An IAM-based framework for evaluating the environmental impact of low-cost technological solutions in the container shipping industry

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Introduction

We focus on the container shipping industry and consider a **low-cost technology**, namely a **lighter type of container**, which can **reduce fuel consumption** and **save trees**. We evaluate the global impact of this technology until **2050** using an **IAM**, considering different projections about the future characteristics of the container fleet, including its **capacity** and **size**, as well as the main **types of fuel** and **steaming** practices used by the container ships.

Materials and Methods

MUSE

The **ModUlar energy systems Simulation Environment** is an integrated assessment modeling framework, used to generate national and multi-regional energy systems models by simulating technology transitions.

- Transitions are simulated from 2010 to 2050 on a global scale using a 28-regions representation of the world
- The value and role of each technology is assessed
- Robust strategies, business models, and R&D investments are identified while consistent climate change mitigation pathways are determined

Container 2.0

Container 2.0 is the technological game-changer considered for reducing fuel consumption and saving trees. This new type of container:

- **Weighs 21% less** than the ones currently used
- Does **not require wood** for the construction of its floor

Container fleet

Our results build on **projections** made about the future characteristics of the container fleet, as follows:

- We examine the **seven most popular classes of container ships**, namely Small Feeder, Feeder, Feedermax, Panamax, Post Panamax, New Panamax, and Ultra Large Container Vessel
- We consider **new-buildings** projections and existing **decommissioning** profiles
- We estimate the fuel consumption reduction of each class of container ship separately when freight weight is declined according to the **technical characteristics** of each class

Scenarios

Fuel consumption reduction and tree savings are computed by:

- Exploiting **GDP**, **population**, and **demand** projections, as captured by the **SSP2** pathway and MUSE simulations
- Considering three scenarios of adopting different fuel technologies, namely **MDO**, **HFO**, and **LNG**
- Considering four **steaming** (operational speeds) scenarios, namely "steaming" (S), "slow-steaming" (SS), "super-slow-steaming" (SSS), and "economical steaming" (ES).

Container fleet capacity and size projections

- MUSE demand projections are used to determine the growth rate of the industry and fleet capacity
- Recent trends in new-buildings are also considered exogenously

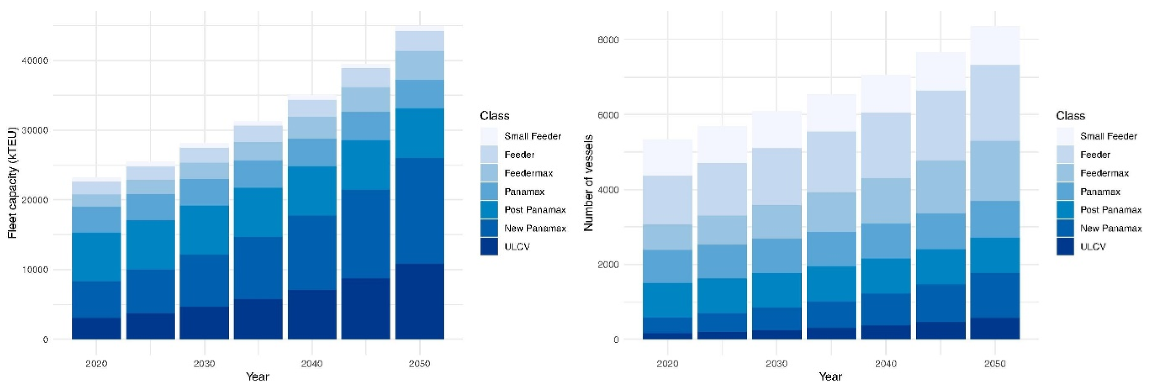

Figure 2: Projections made about the capacity and the size of the global container fleet from 2020 to 2050 per vessel class, as specified by MUSE and the most recent trends in new-buildings.

CO2 emission reductions due to freight weight decline

- Our calculations are based on the **EcoTransIT World** calculator, determining CO_2 emissions on the basis of fuel consumption and transportation distances
- The calculations were performed assuming a "**reference**" ship of each class, the key characteristics of which have values equal to the average vessel of the corresponding class
- In each case, the four **steaming** scenarios are considered

Class	Number of vessels	Total capacity (TEU)	Proportion of fleet (%)	Proportion of capacity (%)	Average Capacity (TEU)	Average Freight (TEU)	Design speed (knots)	Days at sea	Fuel consumption (liters per km) S	SS	SSS	ES
Small Feeder	968	641,978	18.10%	2.80%	663	431	16.52	190	51.0	37.5	30.4	24.4
Feeder	1,310	1,852,277	24.50%	8.00%	1,414	919	19.49	200	79.8	59.2	48.4	39.9
Feedermax	675	1,723,100	12.60%	7.40%	2,553	1,659	22.95	219	106.6	76.7	60.7	47.5
Panamax	883	3,738,185	16.50%	16.10%	4,234	2,752	24.08	236	189.1	134.0	104.2	78.8
Post Panamax	928	7,026,975	17.40%	30.30%	7,572	4,922	24.89	244	315.3	219.3	166.5	120.2
New Panamax	416	5,230,868	7.80%	22.50%	12,574	8,173	26.4	250	403.0	278.7	210.0	149.3
ULCV	157	3,015,114	2.90%	13.00%	19,205	12,483	25	251	451.0	313.6	238.0	171.6
Total	5,337	23,228,497	100.00%	100.00%	4,352	2,829	21.79	220	173.1	122.3	94.6	70.8

Table 1. Ship specifics and fuel consumption for the seven most popular classes of container ships.

Class	Fuel reduction (liters per km) S	SS	SSS	ES	CO2 reduction (kg per km) MDO	HFO	LNG	CO2 reduction (tonnes per year) MDO	HFO	LNG
Small Feeder	0.33	0.24	0.19	0.16	0.62	0.60	0.53	58	57	50
Feeder	0.45	0.33	0.27	0.23	0.88	0.85	0.75	102	99	87
Feedermax	0.64	0.46	0.36	0.28	1.16	1.13	1.00	174	169	149
Panamax	1.07	0.76	0.59	0.44	1.88	1.83	1.61	319	309	273
Post Panamax	1.82	1.27	0.96	0.69	3.08	2.99	2.64	557	541	478
New Panamax	2.31	1.60	1.20	0.86	3.86	3.75	3.31	758	737	651
ULCV	2.55	1.77	1.35	0.97	4.32	4.19	3.70	807	784	692
Total	1.00	0.71	0.55	0.41	1.75	1.70	1.50	290	282	249

Table 2. Fuel consumption and CO_2 emissions reductions for the seven most popular classes of container ships when the weight of the container is cut by 21%. Fuel consumption reductions are reported for each of the four steaming scenarios separately, while CO_2 emissions reductions (both per km and year) only for the SS scenario, but for three different types of fuels.

Global environmental impact of Container 2.0

We aggregate the emissions reductions due to both fuel decline and tree savings for the **SS steaming scenario**, which is the most probable to be realized in practice

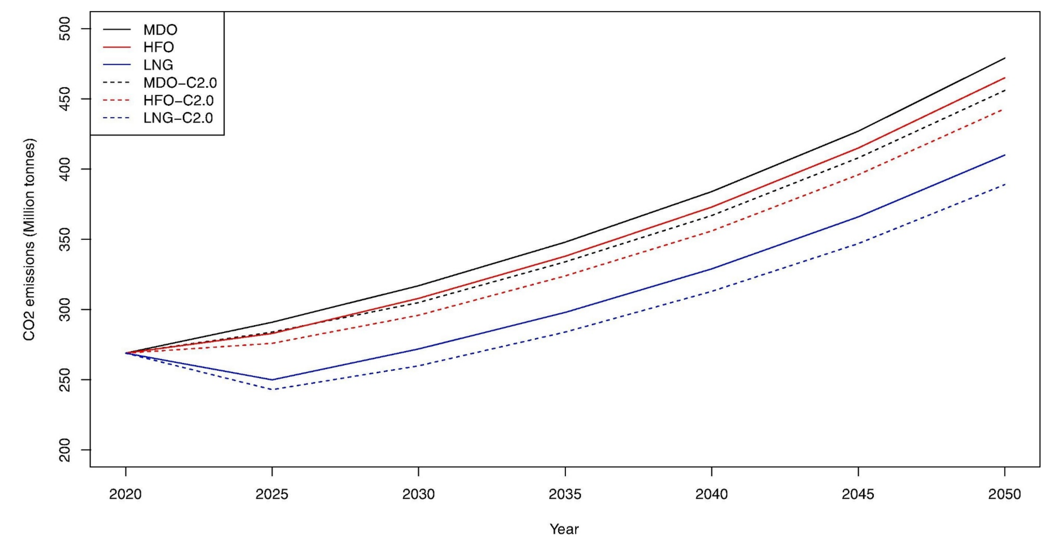

Figure 3: Projections about the global environmental impact of introducing the discussed container till 2050. The projections are presented for three different types of fuels, with and without adopting the proposed technology. In all cases, slow-steaming is assumed to be used by the shipping lines operators. "MDO" represents the business-as-usual scenario according to which container ships use MDO as a fuel, "MDO-C2.0" the previous scenario when light-weighting is considered, and so on.

Results

GDP, population, and demand projections

- To characterize international shipping, MUSE breaks down the global fleet by **vessel class**, each containing a further disaggregation into a set of size categories, representing selected ranges of gross tonnage
- For each class, **efficiencies**, **emissions** per tonne-km, **capital**, and **operating costs** are determined
- Data about **existing fleet**, **decommissioning** profiles, and **new-buildings** are collected
- **Fuel costs** are estimated endogenously, considering among others **price projections** obtained from the current policy scenarios of the IEA
- **Global demand** is predicted by correlating per capita GDP and demand historical data for each of the 28 regions modeled in MUSE
- The **container ship demand** is estimated by calculating the tonne-km from the use of energy in container ships

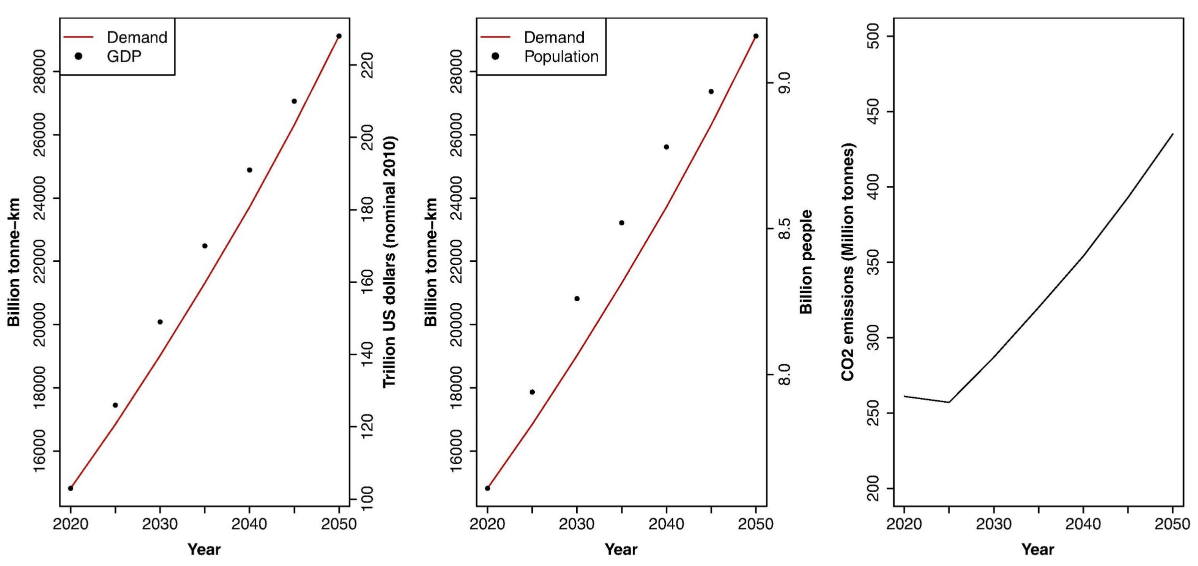

Figure 1: Demand and CO2 emissions projections for the container shipping industry from 2020 to 2050, as specified by MUSE. Global GDP and population projections are also provided for reference. These projections consist the base on which the long-term impact of adopting the proposed technological solutions is evaluated.

CO_2 emission reductions due to tree savings

We estimate the annual benefit from reserving trees, assuming that:

- the absorbed for 1 kg of tree biomass is 0.166 kg per year
- the lifespan of the container is 25 years
- the flooring of the containers has to be replaced at least once during its lifespan
- the containers currently in active service are about 15 million

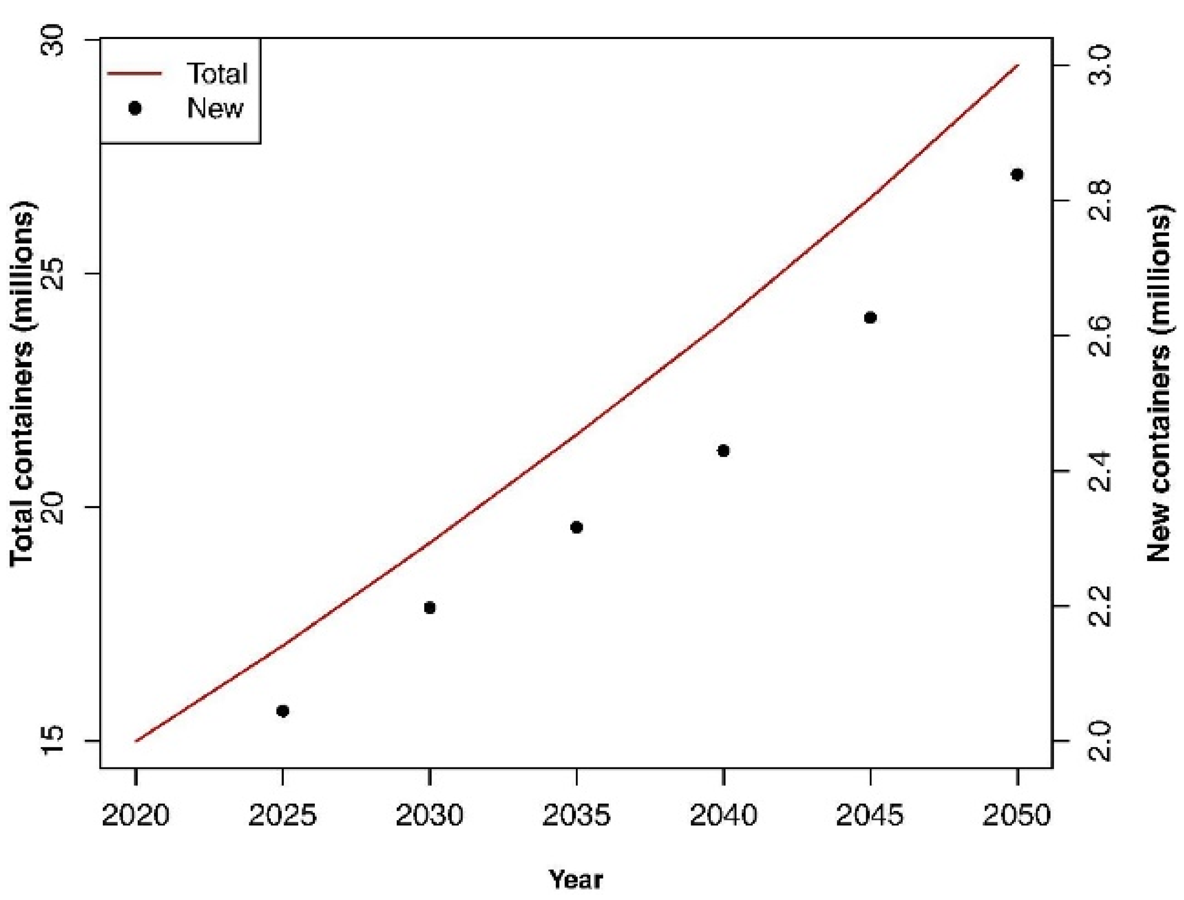

Figure 3: Estimated requirements in containers for 2050 based on the demand projected by MUSE. The additional number of containers that have to be constructed each period is also presented.

Key findings

- Assuming that "MDO" is the BAU scenario of operation, in 2050 the **utilization of greener fuels**, such as HFO and LNG, is expected to lead to **emission reductions of 2.9% and 14.2%,** respectively, corresponding to about 14 and 68 million tonnes of CO_2.
- When conventional containers are replaced by Container 2.0, emissions cuts increase to **7.5% and 18.8%**, respectively.
- This is an **additional 4.7% reduction in CO_2 emissions** that comes at **no additional costs** and **several ecological benefits**.
- Even if the fuel type used by the ships remains the same, the proposed technology could **save up to 22.3 million tonnes of CO_2** when compared to BAU.

Read more

You may read more in the paper:

Doukas, H., Spiliotis, E., Jafari, M. A., Giarola, S., & Nikas, A. (2021). Low-cost emissions cuts in container shipping: Thinking inside the box. *Transportation Research Part D: Transport and Environment*, *94*, 102815.

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