Maritime Sustainability: Decarbonization Efforts in International Shipping & Research @ CMS

NUS Sustainability Connect

Sustainable Maritime Operations

Ng Szu Hui
Department of Industrial Systems Engineering & Management, Centre for Maritime Studies
National University of Singapore

Outline

- International Shipping Ambitions and Actions
- Maritime Decarbonization Research @ CMS
  - Modeling & analysis of current state:
    - Emission and carbon intensity estimations
    - Understanding the drivers of emission and carbon intensity
  - Modeling & analysis of future scenarios:
    - Fuel, technology, policy pathways
    - Global and regional impact assessment on states and stakeholders
  - Identifying opportunities and gaps

Centre for Maritime Studies

Shipping Emissions

Shipping CO_2 emissions compared to global CO_2 emissions (2007 – 2018)

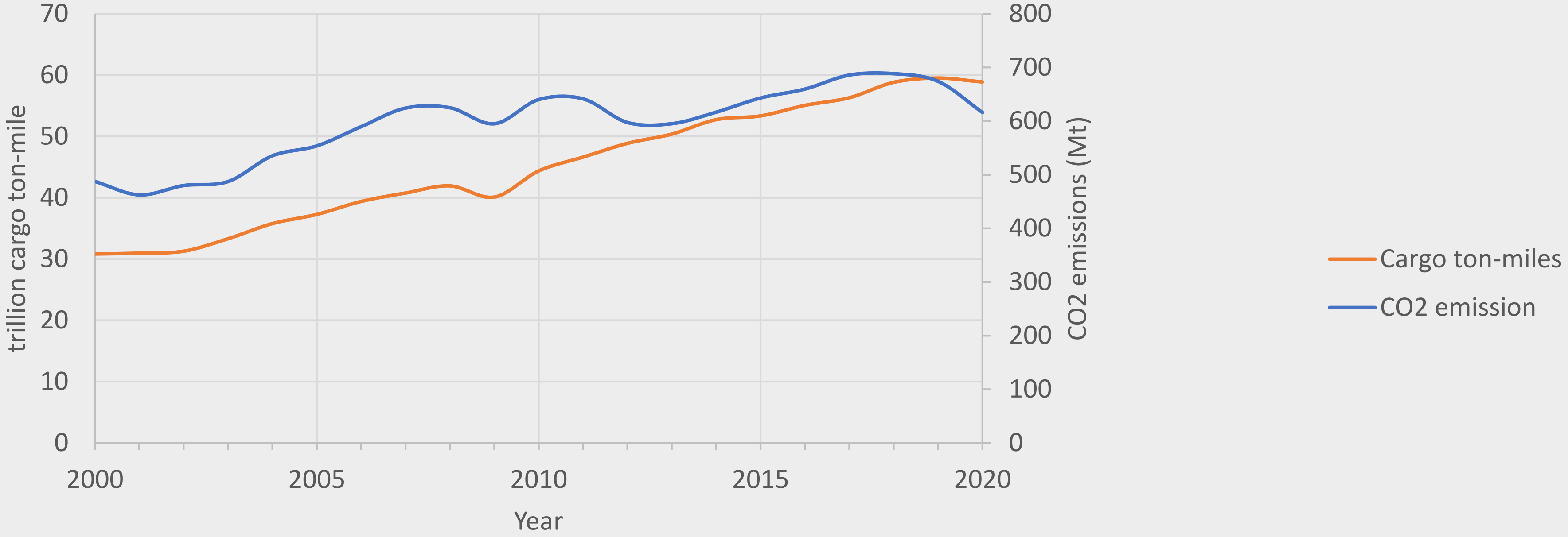
	Third IMO GHG Study (million tons)						Fourth IMO GHG Study (million tons)					
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Global CO2 Emissions	31,959	32,133	31,822	33,661	34,726	34,968	34,959	35,225	35,239	35,380	35,810	36,573
International Shipping	**881**	**916**	**858**	**773**	**853**	**805**	**837**	**846**	**859**	**894**	**929**	**919**
Total Shipping	1,100	1,135	977	914	1,021	942	957	964	991	1,026	1,064	1,056
% of global	3.4%	3.5%	3.1%	2.7%	2.9%	2.7%	2.7%	2.7%	2.8%	2.9%	3.0%	**2.9%**

Observations

- From 2007-2018, CO_2 emissions have been increasing.
- In 2018, total shipping emissions was responsible for 2.9% of global CO_2 emissions from fossil fuel use and other industrial processes.
- International shipping contributed the most, about 87% of total CO_2 from shipping.
- If treated as a country, international shipping would be the 6th largest emitter of CO_2 in 2018.

Emissions from International Shipping

- **Emissions** from international shipping has been increasing as international trade grows



Data sources: IEA World Energy Balances; UNCTAD Review of Maritime Transport series

NUS National University of Singapore | Centre for Maritime Studies

13 CLIMATE ACTION

Global Reduction Targets & Decarbonization efforts

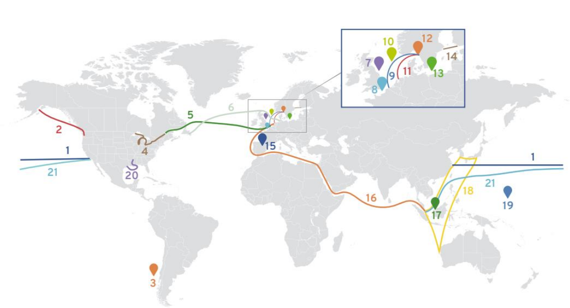
IMO GHG Reduction Targets

- **Reduce CO2 emission intensity** by at least **40% by 2030**, pursuing efforts towards 70% by 2050, compared to 2008.
- To reach **net-zero GHG emissions** by or around **2050**
- Indicative checkpoints to reach net-zero:
  reduce total annual **GHG emissions** by **at least 20%,** striving for 30%, by **2030**;
  reduce by **at least 70%,** striving for 80% by **2040**
  (compared to 2008)
- uptake of **at least 5% zero or near-zero** GHG **emission fuels** and/or energy sources by **2030**

IMO Actions (regulations)

- **EEDI** Energy Efficiency Design Index
  - **mandatory design index** for *new* ships
- **SEEMP** Ship Energy Efficiency Management Plan
  - **mandatory** to have **energy efficiency management** plan for all ships
- **DCS** Data Collection System
  - **mandatory** requirement for all ships to record and **report their fuel consumption** since 2019 to calculate ship's operational carbon intensity
- **EEXI** Energy Efficiency Index for Existing Ship
  - **mandatory design energy efficiency index** for *all* ships
- **CII** Annual Carbon Intensity Indicator rating
  - **mandatory** to collect data for the reporting **annual operational CII**
  - **CII rating A, B, C, D or E** on a scale and mandatory to be recorded in the SEEMP

Regional Targets and Decarbonization Efforts

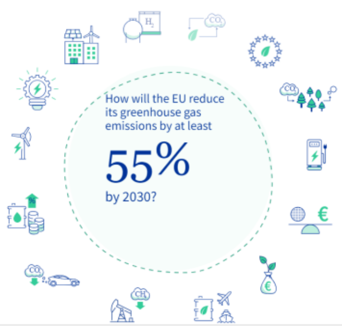


European Union

Targets: **reduce** GHG emissions by **at least 55% by 2030** compared to 1990 levels and achieve **climate neutrality** in **2050** (EU green deal)

Actions:

- FuelEU maritime initiative to increase the demand for and consistent use of renewable and low-carbon fuels and reduce the greenhouse gas emissions from the shipping sector.
  - GHG intensity of fuels used by shipping sector will gradually decrease over time to 80% by 2050
- EU-ETS (pricing mechanism on GHG emissions)



Route based / Green Corridor Initiatives

Zero-emission fuels and technologies along trade routes between two (or more) ports can help accelerate adoption of alternatives to conventional fuels in the maritime industry for GHG emissions reduction

Singapore-Rotterdam Green Corridor

- **20% reduction** in GHG emissions by **2030**, compared to 2022

West Australia-East Asia Iron Ore Green Corridor

- Ships on **clean** ammonia to be deployed by 2028 and reach **5% adoption by 2030**

LA-Long Beach-Singapore Green and Digital Corridor

SILK Alliance

MARITIME DECARBONIZATION PROGRAM @ CMS

To develop analytical models and tools to study decarbonization pathways and its impacts, to further inform policy development and responses, and business decisions on both the local and international stages

- **Current projects / activities**
  - An Integrated Model for Maritime Emission Reduction (**AIMMER**)
  - Planning and design of green & digital shipping corridors

- *Some past projects*
  - Impacts of IMO Technical and Operational Energy Efficiency Measures
  - Greenhouse Gas Emissions Estimations from International Shipping
  - Analysis of Carbon Intensity Indicators for International Shipping

Some track record of team:

- Expert reviewer of 4th IMO GHG Study report
- Invited expert on several IMO ad-hoc committees
- Invited speaker / participant at IMO Expert workshop on Impact assessments
- Active attendance at IMO MEPC and ISWG-GHG meetings

Research on Maritime Decarbonization

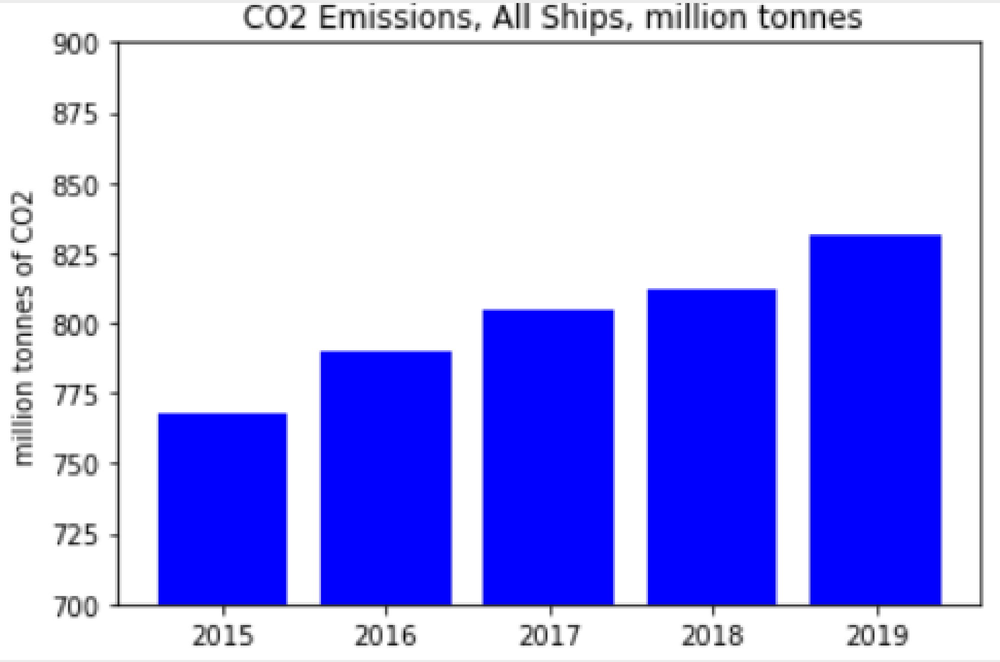
Current Status	Future Scenarios
Emission Modeling & Estimation and Intensity Estimation	**Projecting future emissions under different scenarios**
↓	↓
Understanding the drivers of changes in emissions over time	**Understanding economic and environmental impacts**

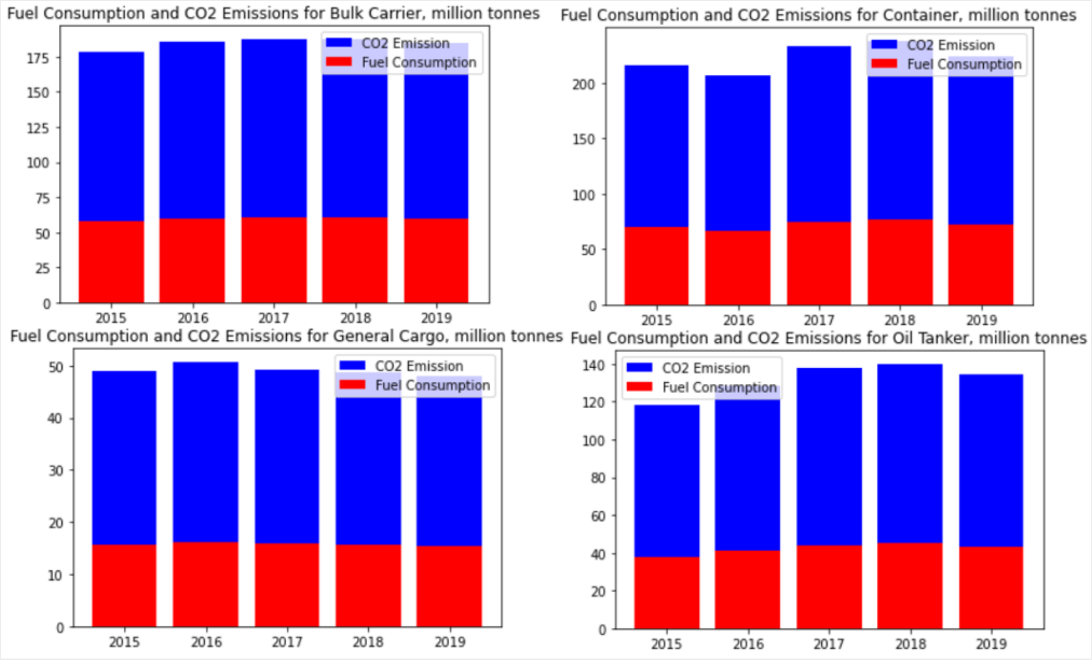
Research on Maritime Decarbonization

Current Status	Future Scenarios
Emission Modeling & Estimation and Intensity Estimation	Projecting future emissions under different scenarios
↓	↓
Understanding the drivers of changes in emissions over time	Understanding economic and environmental impacts

Emission Inventory Estimation

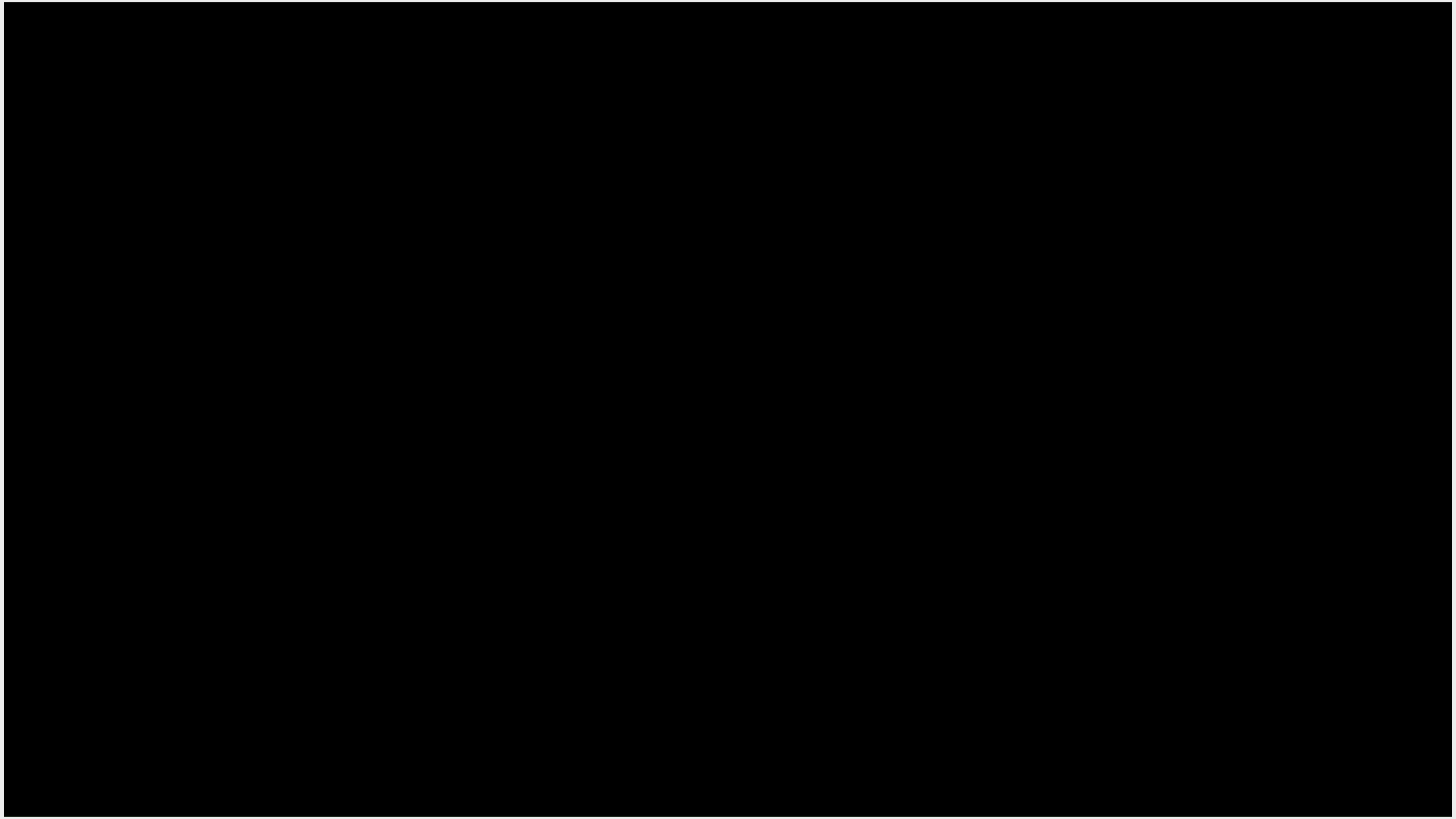
- Using AIS data and ship technical data, the team has developed models to estimate total emissions from international shipping.
  - annual fuel consumption and emissions by ship type and ship size.
  - emissions on particular routes can be further zoomed in and analyzed accordingly.





Centre for Maritime Studies

Visualization of Emissions

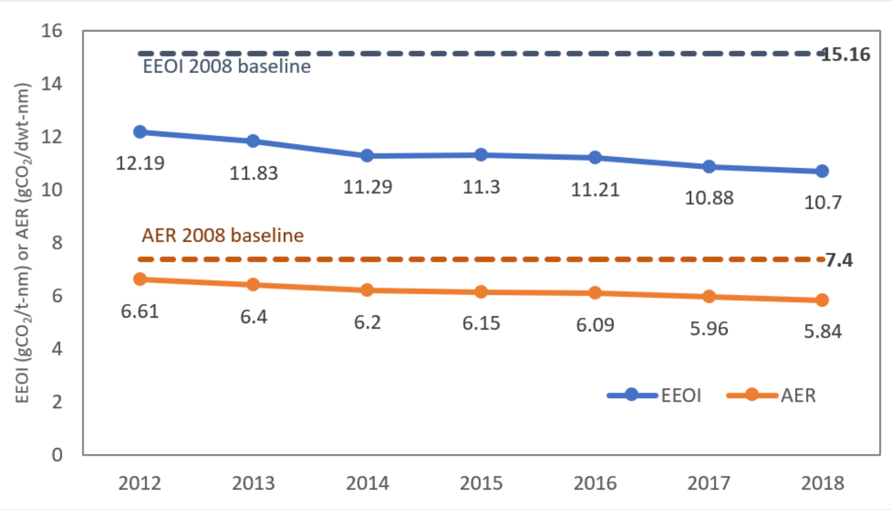


NUS National University of Singapore | Centre for Maritime Studies

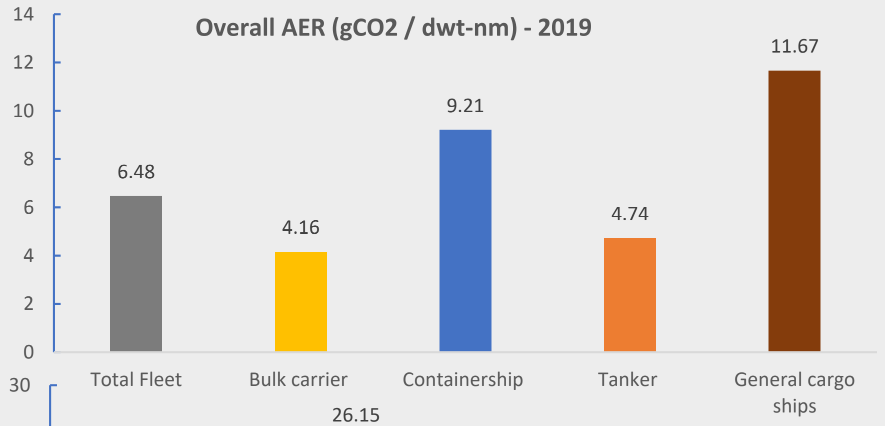
Carbon Intensity of Shipping

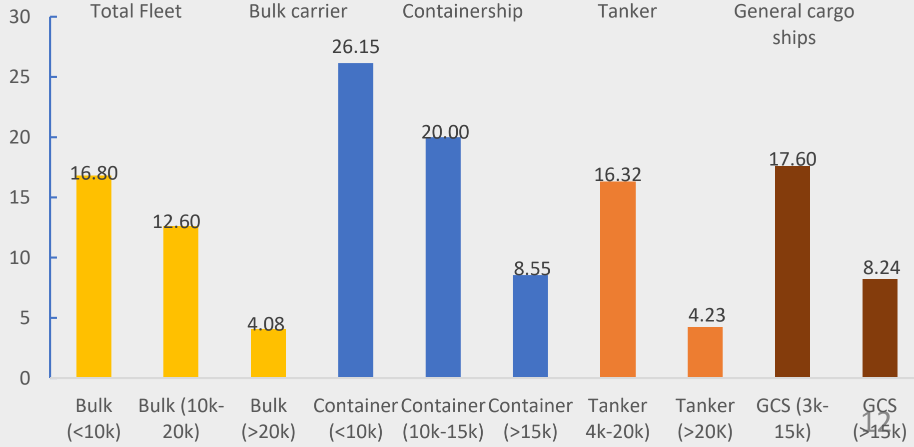
- **Enhancing energy / carbon efficiency** of ships is one of the approaches to reduce GHG emissions.
- IMO targets include reducing the carbon intensity (GHG emissions per transport work done) of international shipping by at least 40% by 2030.
- Operational Indicators:

$$EEOI = \frac{\sum_i (fuel\ consumption_i) C_i}{\boldsymbol{m}_{cargo} \times distance} \qquad AER = \frac{\sum_i (fuel\ consumption_i) C_i}{DWT \times distance}$$



decreasing trends in both the EEOI and AER over the decade





Research on Maritime Decarbonization

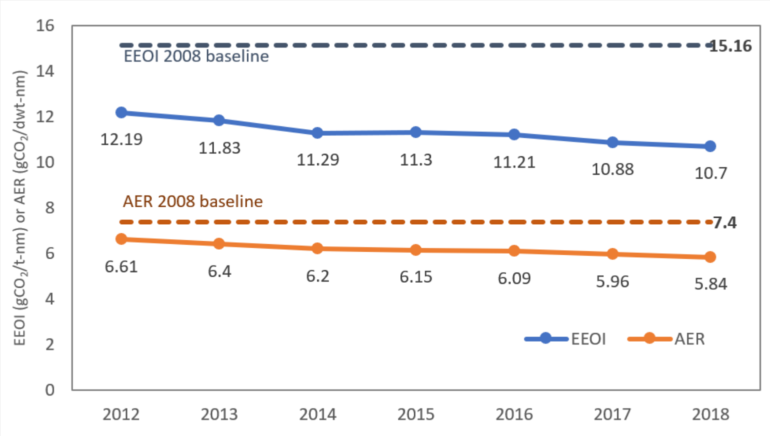
Current Status	Future Scenarios
Emission Modeling & Estimation and Intensity Estimation	**Projecting future emissions under different scenarios**
↓	↓
Understanding the drivers of changes in emissions over time	**Understanding economic and environmental impacts**

Understanding energy efficiency measures

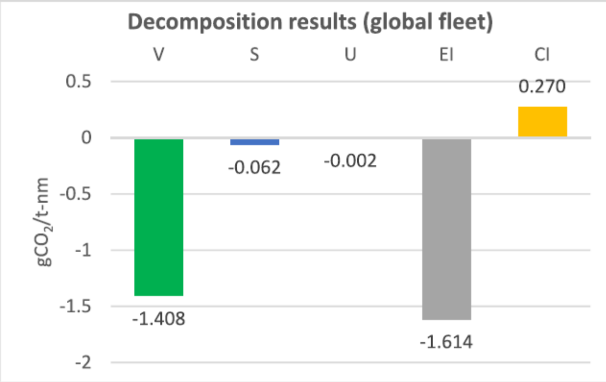
Decomposition identity:

$$V_{EEOI} = \sum_i \frac{CTM_i}{CTM} \frac{DTM_i}{CTM_i} \frac{F_i}{DTM_i} \frac{C_i}{F_i}$$

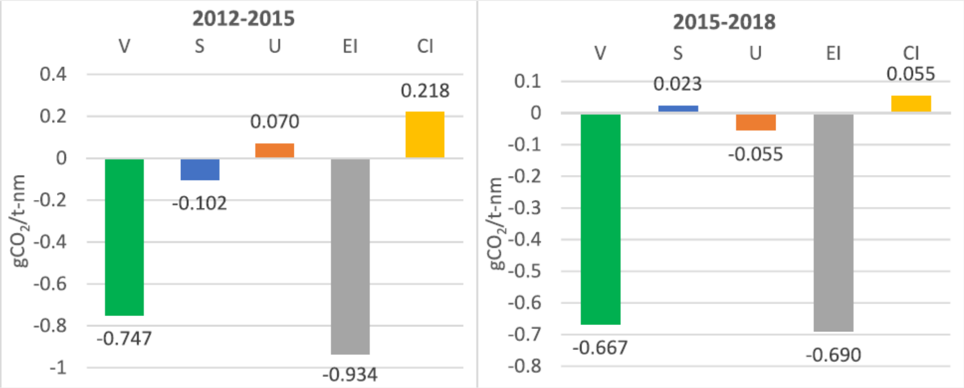
$$V_{AER} = \sum_i \frac{DTM_i}{DTM} \frac{F_i}{DTM_i} \frac{C_i}{F_i}$$



decreasing trends in both the EEOI and AER over the decade



Decomposition results (EEOI) for global fleet (2012-2018)



Decomposition results (EEOI) for global fleet (2012-2015); (2015-2018)

<u>Results and Insights</u>:

- Analyses of EEOI and AER share similar trends.
- **Energy intensity** was the most significant contributors to reductions in carbon intensity globally, and also across all ship types, while capacity utilization had minimal role.
- Indicates that **energy intensity is a significant long-term driver** and policies and actions taken by the industry have had an impact (e.g. EEDI, SEEMP, speed reduction), while **changes in structural and capacity utilization are driven by exogeneous market forces** that can cancel out or *reverse the effects* over long periods or on other drivers
- Further tightening of measures and enhancement of coverage of the energy efficiency requirements to existing ships are likely to bring about further improvements to energy efficiency. However, comparing 2012-2015 and 2015-2018, we see that there are *limitations to improvements in energy efficiency* (technical and operational measures reach their practical limits). Focus on **transformation of energy mix** required **to further improve**.

<u>Additional results</u>: Detailed decomposition by different ship types and joint analyses of EEOI & AER

Sou WS, Goh T, Lee XN, Ng SH, Chai KH (2022), Reducing the carbon intensity of international shipping – The impact of energy efficiency measures, *Energy Policy*, 170, 113239

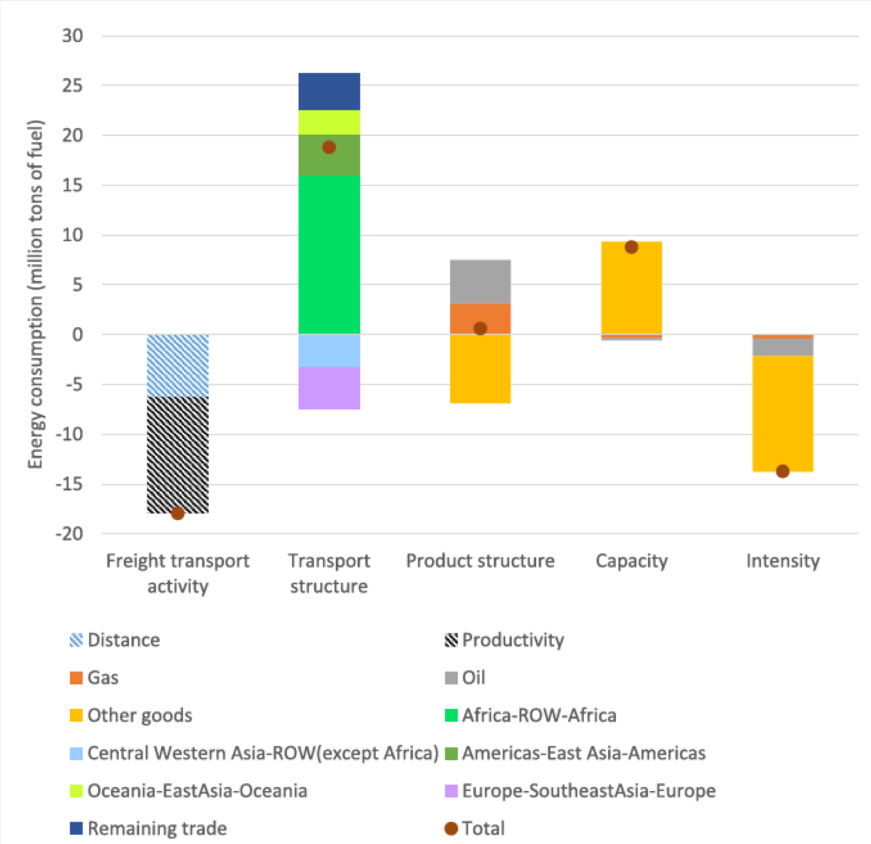
NUS National University of Singapore | Centre for Maritime Studies

Understanding freight transport activity

D – total distance travelled
$\frac{C}{D}$ - ratio of cargo transported to distance (cargo transport productivity)
$\frac{C_i}{C}$ - share of cargo ton transported along route i to total cargo transported
$\frac{C_{ij}}{C_i}$ - share of cargo tons of product j transported along route i
$\frac{K_{ij}}{C_{ij}}$ - inverse of capacity utilization
$\frac{F_{ij}}{K_{ij}}$ - energy intensity (energy consumption per dwt)

Decomposition identity: $F = \sum_{ij} D \frac{C}{D} \frac{C_i}{C} \frac{C_{ij}}{C_i} \frac{K_{ij}}{C_{ij}} \frac{F_{ij}}{K_{ij}}$

Aggregate decomposition results of changes in global fuel consumption (2014 – 2017)



Results & Insights

- Reductions in energy consumption came from improvements in energy intensity.
- Reductions are offset by an increase in energy consumption due to structural effects (changes in transport & product structures).
  - *transport activity shifted to routes involving Africa and East Asia, away from routes from Central & Western Asia* and routes *between Southeast Asia and the European Economic Area*.
  - *product structure shifted towards the transportation of energy products* (o&g), away from other non-energy products.
  - deterioration in capacity utilization was mainly attributed to the worsening utilization in vessels carrying non-energy products.
- The freight intensity effect has slowed the growth of fuel consumption.
  - highlights improvement in the energy consumption per ton of cargo transported, and this improvement is consistent across product types and routes
  - highlights usefulness and effectiveness of measures such as EEDI (mandatory since 2013) and the SEEMP guidelines (developed in 2016)

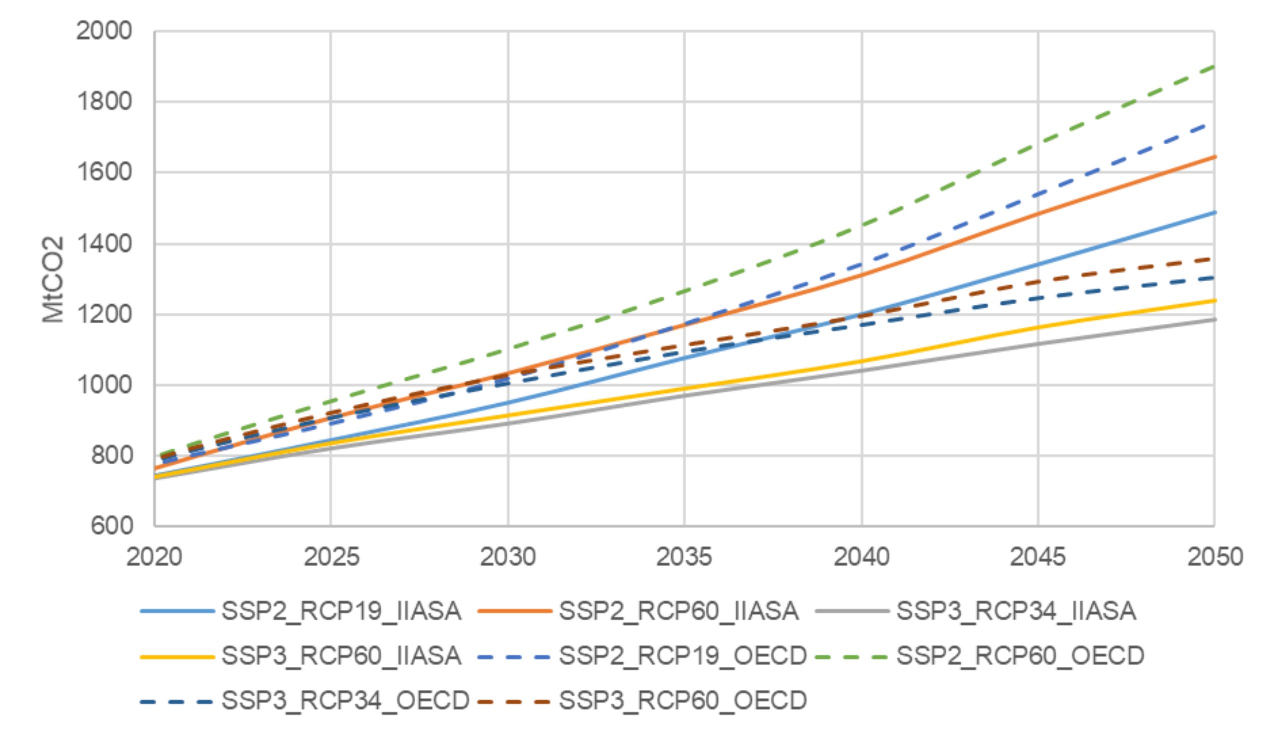
Zhong S, Goh T, Ang BW, Su B, Ng SH, Chai KH (2021), Driving Factors of Changes in International Maritime Energy Consumption: Microdata Evidence 2014 - 2017, *Energy Policy*, 154, 112288

Research on Maritime Decarbonization

Current Status	Future Scenarios
Emission Modeling & Estimation and Intensity Estimation	Projecting future emissions under different scenarios
↓	↓
Understanding the drivers of changes in emissions over time	Understanding economic and environmental impacts

Emissions Projection

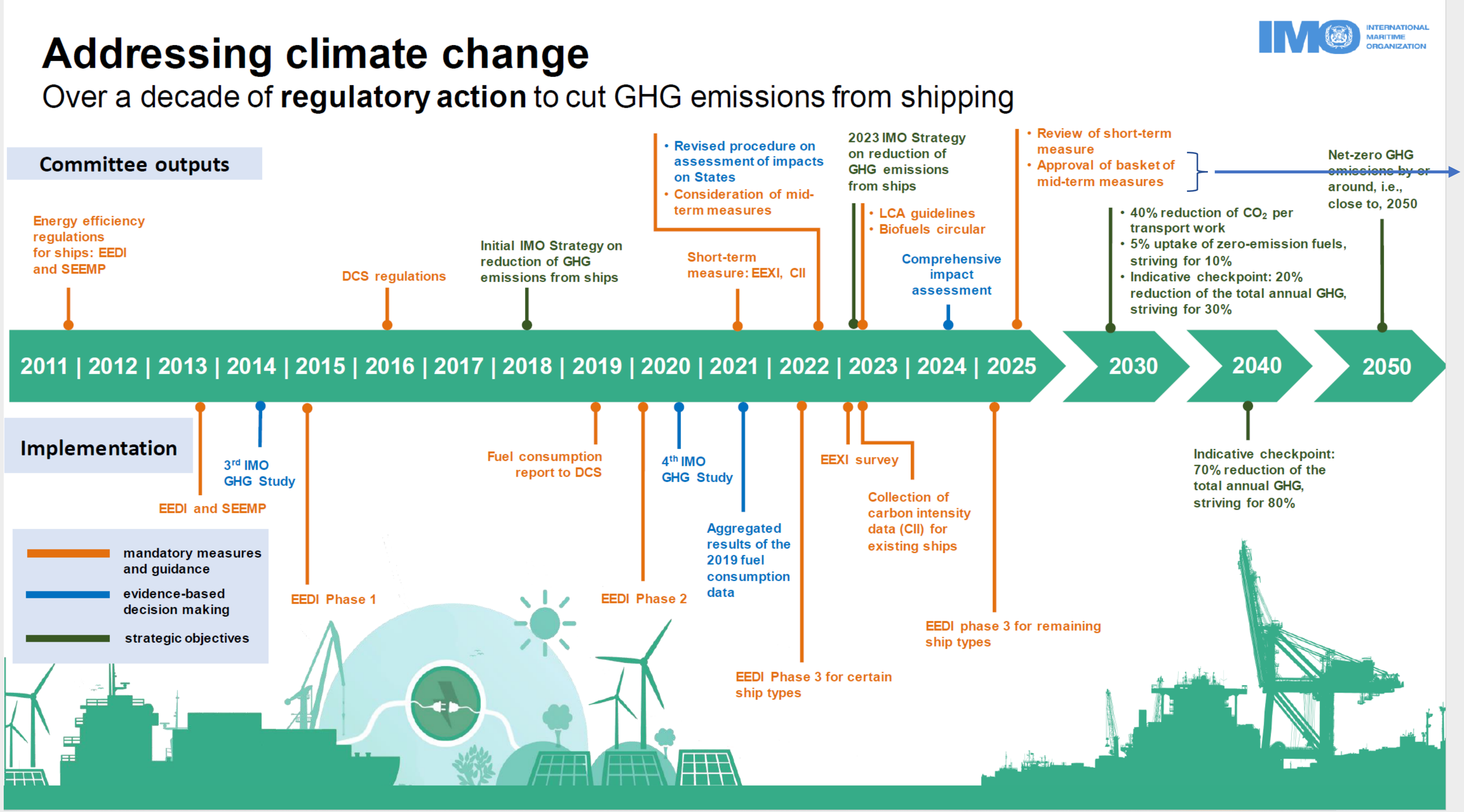
Forecast future emissions under various climate scenarios



Research on Maritime Decarbonization

Current Status	Future Scenarios
Emission Modeling & Estimation and Intensity Estimation	**Projecting future emissions under different scenarios**
↓	↓
Understanding the drivers of changes in emissions over time	**Understanding economic and environmental impacts**

Further regulatory actions



1. Technical measure: marine fuel standard
2. Economic measure: GHG pricing mechanism

Impact Assessment: Global and Regional

- There is increasing pressure to produce actions, and hence a need for greater granularity to answer questions such as:

TARGETS (or LEVELS OF AMBITIONS)

- Are we **on track** to meet 2030 & 2050 targets? If not, what's **the gap**?
- How should international shipping **achieve the targets**?

MEASURES & PATHWAYS

- What **other technologies / measures** need to come in place to fill the gap?
- How would the proposed **mid- & long-term energy measures** contribute to emission reduction?

IMPACT ANALYSIS

- What will be **the economic & environmental impact** of potential global (IMO) and regional measures and policies on **international shipping**?
- If the **Strategy** is tightened, how would it potentially impact international shipping **globally / regionally**?
- How should countries **prepare** for the global shift to decarbonize (e.g. as bunkering hub, transshipment hub, etc.)?

AIMMER

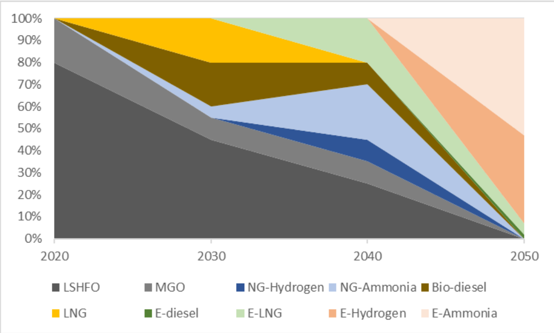
An integrated model developed to

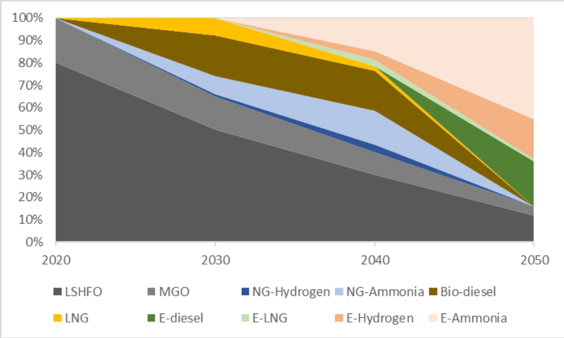
- Evaluate the global maritime transition pathways (policy, regulation & technology) through a series of scenario analysis
- Identify opportunities and gaps in decarbonization capabilities in the global shipping community

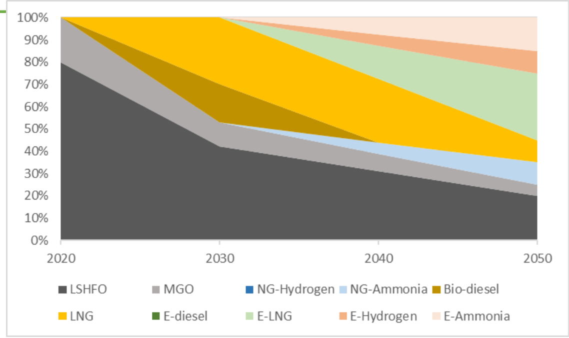
NUS National University of Singapore | Centre for Maritime Studies

Example: some scenarios and impact on global exports

	Scenario 1: High Ambition	Scenario 2: Moderate Ambition	Scenario 3: Low Ambition
	• **IMO Revised Strategy –** Absolute zero target for international shipping by 2050 • **High carbon price**, if agreed to	• **IMO Revised Strategy –** Net-zero target for international shipping by 2050 in Revised Strategy • **Medium carbon price**, if agreed to	• **IMO Revised Strategy –** Retain the same targets in Initial Strategy • **Low carbon price**, if agreed to or none at all
Base climate scenarios	**RCP1.9-SSP1**	**RCP1.9-SSP2**	**RCP2.6-SSP4**
Fuel pathways from UMAS(2021), DNV(2022), IEA(2021), IRENA(2021)	(chart 1 below)	(chart 2 below)	(chart 3 below)
Fuel Standard ISWG-GHG 12-3-3 (Austria et al.)	**High requirement**	**Min requirement to meet IMO Target**	**Min requirement to meet IMO Target**
Carbon prices ISWG-GHG 12-3-14 (Norway); MEPC 77-7-17 (CSC)	**2030: 210 USD/t-CO2** **2040: 255 USD/t-CO2** **2050: 300 USD/t-CO2**	**2030: 140 USD/t-CO2** **2040: 200 USD/t-CO2** **2050: 250 USD/t-CO2**	**2030: 75 USD/t-CO2** **2040: 150 USD/t-CO2** **2050: 200 USD/t-CO2**







Note:

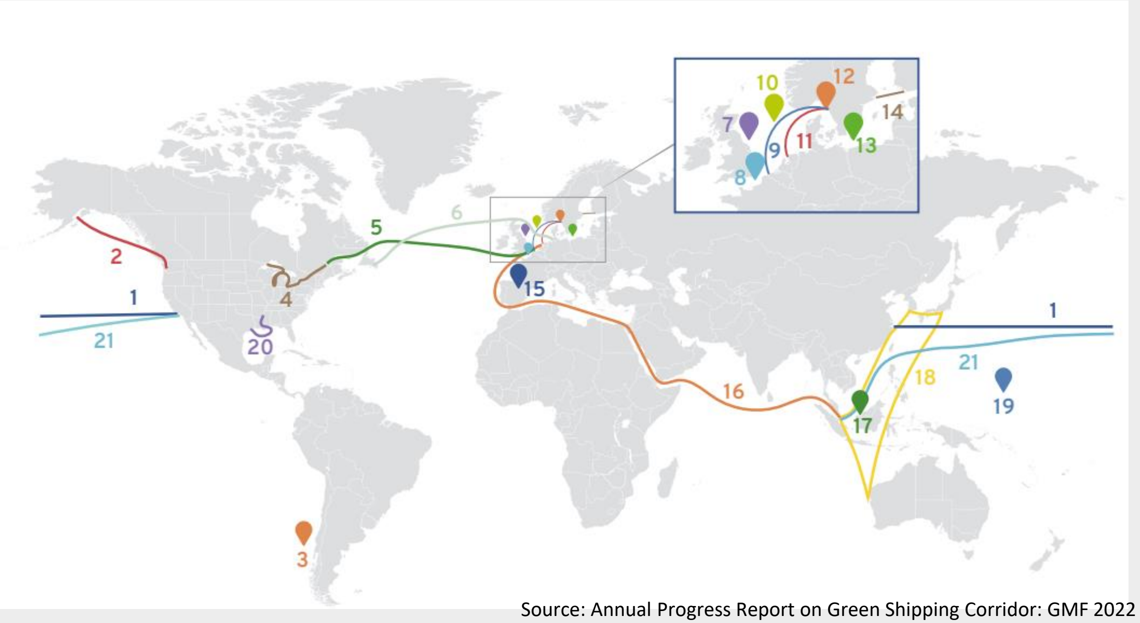
- Low ambition scenario is observed to have smaller adverse impact to global total goods loaded (from BAU)
- By 2050, the high ambition scenario is observed to have positive impact to global goods loaded, due to projected high carbon price and low price for zero-/low-emission alt. fuels (impact sensitive to various scenario inputs such as prices)

Regional - Green & Digital Shipping Corridors

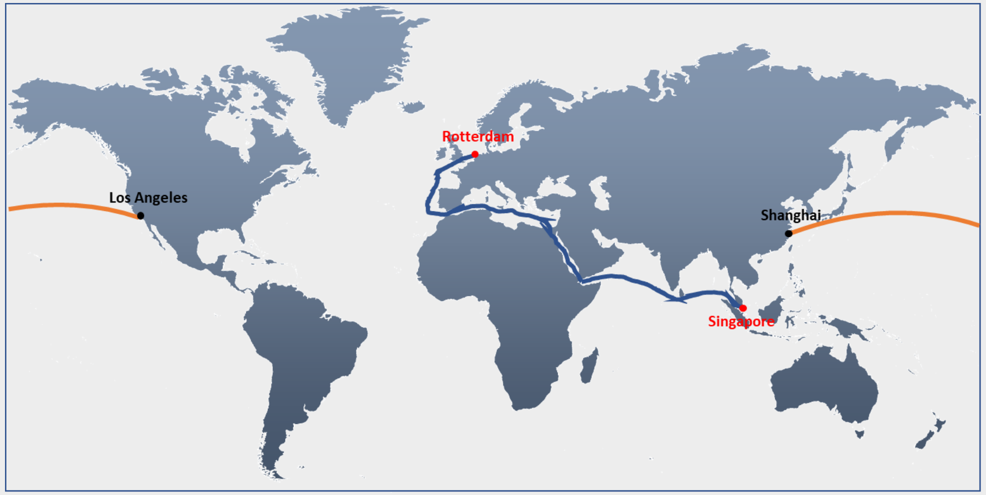
- Arena where value chain stakeholders come together and deploy new technologies and business models (help a diverse and disaggregated industry align and diversify collective risks)
- Increasingly viewed as essential tool to kick-start shipping's transition to zero emissions

*Planning and development of **green** and **digital shipping corridors** to enable low and zero carbon shipping*

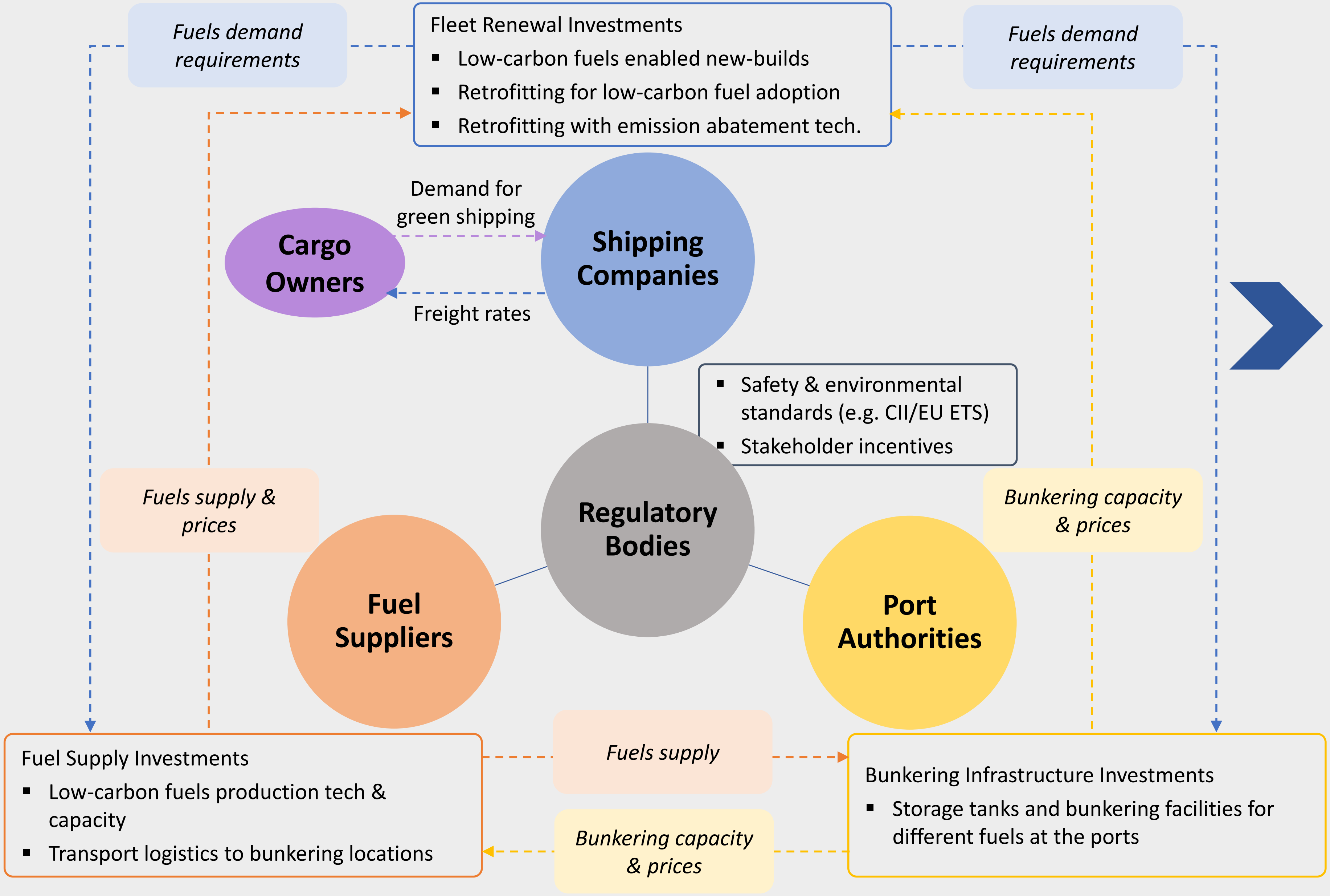
- identify feasible technological (fuel and infrastructure) pathways, cost gaps and policy and instruments (public and private) needed to achieve reduction targets (goals) on major shipping routes.



Source: Annual Progress Report on Green Shipping Corridor: GMF 2022



Green Corridor: Multi-Stakeholder Collaboration



Corridor Green Objectives:

- ✓ Reduction in carbon intensity and GHG emissions
- ✓ Adoption of near-zero & zero emission fuels adoption

Cost Gap for Green Shipping

<u>Cost Gap</u>: "**Additional cost that is incurred to achieve the green shipping targets of the corridor**"

Additional Capex & Opex (vessels, fuels, infrastructure) that corridor stakeholders must invest to meet the green shipping targets in the long-term

Δ Cost = Cummmulative estimated cost under green corridor shipping (GCS) case − Cummulative estimated cost under business−as−usual (BAU) case

BAU Case: Stakeholders operating under existing maritime decarbonization guidelines *(CII, regional ETS)*

GCS Case: BAU guidelines + green shipping targets *(emissions/carbon intensity reduction and low-carbon fuels adoption)*

Cost Gap for Green Shipping

Vessel/Voyage-related investments

- New-build acquisitions (alternative-fuels enabled)
- Existing vessel retrofitting (energy efficiency & alt-fuel conversions)
- Fleet deployment operations utilizing alternative-fuels

Fuel demand

Fuel supply & prices

Fuel-related investments

- Alternative-fuels production: technologies, capacity
- Fuel storage and distribution logistics infrastructure

Cost Gap for Shipping Companies

Financial Incentives & Policy Design
Green loans, CFDs, tax rebates, subsidies

Cost Gap for Fuel Suppliers

Case Study Insights: gaps and driving factors

Output		Insights / Key Driving Factors
Cost Gap GCS case - BAU case	Cumulative cost gap Annual Cost Gap per TEU	• Absolute WtW CO2-eq emissions reduction targets • Fuel Opex major contributor to cost gap between GCS and BAU cases • Lower (Capex) investments in early periods • Higher (Opex) investments in later periods
Fuel Energy Share		• Relative emissions MAC curves of fuels (prices & emissions factors) along with the supply availability drives the adoption choice alt-fuel mix
Fleet Composition		• In all fuel (price & supply) scenarios, a mix of dual fuel Methanol and Ammonia ships come into operation. • No significant variation in fleet composition in different scenarios
Binding Targets	BAU case	• Vessel CII requirements
	GCS case	• Depending on corridor targets. Needs to be more stringent than current CII (e.g. absolute targets, alt-fuel adoption targets)

Key Insights: closing the gap

Output		Value Range
Cost Gap GCS case - BAU case	Cumulative cost gap	**X - Y USD**
	Annual Cost Gap per TEU	**xx - yy USD/TEU**

close the gap

% - cargo owners (e.g. buyers alliance)

% - financial instruments
(private / public); CfD

⋮

% - rebates / subsidies

Summary

- Maritime Decarbonization is a large and challenging problem but shipping must do its part to help mitigate climate change.
- Various international and regional targets have been set to achieve net-zero emissions by 2050.
- Net-zero emissions require aggressive adoption of emission mitigation measures including green fuels, new technologies, regulatory policies and co-operative efforts across states and regions.
- Actions are rapidly evolving to facilitate the transition.
- At CMS, we focus on the *modeling* and *analytics* to understand the complexities of current state and *future* possibilities / *scenarios*; and importantly the economic and environmental impact of various future pathways and regulations.
  - important as states / regions will likely experience different impacts from maritime decarbonization actions

Thank You

isensh@nus.edu.sg