RFF-CMCC-NAVIGATE Webinar
Key findings from the NAVIGATE project

Breakout session Shipping

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CENERGIA/COPPE

RFF CMCC European Institute on Economics and the Environment

NAVIGATE

NAVIGATE work on shipping - examples

Decarbonizing the International Shipping and Aviation Sectors

by Panagiotis Fragkos

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Energies **2022**, *15*(24), 9650; https://doi.org/10.3390/en15249650

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Global futures of trade impacting the challenge to decarbonize the international shipping sector

Eduardo Müller-Casseres [a], Oreane Y. Edelenbosch [b], Alexandre Szklo [a], Roberto Schaeffer [a], Detlef P. van Vuuren [b c]

Production of alternative marine fuels in Brazil: An integrated assessment perspective

Eduardo Müller-Casseres [a], Francielle Carvalho [a], Tainan Nogueira [a], Clarissa Fonte [a], Mariana Império [a], Matheus Poggio [a], Huang Ken Wei [a], Joana Portugal-Pereira [a b], Pedro R.R. Rochedo [a], Alexandre Szklo [a], Roberto Schaeffer [a]

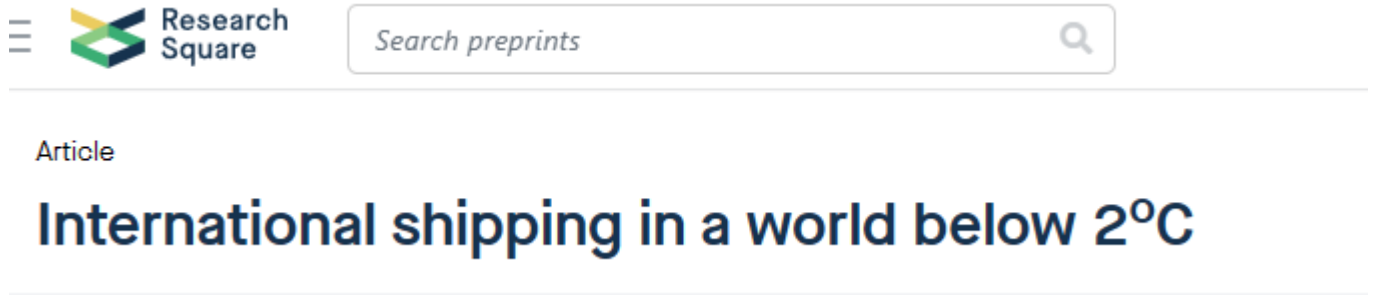
NAVIGATE work on shipping

Model intercomparison 2022

Submission in early 2023

First revision submission in August

Second revision submission in 3 days



International shipping in a world below 2°C

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Rebecca Draeger
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Alexandre Szklo
Roberto Schaeffer

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Nikolaos Tsanakas

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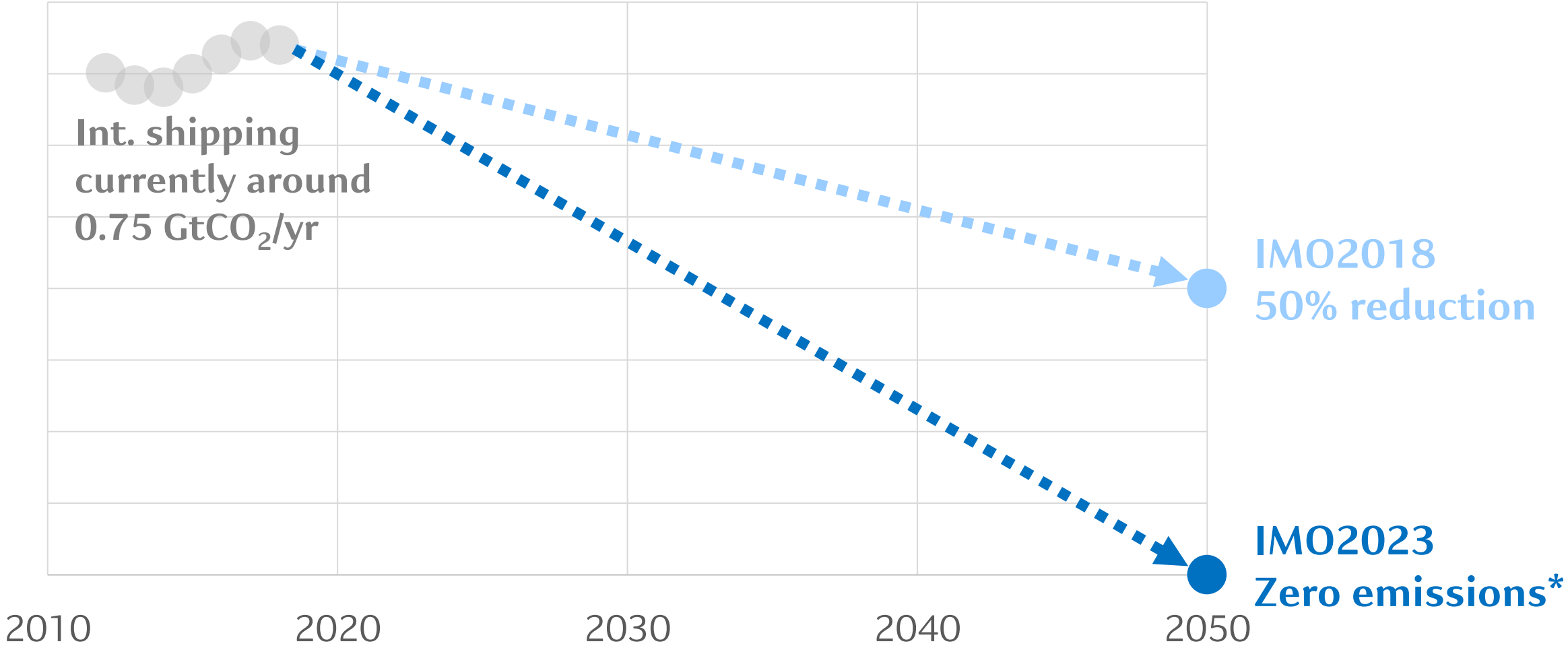
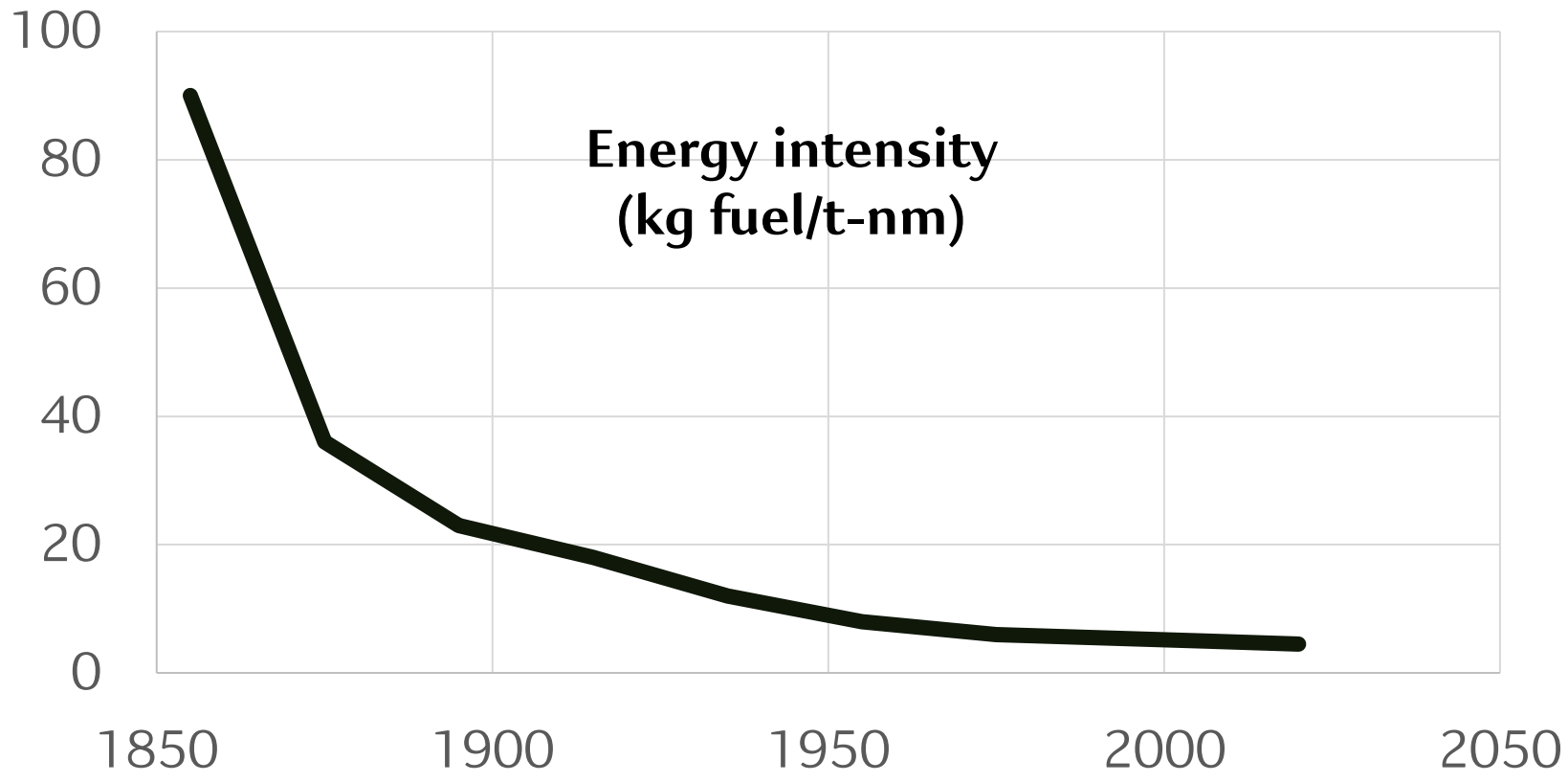
Florian Leblanc
Thomas Le Gallic

Maarten van den Berg
Isabela S. Tagomori
Detlef P. van Vuuren
Harmen-Sytze de Boer

IMO2018 and IMO2023

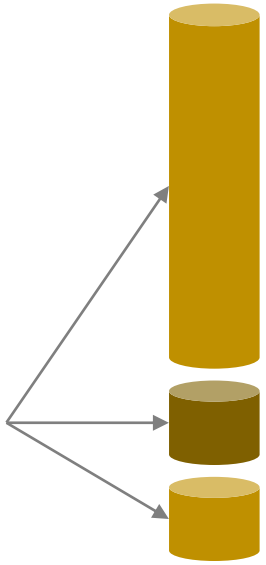


A decreasing energy efficiency improvement potential

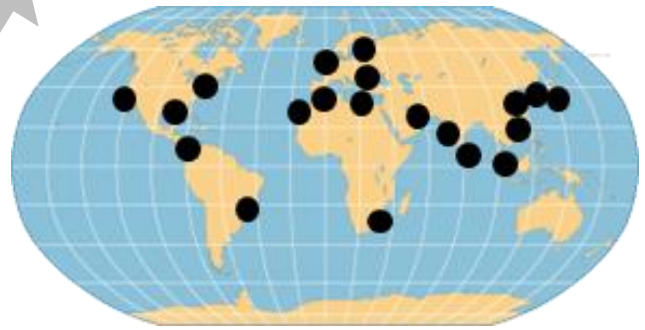


Interactions with the energy system and obstacles to alternative fuels

Crude oil
~170 EJ/yr



Int. shipping
~9 EJ/yr

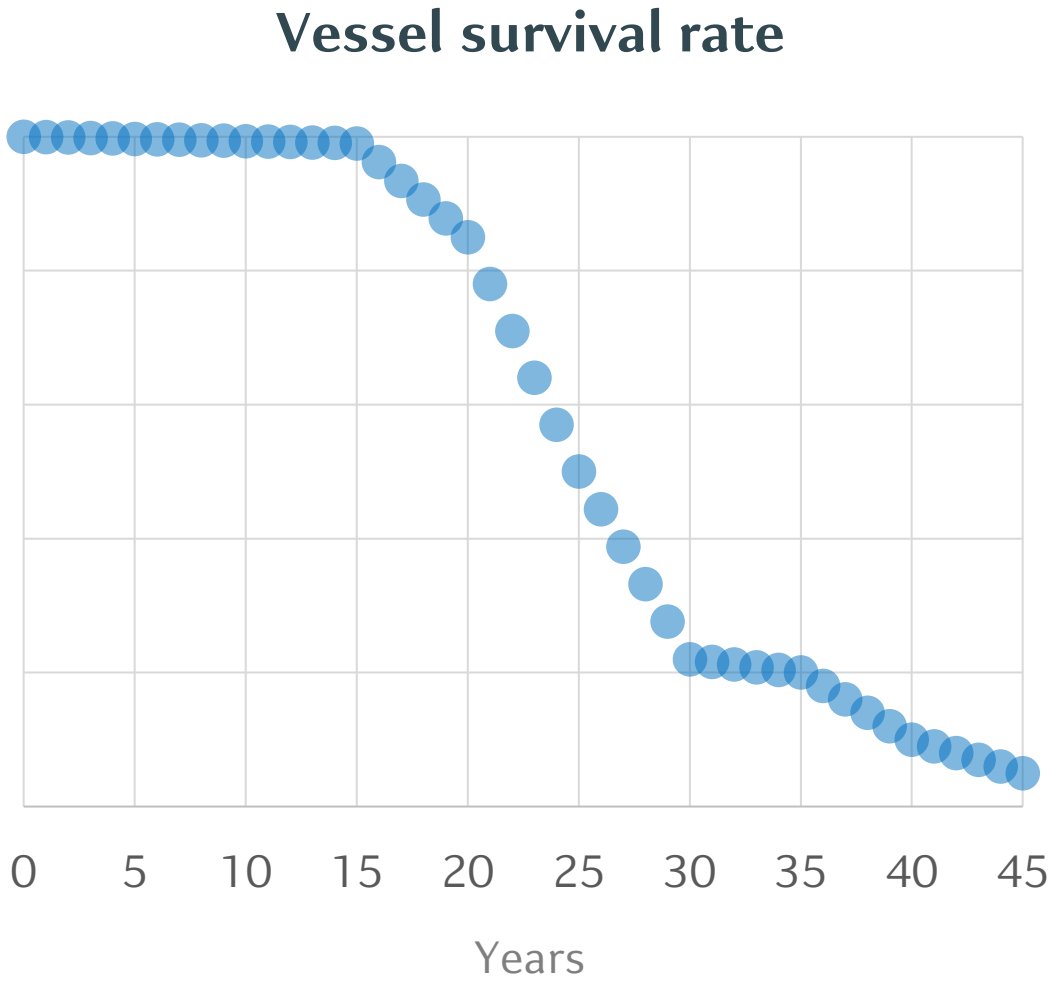


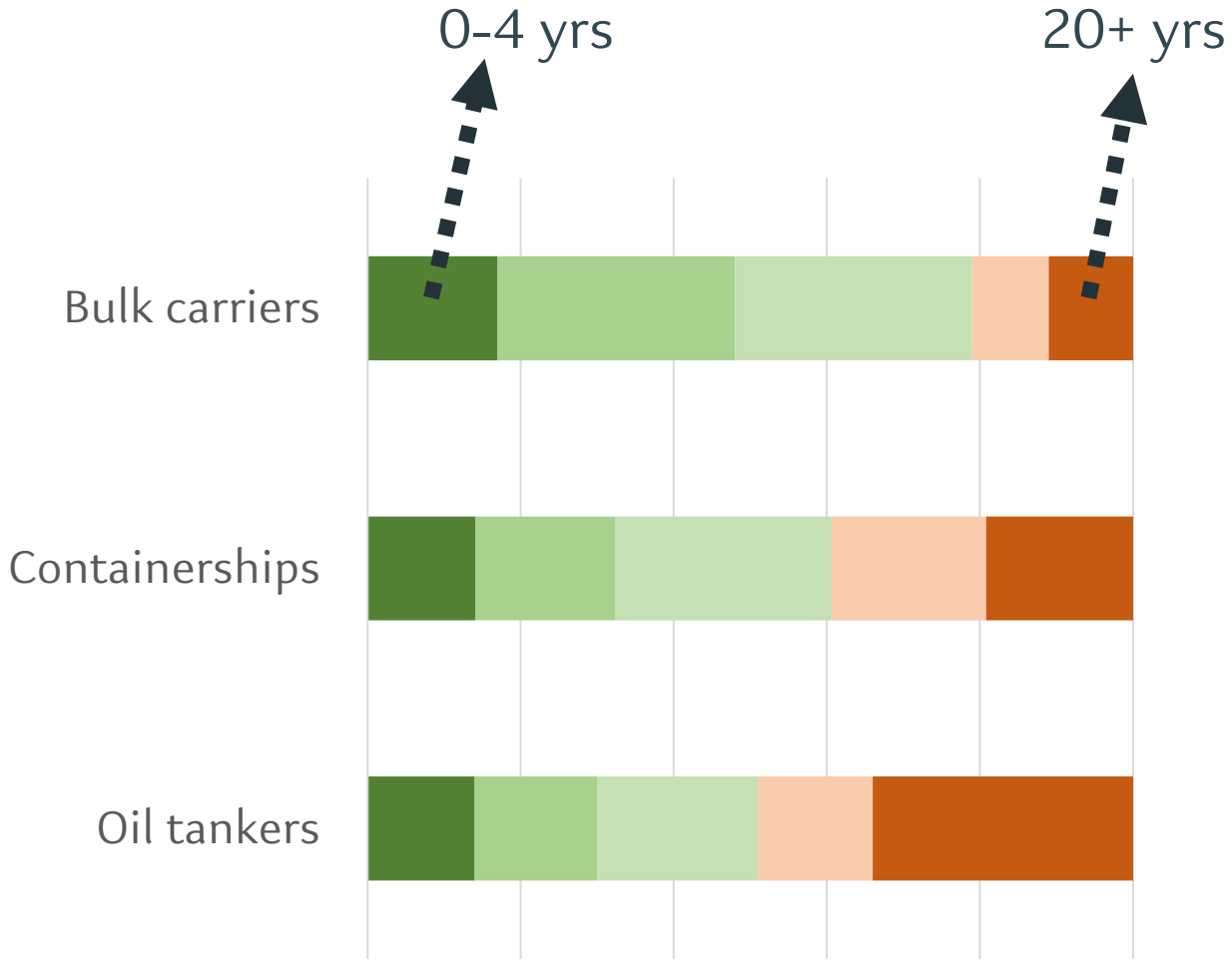
Fuelling hubs
Homogeneous industry

	Production maturity	Applicability	Energy density	Safety and toxicity
Alcohols	+	0	0	+
Ammonia	0	−	−	−
Hydrogen	0	−	x	−
Natural gas	+	0	0	0
Synthetic liquids	−	+	+	+
Vegetable oils	+	0	+	+

In contrast…

Technological inflexibility





1. MODELLING TOOLS

Selection of IAMs suited to the analysis of int. shipping

NAVIGATE project

Focus on improving the capability of IAMs

IMACLIM-R

COFFEE

IMAGE

WITCH

PROMETHEUS

TIAM-UCL

2. SCENARIO DESIGN

IPCC WG3 AR6 categorization

2020-2100 carbon budgets

Models' capabilities

Scenario design

SSP2 assumptions

NDC **C1000** **C600** **C400**

Unfeasibility issues

Model runs

3. RESULTS - SCENARIO ANALYSIS

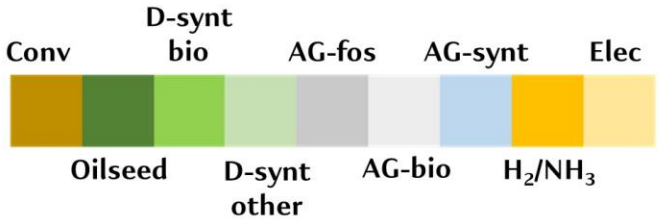
Global CO_2 emissions

Global primary energy

Int. shipping CO_2 emissions

Int. shipping final energy

4. CATEGORIZATION



Intercomparison models

	Time horizon	Type	Solution method	Solution concept	Int. shipping demand	Discount rate % p.a.
COFFEE 1.5	2100	Bottom-up	Intertemporal optimization with perfect foresight	Partial equilibrium, focusing on energy, agriculture, and land use	Endogenous for main energy and agricultural products. General cargo driven by GDP. For most products, int. shipping demand is a result from the global model optimization	5
IMACLIM-R 2.0	2100	Hybrid	Recursive dynamic	General equilibrium (closed economy)	Endogenous to trade activities of all economic sectors	n/a
IMAGE 3.2	2100	Bottom-up	Recursive dynamic	Partial equilibrium (price elastic demand)	Demand is projected with constant elasticity of the industry value added, and demand sensitivity to transport prices depends on its share of energy costs in the total service costs	10
PROMETHEUS 1.2	2050	Hybrid	Recursive dynamic	Energy system simulation model, focusing on demand and supply	Semi-endogenous driven by trade of energy products and GDP developments	8
TIAM-UCL 4.1.2	2100	Bottom-up	Intertemporal optimization with perfect foresight	Partial equilibrium, focusing on the energy system	Endogenous for main energy commodities. General non-energy cargo driven by GDP	3.5
WITCH 5.0	2100	Hybrid	Intertemporal optimization with perfect foresight	General equilibrium	Demand evolution is based on calibrated income and price elasticities	Ramsey rate (3-5)

Energy conversion in ships

COFFEE 1 → 3 → 4 → 5

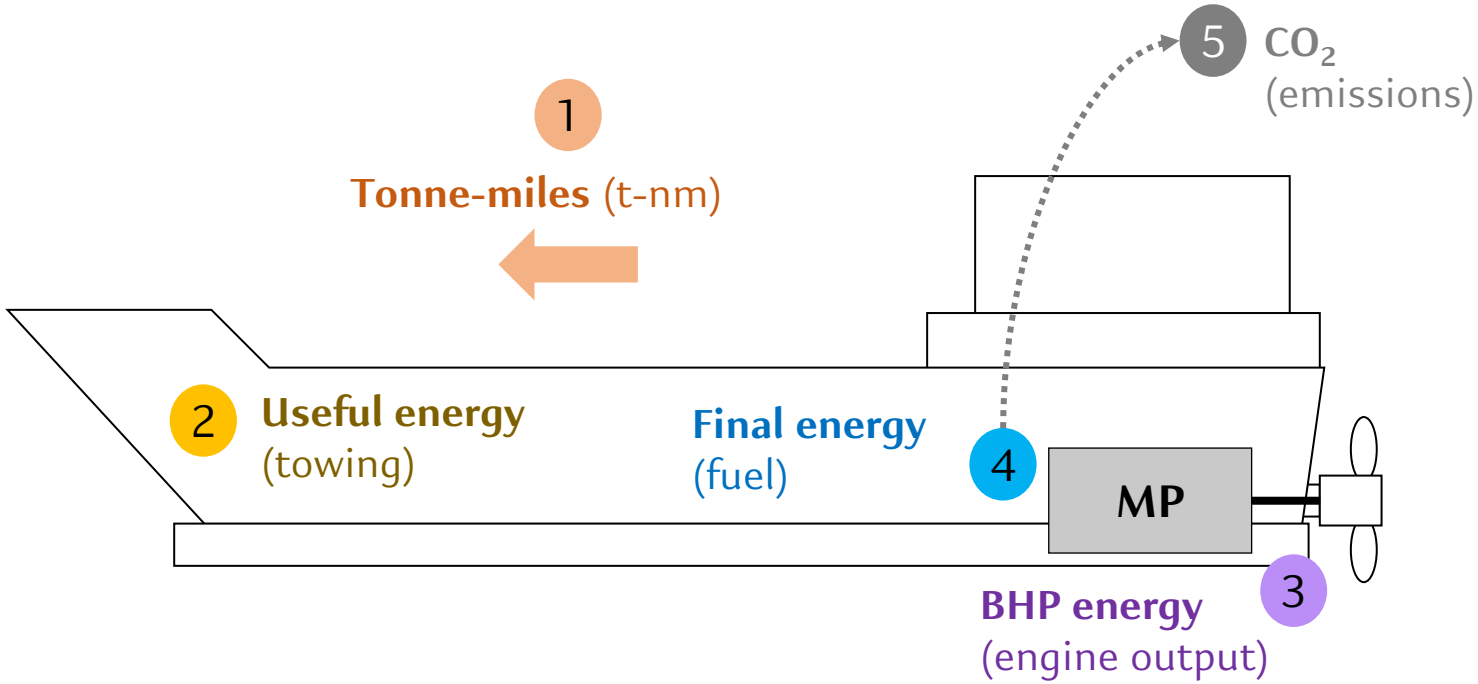
IMACLIM-R 1 → 4 → 5

IMAGE 1 → 4 → 5

PROMETHEUS 1 → 3 → 4 → 5

TIAM-UCL 4 → 5

WITCH 1 → 3 → 4 → 5

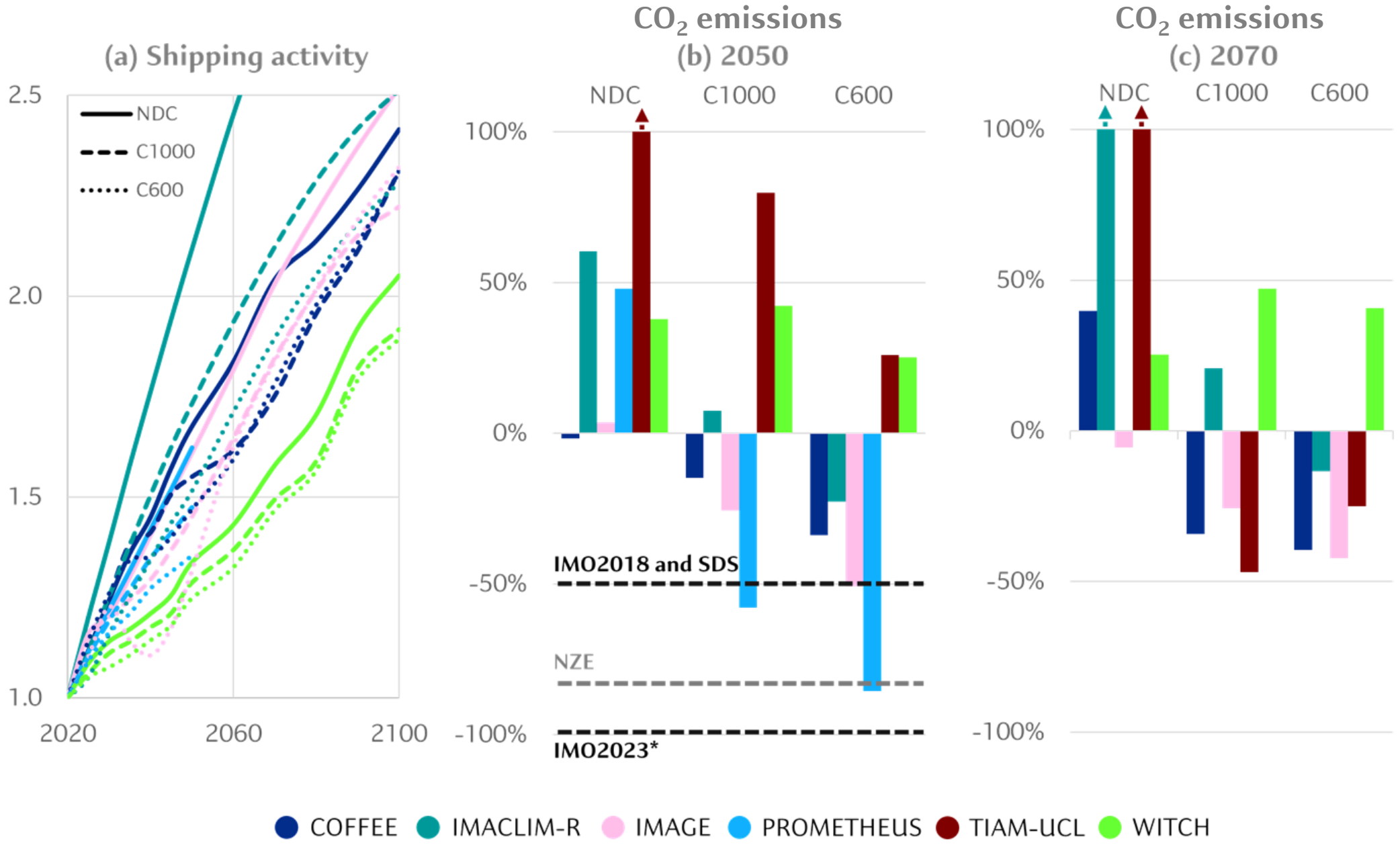


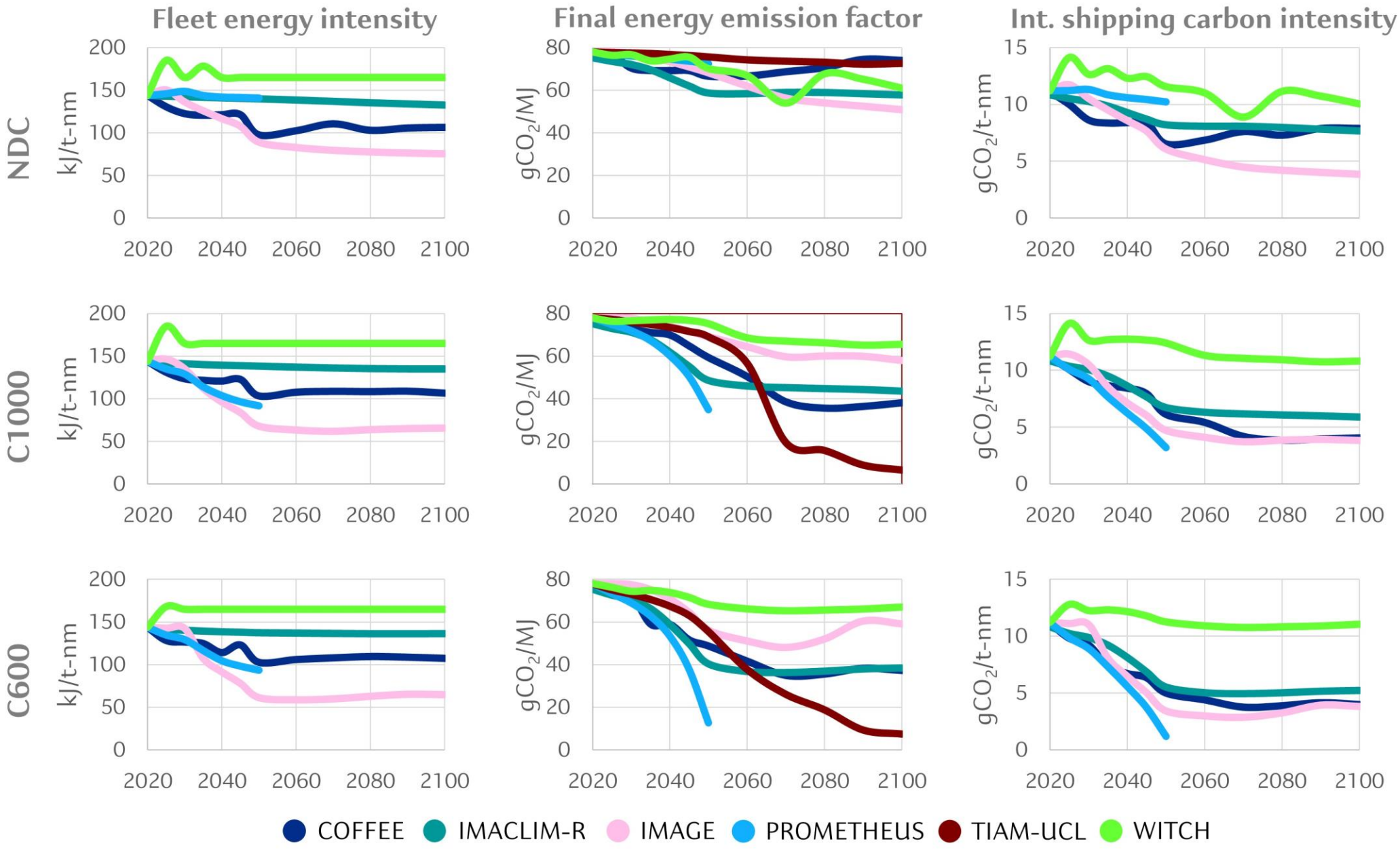
Fuel groups

Group	Description	Examples
Conv	Conventional marine fuels	Heavy Fuel Oil (HFO) Marine Diesel Oil (MDO) Marine Gas Oil (MGO)
Oilseed	Animal fats- and oilseed-based fuels	Biodiesel Hydrotreated Vegetable Oil (HVO) Straight Vegetable Oil (SVO)
D-synt bio	Synthetic drop-in biofuels	Biomass-to-Liquids diesel (BtL-diesel) Biomass-to-Liquids heavy (BtL-heavy)
D-synt other	Other drop-in synthetic fuels	Power-to-Liquids diesel (e-diesel) Power-to-Liquids heavy (e-heavy)
AG-fos	Fossil alcohol and gases	Fossil Liquified Natural Gas (LNG) Fossil Liquefied Petroleum Gas (LPG) Fossil methanol
AG-bio	Bio-alcohols and biogases	Bio-LNG Biomethanol Ethanol
AG-synt	Synthetic alcohols and gases	Power-to-Gas LNG (e-LNG) Power-to-Gas LPG (e-LPG) Power-to-Liquids methanol (e-methanol)
H_2/NH_3	Hydrogen and ammonia	Hydrogen Ammonia
Elec	Electricity	Electricity

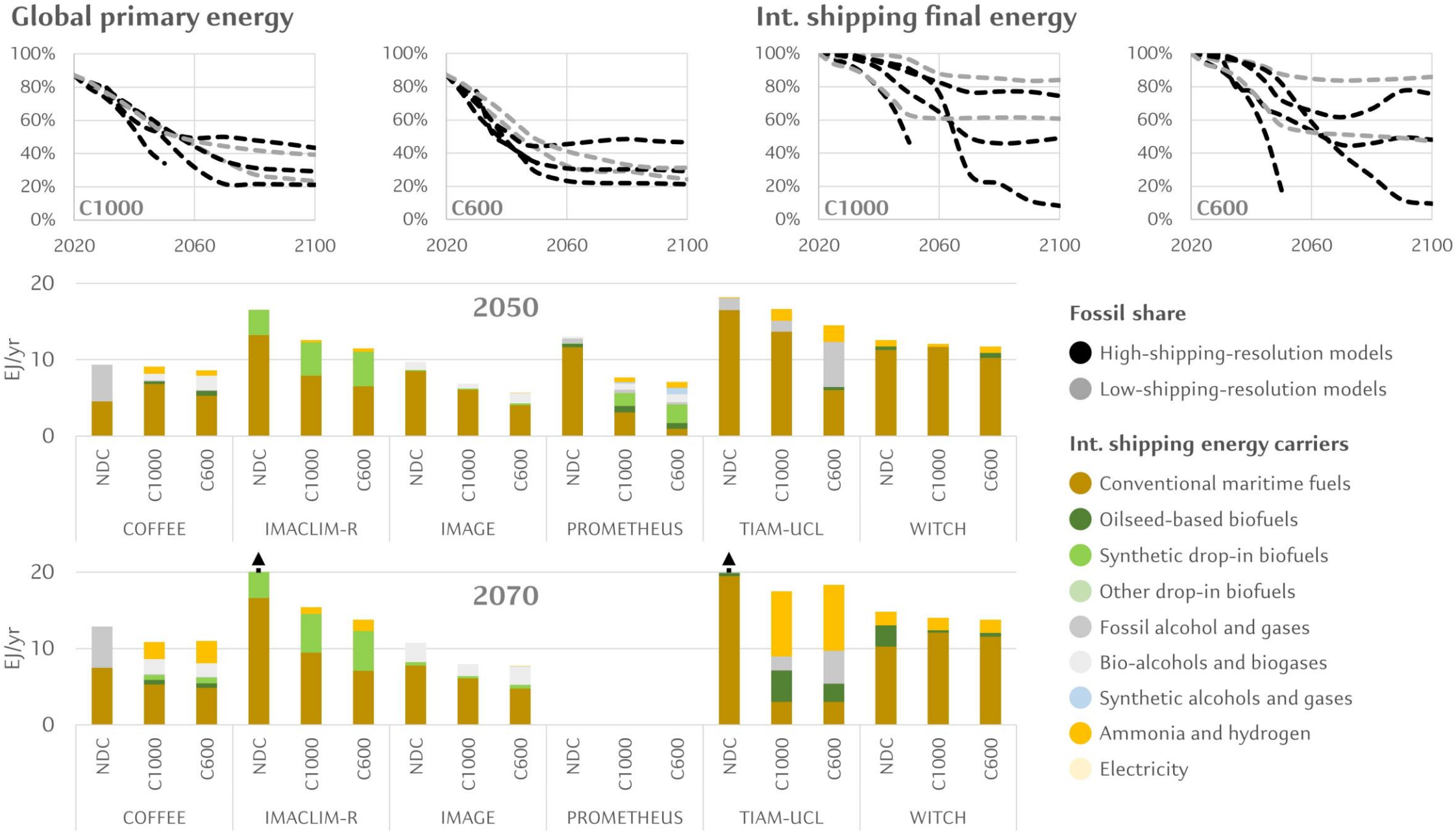
	COF	IMC	IMG	PMT	TIA	WTC	Fuel group
Heavy Fuel Oil (HFO)	X	X	X	X	X	X	Conv
Marine Diesel Oil (MDO)	X	X	X	X	X	X	
Straight Vegetable Oil (SVO)	X			X			Oilseed
Hydrotreated Vegetable Oil (HVO)	X		X	X			
Fatty Acid Methyl Esters (FAME)	X			X	X	X	
Biomass-to-Liquids Diesel (BtL-Diesel)	X	X	X	X			D-synt bio
Biomass-to-Liquids Heavy (BtL-Heavy)	X						
Hydrogen-Based Diesel (H_2-Diesel)	X			X		X	D-synt other
Hydrogen-Based Heavy (H_2-Heavy)	X						
Fossil Liquefied Natural Gas (Fossil LNG)	X			X	X		AG-fos
Fossil Liquefied Petroleum Gas (Fossil LPG)	X						
Fossil Methanol	X						
Bio-Based Liquefied Natural Gas (Bio-LNG)				X			AG-bio
Biomass-to-Liquids Liquefied Petroleum Gas (BtL-LPG)	X						
Biomethanol	X		X	X			
Ethanol	X		X				
Hydrogen-Based Liquefied Natural Gas (H_2-LNG)				X	X		AG-synt
Hydrogen-Based Liquefied Petroleum Gas (H_2-LPG)	X						
Hydrogen-Based Methanol	X					X	
Hydrogen	X		X	X	X	X	H_2/NH_3
Ammonia	X	X		X	X		
Electricity				X			Elec

Results
Int. shipping CO_2 emissions


(a) Shipping activity
2.5
2.0
1.5
1.0
2020
2060
2100
NDC
C1000
C600
CO_2 emissions
(b) 2050
NDC
C1000
C600
100%
50%
0%
-50%
-100%
IMO2018 and SDS
NZE
IMO2023*
CO_2 emissions
(c) 2070
NDC
C1000
C600
100%
50%
0%
-50%
-100%
COFFEE
IMACLIM-R
IMAGE
PROMETHEUS
TIAM-UCL
WITCH


Fleet energy intensity
Final energy emission factor
Int. shipping carbon intensity
NDC
C1000
C600
kJ/t-nm
gCO2/MJ
gCO2/t-nm
0
50
100
150
200
20
40
60
80
5
10
15
2020
2040
2060
2080
2100
COFFEE
IMACLIM-R
IMAGE
PROMETHEUS
TIAM-UCL
WITCH

Results
Int. shipping fuel mix


Global primary energy
Int. shipping final energy
100%
80%
60%
40%
20%
0%
C1000
C600
2020
2060
2100
2050
2070
EJ/yr
20
10
0
NDC
C1000
C600
COFFEE
IMACLIM-R
IMAGE
PROMETHEUS
TIAM-UCL
WITCH
Fossil share
High-shipping-resolution models
Low-shipping-resolution models
Int. shipping energy carriers
Conventional maritime fuels
Oilseed-based biofuels
Synthetic drop-in biofuels
Other drop-in biofuels
Fossil alcohol and gases
Bio-alcohols and biogases
Synthetic alcohols and gases
Ammonia and hydrogen
Electricity

Key findings - shipping

- Diversity of candidate alternative fuels
  - Production routes
  - Final energy carriers
- The decarbonization of shipping should be seen as part of a wider challenge
- IAMs show that a combination of fuel options is required to achieve decarbonization
- Models that represent several low-carbon alternatives tend to show a deeper emission reduction
- Strong relation with CDR
- IMO2018 aligns with the perspective brought by IAMs
- IMO2023 requires further attention – future studies

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Key findings from the NAVIGATE project

Thank you.

Eduardo Müller-Casseres
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