	3.500 - 10.500

The large differences seen in the EF between them has to do with two main reasons:

1. The CH_4 EF used in the IPCC 2006 guidelines are based on the numbers given by Lloyd's Register [214] for only diesel engines using HFO while the Fourth IMO GHG Study covers a wider range of engines and fuels. Normally, diesel engines tend to be located in the lower end of the CH_4 EF scale. For the Fourth IMO GHG Study a diesel engine consuming HFO will have an EF of 2.8 kg CH_4/TJ. Still, there is a difference of between of 20% between the EF – using the lowest value given by IPCC. This difference may be due to the age of the literature used for the IPCC 2006 Guidelines. In the past 30 years, maritime diesel engines have improved with better combustion efficiency thanks to the introduction of fuel injection and exhaust gas actuating systems among others [215].
2. The introduction of LNG as fuel for shipping has existed since LNG has been carried in vessels. But in the past, this type of vessel used the boil-off gas from the tank to burn it inside a boiler to produce steam that in turn powered the ship steam turbines. However, since 2010 LNG as fuel has started to enter into the maritime market for all ship types and sizes. Natural gas is mainly composed by CH_4 and when injected into an internal combustion engine part of it may not get combusted, increasing the emission of this GHG. Depending on the LNG engine technology the CH_4 EF could be between 55.56 and 1,574.78 kg CH_4/TJ.

If LNG becomes a more prominent fuel in the shipping sector, it will be important to update the IPCC 2006 CH_4 EF to account for this powerful GHG.

Nitrous oxide

Table 9 presents the N_2O EF used in Mexico's National GHG Inventory – given as a range – and the ones derived from the Fourth IMO GHG Study. One important difference from the IMO EF is that it recognizes the change of the EF due to engine loading – mainly loads below 20% MCR, engine technology and fuel.

Table 9: Comparison of EF contained in the SGM and the 2006 IPCC Guidelines for National GHG Inventories. It is important to mention that the SGM N_2O ef is given for design engine loads (i.E. 75% Of the MCR).

Fourth IMO GHG Study EF ($g\ N_2O/kWh$)	Converted IMO EF in IPCC-aligned units ($kg\ N_2O$ /TJ)	IPCC 2006 Default EF ($kg\ N_2O$ /TJ)
0.02 – 0.05	5.56 – 13.11	1.2 – 4.8

The N_2O EF differences are significant between the two approaches. The probable reason for this difference could come from a better understanding in the past three decades on the formation of N_2O in traditional diesel engines. Yoo et al. [216] showed in their experimental study onboard a vessel consuming MDO that the N_2O EF ranged between 0.03 and 0.07 g N_2O/kWh. The highest N_2O EF from the Fourth IMO GHG came from gas and steam turbines.

Black carbon

The IPCC 2006 guidelines do not account for BC as a GHG while the SGM following the Fourth GHG IMO Study considers it with a GWP_{100} of 900 [9][44]. For all the annual emission inventories produced by the SGM, BC was among the second most powerful maritime GHG with about 8.0% of the total CO_2e for Mexico's the domestic navigation.

Sensitivity analysis

The aim of this section is to estimate what are the impacts on the GHG inventories due to the different EF used between Mexico's GHG National Inventory and the SGM for Mexico. To do that, the amount of fuel consumed in 2018 by domestic shipping – excluding fishing – from the SGM will be used. Further, the Mexico's National Inventory from 2018 will be used instead of the one reported in their 6th Communication to the UNFCCC [37].

Mexico reported for the domestic *Fluvial Navigation (Navegación marítima y fluvial)* category a total of 2,039 kt CO_2e for 2018 while the SGM estimated 1,890 kt CO_2e a difference of -7.28% or -149 kt CO_2e.

The estimated annual fuel consumption during 2018 from the SGM for Mexico's domestic activity – excluding fishing – was 397.10 kt HFO, 136.20 kt MDO and 0.0 kt LNG. Converting these fuel consumptions into energy using the fuels' LHV[41] gives 15,963.40 TJ for HFO, 5,815.70 TJ for MDO. Now, by using INECC CO_2 EF and middle EF values for CH_4 and N_2O from the IPCC guidelines (and not counting BC as a GHG), the annual GHG emission due to domestic navigation is 1,692.15 kt CO_2, 0.15 kt CH_4 and 0.07 kt N_2O. Converting these quantities to CO_2e gives a total of 1,713.73 kt CO_2e. This is a difference with the projected Mexico's annual GHG emissions of -16.0% and just -0.9% against the SGM estimation without accounting for the effect of BC as a GHG (i.e. 1,698.33 kt CO_2e).

From the previous analysis done it can be said that the main root cause of the difference between the National GHG Inventory and The SGM GHG inventory are:

- The National Inventory's *Water-borne navigation fuel consumption* data source comes from Mexico's National Energy Balance which for the maritime sector is based on annual fuel sales of the domestic fleet [46][37].

- The method used in SGM is an activity-based method so it includes emissions from domestic voyages of international ships (e.g. from one Mexican port to another) which would not be captured in the statistics of fuel sales for domestic use. Finding a discrepancy in GHG when calculating with the two methods is common and has occurred in other countries (e.g. UK) which have since switched to use the activity-based method [47].

- Differences between National Inventories data based on fuel sales to international shipping and activity-based methods also have explainable differences. Fuel sales are only recorded if a ship bunkers (takes on fuel) in Mexico. In practice ships calling at Mexico may not need to bunker (some ships have fuel storage for up to three months so do not refuel for each voyage) and will purchase fuel in Mexico only if its competitive to fuel available at other port calls they will make. The SGM captures all shipping activity regardless of whether it is associated with a purchase of fuel. The statistics estimated here suggest that only a portion of the fuel associated with Mexico's shipping activity is purchased in Mexico and so the activity-based method is helpful for giving an estimated of the potential bunker sales market - should Mexico want to expand its opportunity, especially for SZEF.

- However, fuel sale databases can capture the fuel being consumed of the small boat fleet which tend not to have onboard tracking systems (e.g. AIS

41 For HFO the LHV used was 40.2 TJ/kt, for MDO 42.7 TJ/kt and for LNG 48.0 TJ/kt [9].

transponder). This is clearly seen from Ferrer et al. [48], where the small fishing boat fleet GHG emission – between 3,000 and 3,700 kt CO_2e – has a relevant an important role in the national maritime emissions. This is a limitation from the SGM but which points to the SGM results on domestic shipping GHG and air pollution to be a conservative estimation.

- While the EF differences are large for CH_4 and N_2O, these compounds account for a small share of the total GHG emission. Indeed, CO_2 accounts for 98.5% of the 2018 GHG emissions – not accounting for BC as a GHG – and the CO_2 EF for HFO and MDO have a difference of 2.57% and -3.02% respectively to the IPCC recommended EF. This explains in its majority the -0.9% observed difference when contrasting both inventories EF using the SGM 2018 fuel consumption.

- The SGM considers BC as GHG which after CO_2 is the most impactful gas in the total GHG quantification. But this GHG has only an 8.0% influence – around 190 kt CO_2e – on the total GHG domestic emission in 2018. Still, it is considered that the SGM is on the conservative spectrum on the national GHG emissions.

Finally, from the Mexico Energy Balance report [46] the data source to estimate the maritime emissions considered together fishing, commercial and military fuel sales alongside the rest of the boat fleet. While the disaggregation of the fuel sales per the IPCC 2006 categories is not done in the Energy Balance report this is expected to have been done when generating the Mexico's emission inventories.

Further tests with the SGM results could not be performed since the IPCC inventories aggregate the domestic fishing fleet into the *Agriculture/Forestry/Fishing* category and, in the particular case of Mexico, I*nternational maritime* is not stated.

Under this light, it can be assumed that the differences observed in GHG emissions between both emission inventories for *International maritime* and *Fishing* would be mainly caused by the same root cause seen for domestic shipping. However, it is expected that the influence of the small boat fleet in this segment will be minimal since this ship types tend to perform domestic voyages.

The interested reader can find further detail on this report maritime activity data in Faber et al. [9] subsections 2.2.2 – 2.2.4 with general areas of improvement in Appendix A.

A source of uncertainty in this short sensitivity analysis is the fuel's LHV used since the IPCC 2006 guidelines does not give these values for the maritime fuels. However, this is thought to have a minimal impact on the annual GHG inventories.

About the Getting to Zero Coalition

The Getting to Zero Coalition is an industry-led platform for collaboration that brings together leading stakeholders from across the maritime and fuels value chains with the financial sector and other committed to making commercially viable zero emission vessels a scalable reality by 2030.

Learn more at:
www.globalmaritimeforum.org/getting-to-zero-coalition

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