Shipping's Energy Transition:

Strategic Opportunities in Indonesia

By Global Maritime Forum
& University College London

For the P4G Getting to Zero Coalition Partnership

Table of Contents

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.

About Environmental Defense Fund

Environmental Defense Fund Europe is an affiliate of Environmental Defense Fund (EDF), a leading international non-profit organisation 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 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.

Indonesia Ocean Justice Initiative

Indonesia Ocean Justice Initiative (IOJI) serves as an independent Indonesian think tank and policy advocacy group with the aim of supporting Indonesia, as one of the largest ocean nations, in attaining sustainable and equitable ocean governance, through: enhancing maritime security, promoting sustainable ocean governance and ensuring access to justice for marginalized ocean-dependent people.

Layout by Housatonic.eu

Acknowledgments

This report was written by Katrina Abhold (GMF) and Domagoj Baresic (UCL) with Santiago Suarez De La Fuente, Alison Shaw, James Stewart, Aideé Saucedo Dávila, Wendela Schim Van Der Loeff (UCL); Connor Bingham (GMF); Camilo Perico, Isabelle Rojon, Connor Galbraith (UMAS); Rosa Esi Ennison, Noam Boussidan, Joachim Monkelbaan (WEF); Jeremia Humolong Prasetya, Harish Makarim, Stephanie Juwana, Karenina Lasrindy and Gabriella Gianova (IOJI).

The authors would like to thank the following people and organizations who have helped with reviewing the report: Ingrid Sidenvall Jegou (GMF); Tristan Smith, Joseph Taylor (UCL); and Panos Spiliotis (EDF). The authors would also like to thank local stakeholders from Indonesia engaged by the P4G-GtZ Coalition Partnership project for their continual input and feedback to the project and report draft.

The project partners are grateful for the P4G's financial contribution to the project.

To cite this report, please use: Abhold et al. (2022). Shipping's Energy Transition: Strategic Opportunities in Indonesia. Report for P4G-Getting to Zero Coalition Partnership project.

Local stakeholders from Indonesia engaged through the P4G-GtZ Coalition Partnership project.

Name	Position	Organization
Akihiko Itoh	Manager, Transportation Group, LNG Trading Unit, Global Energy Marketing Division	Inpex Corporation
Basilio Dias Araujo	Deputy Minister for Coordination of Maritime Sovereignty and Energy	Coordinating Ministry for Maritime and Investment Affairs
Budhi Halim	Head	Indonesia National Shipowners Association (INSA)
Chrisnawan Aditya	Director of Various New Energy and Renewable Energy	Ministry of Energy and Mineral Resources
Cipu Suaib	Business Development Manager	HDF Energy
Dr. Mas Achmad Santosa	CEO	Indonesia Ocean Justice Initiative (IOJI)
Emma Rachmawati	Director for Climate Change Mitigation	Ministry of Environment
Hasto Kristiyono	President Commissioner	PT Pertamina Power
Hendra Kesuma	General Manager	Bintika Bangunusa Group
I Ketut Aria Pria Utama	Professor of Ship Hydrodynamics, Dept. of Naval Architecture	Institute of Technology Sepuluh Nopember

Name	Position	Organization
Ibrahim Kholilul Rohman	Senior Research Associate	Indonesia Financial Group Progress
Ikhsan Asaad	Director of Mega Project	Perusahaan Listrik Negara (PLN)
Indah Budiani	Executive Director	Indonesia Business Council for Sustainable Development (IBCSD)
Iqbal Fikri	Production Director	PAL Indonesia
Juanda Abednego Lubis	Program Officer	Indonesia Climate Change Trust Fund
Lars Bo Larsen	Ambassador	Embassy of Denmark in Indonesia
Lesmana Hartanto	Managing Director	Pt Tanto Intim Line
Marizi Nizhar	Deputy Director for Clean Energy and Energy Conservation	Ministry of National Development Planning (Bappenas)
Onny Widjanarko	Executive Director, Head of Communications	Bank of Indonesia
Popy Sartika	Head Of Section for Asia, Australia and Pacific; subdirectorate International Shipping	Ministry of Transport
Randy Rakhmadi	Regional Manager, Asia	P4G
Riva Siahaan	Commercial Director	PT Pertamina International Shipping
Ronald Halim	Manager and Principal Transport Economist	Equitable Maritime Consulting
Tomás Herrero Diez	Senior Transport Consultant	World Bank (former)
Yo Ishizaki	Chief Country Representative of Indonesia/President Director PT MOL Indonesia	MOL Group

Disclaimer

This report is from the P4G - Getting to Zero Coalition Partnership project, a project between the Global Maritime Forum, 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

Ocean transport is an essential part of everyday life in Indonesia, providing connectivity between the country's many islands and supporting the ongoing development and integration of the economy. Many Indonesians rely on ships directly for income in addition to providing the means for supporting several industrial activities. This means that maritime activities are central to supporting Indonesia's wider national objectives.

As maritime decarbonization increasingly accelerates, it is important to understand how to leverage these global trends for the benefit of Indonesia nationally. This refers both to direct economic opportunities connected to these new vessels and fuels, but also ensuring that Indonesia remains connected to these processes as an important and influential maritime nation.

Geographically, Indonesia is situated in close proximity to some of world's major shipping lanes, with a large volume of traffic passing through its waters annually. This has significance both in terms of the high amount of maritime emissions taking place in Indonesian waters, but also the potential to better utilize this traffic as an economic opportunity. Undertaking such efforts could help Indonesia to reduce its emissions while ultimately making progress on national development goals. This could specifically help to secure long term sustainable jobs, decarbonize other industries, improve local health, boost imports and exports, and help to protect the nation's biodiversity.

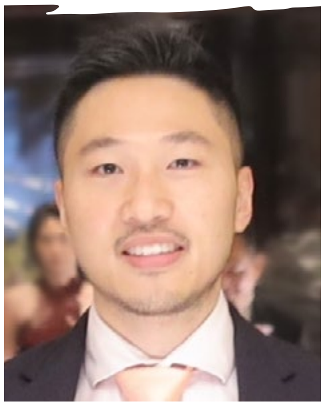
To unlock this potential, there is a clear need for international support in the form of investment, which can help to close gaps in terms of technical assistance and capacity building. Moreover, further efforts are needed in terms of national coordination, ensuring that a direction of travel is set, allowing for public and private stakeholders to come together in collaboration.

As local stakeholders and contributors to this report, we welcome the findings outlined in this report and call on relevant actors to engage further around realizing these opportunities for Indonesia.

Basilio Dias Araujo

Indah Budiani

Budhi Halim



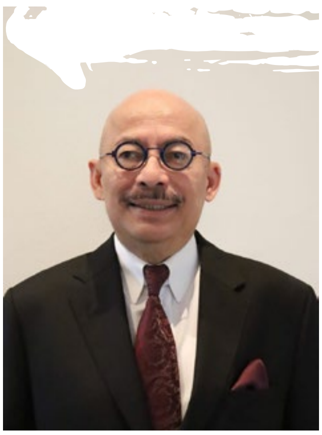
Ronald Halim

Lars Bo Larsen

Nizhar Marizi

Randy Rakhmadi

Ibrahim Rohman



Dr. Mas Achmad Santosa

Cipu Suaib

Prof. Ir. I Ketut Aria Pria Utama

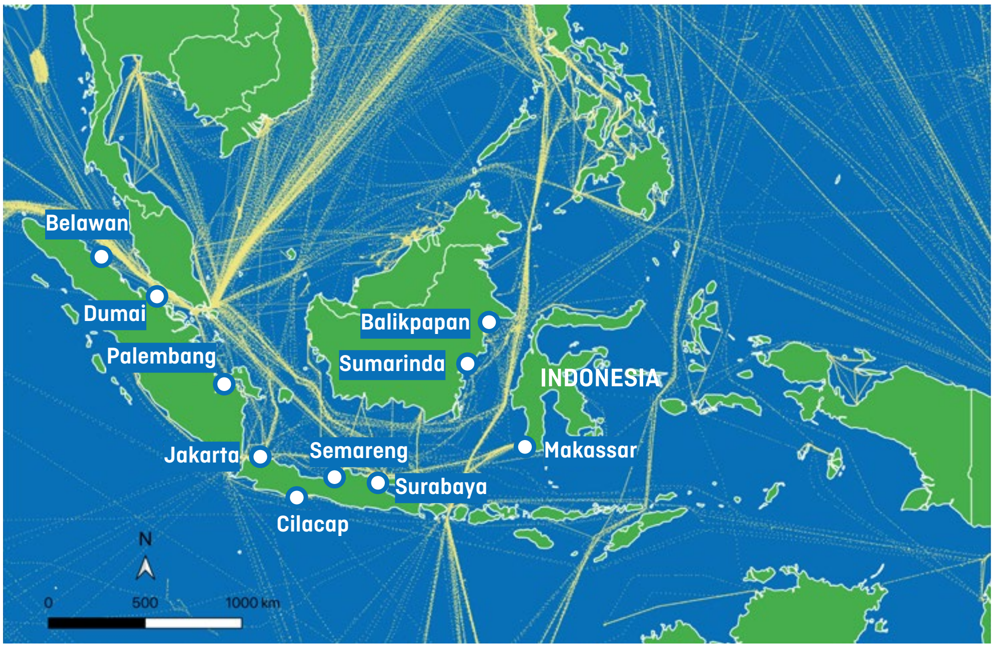
Executive Summary

Advancing Indonesia – a key island nation to support shipping's energy transition by unlocking domestic potential for green fuel production.

Indonesia is the largest archipelagic country in the world, geographically positioned between two of the most important shipping lanes for international vessel traffic. With over 17,000 islands, Indonesia's national identity, politics, society, and economy are intrinsically tied to its maritime industries. Its ocean economy is hugely essential in providing employment for millions of Indonesian citizens, helping to place the country as the world's 3rd largest supplier of seafarers and support a $27 billion USD fishery sector that employs 7 million people.

As the 5th largest emitter of greenhouse gases (GHG) globally, in addition to being acutely exposed to climate impacts as an island nation, there is a clear need for Indonesia to reduce its emissions while also being able to achieve its development objectives. Maritime activities in Indonesia's waters contribute towards these emissions and, depending on the approach taken, calculations show domestic shipping emissions to be heavily underestimated. This can largely be attributed to differences in data handling, but nevertheless clearly indicates the scale of maritime activity as a source of emissions. When considering that a huge amount of vessels pass through without calling at Indonesian ports, the level of maritime emissions from transiting vessels in Indonesia's waters only increases this figure.

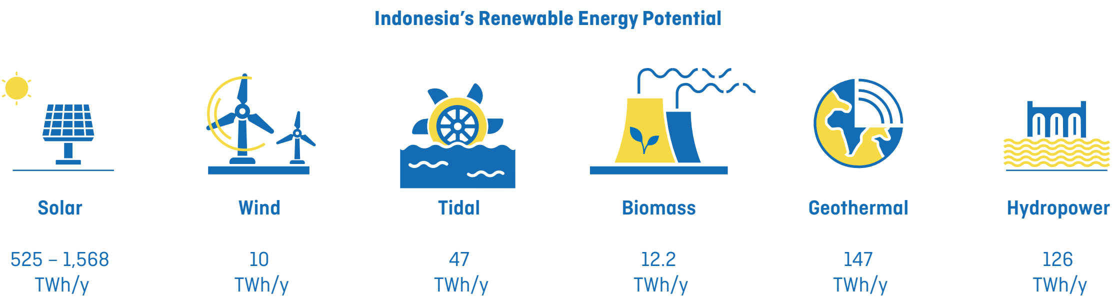
Figure 1: Maritime activity around Indonesia's coastal waters (2018).



As the maritime industry moves ahead in its decarbonization agenda, the need for green fuels and associated technologies are increasing in urgency and relevance. In particular, 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.

Making progress here will require developing Indonesia's largely untapped renewable energy resources. This could allow for 830 – 1,873 Terawatt hours per year (TWh/y) of additional renewable energy production by 2030, largely dominated by leveraging Indonesia's solar energy. This will be necessary to help Indonesia to transition away from a reliance on fossil energy sources like its domestic reserves of coal and import of petroleum products, ultimately providing access to clean energy for the country's needs.

Figure 2: Indonesia's estimated total renewable energy potential by 2030.



Such potential represents enough energy to meet domestic electricity demand, decarbonize local industries, as well as contribute to the decarbonization of domestic shipping. Moreover, should the country manage to cost-effectively access its large reserves of geothermal energy, Indonesia could also explore the opportunity to establish green hubs to bunker and possibly export SZEF where there is a surplus of renewable energy to do so.

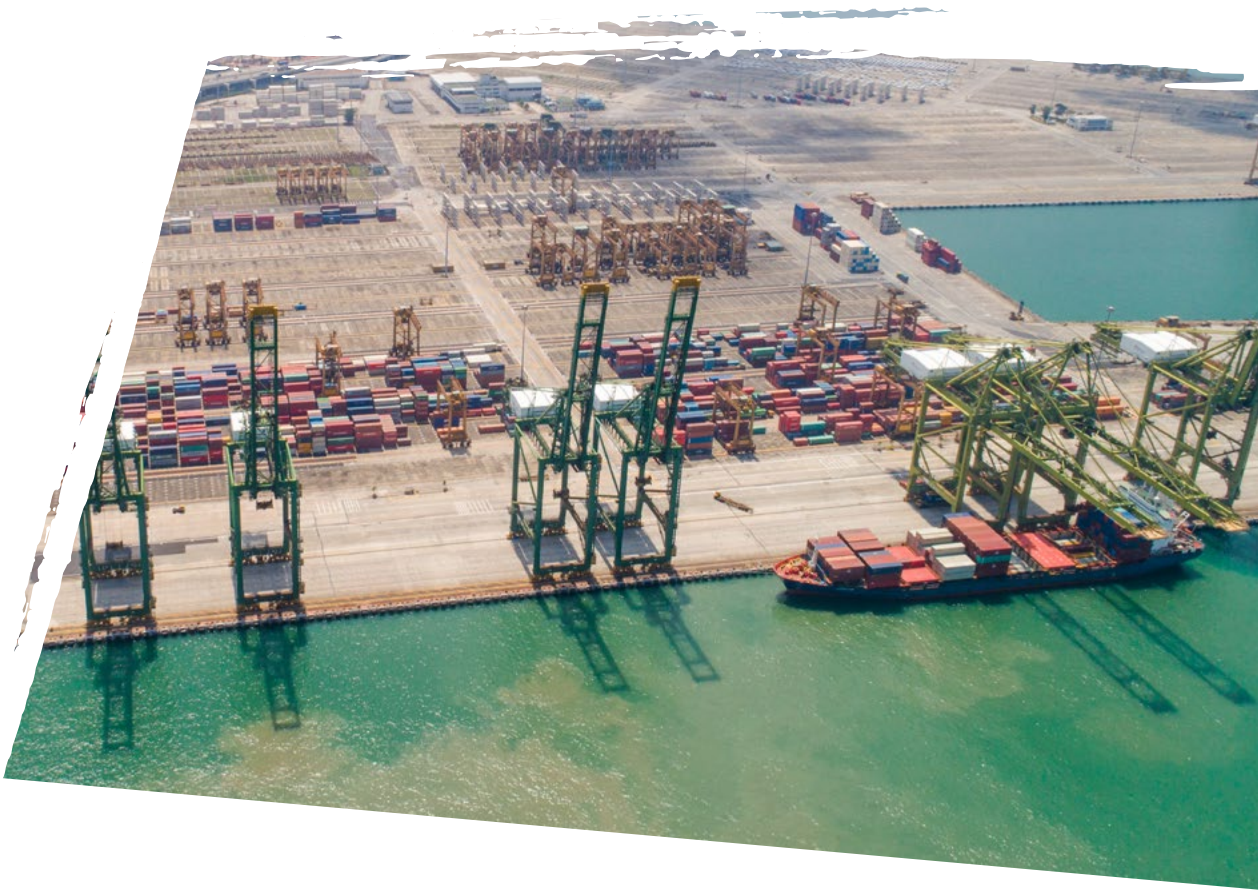
Assuming 5% of the global fleet transitions to SZEF by 2030, then the green energy demand for vessels in Indonesia would represent about 8.3 TWh/y, which conservative calculations shows is only 0.9% of Indonesia's total renewable potential.

Strategic Business Opportunities

This potential could ultimately allow Indonesia to take advantage of its unique position in south-east Asia to facilitate its sustainable development and growth, especially through the creation of maritime hubs for national green corridors targeting short-sea shipping. The country can tap into its nascent renewable energy potential to increase the production and contribution of renewable energy, while also potentially benefiting from being a midstream center of import and export of zero-carbon fuels produced in other countries. Through the energy transition to SZEF, Indonesia can also benefit from the creation of many domestic green jobs in the renewable energy industry and shipbuilding.

Estimates show that development of green fuel infrastructure to serve Indonesia's shipping sector could attract investment up to Rp 46 – 65 trillion IDR ($3.2 – 4.5 billion USD) in onshore infrastructure by 2030.

Scaling its renewable potential with consideration of domestic and possibly international shipping needs, Indonesia could build on existing national ambitions to increase renewable energy penetration and expansion of microgrids. Utilizing the momentum from shipping's energy transition, Indonesia could invest in strategic projects that establish green hubs and ports, open possibilities for domestic green corridors, and develop new sectoral competencies and skills. After extensive consultation with Indonesian stakeholders, three key opportunities were identified, including the planned move of the capital to Kalimantan, the electrification of Indonesia's small boat fleet, and the potential for hydrogen production from geothermal energy.



Capital Shift to Kalimantan

The planned move of Indonesia's capital from Jakarta to the province of East Kalimantan on Borneo Island offers the opportunity to develop the wider region. As part of this move, the capital's relocation plan regulates the utilization of renewable energy and energy efficiency in the new capital.

Fortunately, Kalimantan offers one of the largest renewable potentials in Indonesia of about 180 GW, mainly from solar and hydropower. Various initiatives seek to leverage this potential for the purpose of building an industrial estate in North Kalimantan for metal smelting. In addition, plans for the production and development of green hydrogen and ammonia for domestic use and export are also being considered, aiming to produce 650,000 tons of green hydrogen per annum.

These infrastructure developments can have synergies with shipping decarbonization. Balikpapan port could be developed into a SZEF bunkering hub for domestic shipping, making it a possible commercial gateway to the new capital and an export hub for new products and green fuels made in North Kalimantan. This would support a shift away from Indonesia's "coal-mining heartland" in East Kalimantan and facilitate the decarbonization of the region's hard-to-abate mining sector.

Electrifying Indonesia’s Small Boat Fleet

Indonesia’s large, domestic small boat fleet can be viewed as the backbone of the country’s economy and society, providing an important means for employment and inter-island connectivity as well as a significant source of maritime emissions. Though diesel and biofuels are favored as a fuel source, the switch to electrification for the nation’s small boat fleet would have considerable benefits.

Electrification and the adoption of battery-power propulsion technology is especially suitable for passenger and leisure boats, small fishing vessels, and tugboats, as they often operate on shorter distances and close to shore. Existing and future electrification initiatives in Indonesia could be promoted to pilot and scale in busy passenger and fishing routes around Java and Sumatra.

Sourcing renewable energy for this could be paired with existing government ambitions to expand microgrid installations to increase electricity access in isolated communities. In addition, if Indonesia moves quickly to secure a competitive advantage within battery-technology or shipbuilding of electrified boats, there could be additional benefits to Indonesia’s economic development, in terms of green jobs and export opportunities.

Geothermal-powered Decarbonization Hub

Indonesia is estimated to have roughly 40% of the world's reserves of geothermal energy resources. The majority of which is located on the islands of Sumatra and Java-Bali, with their large population densities and close proximity to important shipping routes.

Accessing these reserves is very costly and comes with multiple challenges; hence, the country has only developed a small portion of this energy source. If Indonesia can successfully and cost-competitively unlock this potential, there is an opportunity for the country to become an international producer and bunkering hub for SZEF.

Some initiatives are already underway, wherein Pertamina Geothermal Energy is exploring the production of green hydrogen. Pertamina manages 15 working sites for geothermal production that they estimate could generate up to 8,600 kg/day of green hydrogen. A pilot project has already commenced at the Ulubelu geothermal site and is set to commercially operate in 2022. Synergies with the maritime sector, aquaculture sector, and fertilizer producers could strengthen the business case for geothermal-based green hydrogen and ammonia.

Recommendations

To appropriately leverage these strategic opportunities, there are several key actions that can be taken to advance zero emission shipping in Indonesia. 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 Indonesia. With appropriate incentives and targeted action towards encouraging investments into relevant areas, Indonesia can ultimately unlock economic opportunities, while simultaneously reducing emissions.

PORTS

Explore options for port electrification
Electrification of existing fossil fuel use in ports is an immediate step towards maritime decarbonization, wherever this change is possible, by switching port activities to rely mainly on electrical energy from renewable sources thereby reducing GHG emissions.

Consider sustainable development in port expansion plans
Stakeholders have noted the need to coordinate port expansion and general infrastructure project development in a coordinated and sustainable manner, especially when planned in areas of high biodiversity such as Kalimantan.

Prepare to source or produce renewable electricity & SZEF for bunkering & port use
Shipping companies are already planning to operate ships on SZEF. Preparing to source or produce renewable energy and green fuels can help the country stay abreast with sector developments as well as prepare to service these new vessels.

Encourage ports as green nodes in an energy distribution network
Ports are focal points for multiple sources of pollution, from arriving and departing vessels, domestic shipping, onshore trucks and rail, as well as their own operations. To handle SZEF, local stakeholders saw the need for development of ports into hubs that can support the distribution of green energy and fuels to isolated island communities.

POLICY

National

Develop a clear strategy for national actions to pursue maritime decarbonization
Developing a national strategy to tackle maritime decarbonization, focusing on actions that can both be done nationally and through international collaboration, could provide a clear and needed policy signal to support further action towards this agenda.

Commission study to assess realistic capacity to produce SZEF that feeds into & supports the development of a national hydrogen strategy or roadmap
Indonesia could commission a study to better understand and scope realistic locations for expanding its renewable energy capacities and production sites for green hydrogen. This knowledge could feed into a national strategy or roadmap for the development and application of green hydrogen.

POLICY

Exploit synergies between shipping's decarbonization & coal phaseout
Indonesia could consider how maritime decarbonization can help to create new jobs that can support the transition of fossil fuel jobs as coal is phased out. Studies estimate that by 2050 at least 3.2 million new jobs could be created should Indonesia transition its energy system.

Support coordination on green ports & hubs
As Indonesia seeks to position itself to become an international bunkering hub for SZEF, increased coordination between ministries, ports, and state-owned enterprises is needed.

Facilitate cross-sectoral synergies for the production & use of SZEF
Opportunities exist for cross-sectoral synergies between industries such as shipping, fertilizer production, aluminum smelting, mining, aquaculture, and electricity production for domestic consumption. Indonesia could look into ways to support such collaborations through, for example, a dedicated task force.

Prepare labor capacity & skills to handle SZEF & technologies
Indonesia could create a strategy to develop qualified talent for a green hydrogen economy, securing the future careers of Indonesian seafarers both onboard and offshore as the maritime sector adopts new digital solutions, green technologies, and transitions away from traditional fossil-fuel energy sources.

Review data aggregation methodology & MRV relating to maritime emissions
To better understand Indonesia's shipping emissions, a review of the various data aggregation methodologies and monitoring, reporting, and verification (MRV) relating to maritime emissions would be useful.

International

Collaborate to secure effective GHG policy at the International Maritime Organization (IMO)
Signing the Declaration on Zero Emission Shipping by 2050 and leveraging Indonesia's role as the host for the upcoming G20 Summit can place shipping's decarbonization more firmly on the agenda. This would help set a clear target supported by effective policy measures, including market-based measures, and ensure a just and equitable transition.

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

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

FINANCE

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.

FINANCE

Boost private renewable electricity generation
As raised by stakeholders, fiscal interventions play a crucial role in encouraging private sectors to collaborate with the government on relevant projects. Incentivizing private sector investment into distributed grid systems could alleviate pressure from stated-owned renewable energy providers.

Explore increased deployment for microgrid installations
Microgrids have already been installed in various places throughout the country with plans to increase their deployment. Such localized systems could potentially supply the energy needs of smaller ports (both through electrification and green fuels) that see a high amount of ferry and fishing vessel traffic.

Leverage international development finance to prioritize funding of strategic projects
Indonesia already has experience in accessing and implementing development bank assistance, which can be used for the benefit of its maritime and land-based industries in scaling SZEF production.

INDUSTRY

Engage in & initiate public-private collaborations
The need for public and private actors to come together and form partnerships is an important way to set a direction of travel and coordinate efforts. This is particularly important in light of the central role played by state-owned enterprises like Pertamina and PLN.

Create awareness of benefits & necessity for a green energy transition
Industry actors could work on creating a set of projects (i.e. seminars, TV debates, publications, etc.) that explain the potential benefits of transitioning to SZEF, which will help create a market for local and possibly foreign companies that are committed to take the first moves to switch to SZEF in Indonesia.

Establish local presence through a regional office or partnerships
For international companies, having a local presence in the country where your organization seeks to expand and grow is extremely valuable. This can strengthen abilities to build networks and have local impact.

Target decarbonization activities in strategic areas
Actors interested in developing concrete projects to produce SZEF and pilot associated technologies could leverage strategic locations within Indonesia that have a convergence of favorable factors.

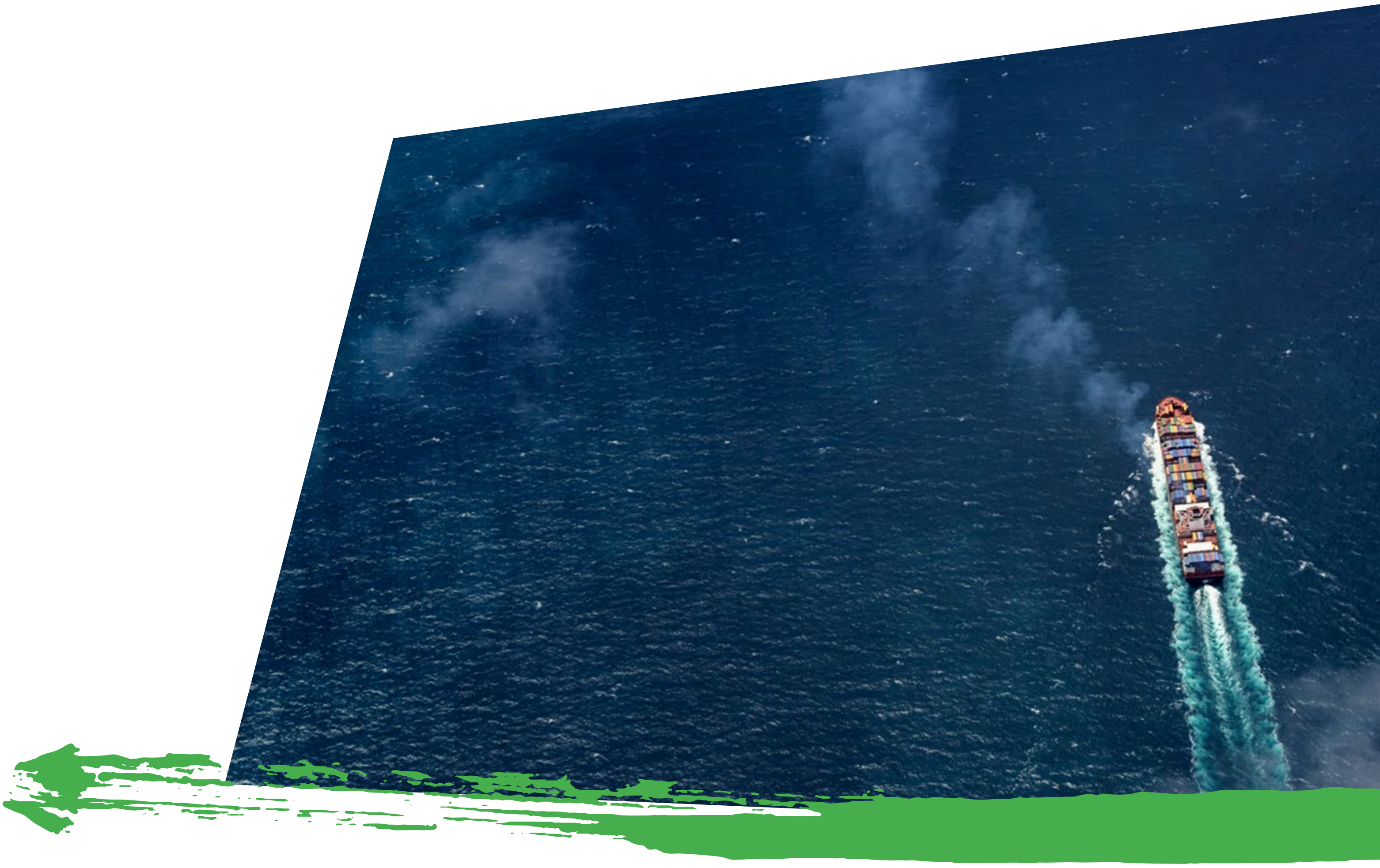
Aggregate SZEF demand
Maritime industries can act as substantial offtakers by themselves, but industry actors could look to aggregate SZEF demand across the value chain as well as from other sectors (i.e. fishing, tourism, mining, and fertilizer and ammonia production)" in order to secure supply.

Explore alternative business model options
Industry actors could seek new and alternative business models that reduce high barriers to entry or adoption for SZEF technology, both onboard vessels as well as on land.

Building connections to the global maritime energy transition would help Indonesia to better position itself to achieve not only its climate targets but also its ambitions towards sustainable development. Building relevant infrastructure would drive Indonesia's ability to leverage this transition and make inroads on several national objectives. Creating enabling financial and regulatory frameworks, establishing collaborative public-private partnerships and initiatives, and investing in renewable energy and climate-proof projects will be fundamental ways to realize this in the years to come.

Shipping's energy transition towards green, alternative fuels is already underway, with an increasing number of projects and initiatives emerging globally. Discussions at the international level are already pushing for increased ambition levels, making it clear that shipping's reliance on fossil fuels will see an end in the next decades.

Countries like Indonesia are essential to include as part of a just and equitable transition towards a low carbon economy. To get there, both national and international action is needed, especially to support the investment and scaling of renewable energy and SZEF infrastructure. This would not only reduce domestic emissions, decrease the country's reliance on coal, and improve air and water quality, but also provide significant benefits for the country's economy and society in the creation of sustainable jobs and skills expertise. The actions outlined above could support Indonesia in its efforts to green its economy and become a key maritime axis in Asia.



Abbreviations

ADB	Asian Development Bank
AIS	Automatic Identification System
ASEAN	Association of Southeast Asian Nations
BC	Black Carbon
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CH_4	Methane
CII	Carbon Intensity Indicator
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	CO_2 Equivalent
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
EEZ	Exclusive Economic Zone
EF	Emission Factor
EIA	Environmental Impact Assessment
GHG	Greenhouse Gas
GWh/y	Gigawatt Hours Per Year
GWP_{100}	Global Warming Potential Over a 100-year Period
HFO	Heavy Fuel Oil
HFO_{eq}	Heavy Fuel Oil Equivalent
IMO	International Maritime Organization
IDR	Indonesian Rupiah

IPCC Intergovernmental Panel on Climate Change

IRENA International Renewable Energy Agency

LHV Low Heating Value

LNG Liquified Natural Gas

MBM Market-based Measures

MCR Maximum Continuous Rating

MDO Marine Diesel Oil

MMSI Maritime Mobile Service Identity

MRV Monitoring, Reporting, and Verification

N_2O Nitrous Oxide

NDC Nationally Determined Contribution

NMVOC Non-Methane Volatile Organic Compounds

NO_x Nitrogen Oxides

PLN Perusahaan Listrik Negara

PM Particulate Matter

QA Quality Assurance

QC Quality Control

RUKN National General Energy Plan for 2019-2038

RUPTL National Electricity Supply Business Plan of 2021

SEEMP Ship Energy Efficiency Management Plan

SFC Specific Fuel Consumption

SGM Shipping Geospatial Model

SOG Speed Over Ground

SO_x Sulfur Oxides

SZEF Scalable Zero Emission Fuels

TWh Terawatt Hours

USD United States Dollar

VOC Volatile Organic Compounds

Section 1

The Need for Maritime Decarbonization

Climate change is one of the biggest challenges 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].

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 [4]. 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 [5][6]. 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] [7]. In so doing, 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].

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 [10], the majority of which are powered by fossil fuels. Recent projections indicate that by 2050, shipping emissions will increase by between 90-130% from 2008 levels [8] (see Figure 1). With an average lifespan of around 25 and 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 can 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 as soon as possible [11]. Actions to support this will be both manufacturing zero emission vessels as well as retrofitting existing assets.

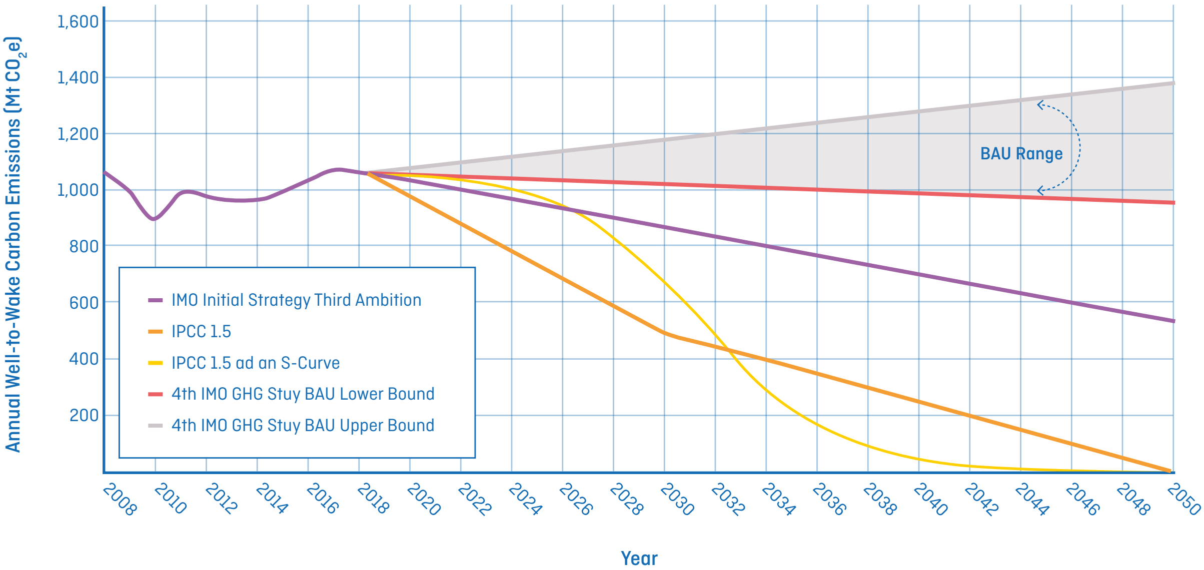
Importantly, increased energy efficiency and natural gas-based fuels alone will be inadequate to meet the Paris climate goals [4]. Thus, the future of international

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.

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 [12].

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 8).



As shown in Figure 2, there are multiple new fuel types with the potential for use in the shipping industry. Indonesia in particular has large amounts of biofuel availability, for which the country has already mandated its use within transport (see Section 5). Biofuels tend to be seen as a carbon-neutral energy source since the environment's CO_2 is captured and locked by animals, plants, microorganisms, or waste that offsets the CO_2 being emitted when used as a fuel [13]. While the carbon neutrality assumption of some biofuels has been refuted [14], they are still likely to offer lower GHG emissions than conventional fossil-based fuels. In addition, the assumption that biofuels are a renewable source is still a matter of discussion and only future life-cycle analysis can tell which biomass feedstock is truly renewable [15]. However, there are concerns at a global scale for this fuel and its continued use in the maritime sector. Indeed, studies and industry experts have noted that biofuels are unlikely to be the industry's main fuel choice for deep-sea shipping, as they suffer from scalability challenges as well as competitive demand from other sectors [16]. Sustainable biofuels from waste could continue to be used for smaller domestic vessels and short sea shipping, or other larger vessels as a transition fuel, though other sectors may offer more lucrative markets for their sale and use.

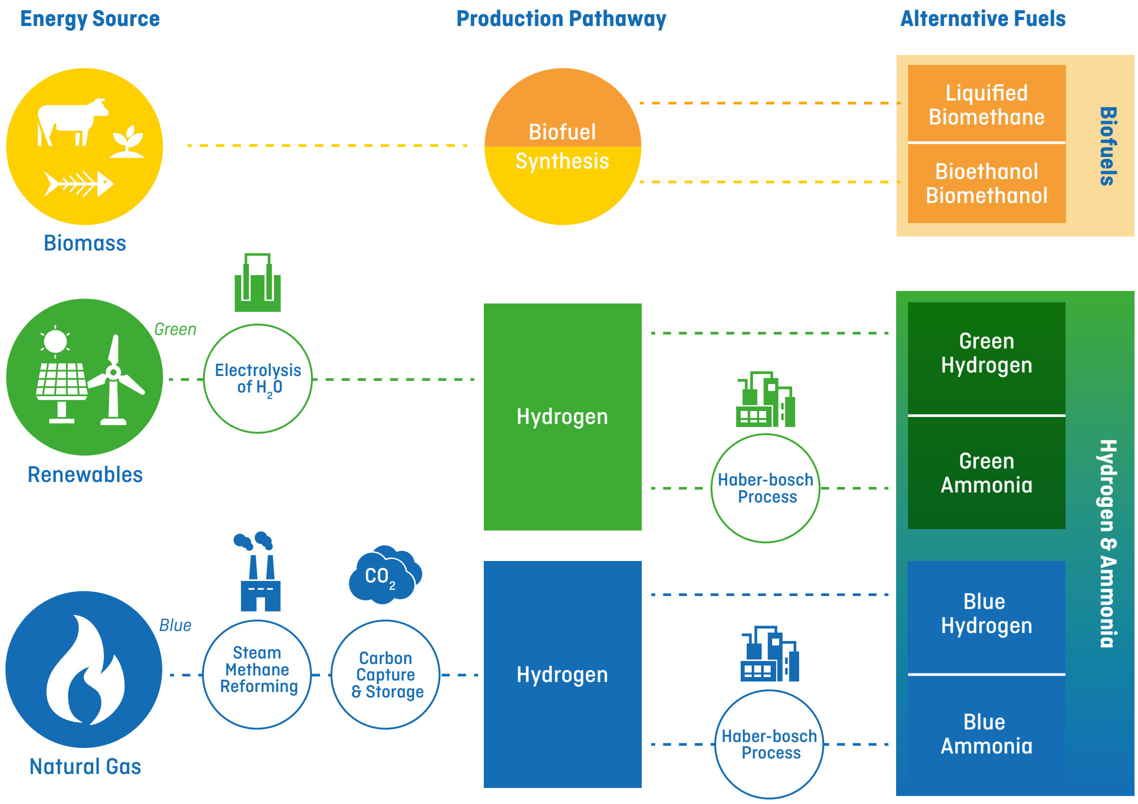
Fuels that have no carbon molecule, such as hydrogen and ammonia, are some of the most viable SZEF due to their potential for production at scale and with no operational CO_2 emissions. These fuels can be produced via two routes, these

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

being 'blue' and 'green' hydrogen and ammonia. Blue hydrogen and ammonia are produced via steam-methane reformation of natural gas and thus still necessitates the use of fossil fuels in their production pathways [17]. In order for such production pathways to be considered zero-carbon, all of the GHG emissions resulting from the manufacturing process would require the utilization of carbon capture and storage (CCS) technology [17]. The long-term viability and price competitiveness of this process remains to be ascertained, since CCS technology is still expensive, and its usage could be argued to prolong the dependence on fossil fuels. On the other hand, green hydrogen and ammonia are produced with no fossil fuels, but by using renewable electricity to power water electrolysis [17].

Taking this into consideration, blue hydrogen and ammonia might play a role in the transition from fossil fuels to SZEF, but in the long term only fuels that are truly fossil-free such as green hydrogen and green ammonia are considered the most promising long-term options for deep-sea going vessels as both can be used through fuel cells of internal combustion engines.Green ammonia, in particular, is thought to be the most suitable long-term option for decarbonizing international shipping [16] [18]. Smaller domestic vessels may also make use of green hydrogen, although other power options such as electrification is attractive.

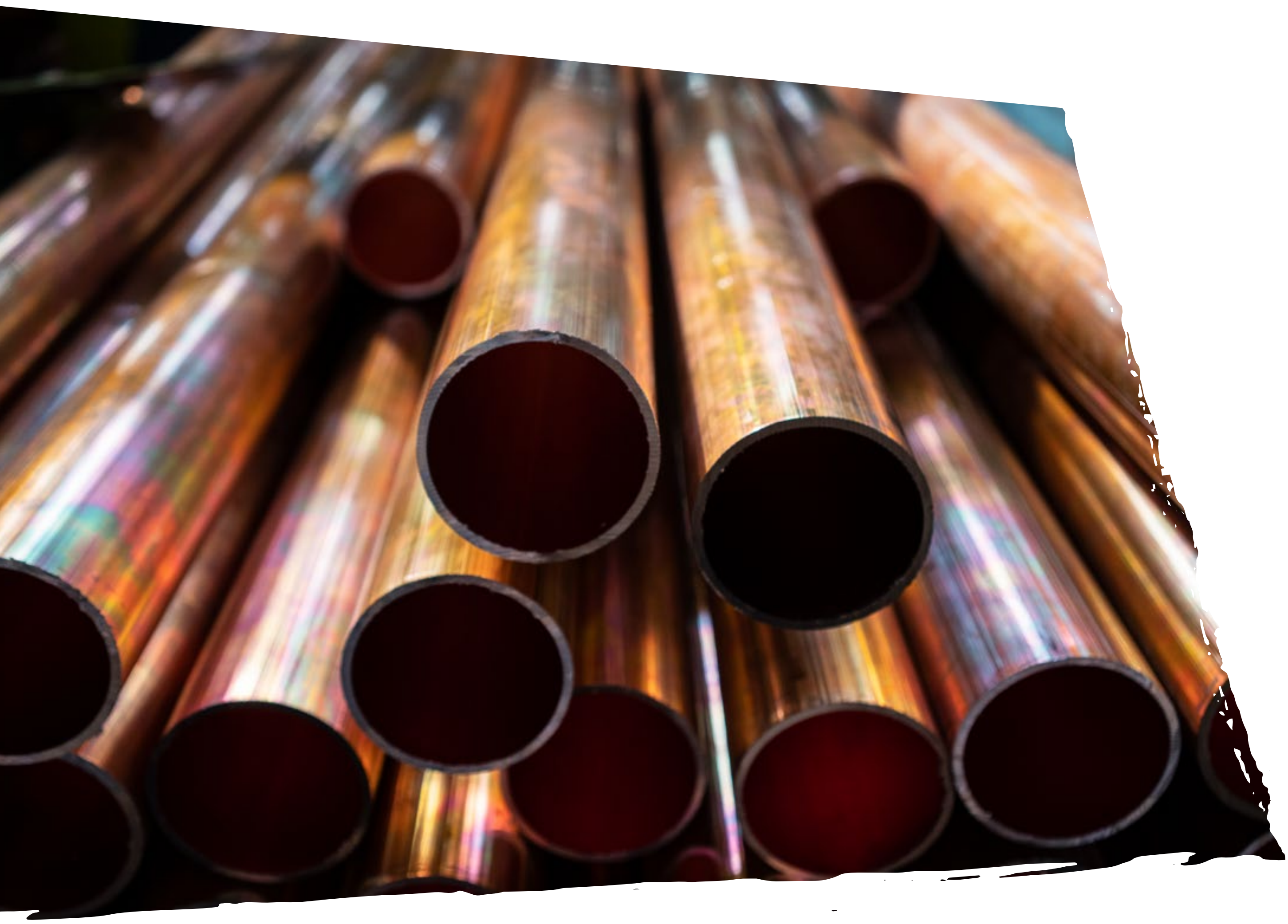
Figure 2: Alternative fuels and their production pathways.



Source: Inspired by World Bank [19]

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 [20].

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 [21][22][23]. 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 expediated creation of SZEF infrastructure [17].



Section 2

Indonesia: A Maritime Nation

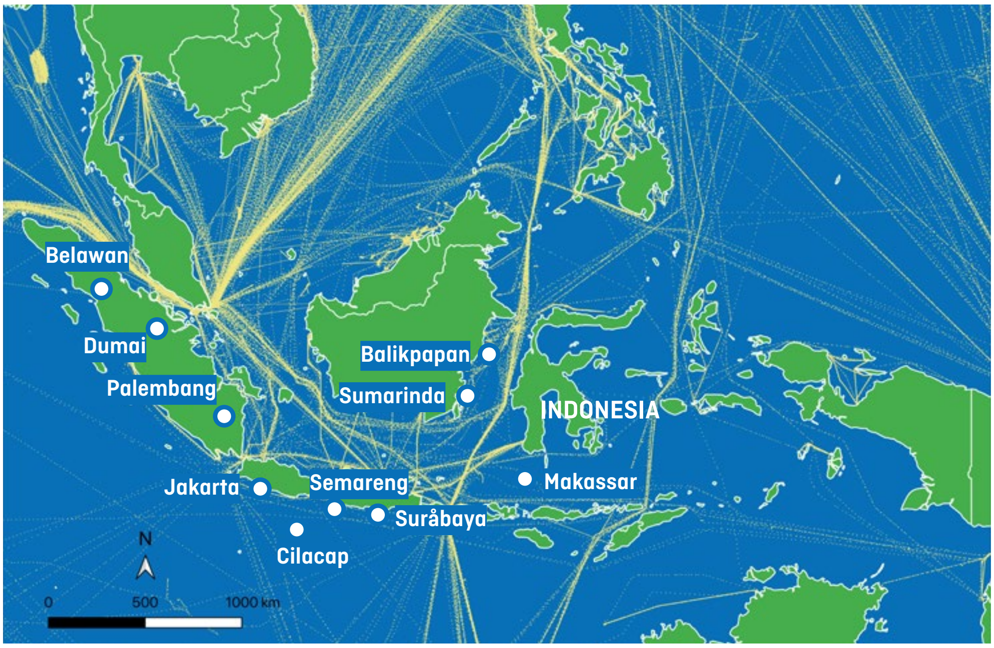
Indonesia is located along two of the most important shipping lanes in the world, the Strait of Malacca and the Sunda Strait. The country's geographical location presents a huge opportunity for investing in a diversified maritime market that needs to transition to lower carbon intensity (see Figure 3), and become a hub for international vessels passing between the world's largest economies.

Indonesia is composed of over 17,000 islands in the Pacific and Indian oceans [24]. With a coastline of 54,720 km and a large coastal population, about 900,000 Indonesians are involved in the local and international maritime economy [25]. As such, the country has a large ocean economy with a fishery sector worth about $27 billion USD, providing 7 million people with jobs in 2019 [26].

Local politics and socio-economic activities are significantly shaped by Indonesia's geography, being the largest archipelagic country in the world and characterized by significant biological and cultural diversity [27][28][29]. These unique geographic attributes form an important part of its national identity. The island nature of Indonesia and its position at the heart of several global trade axes provide several avenues for future maritime trade growth and development.

With this many islands, it's no surprise that there are several hundred small ports spread across the country, 111 of which are commercial ports and 11 container ports [30]. With such a large number of ports, Indonesia has 260 administrations providing oversight, but Pelindo is the main state-owned company managing these ports [25][30][31]. These ports service multiple vessels, both domestic and international. Indonesia's national fleet is made up of 27,114 ships mainly comprised of general cargo vessels, oil tankers, bulk carriers, container ships, and others. 99% of domestic shipping is done via locally registered ships [32][25]. Due to its heavy reliance on maritime activities, the country is also a leader in world seafarer supply, representing the 3rd largest supplier of seafarers behind the Philippines and Russia [5].

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

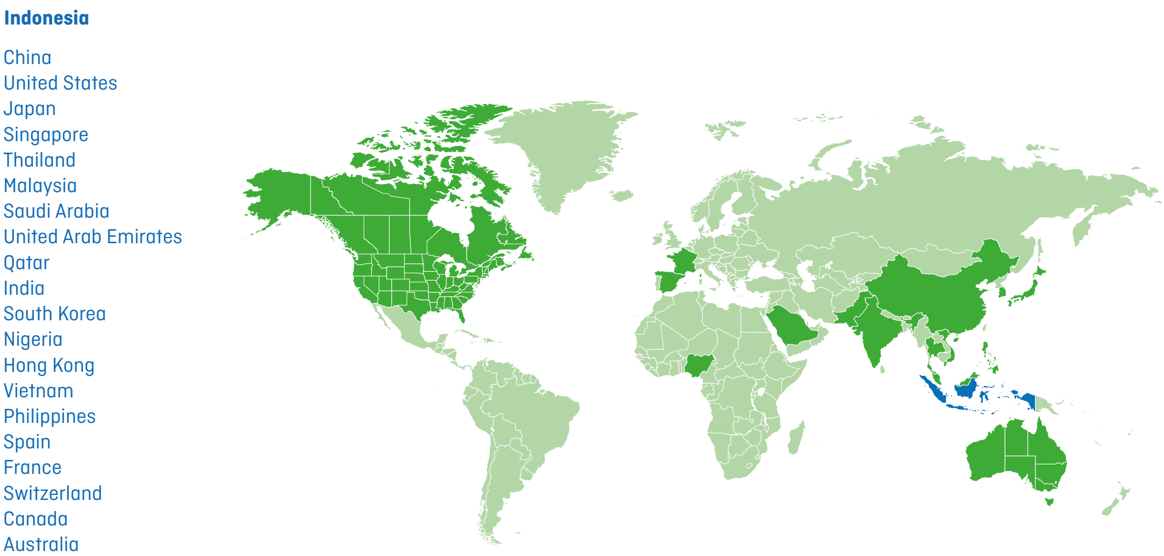


Indonesia has a container port throughput of 14,025,449 TEU [32]. In 2020, Indonesia imported $140 billion USD worth of goods mostly in the form of refined and crude petroleum. The export basket was valued at $178 billion USD and included palm oil, coal briquettes, gold, and petroleum gas (see Table 1). Indonesia's main trade partners are China, United States, Japan, Singapore, India, and Thailand [33].

Table 1: Indonesia's key imports and exports [33].

Imports				Exports			
Product	**Value (USD)**	**% of total imports**	**Origin & Value (USD)**	**Product**	**Value (USD)**	**% of total exports**	**Destination & Value (USD)**
Refined Petroleum	7.45 B	5.32%	Singapore (3.82B) Malaysia (1.28B) Saudi Arabia (487M) United Arab Emirates (365M) South Korea (332M)	Palm Oil	17.9 B	10.06%	India (3.05B) China (2.47B) Pakistan (1.62B) Spain (854M) Malaysia (729M)
Crude Petroleum	3.13 B	2.23%	Saudi Arabia (1.21B) Nigeria (775M) United States (248M) Malaysia (210M)	Coal Briquettes	15.6 B	8.76%	India (3.8B) China (2.67B) Japan (1.85B) Malaysia (1.34B) Philippines (1.27B)
Telephones	2.95 B	2.11%	China (1.95B) Hong Kong (268M) Chinese Taipei (227M) Vietnam (200M) Singapore (188M)	Gold	6.31 B	3.54%	Singapore (3.31B) Switzerland (2.11B) Hong Kong (464M) Australia (371M) Thailand (25.4M)
Planes, Helicopters, and/or spacecraft	2.69 B	1.92%	Thailand (1.45B) Malaysia (934M) France (172M) India (46.8M) Canada (36.4M)	Petroleum Gas	5.71 B	3.21%	Singapore (1.69B) China (1.62B) Japan (836M) South Korea (796M) Chinese Taipei (290M)
Proteleum Gas	2.42 B	1.73%	United States (887M) United Arab Emirates (652M) Qatar (375M) Saudi Arabia (166M) Australia (105M)	Ferroalloys	4.74 B	2.66%	China (4.55B) India (114M) South Korea (41.8M) Chinese Taipei (18.9M) Canada (3.67M)

Figure 4: Indonesia's import and export relationships [33].



Section 3

Maritime Activity & Shipping Emissions

Indonesia is a trading nation located on key shipping routes. As such, there is significant maritime activity within the country's waters. Indonesia's shipping activity is dominated by bulk carriers, tankers, and containerships that are mainly on international voyages. Using an activity-based approach[4], Table 2 breaks down the vessels that departed from Indonesia's ports in 2018 and shows the energy used by each ship type[5]. Large and small tankers account for 27.9% of the total annual energy demand, while small and large bulk carriers and small containerships account for 24.6% and 7.5%, respectively. However, the largest share of the shipping demand is the small industrial boats with a share of 27.2% of the total energy demanded in 2018. This reflects the relevance that the small boat fleet has on Indonesia's insular nature and the great opportunity it has to transition this segment of the shipping sector as it will be discussed in Section 6.

Table 2: The fossil fuel energy demand from different types of vessels that have departed Indonesia's ports on both international and domestic voyages [34].

Vessel category	Fossil fuel energy demand 2018 (GWh/y)	Share of Grand Total (%)
Bulk carriers: Large	14,770	12.9%
Bulk carriers: Small	13,405	11.7%
Tankers: Large	20,079	17.5%
Tankers: Small	11,977	10.5%
Containers: Large	572	0.5%
Containers: Small	8,060	7.0%
People & Vehicle Carrier: Large	959	0.8%
People & Vehicle Carrier: Small	4,838	4.2%
Offshore and Services	2,300	2.0%
Fishing	216	0.2%
Small boats: Industrial	31,192	27.2%
Small boats: Fishing / Other Small Boats	6,364	5.5%
Grand total	114,732	100%

‡ The energy demand presented does not represent fuel sales only the energy expenditure to arrive to any port in Indonesia 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 [8].

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 (AIS).

5 The annual energy is based on all the shipping energy demanded for voyages that departed an Indonesian port to its next port of call in 2018. This accounts for international and domestic voyages.

3.1 Indonesia's national GHG emission inventory

Indonesia compiled its National GHG Inventory in accordance with the IPCC 2006 guidelines for inventories for the period between 2000 and 2019 [35]. The total GHG emissions of Indonesia in 2019 amounted[6] to 920,2214 kt CO_2e. In 2018, Indonesia was the 7th largest GHG emitter [36]. However, it is important to highlight that for Indonesia its Forestry and Other Land Use emissions amounted to 924,853 kt CO_2e, which combined with the rest of the GHG emissions gives a total of 1,845,067 kt CO_2e, increasing significantly the country's emissions and bringing it up the rankings from 7th to the 5th largest GHG emitter.

Water-Borne Navigation[7] was responsible in 2019 for just 0.01% of Indonesia's total GHG emissions[8] (i.e. 95 kt CO_2e). The total share of GHG due to 1.A.3.c Water-Borne Navigation appears low for a large insular nation that depends heavily on this subsector to transport people and goods as well as having some of the busiest international shipping traffic lanes. Further, during COP26, the government of Indonesia through the Coordinating Ministry for Maritime and Investment Affairs, stated that 19% of Indonesia's CO_2 emissions recorded for its Nationally Determined Contributions came from the maritime industry [38]. Clearly stating that shipping has a larger GHG share in Indonesia than what has been recorded in their emission inventories. Potential reasons for the National Inventory lower emission number could be attributed to the way energy consumption is aggregated from the national energy statistics and how fuels are assigned to a mode of transportation. Indonesia uses the 'Handbook of Energy and Economic Statistics of Indonesia' to aggregate fuel consumption by sector, but this is only done at the highest aggregation level – for shipping is Transportation [39]. However, there is a direct translation from the national fuel consumption statistics to the IPCC 2006 categories based on the fuel type. But for the particular case of diesel – where heavy fuel oil (HFO) and marine diesel oil (MDO) are located – and gas, the Indonesian GHG inventory cannot differentiate or disaggregate the diesel and gas consumption between transport modes [40]. This could well be the strongest root cause for the low GHG emissions reported for the maritime sector since the majority of the diesel and gas usage could have gone to a different transport category within Indonesia's GHG inventory[9].

A more detailed presentation of the 2006 IPCC Guidelines for water-borne navigation can be found in Annex I or in Davies et al. [37] with further explanation of the Indonesia national GHG inventory available in "Greenhouse Gas Inventory Report, Monitoring, Reporting, and National Verification 2020" [40].

6 Excluding Forestry and Other Land Use.
7 A country only needs to account for domestic maritime emissions in their national inventories, of which fishing activities should be aggregated, as suggested by the IPCC Guidelines under the *Agriculture/Forestry/Fishing* category of the Energy sector. However, for the Indonesia's GHG Inventory this category is not present and it is inferred as to be aggregated under the category 1.A.5 *Non-Specified*. 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 can be reported separately [37]. In the case of Indonesia, these are not reported.
8 Excluding Forestry and Other Land Use.
9 It was not stated in the references used in this report to which transport sector the diesel consumption is assigned.

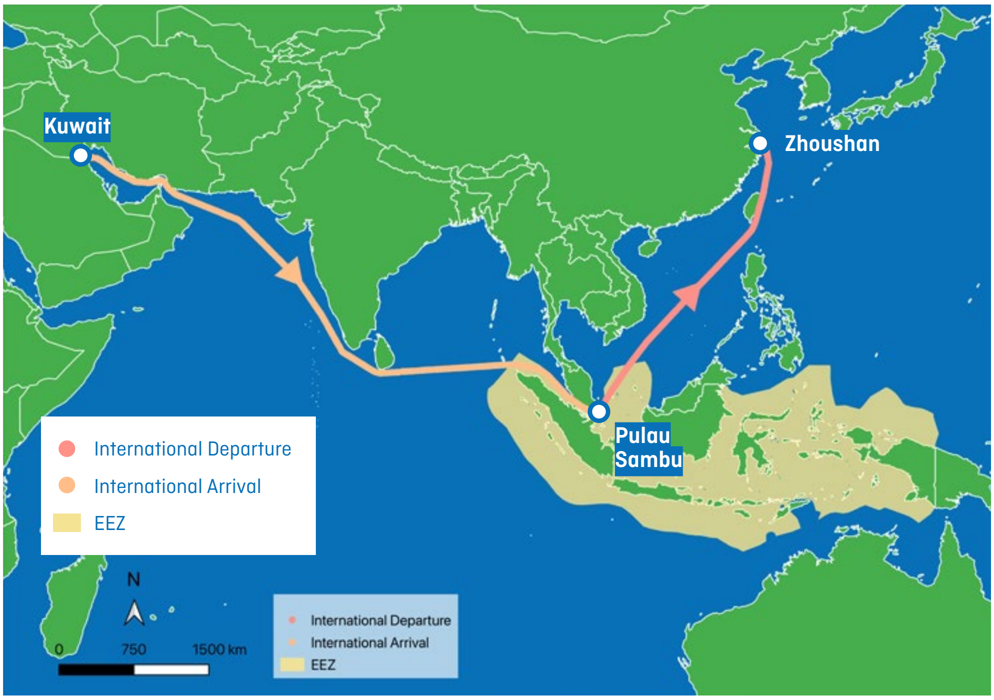
3.2 Shipping Geospatial Model: A new approach for estimating maritime emissions

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 Indonesia through different lenses, the SGM aggregated hourly ship data[10] as follows:

- **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.
- **Arrival.** 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 nm which includes the Territorial Sea) is aggregated. It includes the international shipping, domestic navigation, and 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 [41].

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



10 It only accounts for the activity of ships above 100 gross tonnage, the small boat fleet activity and emissions are not considered.

In general, the SGM approach should be seen as complementary to Indonesia'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, in particular, illustrates the environmental, economic, and health impacts of emissions from ships transiting to, from, and through Indonesian waters and makes the case for decarbonization of shipping, especially considering that not all emissions are resulting from Indonesia's imports and exports. In summary, the SGM can illustrate the opportunity Indonesia has on SZEF all while supporting and driving the reduction of GHG emissions from shipping.

The results of the SGM approach show that vessels operating within the EEZ generated the greatest quantities of CO_2e in 2018 at 56,861 kt. Internationally arriving vessels gave 16,306 kt CO_2e followed by international departures with 16,026 kt (see Table 3). Roughly 9.9% of the total EEZ air pollution emissions take place within Indonesia's territorial waters[11] which negatively and disproportionately affect coastal communities. Under this light, the geofenced EEZ approach can support the study of the benefits of having Indonesian emission control areas, but as well emphasizes the prime position Indonesia has to support the maritime transition by utilizing SZEF.

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

Pollutant[12]	International Departures	International Arrivals	Domestic Navigation	Domestic Fishing	Geofenced EEZ (200 nm)
GHG (kt)					
CO_2	14712.97	14991.05	6841.22	4.21	51774.91
CH_4	1.74	1.47	0.19	7.58×10^{-5}	11.31
N_2O	0.82	0.84	0.37	2.38×10^{-4}	2.81
BC§	1.16	1.17	0.81	7.05×10^{-4}	4.47
CO_2e	16025.62	16306.03	7676.88	4.91	56860.53
Air Pollution (kt)					
SO_x	219.80	225.00	63.23	1.80×10^{-2}	672.00
NO_x	358.43	367.19	131.11	8.18×10^{-2}	1129.39
CO	13.95	14.13	5.83	3.96×10^{-3}	47.20
PM_{100}	33.45	34.19	9.82	1.29×10^{-3}	102.00
PM_{25}	30.77	31.46	9.03	1.18×10^{-3}	93.84
NMVOC	15.26	15.52	5.89	3.56×10^{-3}	49.07

‡ 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 [8].

§ A value of 900 was used for black carbon 100-year Global Warming Potential [42].

11 This includes all shipping activity that occurred within the country's territorial seas, up to 12 nautical miles offshore.

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

The maritime domestic emissions captured by the SGM were produced from 83,509 domestic voyages[13] occurring in 2018. This level of activity amounted to 7,677 kt CO_2e while domestic fishing was estimated to be emitting 5 kt CO_2e. The difference with Indonesia's 2018 National Inventory is 7,569 kt CO_2e since the Water-Borne Navigation GHG emissions amounted to just 108 kt CO_2e [40]. As discussed in the previous subsection, the main causes for this large difference are:

- 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 Indonesia. In practice, ships calling at Indonesia 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 Indonesia only if it's 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 Indonesia's shipping activity is purchased in Indonesia and so the activity-based method is helpful for giving an estimation of the potential bunker sales market - should Indonesia want to expand its opportunity, especially for SZEF.

    ◊ Indonesia's maritime annual fuel consumption is aggregated with all other modes of transportation under the Transport category [39]. At this stage, the connection between fuel consumed and the transport mode that consumed the fuel is lost. In the SGM case, the fuel being consumed from, to, and within Indonesia is estimated by hourly satellite data coupled with a technical methodology that delivers fuel consumption and emissions per individual ships.

    ◊ When building the National GHG Inventory, the fuel consumed from the Transport category is disaggregated to the IPCC 2006 categories based on groupings of fuel per mode of transportation. For example, avgas and jet fuel is only assigned to civil aviation. For the case of shipping, it was not found the fuel group assigned to it, but it is stated that for diesel and gas the fuel consumption and GHG estimations cannot be disaggregated by mode of transportation. This is potentially the main root cause for the large difference between the inventory reports since it is highly probable that the fuel consumed by Indonesia's domestic maritime activity is allocated to another mode of transport within the National Inventory. Due to the importance of maritime activity within Indonesia's economy, the introduction of dedicated fuel consumption accounting based on modes and fuel types is therefore recommended.

- The method used in SGM is an activity-based method so it includes emissions from domestic voyages of international ships (e.g. from one Indonesian 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. United Kingdom) that have since switched to use the activity-based method [43].

---

13 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.

- 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 transponder). In the case of Indonesia, this segment, due to its energy demand as seen in Table 2, has a relevant and important role in the country's 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.

Now, looking at the SGM aggregation of all maritime activity in 2018 to, from, and within Indonesia, the total GHG emissions amounts to 40,013 kt CO_2e – about 12,850 kt HFO_{eq} – which represented about 3.7% of the total shipping GHG emissions in 2018[14] as reported by the IMO. Employing the SGM clearly shows the important role Indonesia has in supporting shipping decarbonization in the decades to come and emphasizes the importance of international collaboration between Indonesia 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.

3.2.1 Analysis by ship type

In this section the SGM analysis is disaggregated by ship type (see Figure 6). Across the approaches considered, the most polluting ship types for Indonesia are bulk carriers, oil tankers, and chemical tankers emitting on average 61.1% of the 2018 GHG emissions. This is in line with the level of activity observed in Table 2 where bulk carriers, oil tankers, and chemical tankers demanded about 60,230 GWh/y (i.e. about 5,395 kt HFO_{eq}[15]) of fossil fuel energy. The domestic navigation GHG emissions represented about 47.9% and 47.1% of the total CO_2e generated by international departures and arrivals respectively. Domestic fishing represented about 0.03% of the total GHG emissions from international departures and international arrivals. This would seem a small percentage for a large insular nation that has one of the largest fishing activity and landings in the world [44]. But what it points out, in conjunction to Table 3, is that the great majority of the domestic fishing activity, about 95%, is done by the small boat fleet [45]. As explained before, one of the limitations from the SGM model is that it only captures any activity of ships above 100 gross tonnage, leaving the small boat fleet, and probably the largest source of domestic fishing activity, not accounted for. However, this limitation highlights that the SGM results on domestic shipping GHG and air pollution are a conservative estimation.

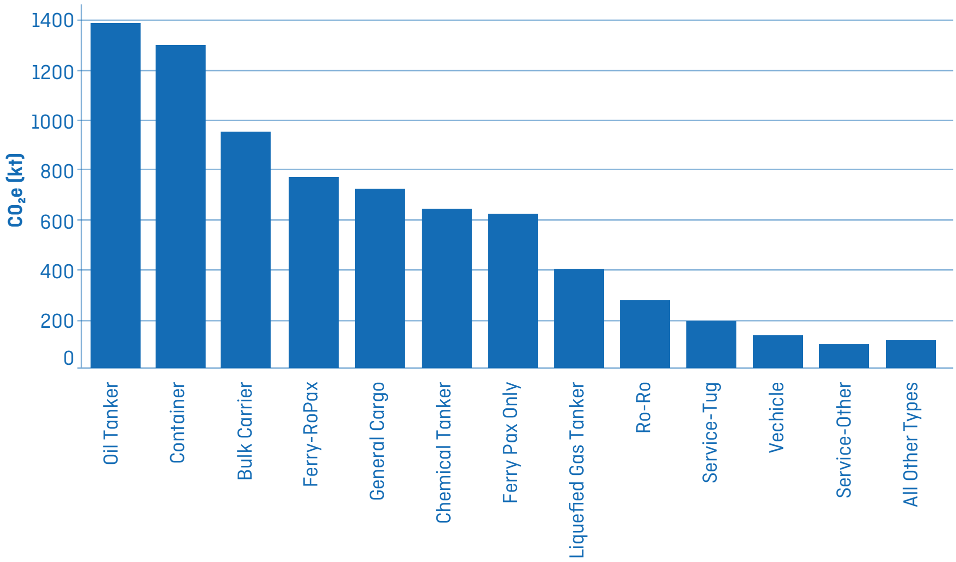
14 The total GHG emissions in 2018 was 1,076,000 kt CO_2e formed by international and domestic shipping and fishing [8].

15 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 [8].

Figure 6: CO_2e inventories by ship type for Indonesia in 2018.

A detailed disaggregation of domestic shipping by vessel type is presented in Figure 7, which shows that domestic shipping emissions are dominated by oil tankers at around 1,392 kt CO_2e followed by containerships with about 1,304 kt CO_2e and bulk carriers with around 959 kt CO_2e. Domestic fishing for ships above 100 gross tonnage is the 15th greatest source of national shipping GHG with 5 kt CO_2e during 2018 – aggregated under the *All Other Types* in Figure 7. From the IPCC method, domestic fishing is aggregated under the *Agriculture/Forestry/Fishing* category of the Energy sector. However, for Indonesia's GHG National Inventory this category is not present. It is mentioned that emissions related to agricultural transport energy consumption are allocated to the category *1.A.5 Non-Specified* and it is assumed that domestic fishing is aggregated under this category [40]. However, under this assumption, it is not possible to know what is the share of domestic fishing in this category due to the way the data has been aggregated.

Figure 7: Share of domestic emissions by vessel types. Domestic fishing is added for comparison purposes.



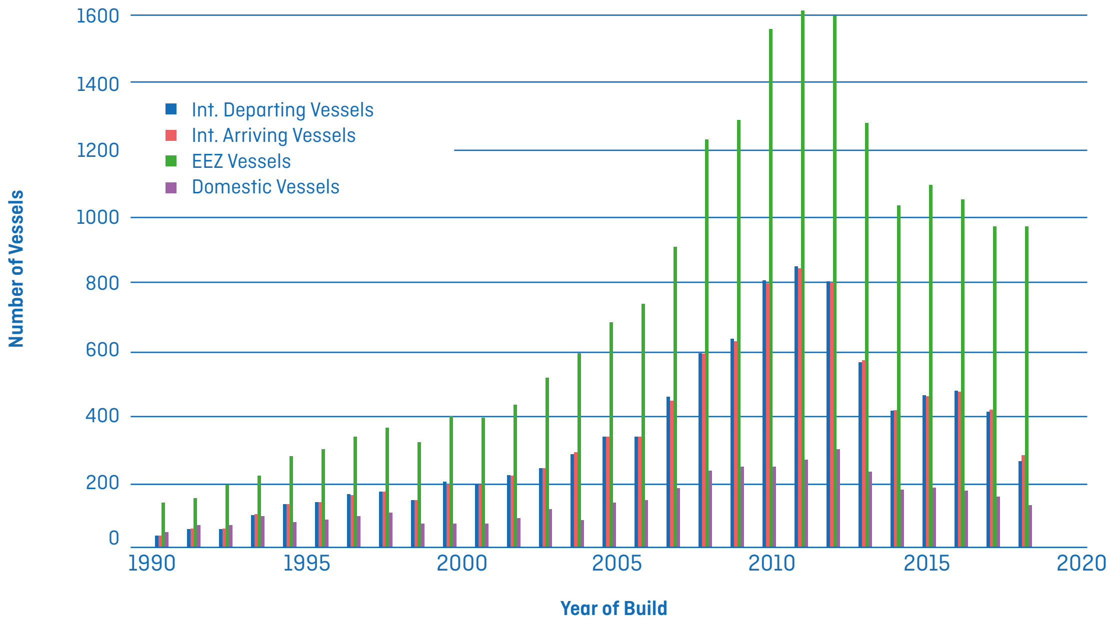
3.2.2 Analysis by age

An important aspect to consider when analyzing shipping emissions is the fleet characteristics and in particular age, which has a strong correlation with fuel efficiency and emission production. Figure 8 presents the spread of build years for vessels navigating Indonesia's waters after 1990. The greatest share of vessels operating in 2018 were built between 2010 and 2012. This implies that the largest share of shipping activity occurring in Indonesia is coming from relatively new ships that will tend to have good fuel efficiency and pollution control measures in accordance with the International Maritime Organization (IMO) regulations.

Of the 9,975 unique vessels to depart Indonesia's ports internationally, 2.0% (203) were built before 1988 making them 30 years old or more throughout 2018. This compares with just 3.3% (712) of the 21,739 vessels that traversed Indonesia's EEZ during the same year and 8.0% of domestic vessels (368 of 4,624), 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 2004. Essentially, under this lens we can see that the international fleet is younger and potentially more energy efficient. 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 IMO level would likely have a significantly positive effect on the emissions experienced by Indonesia, shown in the ship type and geofencing sections. In the short term, the domestic fleet would benefit from energy efficiency improvements.

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

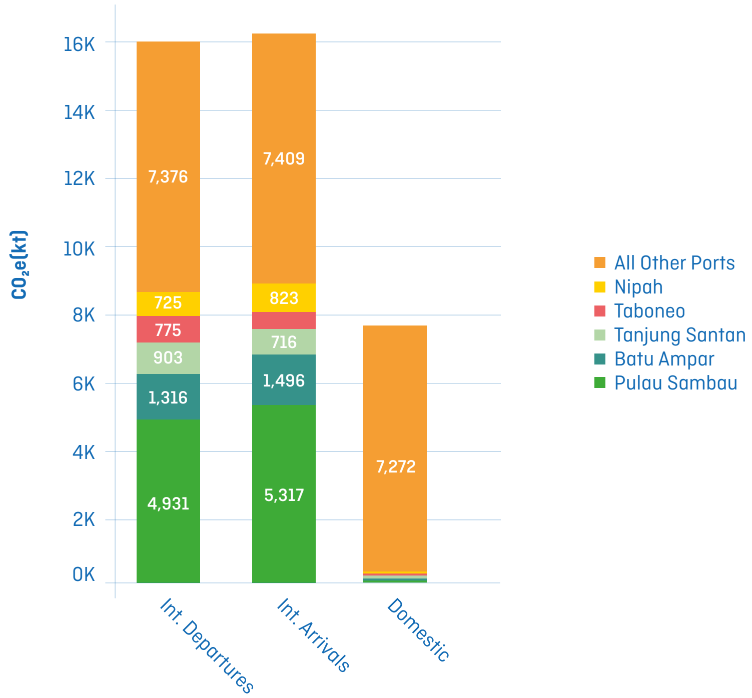


3.2.3 Analysis by port arrivals and departures

Using the SGM to focus on port-based activity allows a clear picture of emissions that can affect port communities and local populations. Figure 9 presents the breakdown of CO_2e emissions from international voyages departing and arriving at five most polluting (by international departures) Indonesian ports, namely Pulau Sambu, Batu Ampar, Tanjung Santan, Taboneo, and Nipah while simultaneously aggregating the rest of the ports in a single class. It's important to recognize that the ports of Pulau Sambu and Batu Ampar represent bunkering hubs and are therefore responsible for a disproportionately high amount of energy demand and emission generation compared to their size.

The greatest contribution to the international departures inventory is Pulau Sambu which generated 30.8% of the total annual emissions from international departures (4,931 kt CO_2e) in 2018, followed by Batu Ampar with around 8.2% (1,316 kt CO_2e) and Tanjung Santan with around 5.6% (903 kt CO_2e). Ports outside the top five were responsible for 46.0% of emission generation from international departures (i.e. 7,376 kt CO_2e) with Jakarta participating with around 640 kt CO_2e. From the international arrival point of view, Pulau Sambu produces the largest amount of CO_2e at 5,317 kt that represented 32.6% of the total in 2018. This is followed by Batu Ampar and Jakarta with a share of 9.2% and 6.1% respectively. The All Other Ports class has a larger share of the total international arrivals with 46.0% or 7,409 kt CO_2e which shows the maritime activity all across Indonesia.

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



3.2.4 Geofencing around large port cities

It has been established that air pollutants can travel hundreds of miles while the maritime GHG emissions around ports contribute to the cities' carbon footprint. In an effort to capture the implications of maritime emissions on Indonesia's coastal populations and its maritime GHG, three cities with sizable coastal populations and with active ports have been selected for further analysis. Regions of 100 km radius surrounding Indonesia's ports of Jakarta, Belawan, and Surabaya were chosen to estimate the emissions generated by shipping activity[16] during 2018 (see Figure 10).

Table 4 indicates that the population of Jakarta had the highest exposure with 11 kt SO_x, 21 kt NO_x and 175 t of BC generation. In regards to maritime CO_2e, emissions for Jakarta amounted to 1,607 kt. Belawan 100 km radius geofence approach had a total annual GHG emission of 1,154 kt CO_2e and an annual emission of SO_x of about 15 kt and 25 kt NO_x. For Surabaya, shipping activities amounted to 938 kt CO_2e, 5 kt SO_x and about 12 kt NO_x. The total annual BC emission for the three port cities was estimated to be over 300 t BC.

16 The emissions quantified here only considered the activity performed by the ships present in the regions. This does not account for the emissions produced by the port and its systems (e.g. cranes, forklifts).

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 Jakarta, Belawan, and Surabaya during 2018.

Pollutant	Jakarta	Belawan	Surabaya
GHG (kt)			
CO_2	1428.26	1059.03	828.42
CH_4	3.38×10^{-2}	6.01×10^{-2}	1.05×10^{-2}
N_2O	7.41×10^{-2}	5.81×10^{-2}	4.31×10^{-2}
BC	1.75×10^{-1}	8.62×10^{-2}	1.08×10^{-1}
CO_2e	1606.53	1153.66	937.57
Air Pollutants (kt)			
SO_x	11.11	15.14	5.20
NO_x	20.62	24.57	11.82
CO	9.79×10^{-1}	9.57×10^{-1}	5.81×10^{-1}
PM_{100}	1.63	2.30	8.22×10^{-1}
PM_{25}	1.50	2.11	7.56×10^{-1}
VOC	9.16×10^{-1}	1.04	5.37×10^{-1}

The creation of focused inventories for port cities through the SGM can aide 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 nm 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 [46]. In the particular case of Indonesia, the study and mitigation of maritime air pollutants near its ports can help improve the air quality of its coastal population, which is estimated to be between 150 and 180 million people [47][48].

«There is a clear need to modernize and future proof Indonesia's port systems by building up the infrastructure necessary to transition operations to cleaner forms of energy. In addition to latest science and technology, this modernization needs to take into account the needs and concern of domestic shipping companies.» – Budhi Halim, Indonesia National Shipowners Association (INSA)

3.3 Implications for Indonesia

National GHG inventories present reliable estimates of emissions allowing governments to formulate and implement mitigation measures, taking respective national circumstances and capabilities into account. Indonesia'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 W*ater-Borne Navigation*. Although emissions from the international shipping sector are acknowledged in the IPCC 2006 methodology, they are not quantified in Indonesia's National Inventory. 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 Indonesia's national waters and at its ports. The SGM complements Indonesia's National GHG Inventory by presenting domestic and international maritime emission 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 showed that:

- Domestic emissions and fuel demand from vessels larger than 100 gross tonnage, which are more likely driven by national legislation, are a lot smaller than the international arrival/departure emissions and fuel demand. The IMO regulation will be key in driving change in the ships that call at Indonesian ports.

- Still, it was observed that the largest share of energy demand in Indonesia comes from the small boat fleet representing 32.7% of the total energy demanded in 2018. This in turn will have an important implication in Indonesia's GHG emissions and air pollution. For this segment of the Indonesian maritime sector, national legislation and policies will play a central role on its energy transition and reducing the segment's air pollution.

- Bulk carriers, tankers, chemical tankers, and containerships above 100 gross tonnage are the type of vessels that emit the most GHG and air pollution from maritime activity to, from, and within Indonesia's ports and national waters.

- Despite their relative magnitudes, there is still a significant domestic fleet/ emission, 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 Indonesian centers of population. Decarbonization of shipping, if enabled through fuels with lower air pollutant levels, can be a significant driver of air quality improvement in several important locations.

- Compared to other methods to quantify GHG emissions and air pollution, the SGM method is a conservative estimation since it does not capture the emissions from the small boat fleet, which in the case of Indonesia represents a large part of the domestic fleet.

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

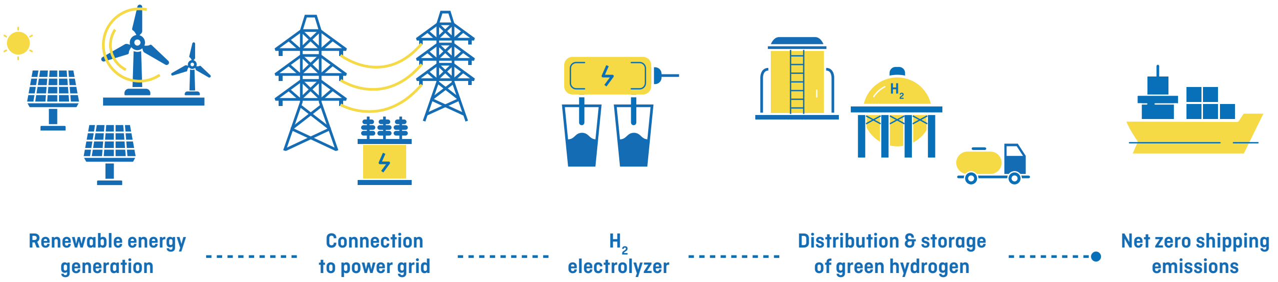
«Indonesia is hugely reliant on maritime activities, both as a source of employment and also as a sector that is central to supporting Indonesia's wider national objectives. In order to ensure that the maritime sector is sustainable, there is a clear need to transition away from traditional fossil fuel based activities over the coming decades, that can benefit Indonesia nationally as an important and influential maritime nation.»
– Indah Budiani, Indonesia Business Council for Sustainable Development (IBCSD)

Section 4

Harnessing Indonesia'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 [4]. The need for green SZEF and its 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).

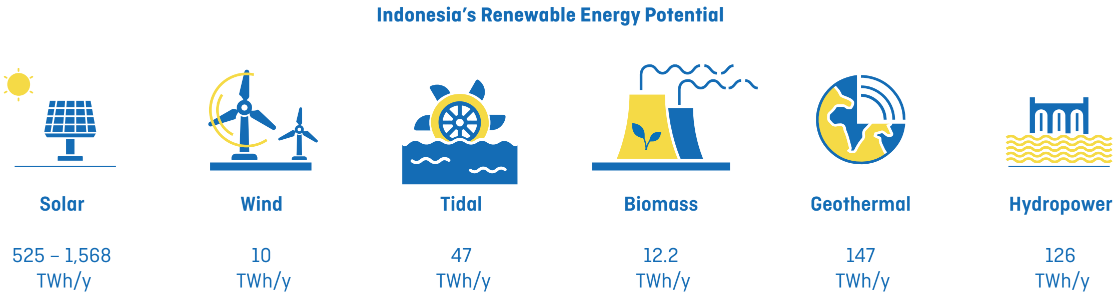
Figure 11: Illustrative production pathway for green hydrogen.



Source: Inspired by Quadrant Smart [58]

In 2019, 16% (47.6 TWh) of the country's electricity generation came from renewable sources, a decrease from the year before where renewables accounted for 22%, and a significant decrease from 2013 where renewables accounted for 34% of electricity generation [50]. In the coming decades, this percent is expected to increase substantially. Indonesia's National General Energy Plan estimates renewable energy to constitute 28% of the country's energy production share by 2038 [51]. In particular, considering the current technologies available and restrictions regarding land use, Indonesia can reasonably produce by 2030 an additional 830 – 1,873 TWh/y of renewable energy: 525 – 1,568 TWh/y of solar, 10 TWh/y of onshore wind, 47 TWh/y of tidal, 133 TWh/y of geothermal, and 105 TWh/y of hydropower energy [34]. When combined with existing renewable generation, Indonesia could produce a total of 877.6 – 1,920.6 TWh/y by 2030 (see Figure 12).

Figure 12: Indonesia'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 on available studies and Indonesia's renewable energy potential can be 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 value. This is the case for new technologies like 'Floating Solar Farming', which has progressed in the last few years. In Indonesia, development of solar farms on land could damage the environment and endanger biodiversity. Instead, interest has turned towards other areas such as lakes, reservoirs, and the sea. Projects for floating solar farms are being undertaken in West Java on the Cirata Reservoir as well as in Batam Island on the Duriangkang Reservoir, the latter considered the world's largest floating solar farm [52][53]. However, the limited surface area of reservoirs also impacts the amount of solar energy that can be collected. Therefore, development of floating solar farms on the sea or in Indonesian waters is of great interest.

Furthermore, to ensure a fair and equitable transition, additional renewable energy plans for shipping must be built alongside those estimated by Indonesia's National General Energy Plan 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 Indonesia'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. This is especially the case for any plans to scale the production and use of sustainable biofuels from waste sources, which could have a limited role as a transition fuel but is not seen as a long-term viable option for deep-sea shipping [16].

Overall, however, Indonesia has limited renewable potential due to challenges associated with accessing these resources. These challenges include land availability, feasibility of site development, and its disconnected grid across the country. Such technical challenges are compounded by political and social challenges associated with the government's commitment and political will to transition into renewable energies, which some stakeholders have argued is compromised due to vested financial interest in the existing oil and gas system. Unless these are addressed, Indonesia has diverse but limited potential to produce green fuels for the international shipping sector, but enough potential to address its domestic shipping needs [34]. Nevertheless, local stakeholders note that shipping decarbonization is relevant for Indonesia, with political ambitions to compete with the likes of Singapore as a green fuels bunkering hub. With the current shipping traffic and bunker demand, assuming 5% of the global fleet transitions to SZEF by 2030 then the green energy demanded from visiting international and domestic vessels would represent about 8.3 TWh/y [34].

Conservative calculations show that 8.3 TWh/y represents only 0.9% of Indonesia's total renewable potential, comfortably leaving more renewable energy potential than needed for both decarbonizing the national grid and vessels stopping at Indonesian ports. This supports local stakeholder perceptions that the country is well-positioned to produce green hydrogen and its derivatives, where 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 some 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 countries and would need to import fuels to meet their energy demands. Indeed, the war in Ukraine has exacerbated this 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.

«Indonesia has largely untapped renewable energy resources due to technical and geographical challenges. Green hydrogen might play an important role in addressing these challenges given its versatility. HDF Energy is already exploring this in the country today, and efforts should be scaled in the coming years as sustainable forms of energy become increasingly in demand.» – Cipu Suaib, HDF Energy

Hydrogen Trade

As countries like Indonesia eye 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 [54]. The International Renewable Energy Agency reports that more than 30% of hydrogen produced will be traded internationally by 2050 [55]. This will require international and multi-stakeholder cooperation to prevent interruptions in the clean hydrogen supply chain, ensuring products can freely move across borders.

Standards targeting safety and quality of green hydrogen goods and services is one way to build a resilient global green hydrogen economy and reduce the risk of impeding trade in the future. Questions 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, remain. 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 greenhouse gas emissions accounting, ESG metrics considering broader impacts of hydrogen production, and assessment of hydrogen development with the Sustainable Development Goals in mind [56]. 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.

Bilateral and regional trade agreements could also stimulate export of green hydrogen. Though Indonesia doesn't have any to date, there have been industry interest on this front, such as the Memorandum of Understanding between the Global Green Growth Institute and the Korea Gas Corporation that aims to promote green hydrogen in developing and emerging countries, including Indonesia. Both organizations are "hoping to support emerging economies to leverage the wealth of renewable energy available in the country, promoting its use in local heavy industry and potentially for export to other countries" [57]. 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 in order to create a level playing field, shape an efficient global green hydrogen economy, and work towards full industry decarbonization by 2050.

Section 5

Policy Framework & Climate Ambition

5.1 Climate & energy policies

Indonesia has unique development requirements that play an important role in shaping its domestic and international climate and energy policies. As shown in Section 3, total GHG emissions from Indonesia were estimated at 920.2 Mt CO_2e in 2019[17]. Indonesia is heavily reliant on coal power, which accounts for almost 60% of the energy used for electricity production [58]. Current policies will likely need to be adjusted in the medium term in order for Indonesia to decarbonize in line with its commitment to the Paris Agreement and its temperature goals [59][60].

The policy development landscape in Indonesia is made up of a range of diverse stakeholders, including ministerial departments, the Executive Office of the President of the Republic of Indonesia, the national parliament (i.e. the People's Consultative Assembly), several agencies, and non-governmental organizations. However, the key policymaking bodies are concentrated in Indonesian ministries that pass regulations regarding energy developments and the environment. Importantly, the Ministry of Energy and Mineral Resources governs renewable energy support mechanisms, while the Ministry of Finance has power to set the size of renewable energy subsidies, fiscal incentives, and other financial measures. The Ministry of Industry and Ministry of Villages, Disadvantaged Regions, and Transmigration have also set several regulations supporting creation of local grants and renewable energy requirements. The Ministry of Environment and Forestry is mandated to coordinate the overall implementation of Indonesia's Nationally Determined Contributions (NDC) and carbon pricing mechanism.

Recent policy developments in Indonesia are promising. In 2021, the country submitted its updated NDC to the UN, which increased sectoral targets and reconfirms a 41% GHG reduction target by 2030 'subject to availability of international support for finance' [61], to achieve an electrification ratio of 99.7% by 2025, and to reduce energy intensity by 1% per year up to 2025 [61][62]. In the same year the Indonesian Ministry of Energy and Mineral Resources signed a partnership with the International Renewable Energy Agency (IRENA) to work towards a 1.5 °C future, by focusing on identification and implementation of relevant decarbonization pathways [63].

The country has also joined in 2021 the international aviation's CORSIA Offsetting Scheme as a voluntary participant [64]. 2021 also saw President Joko Widodo sign a presidential regulation with a legal framework of carbon pricing [65], which regulates the implementation of Indonesia's NDC and control of GHG emissions. The Minister of Transport is mandated to develop a GHG emission baseline and upper limit of the sub-sector for transport, which serves as the reference for carbon trading and carbon tax implementation in the energy sector.

17 Excluding Forestry and Other Land Use.

This level of ambition is welcomed, especially given that Indonesia is the 4th largest producer of coal and is the largest gas supplier in Southeast Asia [66]. The government has published several strategies on energy such as the National Energy Policy, the National Energy Plan, and a Biofuel Roadmap [67]. It has also adopted policies to accelerate the development of renewable energy [67]. In line with these, Indonesia has set a goal to increase access to electricity and renewable contribution to the grid above 20% by 2025 [34]. In this process, it has identified the importance of moving away from fossil fuels, increasing the role of renewables, investing in carbon capture and storage, while improving human welfare [68]. Similarly, the government has identified the risk of stranded assets as something that has to be considered [68], an area of significant relevance when discussing the potential role of transitional fuels compared to SZEF in the medium term.

To date, Indonesia has passed 4 laws that explicitly address climate change. Besides the ratification of the Paris Agreement, the others include:

1. **Law No. 7 of 2021 on the Harmonization of Tax Regulations**, which regulates the implementation of the carbon tax. Carbon emissions having negative impacts to the environment are subject to carbon tax of a minimum Rp 30 IDR/kg CO_2e ($2 USD/ton). At the initial stage (starting 2022), the carbon tax is applied to the coal-fired power sector within the cap-and-trade mechanism [69];

2. **Law No. 32 of 2009 on Environmental Protection and Management**, as amended by Law No. 11 of 2020 on Job Creation, which requires climate change consideration within all instruments of environmental protection, including Environmental Impact Assessment (EIA) [70]; and

3. **Law No. 31 of 2009 on Meteorology, Climatology, and Geophysics**, which mandates the Indonesian Government to conduct climate mitigation and adaptation efforts [71].

In addition, there are various climate-related laws and policies in the sectors of shipping, energy, forestry, conservation of living resources, and waste management [35]. Regarding sustainability and renewable energy development, in 2021 Indonesia passed the 'Implementation of Environmental Protection and Management' [72] requiring companies to submit environmental impact analysis of any renewable energy projects they are planning, further showing the country's effort to preserve its biodiversity.

There have been numerous changes regarding energy regulations and some of these have aimed to increase energy justice, and while the success of these attempts has been questioned [73], they show a general trend towards more progressive energy policies. Indeed, the 2016 "Bright Indonesia" program launched by the Ministry of Energy and Mineral Resources in collaboration with the Asian Development Bank and support from General Electric exemplifies this, wherein the $3 billion USD microgrid initiative aims to use renewable solar power to illuminate Indonesia's eastern provinces such as Papua, West Papua, Maluku, North Maluku, and east and west Nusa Tenggara but is still under construction in 2022 [74][75][76].

Indonesia has so far enacted several legislative rules which align it with a more ambitious future decarbonization trajectory, these are the first step in aligning the country with a trajectory towards renewable energy and possibly zero-carbon fuels:

- **Law No. 21 of 2014 on Geothermal Energy as amended by Law No. 11 of 2020 on Job Creation** – lessens restrictions on geothermal exploitation [77].

- **Ministry of Energy and Mineral Resources Regulation No. 50 of 2017 on Renewable Energy Utilization for Electricity Supply** as lastly amended by MEMR Regulation Number 4 of 2020 – provides a detailed plan on development of renewable energy infrastructure and creates a mechanism for prioritization of renewable energy purchases by the state-owned company, Perusahaan Listrik Negara (PLN) [78].

- **National Electricity Supply Business Plan of 2021** (RUPTL) – lays out a 10-year development plan for electricity generation, transmission, and distribution assets in Indonesia. In the low carbon scenario, energy mix composition by 2030 is planned to be coal (59.6%), natural gas (15.6%), renewable energy (24.2%), and fuel oil (0.4%) [79].

- **National General Energy Plan for 2019-2038** (RUKN) – sets target for 2038 to have 28% for 'new renewable energies' [51].

- **Ministry of Villages, Disadvantaged Regions, and Transmigration Regulation No. 11 of 2019** – creates regional financial support for off-grid (in particular microgrid) renewable energy projects [80].

- **Presidential Regulation No. 10 of 2021 on Investment Business Sector** – creates a range of fiscal incentives for renewable energy generation, including corporate income tax reduction [81].

- **Presidential Regulation No. 98 of 2021 on the Implementation of Economic Value of Carbon for Achieving NDC Targets and Control of GHG Emissions in National Development** – presidential decree issued by President Joko Widodo with the aim of establishing a legal framework for carbon pricing [82].

5.2 Maritime policies

Inherently, the sea is an important natural resource for Indonesia as a source of food, communication, transport, and trade. As such, the President of Indonesia Joko Widodo has made a commitment to transform the country into a "Global Maritime Axis" that builds on the unique geography of the country bordering the Lombok and Malacca straits on a crossroads between trade routes and cultures [83]. The country's large marine resources are key for economic development, exhibited by its ocean economy that is the largest across the Association of Southeast Asian Nations (ASEAN) [84].

Indonesian maritime policies can come from multiple levels of national, regional, and local authorities, including the Ministry of Transport and Ministry of Marine Affairs and Fisheries [85][25]. The Ministry of Marine Affairs and Fisheries has passed multiple regulations to protect coastal zones and fishery environments [86].

In 2008, regulation was adopted that made provisions for safety, security, and marine environment protection of shipping, navigation, and ports [87]. This law introduced the separation between regulatory and operational functions, aiming to foster competition and encourage private sector participation. Subsidiary legislation in 2009 and 2010 established Port Management Units, restructuring the port sector into a "landlord" model [88]. The potential transformation for the decarbonization of the national port sector is aimed at a "shift from land to ocean-based development" [89]. In fact, with the slogan of "Jalesveva Jayamah" ("In the ocean we triumph"), the current executive administration seeks to position the country as a maritime power [83]. This led to the establishment of the Indonesian Ocean Policy in 2017, comprised of two components: the National Ocean Policy containing broad pillars[18], and the Ocean Policy Action Plan that converts these pillars into programs and designates the institutions in charge of their implementation [90]. It should also be noted that several stakeholders highlighted that shipping/ maritime sectors are included in the current carbon tax roadmap being developed by Indonesia.

In the international shipping context Indonesia 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. Indonesia 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.

Indonesia has ratified several international conventions, including the International Convention on Civil Liability for Oil Pollution Damage of 1969 and its amendment of 1992 [91]. In 2010, Indonesia passed regulation on the protection of marine environment aimed at preventing marine pollution caused by ships or by port activities and by waste discharge in waters in relation to MARPOL 73/78 [92]. In 2012, Indonesia ratified MARPOL Convention Annexes III, IV, V and VI that is domesticated by Ministry of Transport Regulation No. 29 of 2014 [93][94].

Furthermore, marine environment protection is governed by the law on Environmental Protection and Management [70] and regulation on the Control of Marine Pollution and/or Degradation [95]. Management of coastal areas and small islands are covered by Law No. 27 of 2007, as lastly amended by Law No. 11 of 2020 [96]. In addition to significant progress on draft domestic legislation to align itself with ratified international agreements, Indonesia has also been active within the IMO. It has one of the largest IMO delegations and is top in terms of ratio of delegation/ fleet size [97]. Indonesia also serves as a member of the IMO Council Category C in the period of 2022-2023. In the 72nd session of the Marine Environmental Protection Committee, Indonesia recognized the mandate of the IMO in addressing GHG emissions from international shipping and supported the alignment of the Initial IMO GHG Strategy with the Paris Agreement.

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

United Nations Convention on the Law of the Sea (UNCLOS Convention) (ratified in 1985)
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (ratified in 1993)
The International Convention on Civil Liability for Oil Pollution Damage of 1969 and its amendment of 1992 (ratified in 1999)
International Convention for the Prevention of Pollution from Ships (MARPOL Convention), particularly its Annex VI for Air Pollution (acceded in 2012)

18 Seven pillars of the policy include: (i) resource management and human resource development; (ii) maritime defense, security, law enforcement and safety at sea; (iii) maritime governance; (iv) maritime economy, infrastructure, and welfare improvement; (v) maritime spatial management and environmental protection; (vi) nautical culture; and (vii) maritime diplomacy.

The IMO has successfully adopted multiple instruments and policies aimed at reducing GHG emissions from ships[19]. 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 and 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 [98]. 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. 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 [99]. However, Indonesia's ambition regarding decarbonization will also have to address its unique position as an archipelagic country, as some studies imply that as a result of shipping decarbonization and associated increases in transport costs Indonesia could see a potential GDP decline of -0.11% [100].

The forthcoming year is crucial in the IMO regulatory timeline. In the 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. Additionally, further discussion of the tabled mid-term measures proposals will take place. Multiple proposals for MBMs have been submitted for consideration at the upcoming meetings. How these proposals proceed and in particular how a revenue generating measure is designed will have significant bearing on the shape of the transition. Funding created 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[20] 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 [101].

Work by the World Bank finds political viability in a scenario where a portion of revenue is allocated for out-of-sector use [102][103]. Revenue generation, collection, and deployment are dependent on the policy design and therefore uncertain as yet. However, 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 [104].

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 to align with IPCC climate science and send strong policy signals to drive long-term investment in the production and provision

---

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

20 Estimates suggest that across the 2030s and 2040s SZEF may be approximately double the price of conventional fossil fuels [17].

of alternatives fuels that emit zero-GHGs on a life-cycle basis and to enable an equitable transition for all.

The currently adopted IMO measures have yet to achieve sufficient reductions to put the sector on a trajectory that is compatible with the goals 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 [12]. 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

Furthermore, while a MBM adopted at IMO level may offer in-sector financial support at some stage, in this initial phase private sector investment, as well as public-private partnerships, collective action by the maritime industry, the energy sector, financial institutions, and governments/ intergovernmental organizations need to provide significant funding. Indeed, in consideration of the competitiveness gap between fossil fuels and alternative SZEF [101], 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 [105].

In the evolving policy landscape, combining a focus on domestic ambitions that are aligned with renewable energy production and GHG emissions mitigation, with international engagement in IMO discussions and public-private collaboration provides a promising outlook for Indonesia's role in the transition.

Section 6

Strategic Business Opportunities in Indonesia

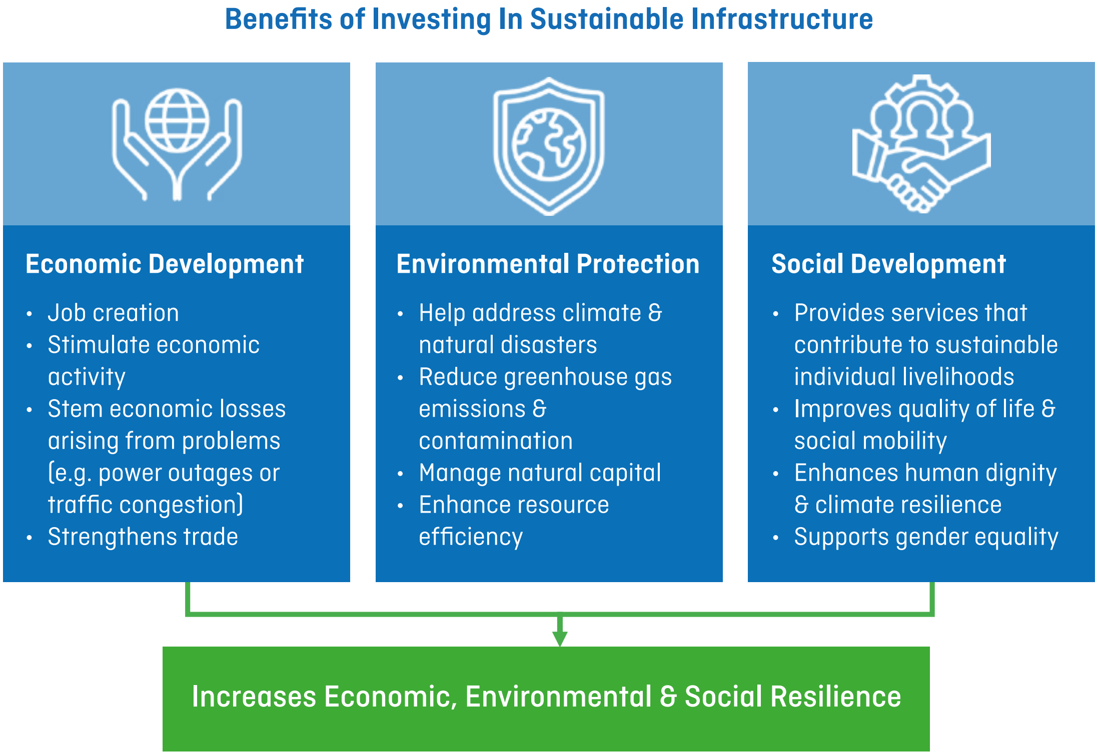
6.1 Green fuels as a regional development opportunity

Infrastructure projects can play a key role in the development of countries, both economically and in terms of forging a joint identity. New, large-scale infrastructure projects can lead to a changed national narrative, rally human capital, and lead to multiple opportunities for socio-economic change [106]. Some of the most ambitious infrastructure projects involve the creation of new urban areas or whole cities where new communities emerge and forge their identities, with associated novel demand clusters for goods, services, and the infrastructure which supports these, such as shipping, energy production, transportation, and environmental protection.

As such, infrastructure should be viewed as a system or portfolio of assets that can collectively support sustainable development goals, rather than viewed on their own as individual contributing assets, such as a power plant or a water network. Economic benefits from infrastructure projects include the jobs created during construction and maintenance, in addition to generating economic activity [107]. If Indonesia increased infrastructure investment by 1% of GDP, there would be a resulting 700,000 of additional direct and indirect jobs created [108]. "By connecting communities to cities, education and employment, infrastructure such as transportation and telecommunications underpins national economic goals" [107].

Indeed, infrastructure can help conserve natural resources and reduce climate change impacts. Especially for energy projects, local communities and society as a whole benefits from the delivery of power supply, a service that is essential for sustainable development. Climate-resilient infrastructure, in particular, supports overall societal resilience by providing stable vital services that are less vulnerable to extreme events and disruptions [107]. These projects if done in coastal areas can play an especially important role in facilitating creation of novel shipping demand, to move goods and services, and facilitate long-term economic development.

Figure 14: Benefits associated with investing in sustainable infrastructure projects.



«Establishing Indonesia as a green hub for sustainable fuels could help to ensure that Indonesia realizes its ambitions as a maritime axis, bringing additional economic activity, green jobs, and growth nationally.» – Basilio Dias Araujo, Coordinating Ministry for Maritime and Investment Affairs

Kalimantan as the new Indonesian capital

Indonesia's government plans to move the capital of the country from Jakarta to Nusantara in the province of East Kalimantan located on the eastern shore on the Indonesian portion of Borneo Island. The public announcement of the decision to move the capital to Borneo Island was made by Indonesian President Joko Widodo in 2019 [109]. This move is hoped to bring more economic development, employment, and innovation opportunities to the region, while also alleviating some of the challenges facing Jakarta, principally rising sea levels, growing population, and inadequate long-term development prospects [110]. The relocation plan is guaranteed in the recently promulgated law, which regulates *inter alia* the utilization of renewable energy and energy efficiency in the new capital [111].

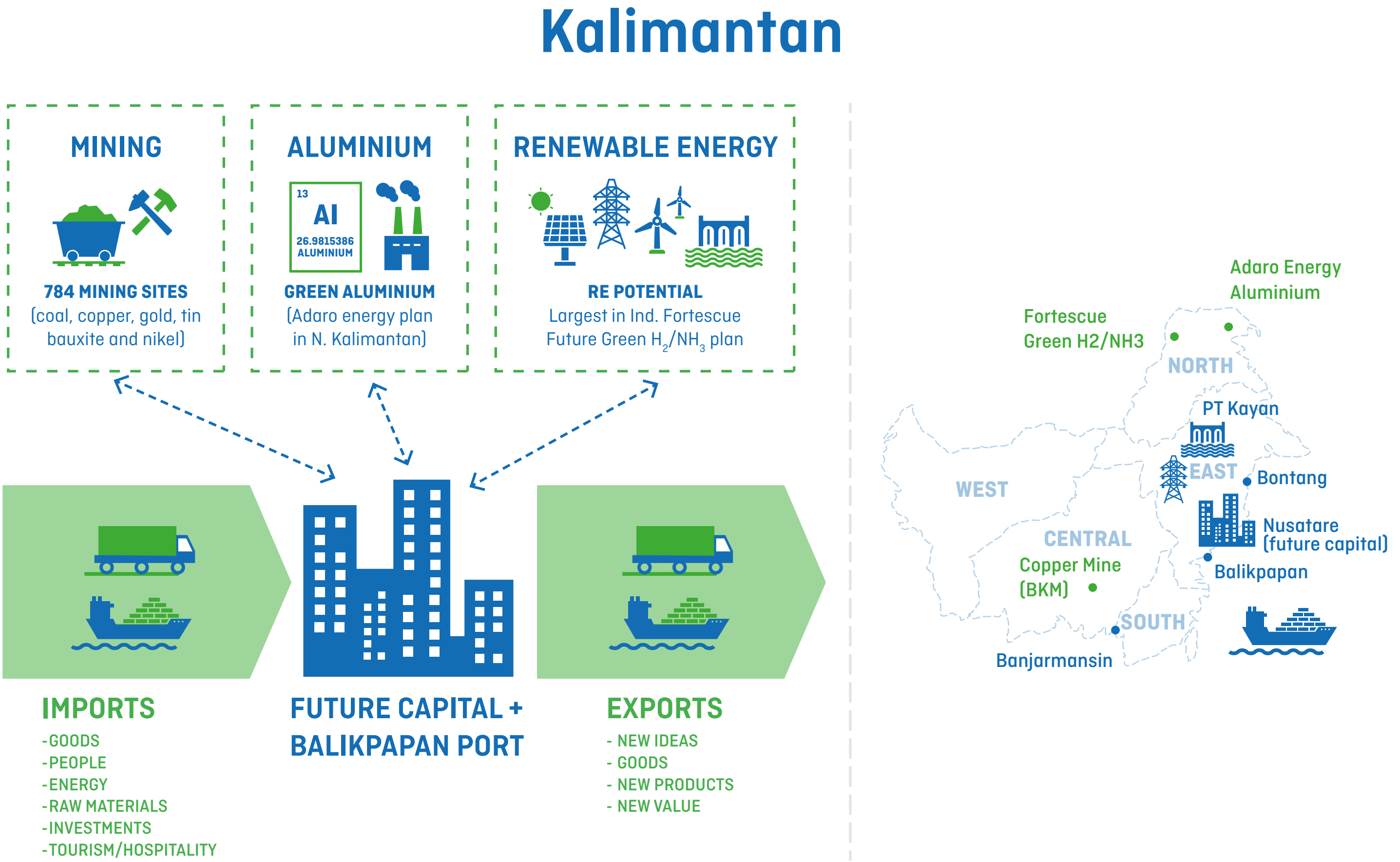
Kalimantan offers one of the largest renewable potentials in Indonesia of about 180 GW while offering a 95% electrification rate. The largest share of this renewable energy potential is from solar PV (150 GW) and hydropower (22 GW) [112]. However, actual realistic amounts of solar PV for utilization remain to be seen, as they depend on availability of land, taking into account protected forests, accessibility, and other land use considerations [113].

The two key areas on Kalimantan from a development perspective are East Kalimantan, due to its geographic proximity to the new capital of Indonesia, and South Kalimantan, due to its unique position close to several busy shipping trade routes and existing relatively high-density population centers (i.e. Banjarmasin and Banjarbaru). Hydroelectric potential in the region could increase in the future, since rainfall is projected to increase by up to 20%, beyond 2045 as a consequence of increasing air surface temperatures [68].

In North Kalimantan, a new hydropower project will be created along the Kayan river. The Kayan hydropower plant will have a power output of 11 GW, planned to supply a metal smelting plant to be built in the vicinity [114]. The hydropower potential has also been a source of interest for investors in Aluminum smelting, a highly energy intensive industry that has faced growing pressure to decarbonize. In 2021, Fortescue Metals Group from Australia has jointly declared interest with Tsingshan Holding Group from China to develop an industrial estate for metal smelting in the region [115]. Similar plans in North Kalimantan for development of an aluminum smelter have been announced by Indonesia's Adaro Energy [116]. This growing interest in the region's hydropower potential follows the signing of a 'Cooperation Agreement' in 2021 between Fortescue Future Industries and the North Kalimantan Provincial Government for the production and development of green hydrogen and ammonia resources from renewable energy for domestic use and export. The plan sets out production targets of 650,000 tons of green hydrogen per annum [117]. At the same time, solar power potential has also started to be more utilized, with Pertamina developing the 4 MW Badak Solar Power Plant on Kalimantan [118].

Such activity means that Kalimantan can develop novel infrastructure to address the local energy needs of a rapidly growing new metropolis, associated transport needs, and shipping needs to the new capital. All of this offers unique opportunities for development synergies for shipping decarbonization. With the planned shift of the capital to Kalimantan, nearby Balikpapan port could be developed into a SZEF bunkering hub for domestic shipping with an industrial park to meet the needs of the future capital of Indonesia. With this in mind Balikpapan could serve as the main commercial gate to Indonesia's new capital and an export hub for new products and green fuels made in North Kalimantan [119].

Figure 15: Outline of Kalimantan with key developments related to business opportunity.



Balikpapan is currently the largest port in East Kalimantan, a multipurpose port with significant tanker traffic due to its location on the western shore of the Makasar Strait along several important shipping routes. In 2018, the port handled 1,059 vessels, the majority of which were bulk carriers (416 vessels), oil tankers (185 vessels), and chemical tankers (144 vessels). As such, the port's shipping traffic required 0.94 TWh of energy and emitted about 922 CO_2e [34]. Due to this, Balikpapan ranks as the 3rd highest port for fuel energy demand based on domestic departures.

Much of the goods exported from Balikpapan are minerals, as Kalimantan has 784 mining sites of which 574 are located in East Kalimantan [120]. Key mineral resources in the region include coal but also metallic resources of copper, gold, and nickel that are important components in electronics and are paramount for continued global and sustainable growth. Kalimantan is the largest area for coal production in Indonesia , with East Kalimantan being known as the country's "coal-mining heartland" [121][122]. However, there are important similarities between mining systems (e.g. mine-haul trucks) and shipping propulsive and auxiliary systems, which offer synergies for the uptake and use of SZEF. Should the region explore the opportunity to locally produce green fuels, this would offer not only the decarbonization of mining operations but also an avenue to transition the coal jobs in the region towards a more sustainable career path. This transition is in line with the President's ambition to move away from exporting raw materials in favor of developing its downstream industries, especially as the mineral and coal sector only accounted for 5% of the country's GDP in 2019 [123].

Kalimantan is renowned for its high biodiversity [68]; reaching the energy potential will require substantial investment in infrastructure while balancing the island's rich biodiversity needs. Synergies with the mining industry could help transition the coal industry, as well as facilitate the decarbonization of Indonesia's hard-to-abate mining and shipping sectors, while fostering the country as an innovator in the fields of alternative power plants, zero-carbon fuels, safety standards, education, and training. Balikpapan port offers a unique opportunity of the development of new green corridors, with associated domestic bunkering infrastructure. Piloting and scaling-up maritime energy transition projects can be based in or around Balikpapan port to further emphasize Indonesia's commitment towards climate change, energy innovation, and collaborative investment.

6.2 Electrifying Indonesia's small boat fleet

Electrification based on renewable energy is a widely recognized decarbonization option that can not only be utilized to power ships at berth, directly reducing port emissions, but also via battery-technology to allow for hybrid and full-electric ship propulsion solutions. While the former serves to improve the energy efficiency of ships, the latter allows ships to be run entirely on batteries that are powered via an onshore grid [124]. The capacity of today's battery-technology used for full-electric ships has been identified as a readily available green solution for smaller boats travelling shorter distances [4][124][125], and can serve as an important opportunity for decarbonizing boats in developing island states where smaller boats constitute a significant portion of the domestic shipping fleet.

Switching to electrification provides multiple benefits, including reduced air pollution and lower fuel consumption, which are important considerations for developing island states where the transportation of fuels (to the islands) constitutes an additional source of emissions and costs [34]. Further benefits like less noise, vibration, and maintenance have also been identified as general advantages from using battery-driven boats, directly improving the user experience of boat owners and passengers as well as local port and coastal communities [125][126]. Reasons to adopt this technology, especially for countries with a vast small boat fleet, could be to reduce national emissions [97]. Additionally, energy security has also been identified as an advantage and potential driver of electrification for countries dependent on fuel imports, reducing vulnerability related to fluctuating fuel prices and carbon regulations [127]. The development of national competitive advantages within battery-technology or shipbuilding of electrified boats could constitute additional drivers [128], with the potential to bring wider benefits to countries' sustainable economic development in terms of green jobs and export opportunities.

Figure 16: Fishing boats anchored in Port Muara Baru near Jakarta.

To date, electrification of small boats is mainly seen among passenger and leisure boats, traveling shorter, pre-set routes offering green maritime transportation to tourists and locals. For popular tourist areas, where activities such as island-hopping or green cruising are attractive, electrification of small boats could constitute a promising opportunity in light of high maritime transport demand and potentially lower price elasticity among foreign visitors. Fishing and tugboats could also potentially adopt this technology, as these vessels often operate on shorter distances and close to shore [34][129][130]. With the continued, rapid development of battery-technology, the uptake of boat electrification is likely to enable an even bigger user group in the years to come [131].

Green power for tugs, fishing boats, & ferries

Indonesia's insular nature requires significant use of small domestic boats to transport goods and people between islands, supporting regional economic growth and inter-island connectivity. Considering the 6,000 inhabited islands spanning the country's territory, the market size of Indonesia's small boat fleet is vast [34][132]. The country's international and domestic shipping departures are dominated by smaller vessels, where around 42% of domestic shipping departures are represented by small passenger and vehicle carriers, fishing boats, tugs, and offshore service vessels, making up around 28% of total energy demand by Indonesian ship departures [34]. Indonesia is also the world's 2nd largest fishing nation after China [133], and in 2016, the country estimated that it had more than 544,000 fishing boats of which 32% are motorized. Most of these motorized boats were also estimated to be smaller than 5 gross tonnage [45].

Indonesia aims to make biofuels a key energy source for its transport sector by 2050, making up 46% of transport's energy by 2050 [68]. Regulation dictates that all Indonesian ships should be fueled with B-30[21] biodiesel, and recent discussions suggest that the biomass percentage could increase to 40% in the near future [134][135][136]. Given the vastness of Indonesia's small boat fleet, as well as competing interests for biofuels as an energy source from other transport sectors such as aviation and land-based vehicles, this will impact the availability of sustainable biofuels and hence drive up their price in the long term. In addition to biofuels, a regulation was passed to incentivize the use of Liquified Petroleum Gas (LPG) for small fishing vessels (below 5 gross tonnage), and aims to increase energy resilience and improve the welfare of small-scale fishers [137].

However, electricity is planned as a second main source of mitigating transport related emissions, accounting for 30% of transport's energy by 2050 [68]. Electrifying Indonesia's small boat fleet could reduce the segment's carbon footprint and constitutes an opportunity for decarbonization, while drawing on synergies with the country's aim to increase the share of renewable energy derived electricity [68]. The majority of small boats in Indonesia travel shorter distances and frequently visit the same ports [34], which lends itself well to existing electrification technologies like that of battery propulsion. Stakeholders communicated that small fishing and leisure boats and ferries with short trips and low operational speeds would be attractive candidates for pilot and demonstration projects. These could be tested on busy passenger routes like that of Java – Bali and Java – Sumatra, where the number and frequency of ferries travelling between the islands are high, as well as in areas with high fishing density, with Sumatra representing 34.2% and Java 39.8% of fishing vessels. Eastern Indonesia is also a good testing ground, as the area is mainly comprised of small islands, making the maritime sector vital for people and goods transport.

Multiple organizations in Indonesia, both local and international, have already started to scope this opportunity (see Table 6 below). Though, stakeholders highlighted that electrifying Indonesia's small boat fleet comes with several considerations, including technological constraints to the adoption and usage of electrified boats. This includes challenges related to speed, range, maintenance, and charging infrastructure, and may have different implications for different user segments. For the fishing sector, the limited battery range of today's battery-technology might prove difficult for fishing vessels operating over longer hours, and for passenger vessels or ferries, long charging times and reduced speed might impact the operating schedules and capacity.

---

21 Indonesian biofuels are generally made from palm oil and, when mixed with traditional hydrocarbon fuels like diesel, act as blends that can be used in vessels. 'B30' means that 30% of the fuel is composed of palm oil fuel.

Table 6: Selection of electrification initiatives for small boats within Indonesia.

1. Indonesia's largest power provider – state-owned PLN – is committed to the development of an electric vehicle ecosystem, one of which is electrifying maritime transport, where an E-boat project in West Nusa Tenggara Province has been undertaken [138].	**2.** Energy Renewed, an NGO focusing on clean energy access, has developed a conceptual low-cost electric boat for South Asia [139]. The conceptual boats include electrical motors, batteries, and solar panels with affordable monohull or catamaran designs, with Indonesia as one of the target markets [140].
3. On the tourism front, eco-resorts in Raja Ampat are electrifying their dive boats to reduce their environmental impact and offer visiting tourists green solutions for leisure activities [141].	**4.** The M/V Ellen, an electric ferry developed by the Danish company OMT, has capacity for 200 passengers and 30 cars powered by 4.3 MWh batteries [142]. OMT has already developed standardized zero-emission ships that they claim can be adapted for the Indonesian market.
5. The Asian Development Bank in Batam piloted two e-boat taxis in cooperation with local boat operators, the city government, and a boat manufacturer, demonstrating the short and long-term advantages over traditional boats [143].	**6.** A full electric harbor tug is being developed at Vallianz's shipyard in Batam, driven by an electric battery system [144].

However, technological constraints of battery-powered boats have been acknowledged and tested by different actors, where developed countries, like that of Norway [145], are perceived as being in the forefront of this development. Learnings from these countries, as well as those gathered by pilots and demonstration projects specific to Indonesia, could constitute important ways forward to disrupt the Indonesian market and investment sector. Performing pilot tests centered on the user experience to scale up affordable and viable solutions therefore constitutes an opportunity going forward. In combination with the need for increased awareness and knowledge transfer, as highlighted by stakeholders, this demonstrates the need to incorporate boat owners and operators during demonstration projects where the benefits of the technologies can be contrasted and documented against the perceived shortcomings. Lower fuel costs, less noise, and reduced marine pollution were some of the stakeholder feedbacks from pilots to date [143].

In addition to technological considerations, the country's grid infrastructure and renewable energy integration was also highlighted by stakeholders as a barrier to electrifying the country's small boat fleet. The country's grid infrastructure does not only need upgrading to enable the inclusion of renewables but must also be expanded to increase electricity access across Indonesia's many islands. Eastern Indonesia's islands still heavily depend on diesel power plants and have difficulties incorporating renewable energy into their grid system. In a bid to address this, HDF Energy has started to develop a hybrid solar PV, battery, and green hydrogen system power plant in the region. They are also exploring the potential for sector coupling wherein excess green hydrogen generated from the power plant could feed into local ports as fuel for retrofitted vessels running on fuel cells.

The increased development of offgrid solutions like that of microgrids is a priority area of the Indonesian government to increase energy access in remote areas and accommodate the growing demand for electricity in the years to come [68][74]. The implementation of microgrids in off-grid communities, powered by renewables like that of solar energy, offers the opportunity to electrify small boats anchoring in these areas and to couple the electricity demand with that of local communities[129][146]. This has the opportunity to overcome highlighted challenges related to too few quantities of boats demanding electricity in these areas, spurring the decarbonization of the country's domestic small boat fleet, while bringing wider benefits to the development of Indonesia's rural areas. For port communities, this also offers an opportunity to couple the electricity demand further with that of electrification of ports.

For these opportunities to occur, government support through policies and informative campaigns – about the benefits of electrification – coupled with international financing and investment will be needed. This includes considerations with regards to Indonesia's enabling environment for foreign and private investments in renewable energy technology, as well as the inclusion of the decarbonization of the domestic boat fleet on the political agenda and a shift i n focus from biofuels as a main, renewable energy source to that of electricity. Lastly, Indonesia's land-based electric vehicle program, which currently aims to strengthen the electric vehicle ecosystem relating to battery production and infrastructure for exchanging batteries [147] constitutes an important opportunity for drawing on synergies and couple demand with the electrification of the country's small boat fleet.

«The electrification and decarbonization of Indonesia's domestic small boat fleet is an important step in our national efforts to reduce GHG emissions. It has significant opportiunity to not only build on and support existing microgrid policies and initiatives, but also support the sustainable development of many disconnected regions and communities.» – Marizi Nizhar, Ministry of National Development Planning (Bappenas)

6.3 Decarbonization hub powered by geothermal

A key resource in Indonesia is geothermal energy, with current estimates putting untapped geothermal energy resources as high as 29.5 GW [112] with more conservative estimates putting it at around 24 GW [148], or as low as 19 GW [60]. Even at the lowest estimates, Indonesia still has significant geothermal energy potential, holding an estimated 40% of the world's geothermal energy resources [149]. Of this, the developable potential is estimated at 133 TWh/year with current installed capacity only 1,877 MW [60]. To put this into perspective, if the current installed capacity was running 24/7 for the entire year generating electricity at 100% efficiency, it would generate 16.4 TWh/year, only 13% of the estimated developable potential. Note that Indonesia's green energy demand from visiting vessels would represent about 8.3 TWh/y, assuming 5% of the global fleet transitions to SZEF by 2030.

Geothermal energy could in principle be used to produce electricity for usage by large population centers in the country and other sectors, including the electrification of the small boat fleet, where these resources are in proximity. It can also be used for the development of SZEF via production of green hydrogen and ammonia, especially in locations where the geothermal potential is located away from large, populated areas.

Stakeholders identified domestic shipping as being an area of large potential for decarbonization in Indonesia. Similarly, they identified challenges facing development of a mobile, diverse, and widespread bunkering network in a country of so many small ports and islands as being a key area to address. In this sense, co-locating SZEF production nearby demand centers decreases transportation costs, but this might not always be feasible or most cost effective depending on local constraints relating to development space and nearby renewable energy potential. Hence, decoupling location of consumption from production of SZEF would allow production to take place offsite at a larger scale where the production cost is lower, offering more business opportunities since less expensive SZEF can be sold to more clients.

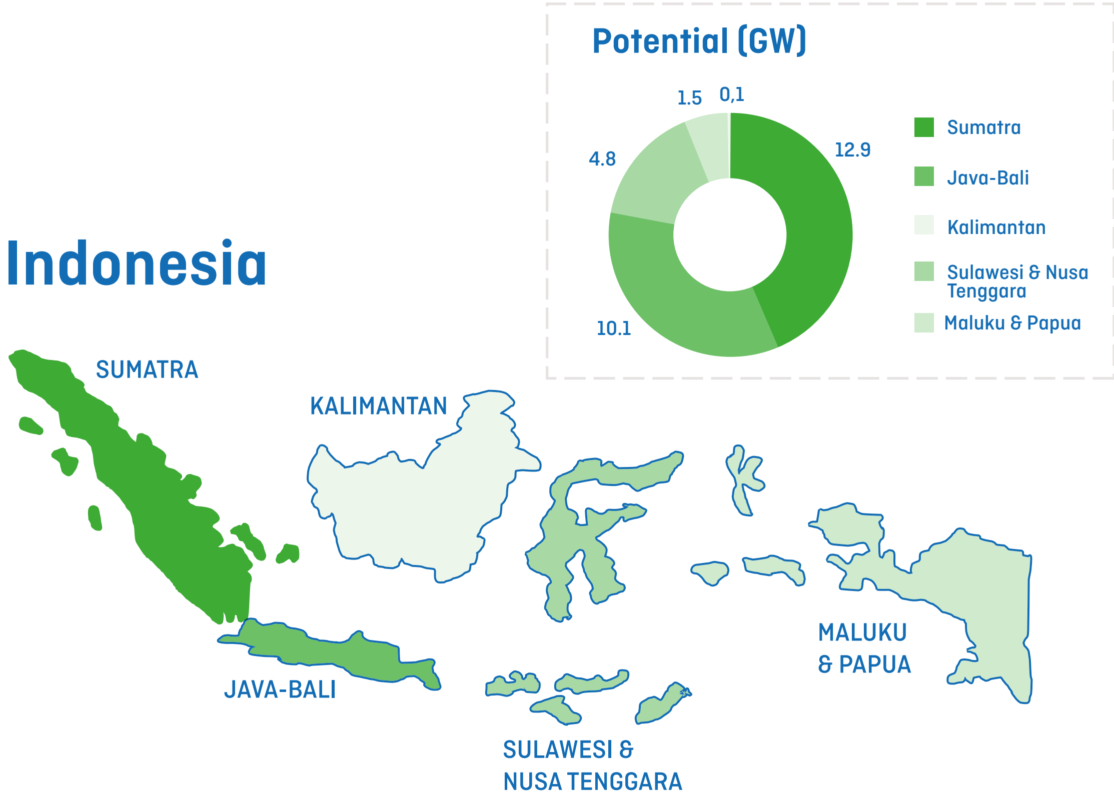
The majority of the country's geothermal potential is located on the islands of Sumatra and Java-Bali, generally islands with a large population density, and in close vicinity to important shipping routes in the Java Sea, connecting Australia with East Asia (see Figure 17). However, consideration should be given to the fact that on a more localized scale some of these resources could be in areas that are inaccessible due to limited road and port infrastructure, and could potentially be away from larger population centers and trade routes.

Pertamina geothermal energy

Existing efforts are already underway at the national level to assess several means of exploring and utilizing geothermal capacity for development. Currently, Indonesia's national oil and gas company, Pertamina, through its subsidiary Pertamina Geothermal Energy manages 15 working sites for geothermal production. These 15 sites are all planned to produce green hydrogen, which is expected to generate 8,600 kg/day [150]. Indeed, the "Green Hydrogen" pilot project has already commenced at the Ulubelu geothermal site, with a capacity of producing around 22 to 100 kg of green hydrogen per day and is set to commercially operate in 2022 [151]. Stakeholders familiar with the project indicated that Pertamina Geothermal Energy plans to use this energy for internal purposes only, though discussions have raised the option to utilize this green hydrogen for other purposes, including for the maritime sector.

Nevertheless, there are expectations that current development plans could be increased even further through policy and regulatory changes that could increase geothermal energy targets by 2026 [150]. Pertamina aims to expand its commitment to decarbonization by being closely aligned with the National General Energy Plan [51], with a general move towards renewable energy sources in its refining and fuel production processes [150]. In addition, the company has shown interest in developing green hydrogen, but recognizes the transportation, production, and storage challenges associated with this process. According to recent announcements, Pertamina aims to double its geothermal capacity by 2027-2028. This plan could result in an additional $4 billion USD investments, which includes investing into geothermal wells at around $5-7 million USD/MW [152].

Figure 17: Estimated geothermal energy potential in Indonesia [112].



Should Indonesia manage to cost-effectively unlock and leverage its geothermal potential, it could produce significant amounts of SZEF required to meet its domestic demand. In addition, depending on how economically viable other renewable energy resources such as solar prove to be, Indonesia could in principle also become an international bunkering hub for green fuels in Southeast Asia. Jakarta could be a possible location for one such bunkering hub, due to its proximity to both large domestic and international shipping routes, such as the Sunda Strait. In addition, Jakarta is located on Java Island, in an area with some of the highest geothermal potential in the country and a large population of the existing capital city that could act as offtakers of SZEF.

Furthermore, synergies with local industries like the aquaculture sector and fertilizer producers could strengthen the business case for geothermal-based green hydrogen and ammonia. Indonesia's aquaculture industry is already large, and has a significant growth potential, with key commodities such as shrimp and fish continuing to experience large domestic and international demand [153]. Growing emphasis on sustainability in aquaculture also highlights the requirement to make all segments of the aquaculture business more environmentally friendly and in line with wider decarbonization ambitions. A large proportion of Indonesia's aquaculture industry is located in the coastal waters surrounding Java and Sumatra [154], areas which also have significant geothermal potential. This geothermal energy could be used to support the decarbonization of the aquaculture industry, by decarbonizing the most energy intense components of the aquaculture production process [155] through usage of renewable electricity and SZEF in processing, transport, and feed production, where possible. In addition, some aquaculture production facilities use water oxygenation to increase their yield and guard against oxygen deficiencies [156]; as oxygen is a byproduct of hydrogen electrolysis it could be used as an input for the aquaculture industry.

For the fertilizer industry, inorganic fertilizer is produced using ammonia as the principal feedstock. As such, the fertilizer industry is one of the main demand sources for ammonia globally. Currently, fertilizer is mainly produced from grey and brown ammonia, which uses coal and natural gas as feedstocks. The decarbonization of the fertilizer industry through the transition to green ammonia would play an instrumental role in decarbonizing global food production chains [157]. Indonesia has significant demand for fertilizers, and the country's fertilizer producers are organized into the Indonesian Fertilizer Producers Association [158]. One of the key companies in the fertilizer industry is state-owned PT Pupuk. In 2022, Pertamina signed a Memorandum of Understanding with PT Pupuk and Mitsubishi Corp to develop a green hydrogen and ammonia value chain together with a Carbon Capture Utilization and Storage (CCUS) business [159]. One of the aims of the proposed business venture is to use the produced green hydrogen for ammonia production that can then be used in the fertilizer industry [159]. Though geothermal energy isn't mentioned, there are potential synergies where multiple renewable energy sources for green hydrogen production, including geothermal energy, could potentially be utilized.

Stakeholders, however, have highlighted several concerns regarding this business opportunity, one of which was the extraction difficulty of geothermal resources due to the country's large size and archipelagic geography. One stakeholder also raised concerns around long-term viability of such projects due to potentially higher development costs and risks of exploration in development areas. Such concerns should be considered when continuing to develop the geothermal potential in Indonesia, especially given the currently ambitious plans to further tap into this resource. Similarly, the possibility to partner with technological providers to explore new technical solutions to reduce geothermal exploration and utilization costs was also suggested. This is already being undertaken by the Indonesian government, though to date no concrete actions have resulted from such discussions.

Local stakeholders insist that using geothermal energy to produce green hydrogen needs to be price competitive. Using multiple energy sources could be a way to balance electricity price concerns while supporting the case for international investment into green hydrogen development in Indonesia. Stakeholders also highlighted that using geothermal energy to produce SZEF for bunkering could offer a possible viable business case, if sufficient quantities of SZEF could be delivered to the Sunda Strait, between Java and Sumatra, due to the location having a high international shipping bunker demand. However, in order for this development to be viable, and for geothermal energy to play a substantial role in it, stakeholders have mentioned that it would be essential to viably link localized geothermal resources into a national supply network.

There is also potential for Pertamina to utilize its developed resources for its own fleet. According to stakeholder interviews, Pertamina can 'give good contribution' with regards to decarbonization since Pertamina International Shipping has 85 vessels and charters another 200 vessels. The company has stated that geothermal energy development is part of its energy transition program with the aim of new and renewable energy reaching 30% of the energy mix by 2030 [160]. While this opportunity is still in its initial stages, considering Indonesia's strategic geolocation and domestic shipping density, Indonesian green hydrogen could support shipping decarbonization and quickly enter the bunkering market.

Should Indonesia pursue development of its geothermal potential, it is important to note that the current developments for geothermal energy would have to be significantly increased to create enough green hydrogen and ammonia at scale required to supply the maritime industry with SZEF. Many stakeholders agreed that Indonesia's government could continue its policy development plans by creating a roadmap towards outlining how Indonesia could produce SZEF, while coordinating through public institutions future supply and demand developments (e.g. information sharing, access to investment, etc.).

Section 7

Finance & Investment Requirements

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 [17]. In other words, the fuels transition in shipping is linked to the evolution of global energy systems and renewable capacity, which must increase in order to drive down the price of renewable energy [11].

To meet global GHG reduction requirements, a market and infrastructure for SZEF and zero emission ready ships must be created. However, there exists a price- and hence a competitiveness gap between incumbent fossil fuels and zero emissions alternatives. The competitiveness gap between fuel types is driven by a number of factors including production costs, capital and infrastructure requirements, availability issues, lack of information, and other market barriers [101]. Estimates suggest that across the 2030s and 2040s SZEF may be approximately double the price of conventional fossil fuels [17].

To close this gap, it is likely that a revenue-generating regulatory mechanism will be applied to shipping at an international level, or at least that a collection of regional measures will expand to capture the sector's emissions. In terms of financial investment to achieve this transition, a significant amount of funding is needed. Estimates suggest that $1.4-1.9 trillion USD will be needed to fully decarbonize by 2050, with the majority of funds (87%) needed for land-based infrastructure [161]. While it is suggested that some portion of this investment needed could and should come from a global MBM for shipping, it is also understood that initially 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.

In particular to Indonesia, the development of SZEF infrastructure in line with a 5% adoption of zero emission vessel technologies by 2030 could lead to an investment of between Rp 46 – 65 trillion IDR ($3.2 – 4.5 billion USD) [34]. This is in addition to the potential development of other industries, expertise, environmental protection benefits, and R&D emanating from decarbonization of maritime shipping and the adoption of SZEF.

To ensure that private capital can be mobilized towards relevant projects, it will further be necessary to identify sources of funding that are capable of lowering barriers to entry for subsequent investments. This will largely be in the form of blended finance, combining different sources of preferential loans and grants from a range of sources. Moreover, the reception of particularly international financing is especially important for Indonesia from a climate perspective, due to Indonesia's commitment under its NDC to reduce its emissions by 29% without international support and 41% with international support by 2030 [61]. This means that the reception of international finance will further drive national policies and investments towards achieving a higher level of climate ambition, which in turn could improve access to further funding.

Indonesia is firstly eligible to take out large loans from multilateral development banks, such as the World Bank Group, Asian Development Bank (ADB), European Investment Bank and Islamic Development Bank [162][163][164][165]. As a recently designated lower-middle income country [166], Indonesia is unable to receive a large proportion of grant funding reserved for countries with lower levels of development. However, through these institutions, the provision of loans, certain types of grants, and general technical assistance and expertise is still an important way for Indonesia to leverage financial support for the opportunities outlined in this report.

The World Bank, for example, offers loans from the International Bank for Reconstruction and Development [167] on preferential terms, with a low cost of borrowing. It can also assist private individuals in securing loans, loan guarantees, and equity financing through the International Finance Corporation [168]. These types of loans can provide security and access to capital over long time periods, helping to de-risk large scale infrastructure investments.

ADB also offers similar access to preferential loan funding, with Indonesia playing a key role as both a large shareholder and borrower. In 2021, Indonesia loaned or was granted around $2.1 billion USD from ADB [169], including funds designated towards furthering a green energy transition and the development of Indonesia's grid. Moving forward, the ADB is targeting climate change and a green recovery as key priority agendas for Indonesia, with Indonesia a pilot country for the ADB's Energy Transition Mechanism in addition to housing the Blue SEA Finance Hub [169].

Key factors to attract institutional finance:

- Demonstration of government support
- Mobilization of private investment
- Showing climate impact
- Scalability of the project

Multilateral banks can additionally provide grant funding in some specific areas. Grants are an important source of finance for direct feasibility and technical support funding from mechanisms like the World Bank's Public-Private Infrastructure Advisory Facility [170] that can be employed to help develop technical capacity building and regulatory infrastructure. This type of funding is particularly relevant for project development, especially for pre-feasibility studies, helping to assist with permits, approvals, and supporting the development of effective regulatory frameworks. In addition to feasibility funding, there are several multilateral sources of grant funding focusing on specific objectives, such as the Climate Investment Funds [171] and Green Climate Fund [172], which aim to fund projects targeting efforts to tackle climate change. For these outcome specific funds and in general, Indonesia's demonstration of climate action and alignment through international commitments and collaboration can hugely support its ability to attract funding.

Indonesia is also party to several bilateral agreements capable of supporting its transition to zero emission marine fuels. Notably, Indonesia has in the past benefitted from its relationships with Agence Française de Développement (France), KfW (Germany), Australia Department of Foreign Affairs and Trade, United Kingdom Department for International Development, USAID (United States of America), the European Union and through other partnerships like with the G7 [173][174][175][176][177][178][179]. Through these partnerships, Indonesia can implement blended finance instruments capable of supporting national efforts to realize relevant projects.

Nationally, there are also several institutions and tools that can be utilized to de-risk the business case for producing zero emission marine fuels. For example, Indonesia's Climate Change Trust Fund [180] helps to coordinate national and international financing around initiatives aimed at reducing GHG emissions. The fund also helps to integrate objectives into development plans at the national level, helping to support Indonesia's emission reduction targets. Other funds like the Millennium Challenge Account Indonesia [181] and Indonesia Environmental Fund (Badan Pengelola Dana Lingkungan Hidup) [182] are also potentially relevant sources of funding at the national level. The role of Indonesia's Ministry of Finance in this area is also important to note, due to their responsibility for coordinating public-private partnerships.

Other streams of international grant finance specifically target climate impact and other philanthropic causes, given that the objectives of the funders are demonstrated. Examples of relevant institutions include ClimateWorks Foundation [183], which can provide grant financing for projects that demonstrate a tangible climate impact. Lastly, some types of private finance may also be capable of providing capital which is more capable of taking long term risks, for example pension funds and hedge funds.

Indonesia's conditional target to reduce GHG emissions by 41% with international support means that the reception of blended finance is a crucial component for unlocking the opportunities outlined in this report. Not only would this funding help to stimulate the movement of private funding around specific projects, but also help to increase climate ambition, in turn leading to the potential for even more financing. To leverage this opportunity, Indonesia should continue to set a clear direction for zero emission shipping nationally, defining a direction of travel and ensuring that relevant projects can serve development objectives and attract international finance capable of de-risking national efforts.

«Attracting international support and finance is a key objective for Indonesia, with international maritime decarbonization providing an opportunity to channel new sources of funding towards large scale projects.»
– Lars Bo Larsen, Embassy of Denmark in Indonesia

Section 8

Recommendations

Indonesia, an archipelagic nation positioned nearby several of the most significant international shipping trade routes, is striving in multiple areas to tackle climate change and reduce its carbon emissions. Importantly, the country is eager to become an active player in maritime decarbonization, both domestically and within international fora. As discussed in Section 3, the country has a significant untapped solar and geothermal renewable energy potential that can support these ambitions and facilitate decarbonization of its substantial domestic shipping sector as well as potentially produce SZEF for international bunker sales and/or export. Leveraging these resources can place Indonesia on a path towards a zero-carbon future, enabling the country to not only become a potential regional leader in decarbonization but also a developer of multiple solutions to maritime decarbonization both in terms of practice and technology that other countries and island states could learn from.

The suggested recommendations below represent a cumulation 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 local stakeholders. 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 journey in shipping's decarbonization as part of a just and equitable transition.

Ports

As seen in Sections 3 and 4, Indonesian ports have a significant and growing energy demand that requires considerable developments in order to not only decarbonize but also service vessels running on electricity and SZEF. The opportunities identified in Section 6 highlight how Indonesia can act on both fronts, through upgrading and developing its major ports as well as transitioning its small boat fleet to run on more sustainable energy sources. In the short term, Indonesia's major bunkering ports could work to expand their position in the international market as bunkering hubs and in this process also develop a clear pathway for offering zero-carbon fuels. To do this Indonesia could work on developing supply chain systems and infrastructure for SZEF bunkering while also planning ahead to see various and innovative ways for domestic production of SZEF.

In this way local communities can be assured that decarbonization efforts act as strategic projects that further support local economic development through increased community access to renewable electricity, easing public concerns that such energy goes directly to meet industry demand.

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 proof and support GHG emission reduction goals. When developing new port infrastructure, such as is the case with the construction of Indonesia's new capital on Kalimantan, the expansion of existing ports and possible development of new port terminals should be made with SZEF use and bunkering in mind. The importance of ports as key links in a chain of sustainability and energy supply was emphasized by multiple stakeholders, many of whom felt that Indonesian ports must be ready to engage with the wider shipping sector as it prepares to undertake its fuel transition.

Suggested actions

Explore options for port electrification

Electrification of existing fossil fuel use in 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. Stakeholders highlighted how ports could become first movers to take up initial and maybe intermittent renewable energy for own use. 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 [184] [185]. Efforts such as those by Krakatau International Port are already in line with this ambition, in which the port plans to expand its green port infrastructure and install solar PV power to decarbonize its port operations [186].

Consider sustainable development in port expansion plans

Stakeholders have noted the need to coordinate port expansion and general infrastructure project development in a coordinated and sustainable manner, especially when planned in areas of high biodiversity such as Kalimantan [187]. Taking into account land use change, fairness in local community development, and climate change readiness can support Indonesia along the path of economic development and sustainable infrastructure development. This falls in line with international recommendations that argue to climate-proof maritime infrastructure and services to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change [185]. This is especially relevant to the planned capital move to Kalimantan and the potential upgrades for Balikpapan port described in Section 6, which could become the gateway for the new capital and see an increase in its overall vessel traffic, especially for containership delivering new goods to the capital and exporting green products from North Kalimantan's planned industrial park.

Prepare to source or produce renewable electricity & SZEF for bunkering & port use
Section 1 describes how shipping will need to rapidly transition away from fossil fuels, particularly during the 2030's and 2040's. Due to the large quantity of international ships calling and passing as evidenced in Section 3, Indonesia has significant amounts of maritime-based GHG and air pollutant emissions that the country does not benefit from (either in bunker sales or through port fees). As vessels running on electrification and SZEF start to become more prevalent, ports will need to be prepared to service while vessels through, for example, on shore power supply as well as provision of SZEF bunker fuels. In addition, ports themselves can utilize these green fuels for port vessels, as seen with new vessel designs like the Port of Antwerp's 'Hydrotug' which is powered via a dual-fuel combustion engine that burns hydrogen in combination with diesel [188].
Encourage ports as green nodes in an energy distribution network
Ports are focal points for multiple sources of pollution, from arriving and departing vessels, domestic shipping, onshore trucks and rail, as well as their own operations. To handle SZEF, local stakeholders saw the need for development of ports into hubs, while taking into account the diversity of local conditions and requirements through Indonesia. Additionally, stakeholders highlighted the need to connect renewable energy production to ports, since in many examples renewable energy potential was not located in close proximity to the largest port demand centers. Indonesia could explore creating a port ecosystem that acts as a green node for multiple sectors and can also support distribution of green energy across its various islands. Economies of scale can be leveraged by powering other industries nearby ports, such as chemical plants, fertilizer producers, aluminum smelters, mining operations, 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 Indonesia, collaboration between various stakeholders from different government ministries, the office of the president, as well as the private sector and civil society is required. Through such a process, long term policy planning and setting clear strategies for national development aligned with decarbonization can be outlined. Currently, the Indonesian government has communicated its efforts to increase renewable energy usage, reduce carbon intensity, and increase the national electrification rate [61]. Stakeholders have noted that further support on this trajectory especially as it relates to the maritime sector is necessary in order to facilitate decarbonization and adoption of more sustainable technologies and green fuels.

Fortunately, some Indonesian policymakers realize the benefits and challenges faced on this decarbonization journey, as well as the significant investment requirements and collaborative action that is needed to get there. Targeted strategies and a firm policy stance towards the production and distribution of green electricity and SZEF could contribute to cover international and domestic shipping's energy needs, facilitate the decarbonization of the small boat fleet while also supplying the country's domestic electrical demand. In addition to the clear decarbonization benefits, such developments would also improve air quality, reduce the risk of acid rains and associated effects on Indonesia's rich biodiversity, and create multiple employment opportunities for Indonesia's growing population.

Suggested actions

National

Develop a clear strategy for national actions to pursue maritime decarbonization

As shown in Section 5, the Indonesian government has continued to develop its decarbonization focus with regards to renewable energy capacity expansion, but this development has so far not extended to development of a clear strategy for maritime decarbonization. Local stakeholders did highlight existing efforts to include shipping and the maritime sector within the Carbon Tax policy's roadmap, the implementation for which has been postponed to July 2022 [189]. Nevertheless, Section 3 illustrates that GHG maritime emissions from domestic shipping are significant and are even higher when taking into account international shipping. Developing a national strategy to tackle maritime decarbonization, focusing on actions that can both be done nationally and through international collaboration could provide a clear and needed policy signal to support further action towards this agenda [190]. Short-, medium-, and long-term targets could plan the gradual increase and scale for the use of renewable electricity and SZEF within ports and the domestic fleet as well as greening public transit routes. Work towards this could also be used to raise environmental awareness of maritime GHG emissions among politicians and assess gaps or provide clarity not found in existing climate and maritime policies.

Commission study to assess realistic capacity to produce SZEF that feeds into & supports the development of a national hydrogen strategy or roadmap

Indonesia's renewable energy potential is largely untapped, as discussed in Section 4. However, studies and local stakeholders have pointed to the fact that renewable energy potential for the country has a large range depending on the factors that are taken into consideration. Indeed, solar potential is particularly varied while geothermal energy is extremely expensive to explore and not always accessible. Stakeholders voiced concerns that the lack of more precise estimates could undermine political ambition and decisiveness to pursue SZEF production. To address this, Indonesia could commission a study to better understand and scope realistic locations for expanding its renewable energy capacities and production sites for green hydrogen, as well as for overall domestic and international SZEF demand. This knowledge could feed into a national strategy or roadmap for the development and application of green hydrogen. This roadmap would send a positive signal to the private sector as well as international investors, stimulating investment in renewable energy production, especially low and zero-carbon fuels, as well as renewable energy technologies for shipping.

Exploit synergies between shipping's decarbonization & coal phaseout

Indonesia is one of the world's largest coal producing countries, and shipping and shipping emissions are intrinsically connected to coal as an important traded commodity. Recent announcements have indicated government interest in phasing out coal, such as the 2020 remarks by the Ministry of Energy and Mineral Resources that plans to replace retiring coal plants with new and renewable energy [191]. However, it remains unclear when, exactly, Indonesia will decommission its coal plants and fully switch to a sustainable energy system [192]. Setting a timeline for a complete phase out of coal-based energy in Indonesia would serve the purpose of sending a strong market signal to renewable energy and by association SZEF producers. Furthermore, the government could consider how maritime decarbonization can help to create new jobs that can support the transition of fossil fuel jobs as coal is phased out. This could, for example, build on findings from the planned study on "Financial Implications of the Early Retirement of Coal-fired Power Plants in Indonesia" by the Energy Transition Partnership [193]. Studies estimate that by 2050 at least 3.2 million new jobs could be created should Indonesia transition its energy system [192].

Support coordination on green ports & hubs

As outlined in Sections 2 and 5, Indonesia is a culturally, economically, and geographically diverse nation with requirements for a mixed policy mechanism that can take into account local development needs while ensuring the creation of coherent and robust bunkering infrastructure for SZEF. Stakeholders have highlighted the challenges and opportunities posed by Indonesia's geography that subsequently requires tailored solutions supported by policies based on a coherent approach to renewable electricity generation, hydrogen production, and sustainable development. As Indonesia seeks to position itself to become a SZEF producer, increased coordination between ministries and state-owned enterprises such as Pertamina and PLN is needed. The development of green hubs and ports, some of which to provide sustainable bunkering, should also consider shortsea shipping needs of the local population, having these linked to electricity grid development and requirements of the small boat fleet, while longer distance domestic and international shipping should concentrate on development of SZEF bunkering hubs for larger, deep-sea vessels.

Facilitate cross-sectoral synergies for the production & use of SZEF

As outlined in Section 6, several opportunities exist for cross-sectoral synergies between industries such as shipping, fertilizer production, aluminum smelting, mining, aquaculture, and electricity production for domestic consumption. Indonesian stakeholders recognize the enormous potential for renewable energy and infrastructure that can be deployed to realize the zero emission shipping industry in Indonesia, as well as its overlaps with other sectors and industries. The production and deployment of batteries, for example, could benefit subsistence fishers, especially as fishing vessels account for the majority of Indonesian flagged ships. The Indonesian government could further develop ways in which such collaborations and cross-sectoral synergies can be facilitated through a dedicated task force, organization, or similar fora to ensure decarbonization efforts and developments are done in a more streamlined, holistic manner.

Prepare labor capacity & skills to handle SZEF & 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. Indonesia could create a strategy to develop qualified talent for a green hydrogen economy, securing the future careers of Indonesian seafarers both onboard and offshore as the maritime sector adopts new digital solutions, green technologies, and transitions away from traditional fossil-fuel energy sources. This can be done by fostering dedicated training, academic-industry partnerships, and international cooperation in higher education, research, development, and innovation. More practically, this will include upskilling and training port employees on the handling of these SZEF, adapting safe and efficient bunkering procedures, and preparing and loading vessels for SZEF usage and bunkering.

Review data aggregation methodology & MRV relating to maritime emissions

As was highlighted in Section 3 when trying to estimate Indonesia's maritime emissions, there is a wide range of estimates that can be developed based on what data aggregation methodology is used, creating variability in future emission forecasts and estimates of the scale of the decarbonization challenge. In order to have a clearer picture of Indonesia's shipping emissions, a review of the various data aggregation methodologies relating to maritime emissions, together with detail justification of approaches and recommendations for the most appropriate way forward aligned with international best practices, would be useful. Similarly, a review and discussion around best practices for monitoring, reporting, and verification (MRV), in reference to GHG emissions could also be warranted to ensure that Indonesia continues refining the necessary expertise required to have access to the most up-to-date shipping emission data in line with current and likely future IMO rules.

International

Collaborate to secure effective GHG policy at the IMO

The market for SZEF, and therefore the business case to unlock deep investment, can be strongly enabled by the timely adoption of effective policy at the IMO. A global MBM that directly or indirectly introduces a price for GHG emissions – and thus helps to close the competitiveness gap between SZEF and fossil fuels – would create the necessary market signals for global investment into SZEF projects and associated infrastructure. International policy measures such as a potential MBM need to be developed to support investment and jobs. Indonesia can advance investment by supporting the IMO to work towards zero emissions by 2050 and working with other countries on the adoption of policy measures to achieve that outcome for a just and equitable transition. Supporting an international climate target for shipping that is aligned with the Paris Agreement would be one step towards this goal. Indonesia's signing of the Declaration on Zero Emission Shipping by 2050 presents a good opportunity to work towards this ambition in the context of the IMO [194]. Furthermore, the G20 presidency in 2022 can have the right momentum for the Indonesian government to pursue this diplomatic effort. As Indonesia is hosting the G20 Summit in 2022, for which energy transition is a key topic on the agenda, an announcement along these lines in such an international forum would send a strong political signal of national intentions towards shipping decarbonization through renewable energy generation and SZEF production.

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

Green corridors are touted as an innovative method to initiate early action along a specific national or international shipping route between two port hubs and can be leveraged to serve national interests in the transition to zero emission shipping [12]. Based on its renewable energy potential, trade relations with other regions, and location along busy shipping routes, Indonesia could sign the Clydebank Declaration to signal its interest in international collaboration on this front. First movers from in Asia are already making their mark, as seen by Singapore signing the Clydebank Declaration [195] and the recent announcement of the Australia-East Asia iron ore green corridor that brings together mining, energy, and shipping companies interested in decarbonizing the iron ore value chain [196].

Support the development of SZEF standards & authorizations

Supporting environmental authorizations and setting standards for new bunkering facilities and processes will be crucial in the near future. Indonesia'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 [197]. 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.

Finance

One of the main concerns regarding a transition to more sustainable forms of energy is the financial implications of such a shift. Stakeholders in Indonesia highlighted the financial challenge of decarbonization, citing the considerable investment required for developing renewable energy projects, SZEF bunkering infrastructure, and solar and geothermal resource development. As seen in Section 5, Indonesia has policies in place that support investment and development of renewable energy resources with a clear plan to increase their usage over this decade. However, further expansion of this ambition and development of a clear funding plan for green projects, especially hydrogen development, is necessary to structure and align efforts for transitioning to electrification and SZEF.

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. Indonesia could reach its decarbonization goals with proper investment and long-term planning.

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 respective structures to ease their adoption. Incentives such as green premiums are one such option. Contracts for difference[22], direct subsidies, tax exemptions, carbon price, feed-in-tariffs, competitive tenders/auctions, and renewable energy funds that support buy-back arrangements, public credit guarantees, and green bonds are also alternative options that could be used [101][184][192]. In particular, repurposing energy subsidies to fund green energy projects instead of supporting traditional coal and other fossil fuels would help create a level playing field for renewable energy [192].

Boost private renewable electricity generation

As raised by stakeholders, fiscal interventions, especially financial incentives, play a crucial role in encouraging private sectors to collaborate with the government for such a transition. One suggestion would be to incentivize private sector investment into distributed grid systems, especially to alleviate pressure from the government given that most of Indonesia's renewable energy production is stated-owned. Removing barriers to the production of renewable electricity and relaxing the regulatory framework is essential to build Indonesia's green energy capacity and scale its potential, including in SZEF production. Efforts to address this are underway, wherein a new bill is being debated by the Indonesian Parliament on "New & Renewable Energy (EBT)", which entails a renewable energy tariff that contains feed-in-tariffs for small scale renewables [192][198]. However, stakeholders have also noted that additional attention to streamlining purchase agreements and tendering processes would also help reduce investor risks and support mobilization of private capital into renewable energy [192].

Explore increased deployment for microgrid installations

Solar power has been heavily mentioned through studies and by local stakeholders as an underutilized resource in Indonesia. As mentioned in Sections 5 & 6, microgrids are already supported by the Indonesian government and have been installed in various places throughout the country. Indeed, nearby microgrid installations that leverage the country's solar potential and, in some cases along Java's southern coastline, onshore wind potential could feed the need of smaller ports that see a high amount of ferry and fishing vessel traffic. Local stakeholders pointed to the fact that a lot of small-scale fishers in Eastern Indonesia are unable to store their catch properly due to the lack of stable electricity for their cold storage. Increasing uptake of renewable microgrid installations to provide electricity in smaller ports and dispersed local communities could alleviate some of these existing challenges.

22 '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.

Leverage international development finance to prioritize funding of strategic projects

As seen in Sections 6 & 7, Indonesia has experience in accessing and implementing development bank assistance, which can be used 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 Asian Development Bank, World Bank, and bilateral country funding are all relevant options. Exploring project financing through and potential revenue from a global MBM or carbon price were also highlighted by stakeholders as avenues to pursue.

Industry

Given the political ambitions of the country towards becoming an global maritime axis and recent efforts to increase the uptake and penetration of renewable energy, there is quite a bit of industry interest in supporting green energy projects that can support shipping decarbonization. Indeed, Section 6 shows how some Indonesian industries and regional actors support the development of fuels such as hydrogen and ammonia and for their potential use as SZEF. Even state-owned companies such as Pertamina have shown their commitment to national decarbonization plans and have continued investing in numerous projects that can in the long-term support SZEF production and uptake.

Indonesia's renewable energy potential has the capacity to supply its domestic electrical demand and the hard-to-abate industries with SZEF. 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 called on governments and international regulators to take decisive action in support of making zero emission shipping the default choice by 2030 [99].

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 [199]. 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

Engage in & initiate public-private collaborations

As seen in Section 5, it is clear that Indonesia's government is keen to promote green ports and the expansion of its renewable energy generation capacity. To do this, there is a need for public and private actors to come together and form partnerships. This is an important way to set a direction of travel and coordinate efforts, which is particularly important in light of the central role played by state-owned enterprises like Pertamina and PLN. Actions on this front were highlighted in the strategic business opportunities described in Section 6, wherein pilots for electric ferries and scoping of green hydrogen production from geothermal energy were facilitated through the State. Supporting such efforts and developing business cases for specific opportunity areas can not only help inform decision makers of the benefits of shipping decarbonization, but also ease potential bureaucratic hurdles by already having the support of municipal or state actors.

Create awareness of benefits & necessity for a green energy transition

There is a need to work closely across the maritime and energy industries as well as civil society stakeholders to continually expand the understanding of the risks faced by climate change and the ways in which various organizations can support Indonesia on its path to decarbonization. Stakeholders have highlighted the need to create better awareness around the urgency to transition to a zero emission transport system. Industry actors could work on creating a set of industry, civil society, and public engagement projects (i.e. seminars, TV debates, publications, etc.) that can be used to inform, educate, and expand the knowledge of potential benefits of transitioning to SZEF. Ultimately, this will also help create a market for local and possibly foreign companies that are committed to take the first moves to switch to SZEF in Indonesia.

Establish local presence through a regional office or partnerships

Having a local presence in the country where your organization seeks to expand and grow is valuable, in that it can greatly support building networks and having a local impact. Indeed, though many Indonesians speak English and other common languages, the ability to communicate with local communities, some public officials, and other relevant actors in Bahasa can be a distinct advantage. This includes not only support in navigating perhaps unfamiliar social, political, and economic situations, but also flagging local changes that may positively or negatively impact business plans. Though establishing a direct presence in Indonesia is perhaps not feasible for many SMEs and other private companies, partnerships with local organizations and affiliates is another avenue that can support engagement efforts. It should be noted that foreign and multinational companies should endeavor to align their strategic objectives with the interests of Indonesia's local communities, supporting them through capacity building, new production opportunities, and other forms of sustainable development [200].

Target decarbonization activities in strategic areas

Stakeholders highlighted that various islands in Indonesia face differing challenges, requiring tailored solutions and subsequently provide a range of opportunities when decarbonization is discussed. These range from high to low population densities, remote off grid communities to large population centers, areas of high and low renewable energy potential, and generally rich biodiversity, to name but a few. Areas with dense rainforests (i.e. Borneo and Papua) should be avoided for large development projects, in order to protect existing biodiversity. Whereas areas close to high density shipping routes (i.e. Sunda Strait, between Java and Sumatra) with renewable energy availability could provide niche markets for early adoption of SZEF. Industry actors interested in developing concrete projects to produce SZEF and pilot associated technologies could leverage strategic locations within Indonesia 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 Indonesia that can aggregate their demand for green electricity and SZEF include fishing, tourism, mining, and fertilizer and ammonia production. 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. Interested industries could join initiatives like the Hydrogen Energy Center Indonesia, which is dedicated to the development of green hydrogen and related business opportunities [201].

Explore alternative business model options

Industry actors could seek new and alternative business models that reduce high barriers to entry or adoption for SZEF technology, both onboard vessels as well as shoreside [202][203]. Book and claim systems, subscription services, wholesale power purchase agreements, leasing models, and reverse auctions can act as new ways the maritime and energy sectors do business [204].

In conclusion, Indonesia's renewable energy potential, strategic location in southeast Asia, as well as established maritime trade with key countries places the country 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, while creating new supply chains. To leverage existing and emerging opportunities within the country, the Indonesian government and its private industry actors will need to take targeted and decisive action to ensure the country stays 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 could support Indonesia in decarbonizing and becoming a strong regional player in the years to come.

References

[1] IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_FullReport.pdf

[2] IPCC (2018). Summary for Policymakers of Global warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, … T. Waterfield, Eds.). Intergovernmental Panel on Climate Change. Switzerland.

[3] IPCC (2018). Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments — IPCC. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/

[4] IPCC (2022). Climate Change 2022: Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

[5] UNCTAD (2019). Review of Maritime Transport 2018. United Nations Conference on Trade and Development. Geneva, Switzerland.

[6] Walker et al. (2018). Environmental Effects of Marine Transportation. In World Seas: An Environmental Evaluation Volume III: Ecological Issues and Environmental Impacts, 1st ed., 505–30. Elsevier. https://doi.org/10.1016/B978-0-12-805052-1.00030-9

[7] Bloomberg L.P. (2022). Energy/Crude Oil & Natural Gas February 2022. https://www.bloomberg.com/energy

[8] Faber et al. (2020). Fourth IMO GHG Study 2020. (MEPC 75/7/15). London, United Kingdom: International Maritime Organization.

[9] International Maritime Organization (2018). Ship Emissions Toolkit. Guide No. 1: Rapid assessment of ship emissions in the national context. https://gmn.imo.org/wp-content/uploads/2018/10/ship_emissions_toolkit-g1-online.pdf

[10] Suárez de la Fuente, S., Baresic, D., Smith, T. (2022, in press). Greenhouse Gases and a Low-Carbon Future. Chapter for Marine Engineering, 4th Edition, Society of Naval Architects and Marine Engineers, United States.

[11] Parker, S., Shaw, A., Rojon, I., Smith, T. (2021). Harnessing the EU ETS to reduce international shipping emissions: assessing the effectiveness of the proposed policy inclusion of shipping in the EU ETS to reduce international shipping emissions. London, United Kingdom: Environmental Defense Fund Europe.

[12] Smith, T., Baresic, D., Fahnestock, J., Galbraith, C., Velandia Perico, C., Rojon, I., Shaw, A. (2021). A Strategy for the Transition to Zero-Emission Shipping: An analysis of transition pathways, scenarios, and levers for change. Getting to Zero Coalition. https://www.u-mas.co.uk/wp-content/uploads/2021/10/Transition-Strategy-Report.pdf

[13] Matsuda, H., Takeuchi, K. (2018). Introduction, in: Takeuchi, K., Shiroyama, H., Saito, O., Matsuura, M. (Eds.), Biofuels and Sustainability. Springer, Tokyo, Tokyo, pp. 1–8. https://doi.org/10.1007/978-4-431-54895-9_1

[14] DeCicco, J.M., Liu, D.Y., Heo, J., Krishnan, R., Kurthen, A., and Wang, L. (2016). Carbon balance effects of U.S. biofuel production and use. Clim. Change 138, 667–680. https://doi.org/10.1007/s10584-016-1764-4

[15] Aro, E.M. (2016). From first generation biofuels to advanced solar biofuels. Ambio 45, 24–31. https://doi.org/10.1007/s13280-015-0730-0

[16] Englert, D., Losos, A., Raucci, C., & Smith, T. (2021). The Potential of ZeroCarbon Bunker Fuels in Developing Countries. Washington DC: World Bank, Washington, DC.

[17] Lloyd's Register & UMAS (2019). Zero-Emission Vessels: Transition Pathways. Low Carbon Pathways 2050 series, London.

[18] Smith, T.W.P., O'Keeffe, E., Hauerhof, E., Raucci, C., Bell, M., Deyes, K., Fabre, J., and Hoen, M. (2019). Scenario Analysis: Take-up of Emissions Reduction Options and their Impacts on Emissions and Costs. London.

[19] World Bank Group (2021). The Potential of Zero-Carbon Bunker Fuels in Developing Countries. https://openknowledge.worldbank.org/handle/10986/35435

[20] Krantz, R., Søgaard, K., Smith, T. (2020). The scale of investment needed to decarbonize international shipping. The Getting to Zero Coalition Insight Series. Copenhagen, Denmark: Getting to Zero Coalition.

[21] MAN Energy Solutions (2022). MAN B&W two-stroke engine operating on ammonia. Copenhagen. https://www.man-es.com/docs/default-source/document-sync/man-b-w-two-stroke-engine-operating-on-ammonia-eng.pdf?sfvrsn=c4bb6fea_0

[22] MAN Energy Solutions (2022). Unlocking Ammonia's Potential for Shipping. https://www.man-es.com/discover/two-stroke-ammonia-engine

[23] Hydrogen Central (2022). MAN Engines: The First Dual Fuel Hydrogen Engines in Use on a Work Boat. https://hydrogen-central.com/man-engines-first-dual-fuel-hydrogen-engines-work-boat/

[24] BBC (2017). Indonesia counts its islands to protect territory and resources. https://www.bbc.com/news/world-asia-40168981

[25] International Maritime Organization (2022). MEPSEAS: Indonesia. https://mepseas.imo.org/about/countries/indonesia

[26] World Bank (2021). A Sustainable Ocean Economy is Key to Indonesia's Prosperity. Press release. https://www.worldbank.org/en/news/press-release/2021/03/25/sustainable-ocean-economy-key-for-indonesia-prosperity

[27] Cribb, R. and Ford, M. (2009). Indonesia as an archipelago: Managing islands, managing the seas. In Cribb, R. & Ford, M. (Eds.), *Indonesia beyond the Water's Edge. Managing an Archipelagic State*. (pp. 1-27). Singapore: ISEAS Publishing. https://doi.org/10.1355/9789812309815

[28] Adam, A.W., Legge, J.D., Mohamad, G.S., McDivitt, J.F., Leinbach, T.R. and Wolters, O.W. (2022). *Indonesia. Encyclopedia Britannica*. https://www.britannica.com/place/Indonesia

[29] Purwanto, Y., Sukara, E., SabilaAjiningrum, P., and Priatna, D. (2020). Cultural diversity and biodiversity as foundation of sustainable development. *Indonesian Journal of Applied Environmental Studies*, Vol. 1, No. 1. DOI: 10.33751/injast.v1i1.1976.

[30] Open to Export (2013). Ports sector in Indonesia. https://opentoexport.com/article/ports-sector-in-indonesia/

[31] Pelindo (2022). About Us. https://pelindo.co.id/page/tentang-kami

[32] UNCTAD (2022). Maritime Profile: Indonesia. https://unctadstat.unctad.org/countryprofile/maritimeprofile/en-gb/360/index.html

[33] Observatory of Economic Complexity (2022). Indonesia. https://oec.world/en/profile/country/idn

[34] Carpenter-Lomax, O., Wilkinson, G. and Ash, N. (2021). Indonesia: fuelling the future of shipping. https://www.globalmaritimeforum.org/content/2022/06/Zero-carbon-shipping-Indonesia-Issue-2.pdf

[35] Directorate General of Climate Change, Ministry of Environment and Forestry. (2021). Indonesia. Third Biennial Update Report under the United Nations Framework Convention on Climate Change. Jakarta, Indonesia: Ministry of Environment and Forestry Directorate General of Climate Change, Ministry of Environment and Forestry https://unfccc.int/sites/default/files/resource/IndonesiaBUR 3_FINAL REPORT_2.pdf

[36] Climate Watch (2022). *Historical GHG Emissions*. https://www.climatewatchdata.org/ghg-emissions?end_year=2018&start_year=1990

[37] Davies Waldron, C., Harnisch, J., Lucon, O., Mckibbon, R.S., Saile, S.B., Wagner, F., et al. (2006). Mobile Combustion. In: 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2: Energy, 1st ed. Geneva: Intergovernmental Panel on Climate Change. p. 3.1-3.78.

[38] Junida, A.I. and Ihsan, N. (2021). Indonesia ready for decarbonization measures in marine activities. Jakarta. Junida and Ihsan https://en.antaranews.com/news/199065/indonesia-ready-for-decarbonization-measures-in-marine-activities

[39] Ministry of Energy and Mineral Resources (MEMR) (2021). Handbook of Energy & Economic Statistics of Indonesia 2020. Jakarta. Ministry of Energy and Mineral Resources Republic of Indonesia https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2020.pdf

[40] Kementerian Lingkungan Hidup dan Kehutanan. Direktorat Jenderal Pengendalian Perubahan Iklim. Direktorat Inventarisasi GRK dan Monitoring, Pelaporan, Verifikasi (2021). Laporan Inventarisasi Gas Rumah Kaca, Monitoring, Pelaporan, dan Verifikasi Nasional Tahun 2020. Jakarta. http://ditjenppi.menlhk.go.id/reddplus/images/adminppi/dokumen/igrk/LAP_igrk2020.pdf

[41] Flanders Marine Institute (2019). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 11. https://doi.org/10.14284/386

[42] Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., Deangelo, B. J., et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres, 118(11), 5380–5552. https://doi.org/10.1002/JGRD.50171

[43] Scarbrough, T., Tsagatakis, I., Smith, K., Wakeling, D., Smith, T., O'Keeffe, E., and Hauerhoff, E. (2017). A review of the NAEI shipping emission methodology. London.

[44] Parker, R.W.R., Blanchard, J.L., Gardner, C., Green, B.S., Hartmann, K., Tyedmers, P.H., and Watson, R.A. (2018). Fuel use and greenhouse gas emissions of world fisheries. Nature Climate Change, 8(4), 333–337. https://doi.org/10.1038/s41558-018-0117-x

[45] Pet-Soede, L. (2019). Around the Boat. What happens around Indonesia's vast marine areas? The Seven Seas. Indonesia. https://www.thesevenseas.net/fishing-boats-in-indonesia/

[46] Biggeri, A., Barbone, F., Lagazio, C., Bovenzi, M., & Stanta, G. (1996). Air pollution and lung cancer in Trieste, Italy: Spatial analysis of risk as a function of distance from sources. Environmental Health Perspectives, 104(7), 750–754. https://doi.org/10.1289/EHP.96104750

[47] Rudiarto, I., Handayani, W., Sih Setyono, J. (2018). A Regional Perspective on Urbanization and Climate-Related Disasters in the Northern Coastal Region of Central Java, Indonesia. Land 2018, 7(1), 34; https://doi.org/10.3390/land7010034

[48] Hoegh-Guldberg, O. and Jompa, J. (2016). Indonesia and Australia are sleeping ocean superpowers. The Conversation. https://theconversation.com/indonesia-and-australia-are-sleeping-ocean-superpowers-69886

[49] Quadrant Smart (2022). Is ScottishPower Scaling up Green Hydrogen? https://quadrant-smart.com/scaling-up-green-hydrogen-with-scottishpower/

[50] IRENA (2021). Energy Profile: Indonesia. International Renewable Energy Agency. https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Indonesia_Asia_RE_SP.pdf

[51] KESDM (2019). National General Energy Plan (RUKN) for 2019-2038 (ESDM Decree No. 143K/21/MEM/2019). Keputusan Menteri Energi dan Sumber Daya Mineral Nomor 143 K/20/MEM/2019 tentang Rencana Umum Ketenagalistrikan Nasional Tahun 2019 Sampai Dengan Tahun 2038. Kementerian Energi dan Sumber Daya Mineral. https://jdih.esdm.go.id/index.php/web/result/1973/detail

[52] Bellini, E. (2021). Work begins on 145 MW floating solar plant in Indonesia. PV Magazine. https://www.pv-magazine.com/2021/08/05/work-begins-on-145-mw-floating-solar-plant-in-indonesia/

[53] Lewis, M. (2021). The world's largest floating solar farm to be built in Indonesia. Electrek. https://electrek.co/2021/07/22/the-worlds-largest-floating-solar-farm-to-be-built-in-indonesia/

[54] IRENA, World Economic Forum and Accenture (2022). Enabling Measures Roadmap for Green Hydrogen. https://www.irena.org/-/media/Files/IRENA/Agency/Press-Release/2021/Nov/Enabling_Measures_Roadmap_for_Green_H2_Jan22_Vf.pdf?la=en&hash=C7E5B7C0D63A0A68C704A019CE81D1B6AA5FBD75

[55] IRENA (2022). Hydrogen Economy Hints at New Global Power Dynamics. https://www.irena.org/newsroom/pressreleases/2022/Jan/HydrogenEconomy-Hints-at-New-Global-Power-Dynamics

[56] Green Hydrogen Organization (2021). Green Hydrogen Organization to Develop Green Energy Standard. https://gh2.org/publication/green-hydrogen-organisation-develop-green-energy-standard

[57] GGGI (2021). GGGI and KOGAS join forces to promote green hydrogen. The Global Green Growth Institute. https://gggi.org/gggi-and-kogas-join-forces-to-promote-green-hydrogen/

[58] Ministry of Energy and Mineral Resources (MEMR) (2018). Electricity Statistic 2018. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2018-final-edition.pdf

[59] UNFCCC (2022). Indonesia. United Nations Framework Convention on Climate Change https://unfccc.int/node/61083

[60] IESR (2021). Deep decarbonization of Indonesia's energy system: A pathway to zero emissions by 2050. https://iesr.or.id/wp-content/uploads/2021/10/IESR-Deep-Decarbonization-2021.pdf

[61] Republic of Indonesia (2021). Updated Nationally Determined Contribution. Republic of Indonesia. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Indonesia%20First/Updated%20NDC%20Indonesia%202021%20-%20corrected%20version.pdf

[62] IEA (2019). *Southeast Asia Energy Outlook 2019*. Paris, France: International Energy Agency. https://www.iea.org/reports/southeast-asia-energy-outlook-2019

[63] IRENA (2021). *Indonesia and IRENA Agree Partnership to Decarbonise Southeast Asia's Largest Economy*. https://www.irena.org/newsroom/pressreleases/2021/Nov/Indonesia-and-IRENA-Agree-Partnership-to-Decarbonise-Southeast-Asia-Largest-Economy

[64] ICAO (2021). CORSIA States for Chapter 3 State Pairs. ICAO document. International Civil Aviation Organization. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_States_for_Chapter3_State_Pairs_Sept2020.pdf

[65] Database Peraturan (2022). Peraturan Presiden (PERPRES) Nomor 98 Tahun 2021. Penyelenggaraan Nilai Ekonomi Karbon untuk Pencapaian Target Kontribusi yang Ditetapkan Secara Nasional dan Pengendalian Emisi Gas Rumah Kaca dalam Pembangunan Nasional. https://peraturan.bpk.go.id/Home/Details/187122/perpres-no-98-tahun-2021

[66] IEA (2022). *Indonesia country profile*. International Energy Agency. https://www.iea.org/countries/indonesia

[67] National Energy Council (2019). *Indonesia Energy Outlook 2019*. Jakarta, Indonesia: National Energy Council. https://www.esdm.go.id/assets/media/content/content-indonesia-energy-outlook-2019-english-version.pdf

[68] Indonesia (2021). Long-Term Strategy for Low Carbon and Climate Resilience 2050. https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf

[69] Database Peraturan (2022). Undang-undang (UU) Nomor 7 Tahun 2021. Harmonisasi Peraturan Perpajakan. https://peraturan.bpk.go.id/Home/Details/185162/uu-no-7-tahun-2021

[70] Database Peraturan (2022). Undang-undang (UU) No. 32 Tahun 2009. Perlindungan dan Pengelolaan Lingkungan Hidup. https://peraturan.bpk.go.id/Home/Details/38771/uu-no-32-tahun-2009

[71] Database Peraturan (2022). Undang-undang (UU) No. 31 Tahun 2009. Meteorologi, Klimatologi, dan Geofisika. https://peraturan.bpk.go.id/Home/Details/38769/uu-no-31-tahun-2009

[72] Database Peraturan (2022). Peraturan Pemerintah (PP) Nomor 22 Tahun 2021. Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup. https://peraturan.bpk.go.id/Home/Details/161852/pp-no-22-tahun-2021

[73] Setyowati, A. (2021). Mitigating inequality with emissions? Exploring energy justice and financing transitions to low carbon energy in Indonesia. Energy Research & Social Science, 71, 101817.

[74] Bellini, E. (2018). Micro and mini-grids to bring power to Indonesia's off-grid communities. PV Magazine. https://www.pv-magazine.com/2018/10/11/indonesia-reveals-national-plan-for-micro-and-mini-grids/

[75] Our Planet (2022). Inspiring Ways Microgrids are Used Around the World. Our Planet https://ourplnt.com/inspiring-ways-microgrids/

[76] GE (2017). GE Predix Initiative: Supporting a Brighter Indonesia. GE https://www.ge.com/news/reports/supporting-a-brighter-indonesia

[77] Database Peraturan (2022). Undang-undang (UU) No. 21 Tahun 2014. Panas Bumi. https://peraturan.bpk.go.id/Home/Details/38684/uu-no-21-tahun-2014

[78] Database Peraturan (2022). Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 50 Tahun 2017. Pemanfaatan Sumber Energi Terbarukan Untuk Penyediaan Tenaga Listrik. https://peraturan.bpk.go.id/Home/Details/142140/permen-esdm-no-50-tahun-2017

[79] Asia Pacific Energy (2022). Rencana Usaha Penyediaan Tenaga Listrik Nasional (RUPTL) 2019-2028 (Keputusan Menteri Energi dan Sumber Daya Mineral Nomor 39 K/20/MEM/2019). https://policy.asiapacificenergy.org/node/4172

[80] Database Peraturan (2022). Peraturan Menteri Desa, Pembangunan Daerah Tertinggal, dan Transmigrasi Nomor 11 Tahun 2019. Prioritas Penggunaan Dana Desa Tahun 2020. https://peraturan.bpk.go.id/Home/Details/139731/permendesa-pdtt-no-11-tahun-2019

[81] Database Peraturan (2022). Peraturan Presiden (PERPRES) Nomor 10 Tahun 2021. Bidang Usaha Penanaman Modal. https://peraturan.bpk.go.id/Home/Details/161806/perpres-no-10-tahun-2021

[82] Database Peraturan (2022). Peraturan Presiden (PERPRES) Nomor 98 Tahun 2021. Penyelenggaraan Nilai Ekonomi Karbon untuk Pencapaian Target Kontribusi yang Ditetapkan Secara Nasional dan Pengendalian Emisi Gas Rumah Kaca dalam Pembangunan Nasional. https://peraturan.bpk.go.id/Home/Details/187122/perpres-no-98-tahun-2021

[83] Shekhar, V. and Chinning Low, J. (2014). Indonesia as a Maritime Power: Jokowi's Vision, Strategies, and Obstacles Ahead. The Brookings Institution. https://www.brookings.edu/articles/indonesia-as-a-maritime-power-jokowis-vision-strategies-and-obstacles-ahead/

[84] OECD (2021). *Sustainable ocean economy country diagnostics of Indonesia*. Paris, France: Organisation for Economic Co-operation and Development. https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DCD(2021)5&docLanguage=En

[85] Database Peraturan (2022). Undang-undang (UU) No. 32 Tahun 2014. Kelautan. https://peraturan.bpk.go.id/Home/Details/38710/uu-no-32-tahun-2014

[86] Poernomo, A. and Kuswardani, A. (2019). Ocean Policy Perspectives: The Case of Indonesia. In Harris, P. G. (Ed.), Climate Change and Ocean Governance (pp. 102-117). Cambridge University Press

[87] Database Peraturan (2022). Undang-undang (UU) No. 17 Tahun 2008. Pelayaran. https://peraturan.bpk.go.id/Home/Details/39060/uu-no-17-tahun-2008

[88] OECD (2012). *OECD reviews of regulatory reform: Indonesia 2012: Strengthening co-ordination and connecting markets, OECD reviews of regulatory reform*. Paris, France: OECD Publishing. https://doi.org/10.1787/9789264173637-en

[89] Suherman, A. M., Yuliantiningsih, A., Indriati, N., and Rusli, H. (2020). Indonesian Ocean Policy: Paradigm Shift in Strengthening Ocean Governance. Journal of East Asia and International Law (JEAIL), 13(2), 359-378.

[90] Database Peraturan (2022). Peraturan Presiden (PERPRES) No. 16 Tahun 2017. Kebijakan Kelautan Indonesia. **https://peraturan.bpk.go.id/Home/Details/62168/perpres-no-16-tahun-2017**

[91] Database Peraturan (2022). Keputusan Presiden (KEPPRES) No. 52 Tahun 1999. Pengesahan Protocol Of 1992 To Amend The International Convention On Civil Liability For Oil Pollution Damage, 1969 (Protokol 1992 Tentang Perubahan Terhadap Konvensi Internasional Tentang Tanggungjawab Perdata Untuk Kerusakan Akibat Pencemaran Minyak, 1969). **https://peraturan.bpk.go.id/Home/Details/58368/keppres-no-52-tahun-1999**

[92] Database Peraturan (2022). Peraturan Pemerintah (PP) No. 21 Tahun 2010. Perlindungan Lingkungan Maritim. **https://peraturan.bpk.go.id/Home/Details/5029/pp-no-21-tahun-2010**

[93] Database Peraturan (2022). Peraturan Presiden (PERPRES) Nomor 29 Tahun 2012. Pengesahan Annex III, Annex IV, Annex V, And Annex VI Of The International Convention For The Prevention Of Pollution From Ships 1973 As Modified By The Protocol Of 1978 Relating Thereto (Lampiran III, Lampiran IV, Lampiran V, dan Lampiran VI dari Konvensi Internasional Tahun 1973 tentang Pencegahan Pencemaran dari Kapal Sebagaimana Diubah dengan Protokol Tahun 1978 yang Terkait Daripadanya). **https://peraturan.bpk.go.id/Home/Details/41273/perpres-no-29-tahun-2012**

[94] Database Peraturan (2022). Peraturan Menteri Perhubungan Nomor 29 Tahun 2014. Pencegahan Pencemaran Lingkungan Maritim. **https://peraturan.bpk.go.id/Home/Details/103722/permenhub-no-29-tahun-2014**

[95] Database Peraturan (2022). Peraturan Pemerintah (PP) No. 19 Tahun 1999. Pengendalian Pencemaran Dan/Atau Perusakan Laut. **https://peraturan.bpk.go.id/Home/Details/54252/pp-no-19-tahun-1999**

[96] Database Peraturan (2022). Undang-undang (UU) No. 27 Tahun 2007. Pengelolaan Wilayah Pesisir dan Pulau-Pulau Kecil. **https://peraturan.bpk.go.id/Home/Details/39911/uu-no-27-tahun-2007**

[97] Psaraftis, N.H. and Kontovas, A.C. (2021). Decarbonization of maritime transport: Is there a light at the end of the tunnel? *Sustainability*, 13. **https://link.springer.com/article/10.1057/s41278-020-00149-4**

[98] IMO (2018). Resolution MEPC.302(72), Initial IMO Strategy on Reduction of GHG Emissions from Ships. (MEPC 72/17/Add.1). London, United Kingdom: International Maritime Organization. **https://unfccc.int/sites/default/files/resource/250_IMO%20submission_Talanoa%20Dialogue_April%202018.pdf**

[99] GMF (2021). Call to Action for Shipping Decarbonization. Global Maritime Forum. **https://www.globalmaritimeforum.org/getting-to-zero-coalition/call-to-action**

[100] Sheng, Y., Shi, X., and Su, B. (2018). Re-analyzing the economic impact of a global bunker emissions charge. Energy Economics (74). 2018, pp. 107-119.

[101] Baresic, D., Rojon, I., Shaw, A., Rehmatulla, N. (2022). Closing the Gap: An Overview of the Policy Options to Close the Competitiveness Gap and Enable an Equitable Zero-Emission Fuel Transition in Shipping. London, United Kingdom: University Maritime Advisory Services. https://www.globalmaritimeforum.org/content/2021/12/Closing-the-Gap_Getting-to-Zero-Coalition-report.pdf

[102] World Bank Group (2022). Carbon Revenues from International Shipping: Enabling an Effective and Equitable Energy Transition. https://openknowledge.worldbank.org/bitstream/handle/10986/37240/80501-DMT-Technical_c11.pdf?sequence=6&isAllowed=y

[103] IMO (2021). *ISWG-GHG 10/5, Market-based measures to decarbonize international maritime transport: carbon revenue use, governance and management submitted by the World Bank*. (ISWG-GHG 10/5). London, United Kingdom: International Maritime Organisation.

[104] IMO (2022). *ISWG-GHG 12/3/6, Enabling an equitable transition submitted by the Marshall Islands, Solomon Islands and Tuvalu*. (ISWG-GHG 12/3/6). London, United Kingdom: International Maritime Organisation.

[105] Delasalle, F., Graham, A., Pandey, A. & Randle, C. (2020). *The First Wave. A Blueprint for Commercial-Scale Zero-Emission Shipping Pilots. A Special Report by the Energy Transitions Commission for the Getting to Zero Coalition*. London, United Kingdom: Energy Transitions Commission. https://www.globalmaritimeforum.org/content/2020/11/The-First-Wave-%E2%80%93-A-blueprint-for-commercial-scale-zero-emission-shipping-pilots.pdf

[106] Damodaran, L., Rubek Hansen, J., Hassan, T.M. and Olphert, C.W. (1999). Impact of Large Scale Engineering products and processes on society. The eLSEwise view, Engineering, Construction and Architectural Management, Vol. 6 No. 1, pp. 63-70. https://doi.org/10.1108/eb021099

[107] Murray, S. (2019). The critical role of infrastructure for the Sustainable Development Goals. Essay by the Economist Intelligence Unit and supported by UNOPS. https://content.unops.org/publications/The-critical-role-of-infrastructure-for-the-SDGs_EN.pdf

[108] McKinsey Global Institute (2013). Infrastructure productivity: How to save $1 trillion a year. https://www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/infrastructure%20productivity/mgi%20infrastructure_full%20report_jan%202013.pdf

[109] CNBC (2019). Indonesian president announces site of new capital on Borneo island. CNBC. [] CNBC (2019). Indonesian president announces site of new capital on Borneo island. CNBC. https://www.cnbc.com/2019/08/26/indonesia-president-jokowi-new-capital-on-east-kalimantan-borneo.html

[110] Dobson, J. (2020). As Jakarta Sinks, A New Futuristic Capital City Will Be Built On Borneo. https://www.forbes.com/sites/jimdobson/2020/01/20/as-jakarta-sinks-a-new-futuristic-capital-city-will-be-built-on-borneo/

[111] Database Peraturan (2022). Undang-undang (UU) Nomor 3 Tahun 2022. Ibu Kota Negara. https://peraturan.bpk.go.id/Home/Details/198400/uu-no-3-tahun-2022

[112] Gielen, D., Saygin, D., Rigter, J. (2017). Renewable Energy Prospects: Indonesia, REmap. Abu Dhabi.

[113] Langer, J., Quist, J., Blok, K. (2021). Review of Renewable Energy Potentials in Indonesia and Their Contribution to a 100% Renewable Electricity System. Energies 2021, 14, 7033. https://doi.org/10.3390/en14217033

[114] Reuters (2021). Indonesia says Fortescue, China's Tsingshan in talks for Borneo investment. https://www.reuters.com/business/energy/indonesia-says-fortescue-chinas-tsingshan-talks-borneo-investment-2021-03-30/

[115] Reuters (2021). Indonesia says Fortescue, Tsingshan to invest billions in Borneo. https://www.reuters.com/article/indonesia-mining-idUSL4N2PV1J4

[116] Reuters (2021). Indonesia's Adaro plans $728 mln aluminium smelter in Borneo. https://www.reuters.com/markets/commodities/indonesias-adaro-plans-728-mln-aluminium-smelter-borneo-2021-12-23/

[117] Fortescue (2021). Fortescue Future Industries signs cooperation agreement to explore potential development of green hydrogen projects in North Kalimantan. Latest News. https://www.fmgl.com.au/in-the-news/media-releases/2021/12/09/fortescue-future-industries-signs-cooperation-agreement-to-explore-potential-development-of-green-hydrogen-projects-in-north-kalimantan

[118] Pertamina (2021). Pursuing 1.1 Giga Watt Target, Pertamina Geothermal Energy Operates 15 Work Areas. https://www.pertamina.com/en/news-room/news-release/pursuing-1.1-giga-watt-target-pertamina-geothermal-energy-operates-15-work-areas

[119] Overseas Coastal Area Development Institute of Japan, Pacific Consultants International (2002). Present Conditions of the Principal River Port in Kalimantan, in: The Study on the Development Scheme for the Principal River Ports in Indonesia. Japan International Cooperation Agency, Tokyo, pp. 4.1-4.30.

[120] Maus, V., Giljum, S., Gutschlhofer, J., da Silva, D.M., Probst, M., Gass, S.L.B., Luckeneder, S., Lieber, M., and McCallum, I. (2020). A global-scale data set of mining areas. Sci. Data 2020 71 7, 1–13. https://doi.org/10.1038/s41597-020-00624-w

[121] Mining Technology (2021). Five largest coal mines in Indonesia in 2020. https://www.mining-technology.com/marketdata/five-largest-coal-mines-indonesia-2020/

[122] Mongabay (2022). Mine pits expose the holes in Indonesia's plan to relocate its capital. https://news.mongabay.com/2022/04/mine-pits-expose-the-holes-in-indonesias-plan-to-relocate-its-capital/

[123] CNBC (2022). Turning nickel into EV batteries: Indonesia wants to take its mining industry to the next level. https://www.cnbc.com/2022/04/14/indonesia-wants-to-stop-exporting-minerals-make-value-added-products.html

[124] Serra, P. and Fancello, G. (2020). Towards the IMO's GHG goals: A critical overview of the perspectives and challenges of the main options for decarbonizing international shipping. *Sustainability*, 12(8).

[125] Mjøs, N. (2018). *Maritime impact: Industry Insights: Leading the charge*. DNV. Retrieved from https://www.dnv.com/expert-story/maritime-impact/leading-the-charge.html

[126] Fan, A., Wang, J., He, Y., Percic, M., Vladimir, N., & Yang, L. (2021). Decarbonising inland ship power system: Alternative solution and assessment method. Energy, 226.

[127] Gagatsi, E., Estrup, T., and Haltsis, A. (2016). Exploring the potentials of electricla waterborne transport in Europe: the E-ferry concept. *Transportation Research Procedia*, 14, 1571-1580.

[128] Saether, R. S. and Moe, E. (2021). A green maritime shift: Lessons from the electrification of ferries in Norway. *Energy Research & Social Science*, 81.

[129] Ehnberg, J., Hartvigsson, E., & Aas-Monrad, I. (2021). Electrifying fishing for rural electrification. IEEE Southern Power Electronics Conference (SPEC). Rwanda, Kigali.

[130] Tenhunen, E. (2022). *Electrification is the future*. Danfoss. https://www.danfoss.com/en/about-danfoss/articles/cf/electrification-is-the-future/

[131] Bloch, C., Newcomb, J., Shiledar, S., and Tyson, M. (2019). *Breakthrough batteries: Powering the era of clean electrification*. Rocky Mountain Institute. https://rmi.org/wp-content/uploads/2019/10/rmi_breakthrough_batteries.pdf

[132] Consulate general of the Republic of Indonesia (2018). Indonesia at a glance. https://kemlu.go.id/vancouver/en/pages/indonesia_at_a_glance/2016/etc-menu

[133] Ministry of Investment/BKPM (2017). Blue economy holds the key to Indonesia's sustainable prosperity. https://www3.bkpm.go.id/en/publication/detail/news/blue-economy-holds-the-key-to-indonesias-sustainable-prosperity

[134] Christina, B. and Suroyo, G. (2021). Indonesia's B40 biodiesel plan faces new delay due to palm price. Reuters. https://www.reuters.com/article/us-indonesia-palmoil/indonesias-b40-biodiesel-plan-faces-new-delay-due-to-palm-price-idUSKBN2FR0GG

[135] Prananta, W. and Kubiszewski, I. (2021). Assessment of Indonesia's Future Renewable Energy Plan: A Meta-Analysis of Biofuel Energy Return on Investment (EROI). Energies 2021, Vol. 14, Page 2803 14, 2803. https://doi.org/10.3390/EN14102803

[136] Suwastoyo, B. (2020). Mandatory B30 Policy Benefits Palm Oil Players, Government. - The Palm Scribe. https://thepalmscribe.id/mandatory-b30-policy-benefits-palm-oil-players-government/

[137] Database Peraturan (2022). Peraturan Presiden (PERPRES) Nomor 38 Tahun 2019. Penyediaan, Pendistribusian, dan Penetapan Harga Liquefied Petroleum Gas untuk Kapal Penangkap Ikan Bagi Nelayan Sasaran dan Mesin Pompa

Air Bagi Petani Sasaran. https://peraturan.bpk.go.id/Home/Details/108811/perpres-no-38-tahun-2019

[138] PT PLN (2021). PLN Peduli Dukung Ekosistem Kendaraan Listrik, Kolaborasi dengan IKM Ciptakan E-Boat. https://web.pln.co.id/cms/media/siaran-pers/2021/12/pln-peduli-dukung-ekosistem-kendaraan-listrik-kolaborasi-dengan-ikm-ciptakan-e-boat/

[139] Energy Renewed PTE LTD (2019). Conceptual boats. https://www.energy-renewed.com/

[140] Kong, Y.X. (2019). An idea to electrify 1 million boats in Southeast Asia—inspired by Ikea. https://www.eco-business.com/news/an-idea-to-electrify-1-million-boats-in-southeast-asia-inspired-by-ikea/

[141] Hicks, R. (2018). Indonesia's scuba diving hotspot Raja Ampat welcomes first electric boats. https://www.eco-business.com/news/indonesias-scuba-diving-hotspot-raja-ampat-welcomes-first-electric-boats/

[142] Murray, A. (2020). Plug-in and sail: Meet the electric ferry pioneers. https://www.bbc.co.uk/news/business-50233206

[143] UCCRTF (2021). Event Snapshot: E-boat taxis launched in Batam, Indonesia. Urban Climate Change Resilience Trust Fund (UCCRTF).

[144] Taylor, I. (2022). *Indonesian shipyard set to build all-electric harbour tug*. Ship Energy. https://ship.energy/2022/02/23/indonesian-shipyard-set-to-build-all-electric-harbour-tug/

[145] Sustainable Tour. (2021). *Electrifying boats to reduce CO2 emissions*. https://www.sustainabletour.eu/electrifying-boats-to-reduce-co2-emissions/

[146] Indradjaja, B.D., Ramadhani, B., Günther, P.M., and Gunawan, P. (2020). Techno-economic Feasibility Analysis of Photovoltaic Charging Station for Electric Boats in Sabangko Island. Indones. J. Energy 3, 34–50. https://doi.org/10.33116/IJE.V3I1.50

[147] Pers, S. (2022). Pertamina and Grab agree to strengthen the EV ecosystem. https://www.pertamina.com/en/news-room/news-release/pertamina-and-grab-agree-to-strengthen-the-ev-ecosystem

[148] Fauzi, A. (2015). Geothermal resources and reserves in Indonesia: an updated revision. Geoth. Energ. Sci., 3, 1–6, 2015 www.geoth-energ-sci.net/3/1/2015/doi:10.5194/gtes-3-1-2015

[149] Wilcox, J. (2012). Indonesia's Energy Transit: Struggle to Realize Renewable Potential. Renewable Energy World.com. 14 September.

[150] Pertamina (2021). Ready for Transition, Pertamina Continues to Grow New Renewable Energy. https://www.pertamina.com/en/news-room/news-release/ready-for-transition-pertamina-continues-to-grow-new-renewable-energy

[151] PWC (2021). Pertamina prepares 8 strategies to increase green energy portfolio. https://www.pwc.com/id/en/media-centre/infrastructure-news/november-2021/pertamina-prepares-8-strategies-to-increase-green-energy-portfolio.html

[152] Reuters (2022). Indonesia's Pertamina aims to double geothermal capacity – CEO. https://www.reuters.com/business/energy/indonesias-pertamina-aims-double-geothermal-capacity-ceo-2022-04-25/

[153] Ipsos (2016). Indonesia's aquaculture industry: Key sectors for future growth. https://www.ipsos.com/en/indonesias-aquaculture-industry-key-sectors-future-growth

[154] FAO (2014). *Fishery and Aquaculture Country Profiles – Indonesia*. UN Food and Agriculture Organization. https://www.fao.org/fishery/en/facp/idn?lang=en

[155] Global Seafood Alliance (2010). *Energy efficiency of aquaculture*. https://www.globalseafood.org/advocate/energy-efficiency-aquaculture/

[156] Linde (2022). Oxygenation in Aquaculture. https://www.linde-gas.com/en/processes/controlled_and_modified_atmospheres/oxygenation_in_aquaculture/index.html

[157] Royal Society (2020). *Ammonia: zero-carbon fertiliser, fuel and energy store*. Policy Briefing. https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf

[158] GFAR (2022). *Asosiasi Produsen Pupuk Indonesia (Association of Indonesian Fertilizer Producers)*. https://www.gfar.net/organizations/asosiasi-produsen-pupuk-indonesia-association-indonesian-fertilizer-producers

[159] Pertamina (2022). Pertamina, PT Pupuk Indonesia, and Mitsubishi Corporation Agree to Develop Blue/Green Hydrogen and Ammonia Business. https://www.pertamina.com/en/news-room/news-release/pertamina-pt-pupuk-indonesia-and-mitsubishi-corporation-agree-to-develop-blue-green-hydrogen-and-ammonia-business

[160] Pertamina (2021). Pursuing 1.1 Giga Watt Target, Pertamina Geothermal Energy Operates 15 Work Areas. https://www.pertamina.com/en/news-room/news-release/pursuing-1.1-giga-watt-target-pertamina-geothermal-energy-operates-15-work-areas

[161] Raucci, C., Bonello, J.M., Suarez de la Fuente, S., Smith, T. & Søgaard, K., 2020. Aggregate investment for the decarbonisation of the shipping industry. UMAS. London.

[162] World Bank Group (2022). Homepage. https://www.worldbank.org/en/home

[163] ADB (2022). Asian Development Bank. Homepage. https://www.adb.org/

[164] EIB (2022). European Investment Bank. Homepage. www.eib.org/en

[165] Islamic Development Bank (2022). Homepage. https://www.isdb.org/

[166] World Bank Group (2022). Indonesia. https://data.worldbank.org/country/indonesia

[167] World Bank Group (2022). International Bank for Reconstruction and Development https://www.worldbank.org/en/who-we-are/ibrd

[168] International Finance Corporation (2022). Homepage. https://www.ifc.org/

[169] Asian Development Bank (2022). Asian Development Bank and Indonesia: Fact Sheet. https://www.adb.org/sites/default/files/publication/27769/ino-2021.pdf

[170] PPIAF (2022). Public-Private Infrastructure Advisory Facility. About us. https://ppiaf.org/

[171] CIF (2022). Climate Investment Funds. Homepage. https://www.climateinvestmentfunds.org/

[172] GCF (2022). Green Climate Fund. Homepage https://www.greenclimate.fund/

[173] Agence Française de Développement (2022). Homepage. https://www.afd.fr/fr

[174] KfW (2022). Homepage. https://www.kfw.de/About-KfW/

[175] Australia Department of Foreign Affairs and Trade (2022). Homepage. https://www.dfat.gov.au/

[176] Foreign, Commonwealth and Development Office (2022). Homepage. Foreign, Commonwealth & Development Office - GOV.UK

[177] USAID (2022). Homepage. https://www.usaid.gov/

[178] European Commission (2022). International Partnerships: Indonesia. https://ec.europa.eu/international-partnerships/where-we-work/indonesia_en

[179] Nikkei Asia (2022). G-7 infrastructure investment to target Indo-Pacific's clean-energy transition. https://asia.nikkei.com/Politics/International-relations/Indo-Pacific/G-7-infrastructure-investment-to-target-Indo-Pacific-s-clean-energy-transition

[180] ICCTF (2022). Indonesia Climate Change Trust Fund. https://www.icctf.or.id/

[181] MCA Indonesia (2022). Millennium Challenge Account Indonesia. https://www.mcc.gov/where-we-work/country/indonesia

[182] Indonesia Environmental Fund (Badan Pengelola Dana Lingkungan Hidup) (2022). https://www.mcc.gov/where-we-work/country/indonesia

[183] ClimateWorks Foundation (2022). Homepage. https://www.climateworks.org/

[184] DNV GL (2020). Ports: Green gateways to Europe 10 Transitions to turn ports into decarbonization hubs. https://sustainableworldports.org/wp-content/uploads/PORTS_GREEN_GATEWAYS_TO_EUROPE_FINAL29JUNE.pdf

[185] UNCTAD (2021). *Review of Maritime Transport 2021*. Geneva, Switzerland: United Nations Conference on Trade and Development.

[186] Investor.id (2021). Perkuat Green Port, KIP Manfaatkan Energi Surya di Pelabuhan. https://investor.id/business/260823/perkuat-green-port-kip-manfaatkan-energi-surya-di-pelabuhan-nbsp

[187] Alamgir, M., Campbell, M.J., Sloan, S. et al. (2019). High-risk infrastructure projects pose imminent threats to forests in Indonesian Borneo. Sci Rep 9, 140.

[188] PoA, n.d. Hydrogen-powered tug is world first for Port of Antwerp. https://newsroom.portofantwerpbruges.com/hydrogen-powered-tug-is-world-first-for-port-of-antwerp

[189] S&P Global (2022). Indonesia defers carbon tax launch to July due to global turmoil, energy market volatility. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/040522-indonesia-defers-carbon-tax-launch-to-july-due-to-global-turmoil-energy-market-volatility#:~:text=Under%20its%2

[190] Gunawan, R. (2021). Counting the Significance of Indonesia in ASEAN Shipping Decarbonization. https://www.linkedin.com/pulse/counting-significance-indonesia-asean-shipping-rachmat-gunawan-1f/

[191] Reuters (2020). Indonesia plans to replace old coal power plants with renewable plants: minister. https://www.reuters.com/article/us-indonesia-power-coal-idUSKBN1ZT17N

[192] IESR, Agora Energiewende, LUT University (2021). Deep decarbonization of Indonesia's energy system: A pathway to zero emissions by 2050. Institute for Essential Services Reform (IESR). https://static.agora-energiewende.de/fileadmin/Partnerpublikationen/2021/IESR_Deep_Decarbonization_Indonesia.pdf

[193] ETP (2022). Indonesia - Projects: Planned. Energy Transition Partnership. https://www.energytransitionpartnership.org/country/indonesia/

[194] Kingdom of Denmark (2021). Declaration on Zero Emission Shipping by 2050. https://em.dk/media/14312/declaration-on-zero-emission-shipping-by-2050-cop26-glasgow-1-november-2021.pdf

[195] Department for Transport (2022). COP 26: Clydebank Declaration for green shipping corridors. Policy Paper. https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors

[196] GMF (2022). Maritime industry joins forces with leading global miners in support of Australia-East Asia iron ore Green Corridor. Global Maritime Forum. https://www.globalmaritimeforum.org/press/maritime-industry-joins-forces-with-leading-global-miners-in-support-of-australia-east-asia-iron-ore-green-corridor-2/

[197] Splash247 (2021). Koreans target hydrogen standards. https://splash247.com/Koreans-target-hydrogen-standards/

[198] Asia Business Law Journal (2021). Renewable energy regulations in Indonesia. https://law.asia/renewable-energy-regulations-indonesia

[199] GMF (2021). Report on Climate Commitments by Signatories to the Call to Action for Shipping Decarbonization. Getting to Zero Coallition. https://www.globalmaritimeforum.org/content/2021/09/Report-on-Climate-Commitments-by-Signatories-to-the-Call-to-Action-for-Shipping-Decarbonization.pdf

[200] Pettinger, T. (2019). Multinational Corporations in Developing Countries. https://www.economicshelp.org/blog/1413/development/multinational-corporations-in-developing-countries/

[201] HECI (2022). Hydrogen Energy Center Indonesia. https://www.hydrogen-indonesia.org/about.php

[202] IRENA (2021). A Pathway to Decarbonise the Shipping Sector By 2050. International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

[203] UNEP (2021). Innovation is key to decarbonizing the maritime sector. https://www.unep.org/news-and-stories/speech/innovation-key-decarbonizing-maritime-sector

[204] C40 (2018). Clean Energy Business Model Manual. https://www.c40knowledgehub.org/s/article/Clean-Energy-Business-Model-Manual?language=en_US

[205] IHS Markit (2018). *IHS Markit*.

[206] Global Fishing Watch (2018). *Global Fishing Watch*. Sustainable Ocean Management. https://globalfishingwatch.org/map-and-data/

[207] Smith, T.W.P., Jalkanen, J.P., Anderson, B.A., Corbett, J.J., Faber, J., Hanayama, S., et al. (2014). Third IMO GHG Study 2014. London.

[208] EMSA (2018). *EU MRV*. https://mrv.emsa.europa.eu/#public/eumrv

[209] Ministry of Environment (2012). Jpedoman Penyelenggaraan Inventarisasi Gas Rumah Kaca Nasional: Buku I, Pedoman Umum. Jakarta. https://www.kemenperin.go.id/download/18859

[210] Ministry of Environment (2012). Pedoman. Penyelenggaraan Inventarisasi Gas Rumah Kaca Nasional Buku Ii - Volume 1: Metodologi Penghitungan Tingkat Emisi Gas Rumah Kaca Kegiatan Pengadaan dan Penggunaan Energi. Jakarta. https://www.kemenperin.go.id/download/11219

[211] EMEP/CORINAIR (2005). *Emission Inventory Guidebook – 2005*. Copenhagen.

[212] Lloyd's Register (1995). *Marine exhaust emissions research programme*. Croydon.

[213] Woodyard, D. (2009). *Pounder's Marine Diesel Engines and Gas Turbines* (9th ed.). Oxford: Butterworth-Heinemann.

[214] IPCC (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland, 151 pp. https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

[215] Yoo, D. H., Nitta, Y., Ikame, M., Hayashi, M., Fujita, H., & Lim, J. K. (2012). *Exhaust characteristics of Nitrous oxide from marine engine*. Program Book - OCEANS 2012 MTS/IEEE Yeosu: The Living Ocean and Coast - Diversity of Resources and Sustainable Activities.

Annex I

SHIPPING GEOSPATIAL MODEL: Technical Information

This annex presents supplementary information to Chapter 3 on Indonesia'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 Indonesia, including the assumptions and limitations of the approach.

It is structured in three sections:

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

Shipping geospatial model

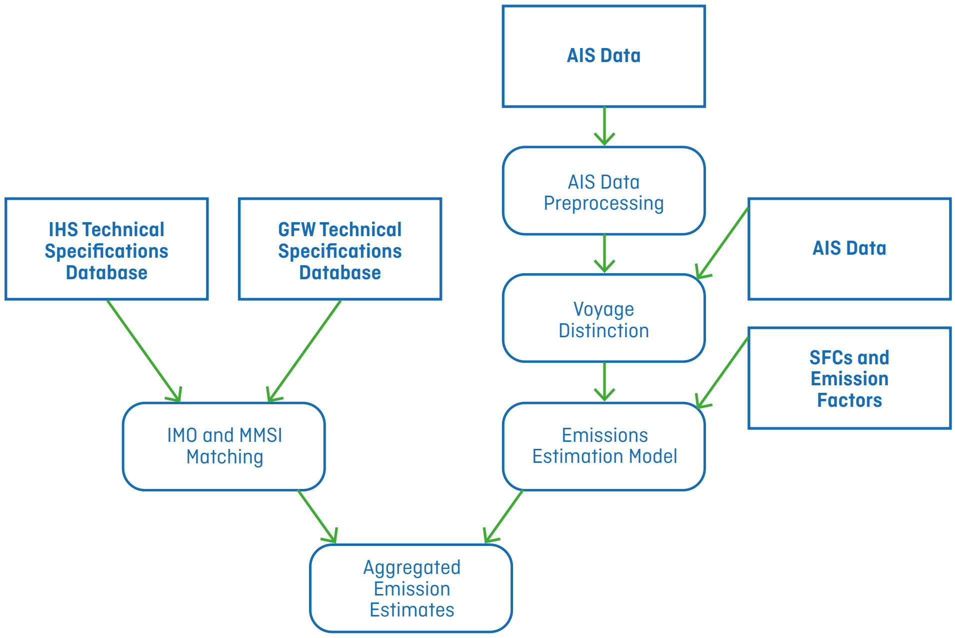
This report provides an estimation of GHG emissions and air pollutants from shipping in Indonesia using an activity-based approach.

The SGM for Indonesia 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 Indonesia. 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 Indonesia's maritime economic activity.

Step I: Building from the Fourth IMO GHG Study

The Fourth IMO GHG Study [8] 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 MIO 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 and Global Fishing Watch databases [205][206]. 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 [207] 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 maritime GHG and air pollution research for domestic and international shipping above 100 gross tonnage [8]. 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 Information Handling Service dataset [205]. 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[23]; 10 different GHG and air pollutants and two fugitive emissions (i.e. refrigerants and Non-Methane Volatile Organic Compounds (NMVOC)).

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.

23 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 while 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 reported draught is combined with ship design characteristics of IHS data. The formula has been adjusted using speed, fouling and weather factors, while auxiliary machinery power demand has been established depending on the ship type, size and operational mode occurring at each hourly observation. It is important to note that reported draught values may often be inaccurately recorded and bear imperfect correlation with quantities of cargo carried by each vessel, leading to uncertainty in final estimations of fuel consumption emissions generated. Furthermore, the lack of information regarding imports results in a lack of clarity surrounding the origin and fair attribution these emissions to the Indonesian economy.

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 and 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 ECA). As in the Fourth IMO GHG Study's activity-based methodology, two different approaches to emission factors (EF)[24] were used: energy-based and mass-based. The energy-based EF are given as mass of air pollutants by energy demand – 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[25]. 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[26].

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, for Ricardo's and this report the shipping energy demanded is given 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[27].

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 [208]. 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.

24 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.
25 A more specific explanation of the EF can be found in the Fourth IMO GHG Study subsection Emission Factors or Appendix B and M.
26 For CH_4 is 28 and N_2O is 265.
27 Conversion factor: 1 kJ equals $2.78x10^{-7}$ MWh.

Step II: Voyages and their geographical location

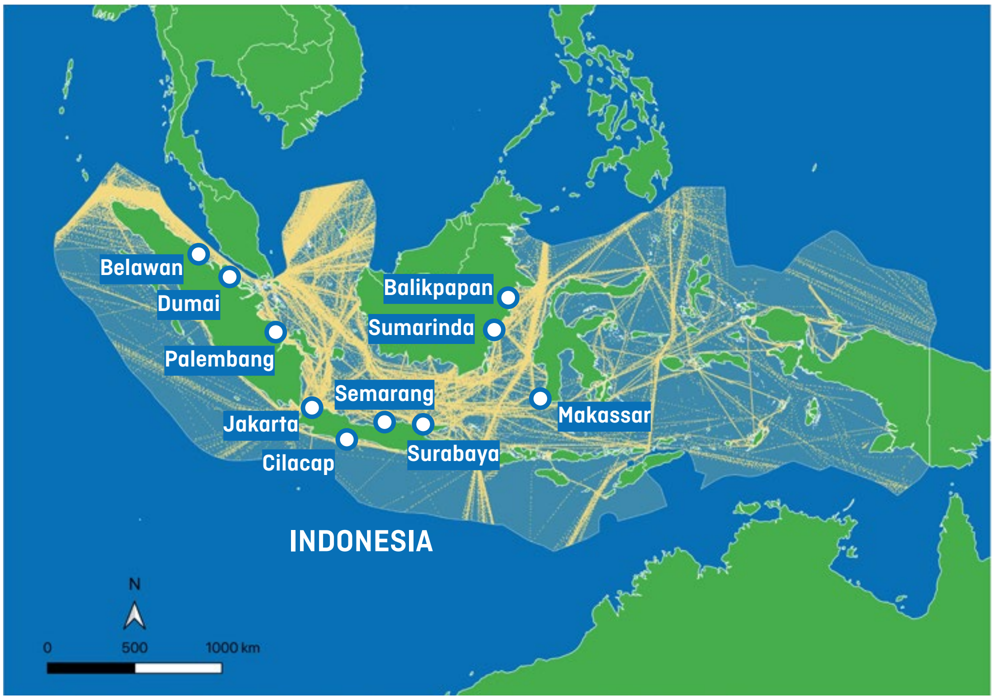
The addition of the stop identification process enables continuous AIS data representing vessel activity as discrete voyages. Emission data with timestamps falling between the start and end times of a given voyage is pulled by the algorithm. Emission data associated with voyages where vessels depart from an Indonesian 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 an Indonesian port, emissions associated with this journey are added to the international arrivals inventory. Where source and destination ports are both Indonesian, voyage emissions are allocated to the domestic inventory, while the emissions of voyages that feature no interaction with Indonesia'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 Indonesia 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 Indonesia as its final or origin destination.
- Taking the first or last voyage leg does not mean that the cargo coming or going from Indonesia is fully loaded in the last port before arriving to Indonesia or fully unloaded at the first port of call after leaving Indonesia. 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 Indonesia occur and shows the important role that Indonesia 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 [41] for the EEZ approach, activity-related emission data that falls within the region is pooled to form the geofenced inventory while 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 Indonesia's EEZ polygon 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 7 with their QA and QC to minimize their impact.

Table 7: Potential sources of error in the SGM for indonesia.

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

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

Indonesia'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 IPCC Reference Approach offers one such method that makes use of readily available energy supply data.

Indonesia's Ministry of Environment and Forestry, coordinates the country's GHG emissions through the preparation of its National Inventory of Greenhouse Gases [35]. The inventory follows the 2006 IPCC Guidelines. The information provided in each of the following subsections is based in the information provided in Indonesia's 3rd Biennal Update Report [35], Directorate of GHG Inventory and Monitoring, Reporting and Verification [40], Guide Conducting a National Greenhouse Gas Inventory: Book I, General Guidelines [209], Guide Conducting a National Greenhouse Gas Inventory National Greenhouse Gas Inventory Book II Volume 1 [210] and the Handbook of Energy and Economic Statistics of Indonesia [39].

More information on the 2006 IPCC Guidelines that the Indonesian 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 [37]. 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 [211]. 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.

Indonesia's GHG inventory report for its water-borne emission estimation of CO_2, CH_4 and N_2O used a Tier 1 approach [210].

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, Indonesia methodology used only six out of the 10 for the CO_2 EF [210].

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 CH_4 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, Indonesia used the default values recommended by IPCC Tier 1 approach.

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 Indonesian domestic maritime emission category data is provided by the Handbook of Energy and Economic Statistics of Indonesia covering the years 2010-2020 [39]. The report uses the sale of fuel during this period to establish the energy demand of the maritime sector. The national fuel sales were aggregated by fuel type per energy sector and then translated to the 2006 IPCC categories [40].

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.

Indonesia's 2019 National GHG Inventory Report recounted that the estimated uncertainty for the whole inventory was 13.8% when not considering Forestry and Other Land Use category was not considered while increasing to 19.9% when considered [35]. It was noted that the uncertainty of the report since 2000 has stayed at the same level. It is important to notice that the uncertainty analysis was only shown for the total GHG inventory and not to the subcategories and the emission factors.

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 Indonesia's emission inventories the QA and QC is extensively explained in the inventories quality policies report [209]. The report set the guidelines to revise the quality of the data estimated, reports produced and communication to the 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 Navigatio*n. 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 Indonesia and Indonesia's National GHG Inventory need to be seen as complementary. Indonesia'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 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 Indonesia with the purpose of exploring the implications of shipping to, from and within the country and establish their role 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[28], which tend to be activity within the national waters and of high relevance for Indonesia's maritime activity as seen in Table 2. For this reason, it is deemed that the results from the SGM are on the conservative side.

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 Navigation* – without accounting for fishing activity – stood -7,676.77 kt CO_2e.

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

Emission factors

As reported by Indonesia's National GHG Inventory for Water-Borne Navigation, default Tier 1 EF were used for CO_2, CH_4 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 8 presents the CO_2 EF used in Indonesia'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 -0.02% for HFO, -1.33% for MDO[29] and 1.96% for liquified natural gas (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.

Table 8: Comparison of CO_2 emission factors used in the SGM and the values used by the Indonesia's GHG inventory for the Water-Borne Navigation based on the IPCC 2006 values [210].

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	77,400	-0.02
MDO	3.206	75,082	74,100	-1.33
LNG	2.750	55,000	56,100	1.96

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 Indonesia's GHG National Inventories the defaults values for methane EF recommended by the 2006 IPCC Guidelines were followed. These EF were 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 9)

29 MDO carbon factor was reported as Solar since it has the same value as recommended by the IPCC Guidelines (Ministry of Environment, 2012b).

.Table 9: 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 [212] 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 [213].

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.

Another minor point of difference is that the GWP_{100} for CH_4 used by Indonesia's National GHG Inventory was 21 [40] instead of the 28 used by the SGM based on the IPCC Fifth Assessment Report [214].

Nitrous oxide

Table 10 presents the N_2O EF used in Indonesia's National GHG Inventory – given as a range and based on the IPCC 2006 Guidelines – and the ones derived from the Fourth IMO GHG Study used for the SGM. 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 10: 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. [215] 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.

Like CH_4, the N_2O GWP_{100} used by Indonesia's National GHG Inventory was different to the latest IPCC recommendations. The National Inventories used a GWP_{100} of 310 [40] instead of the 265 used by the SGM [214].

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 [8][42]. For all the annual emission inventories produced by the SGM, BC was among the second most powerful maritime GHG with about 9.5% of the total CO_2e for Indonesia'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 Indonesia's GHG inventory and the SGM for Indonesia. To do that, the amount of fuel consumed in 2018 by domestic shipping – excluding fishing – from the SGM will be used. Further, the 2018 Indonesia's National Inventory [40] will be used instead of the one reported (i.e. for the year 2019) in their 3rd Communication to the UNFCCC [35] to avoid doing spatial data transformations that can bring uncertainty to the calculations.

Indonesia reported for the domestic *Water-Borne Navigation* category a total of 108 kt CO_2e for 2018 while the SGM estimated 7,677 kt CO_2e a difference of -7,569 kt CO_2e.

The estimated annual fuel consumption during 2018 from the SGM for Indonesia's domestic activity – excluding fishing – was 1,219.23 kt HFO, 911.75 kt MDO and 44.17 kt LNG. Converting these fuel consumptions into energy using the fuels' LHV[30] gives 49,013.05 TJ for HFO, 38,931.73 TJ for MDO and 2,120.16 TJ for LNG. Now, by using Indonesia's National GHG Inventory CO_2 EF and middle EF values for CH_4 and N_2O from the 2006 IPCC guidelines (and not counting BC as a GHG) while using the latest GWP_{100} values from IPCC, the annual GHG emission due to domestic navigation is 6,797.39 kt CO_2, 0.63 kt CH_4 and 0.27 kt N_2O. Converting these quantities to CO_2e gives a total of 6,886.65 kt CO_2e. This is a difference with the projected Indonesia's annual GHG emissions in 2018 of 6,886.54 kt CO_2e and just -0.88% against the SGM estimation without accounting for the effect of BC as a GHG (i.e. 729.00 kt CO_2e). If the analysis is used with the GWP_{100} used by Indonesia, then the difference between the results would be of -0.76%.

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 Indonesia's Handbook of Energy and Economic Statistics of Indonesia [39] which for the maritime sector is based on annual fuel sales [40].

- 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 Indonesia. In practice ships calling at Indonesia 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 Indonesia 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 Indonesia's shipping activity is purchased in Indonesia and so the activity-based method is helpful for giving an estimated of the potential bunker sales market - should Indonesia want to expand its opportunity, especially for SZEF.

30 For HFO the LHV used was 40.2 TJ/kt, for MDO 42.7 TJ/kt and for LNG 48.0 TJ/kt [8].

- The method used in SGM is an activity-based method so it includes emissions from domestic voyages of international ships (e.g. from one Indonesian 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. United Kingdom) which have since switched to use the activity based method [43].

- 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 transponder). In the case of Indonesia, this segment due to its energy demand 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.

- 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 SGM 2018 GHG emissions – not accounting for BC as a GHG – and the CO_2 EF for HFO MDO and LNG have a difference of -0.02%, -1.33% and 1.96% respectively to the IPCC recommended EF. This explains in its majority the -0.88% observed difference when contrasting both inventories EF using the SGM 2018 fuel consumption, and the IPCC recommended GWP_{100}.

- The difference between the CH_4 and N_2O GWP_{100} used in the SGM and Indonesia's National Inventory was responsible for a variation of -0.11% in the total GHG emissions. While the differences in the GWP_{100} values are significant, their impact on the domestic water borne GHG emissions is small due to these compounds being a fraction of the total, as explained above.

- 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 a 9.5% influence – around 730 kt CO_2e – on the total GHG domestic emission in 2018. Still, it is considered that the SGM is on the conservative spectrum for the national GHG emissions.

Further tests with the SGM results could not be performed since the Indonesia's National Inventory probably aggregate the domestic fishing fleet into the *Non-Specified* and *International maritime* is not stated.

The interested reader can find further detail on this report maritime activity data in Faber et al. [8] 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