An Agent-Based Simulator for Maritime Transport Decarbonisation

Demonstration Track

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ABSTRACT

Greenhouse gas (GHG) emission reduction is an important and necessary goal; currently, different policies to reduce GHG emissions in maritime transport are being discussed. Amongst policies, like carbon taxes or carbon intensity targets, it is hard to determine which policies can successfully reduce GHG emissions while allowing the industry to be profitable. We introduce an agent-based maritime transport simulator to investigate the effectiveness of two decarbonisation policies by simulating a maritime transport operator's trade pattern and fleet make-up changes as a reaction to taxation and fixed targets. This first of its kind simulator allows to compare and quantify the difference of carbon reduction policies and how they affect shipping operations.

Keywords: Agent-Based Modelling and Simulation: Applications & Analysis; Emergent Behaviour; Simulation Techniques; Tools and Platforms; Integration of Agent-Based and Other Technologies

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1 INTRODUCTION

Greenhouse gas (GHG) reduction is a major global challenge, and international organisations and governmental bodies are working to formulate laws, policies and strategies to achieve the global emission reduction targets as laid in the Paris Climate Accords. Carbon taxes on emissions is one strategy that is currently applied to most industries excluding maritime. This usually takes the form of either a fixed price carbon tax per tonne of CO_2 emissions or an emission trading system (ETS), requiring emitters to purchase permits to emit. For example, a working paper by the International Monetary Fund (IMF) [7] lists possibilities of global carbon pricing. However, while the maritime shipping makes up 2.89% of global emissions and has seen an increase of 9.3% in emissions compared to 2012 [2], to date there is no global census on carbon taxation.Furthermore, numerous countries have or are in the process of imposing regional carbon taxes for maritime traffic (e.g. EU ETS, China ETS). Besides carbon pricing, the International Maritime Organisation (IMO) has adopted a strategy to reduce emissions by setting carbon intensity targets. These directly define how much the efficiency of vessels have to improve in comparison to the 2008 baseline [5].

Considering above, a fundamental question faced by policy makers and the maritime industry is which policy at what level (e.g. amount of tax) is most effective in achieving the reduction targets with limited disruption to the industry. In general, it is hard to predict the response of maritime transport operators to a particular policy. Yet assuming that operators strive to achieve targets economically they may adapt replacing vessels with more efficient ones, or upgrading vessels with carbon-reducing technologies. Then, a core question for the operators is which combination of actions is most cost effective to achieve the operator's obligations.

There has been considerable research in optimising particular parts of maritime transport. However, few studies take carbon GHG emission reduction into consideration [3, 4, 10]. Moreover, all works which consider emission reduction policies focus on specific areas, routes or policies [1, 8, 9] and do not allow easy comparison of different policies. Additionally, no agent based model has been used to capture the complex interaction between the involved entities.

To address the above, we have developed an agent-based maritime transport simulator to investigate different decarbonisation policies and their impact on operational patterns.

2 SIMULATOR OVERVIEW

The simulator is able to run a range of configurable scenarios, called projects, as detailed below. In each scenario, a fleet of vessels is simulated for a number of years (e.g. 20 years) during which potential trades are generated. These trades are transportation opportunities and the goal is to satisfy as many trades as possible, as long as these are feasible (i.e. there is sufficient capacity to complete the trade within the deadlines) and profitable (e.g. losses can be incurred should a vessel undertake a major detour). This operation is further restricted by carbon taxes and/or carbon targets which can change on a yearly basis. However, additional costs can be counterbalanced by upgrading vessels with energy efficiency technologies.

The fleet, the environment and the policies are highly configurable. For each vessel, the fuel types it can use and the corresponding consumption curves can be specified, which determine

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the fuel consumed given the sailing speed of the vessel. Each fuel type, in turn, generates a different amount of CO_2. Furthermore, any number of possible upgrades to vessels and their efficiency improvement can be specified. The upgrades feasibility also depend on the type of vessel. In terms of policies, both global/regional taxes and carbon reduction targets can be specified on a yearly basis. Moreover, trade frequencies between ports and amount of cargo are generated based on distributions from real data. Other parameters include canal fees which are computed based on the type of vessel and amount of cargo transported.

2.1 Simulation Core

For each project, multiple simulations are run in parallel with a differently seeded random market (see Figure 2), to produce reliable predictions. Each simulation utilises the modular extendable architecture of the simulator and its agents (see Figure 1). The modularity allows easy changes and extensions of the applied procedures and algorithms.

The architecture can roughly be divided into two parts representing the environment and market, and the shipping operation. The market module, integral to the wider environment, emulates the activity of traders. Based on demand and supply, it generates the trades. This trade generation process also includes dynamically determined revenue based on the cost of cargo transportation. Additionally, the market is influenced by the behaviour of regulators represented by the option to set tax levels or carbon targets.

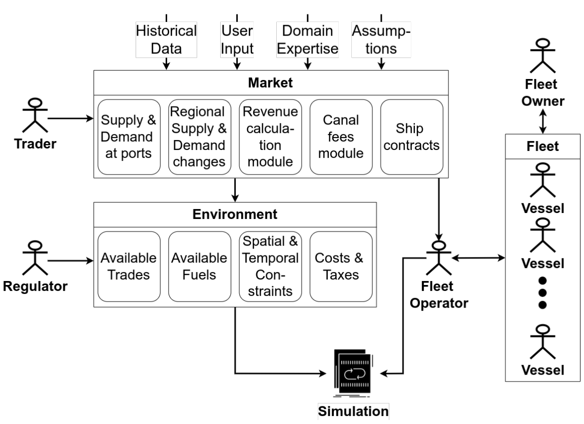

Figure 1: Overview of the simulator's architecture.

The shipping operator is divided into three types of decision makers: the fleet operator, the fleet owner and the vessels. The fleet operator responds to available trades by deciding which cargoes to transport (currently using a greedy profit maximising approach) with a vessel satisfying temporal and spacial constraints. The fleet operator also fixes the order of the cargo fulfilment and thus the routes of the vessels. The vessels fulfils this by setting the sailing speed and choosing the fuel to use on each leg. The routing module uses a world graph including ports and canals.

The fleet owner makes decisions about fleet upgrades. This might be in response to either carbon reduction targets or to save money in response to a carbon tax. Currently, the upgrade installation is determined using a mixed integer linear program (for carbon reduction targets) and choosing the most cost saving upgrades that can be bought within a budget (for carbon taxes).

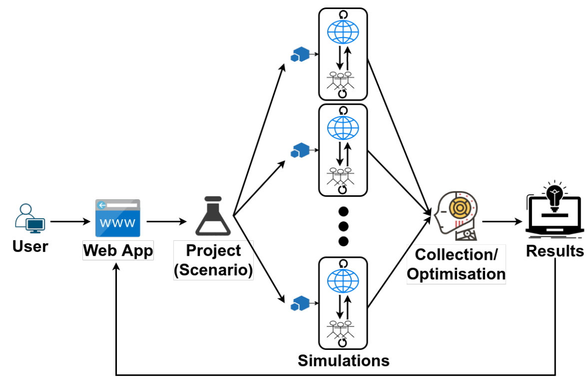

Figure 2: Multiple simulations with different market seeds per project produce results for statistical evaluation.

2.2 Project Evaluation

In order to support the evaluation of policies for every project, we collect location and operation, cost and revenue, and the carbon footprint information for each year and vessel (see also Figure 2). The carbon footprint captures the total emissions of CO_2 as well as the energy efficiency operational indicator (EEOI) and the annual efficiency ratio (AER). The cost includes carbon taxes, fuel prices and canal costs. Finally, operational information about the vessels include their location (e.g. regions, passages) allowing shipping operators to analyse operational shifts.

2.3 Configuration and Results

The project configuration is possible via a web user interface (UI) as well as a command line interface (CLI). Both allow to fully specify all project parameters via input forms or JSON strings, respectively. After the completion of a project the JSON format stored results are queryable via an API and a selection is presented in the web UI.

3 DEMONSTRATION

Our demonstration covers different cases around global carbon tax scenarios and carbon intensity targets scenarios. They highlight that a modest tax encourages fleet operators to upgrade their vessels and present cost effective upgrade schedules for fleet operators to achieve targets. For all cases our simulator shows the impact of the policies on operation and revenue. *See: YouTube link.*

For our demonstration, we are informing the demand and supply of the market module using data provided by Shell as well as obtained from the Sea/ suite[6]. The entire data set spans the 4 years from 2016 to 2019 and the distributions are created from over 3600 trades between 740 ports distributed on all continents.

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