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Decarbonising mobility in port cities

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Abstract

Ports play an important role in the European transport decarbonisation agenda. Due to the complex characteristics of ports, coordinated and holistic approaches between port authorities and municipalities are of utmost relevance to tackle greenhouse gas emissions reduction. This paper analyses the mobility challenges of a port city and associated carbon dioxide CO_2 emissions. The specific objectives of this research are: firstly, to study the implementation of integrated mobility measures in ports to reduce the carbon footprint by promoting an efficient use of transport infrastructure and smart mobility strategies to/from/in the port; secondly, to define and implement electric mobility and digitalization solutions for transport in ports (including the connection between the city and the port). The traffic modelling software PTV VISSIM and the Vehicle Specific Power methodology were used to estimate the emissions of the vehicles present in the road network of a study area. The methodology was applied to the case study of Aveiro, Portugal, which has a port located 8 km from the city centre. The baseline scenario and three alternative scenarios: implementation of electric mobility; digitalization of work patterns through remote work; and mobility-as-a-service (MaaS) were defined. Results showed a reduction in pollutant emissions in all tested scenarios in comparison with the baseline scenario.

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Keywords: Ports; Cities; Electrification; Digitalisation; Emissions.

1. Introduction and Research Objectives

Many economic, socioeconomic, political, and environmental factors require ports to move towards digitalization and sustainability (Belmoukari et al., 2023). The concept of sustainability is becoming increasingly important in the

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European maritime shipping sector, namely to foster maritime transport's gradual decarbonisation in the European Union (EU). According to the European Commission, it is crucial to shift 30% of road freight traffic over distances greater than 300 km to other modes, such as rail or sea, by 2030, and more than 50% by 2050, with the help of ecological corridors. Global warming presents challenges for maritime transport, thus the correspondent activities and operations should be managed in a sustainable way. Currently, there are several initiatives led by the European Commission, EU Member States and industry with the aim of navigating the maritime transport sector towards sustainability and decarbonisation (EEA, 2021). These initiatives support EU priorities (European Green Deal) and endorse international programmes and action plans (International Maritime Organization treaties and the Sustainable Development Goals) (EEA, 2021). They extend from the use of sustainable fuels and emission abatement technologies to decarbonisation; in particular, measures to mitigate pressures and impacts on the marine environment and port-based solutions must be implemented.

Previous research relies mainly on the freight transport in ports without integration with the neighbouring cities, without considering the passenger transport occurring between the city and the port (Jiang et al., 2012; Ignaccolo et al., 2020). Other works analysed the port and city integration, but without any microscopic assessment of traffic performance variables and pollutant emissions (Gurzhiy et al., 2021; Dadashpoor and Taheri, 2023; Yin et al., 2023). Ziemska (2021) used microsimulation in five intersections to determine exhaust emissions of heavy-duty vehicles in the port city of Gdynia. Bok et al. (2021) evaluated the implementation of Zero-Emission Zones in the logistics of the city of Rotterdam, including its port, using a multiagent simulation model of urban freight transport. Zhang et al. (2021) assessed the environmental benefits of a modal shift of port-connecting freight transportation by increasing the use of rail and waterborne systems in Shenzhen, from a macroscopic perspective using transportation activity simulation, well-to-wheel analysis and air quality modelling. Tavasszy (2021) explored the impact mechanisms of carbon taxes on a city case (which involved an application of an agent-based model to evaluate a carbon credit point system for city logistics) and a corridor case (carbon pricing of container transport in the hinterland of the port of Rotterdam over a multimodal network). Miltiadou et al. (2021) presented the implementation, monitoring, and evaluation of sustainable mobility measures, but without emissions quantification. De Luca et al. (2021) analysed the benefits on equivalent carbon dioxide (CO_{2eq}) emissions of changing from road to railway in the Port of Naples, with a special focus on the last mile. A state-of-the-art on the electrification of vessels is presented by Anwar et al. (2020).

On the other hand, Salsas et al. (2022) analysed the current trends that have an impact on ports with Delphi methodology applied to the Port Community of Barcelona. This research has been able to identify the key drivers that will transform ports, namely green measures to decarbonise maritime transport and supply chains.

This paper will provide a comprehensive analysis of the reduction of pressures that arise from mobility in port cities, and the challenges going forward in terms of decarbonisation and pollution reduction. Different levels of pressures arising from mobility can be assumed, as well as developments in the mobility to/from/in the port. These assumptions will influence the scenarios for the responses. Finally, the port cities mobility optimisation, namely through the development of ports as intermodal hubs, will be analysed. The research contributions rely on the assessment of the transport dynamics and emissions between a city and a port in a holistic and integrated manner as well as the simulation of future mobility solutions in the complex context of port cities.

2. Methodology and Methods

This chapter is organised in four sections. The first section describes the microscopic traffic simulation that was undertaken, and the second explains the methodology used to calculate CO_2 emissions. We present the case study of the Port of Aveiro in the third section and we close the chapter with the description of the evaluated scenarios.

2.1. Microscopic traffic simulation

The PTV VISSIM (PTV, 2022) microscopic traffic software was used to develop the traffic model associated with the region of interest under study. Experimental monitoring campaigns were conducted to collect data for network calibration and validation, such as traffic volumes and travel times within the area. The coded network comprised 1460 links and covered a total of 120 km. Due to different road singularities in the studied area, some adjustments had

to be implemented, e.g., traffic light control measures and specific speed limits. The fleet composition considered in this work was (INE, 2020): 98.12% of light passenger vehicles, 1.5% of heavy goods vehicles, and 0.22% of buses, being the remaining fraction negligible. Data from different sources were also used to calibrate and validate VISSIM: truck movements data were provided by the Port of Aveiro; traffic volumes were obtained by combining information from annual freeways reports, advanced communications' sensor infrastructure installed inside the city of Aveiro (Aveiro Tech City Living Lab platform) and also from experimental monitoring campaign in some relevant access points to the Port of Aveiro (for which we did not have any kind of data). Dynamic analysis of the vehicles was used for calibration, by comparing the simulation data with the temporal measurement of routes taken in the experimental campaign, ending up with the calculation of the Geoffrey E. Havers index (GEH). After a warm-up period of 20 min, the simulation was conducted for a 1-hour period, corresponding to the morning rush hour (8:30 to 9:30 AM).

2.2. Estimate emission impacts: the VSP methodology

The Vehicle Specific Power (VSP) methodology has been widely applied to estimate the impacts in terms of emissions, in particular, CO_2, CO, NOx and HC emissions. The specific power of a vehicle is defined as the instantaneous tractive power per unit vehicle mass and it can be determined based on information on instant values of speed, acceleration, and road slope. Concretely, different VSP models have been developed for different vehicle categories, and the VSP value for light-duty vehicles and buses by:

$$VSP_i = v_i\,(1.1\,a_i + 9.81\,r + \alpha) + \beta\,v_i^3 \quad (1)$$

where VSP_i is the Vehicle Specific Power in the second of travel i (kW.ton^{-1}); v_i is the vehicle speed in the second of travel i (m.s^{-1}); a_i is the vehicle acceleration in the second of travel i (m.s^{-2}); and r is the road grade in each 100 m-length (in decimal fraction). The parameters α and β present different values: $\alpha = 0.132$, $\beta = 0.000302$ for light-duty vehicles and $\alpha = 0.092$, $\beta = 0.00021$ for buses (US EPA, 2002; Zhai et al., 2008).

Regarding heavy-duty vehicles, and considering an average mass of 15.790 ton, the VSP value can be given by (Zhang et al., 2015):

$$VSP_i = v_i\,(1.1\,a_i + 9.81\,r + 0.186333) + 0.2345 \quad (2)$$

Based on second-by-second data, VSP values were estimated and then grouped into discrete modes. Modal average emission rates were estimated for each VSP mode, considering that 14 modes can be associated with light-duty vehicles, 8 for buses, and 16 VSP modes for heavy-duty vehicles. In this latter case, CO_2 emissions are not yet available in the literature, thus, an approximate model that uses average speed was applied (Macedo et al., 2020).

All computations related to emission estimation were conducted in a MATLAB platform that requires the vehicle record file returned by the simulation in VISSIM. For each scenario, the respective vehicles' reduction circulating in the network was made based on the survey responses so that the corresponding changes in travel behaviour could be reflected.

2.3. Case Study: Port of Aveiro

The city of Aveiro comprises a port area that is approximately 8 km away from the city center, which causes impacts in terms of generating movements of people and goods (Fig. 1). For conducting our research, the experimental campaign involved counting traffic volumes and dividing by type, including cars, buses, and heavy goods vehicles, in intervals of 15 minutes. External data were also incorporated into the monitoring process. The Port of Aveiro provided vehicle counts for September 2021 for various terminals including the north, dry bulk, and bulk liquid, among others, to enhance the overall data. Data from Aveiro Tech City Living Lab (2022) were also used, as previously mentioned, to complement the characterisation of mobility within the area.

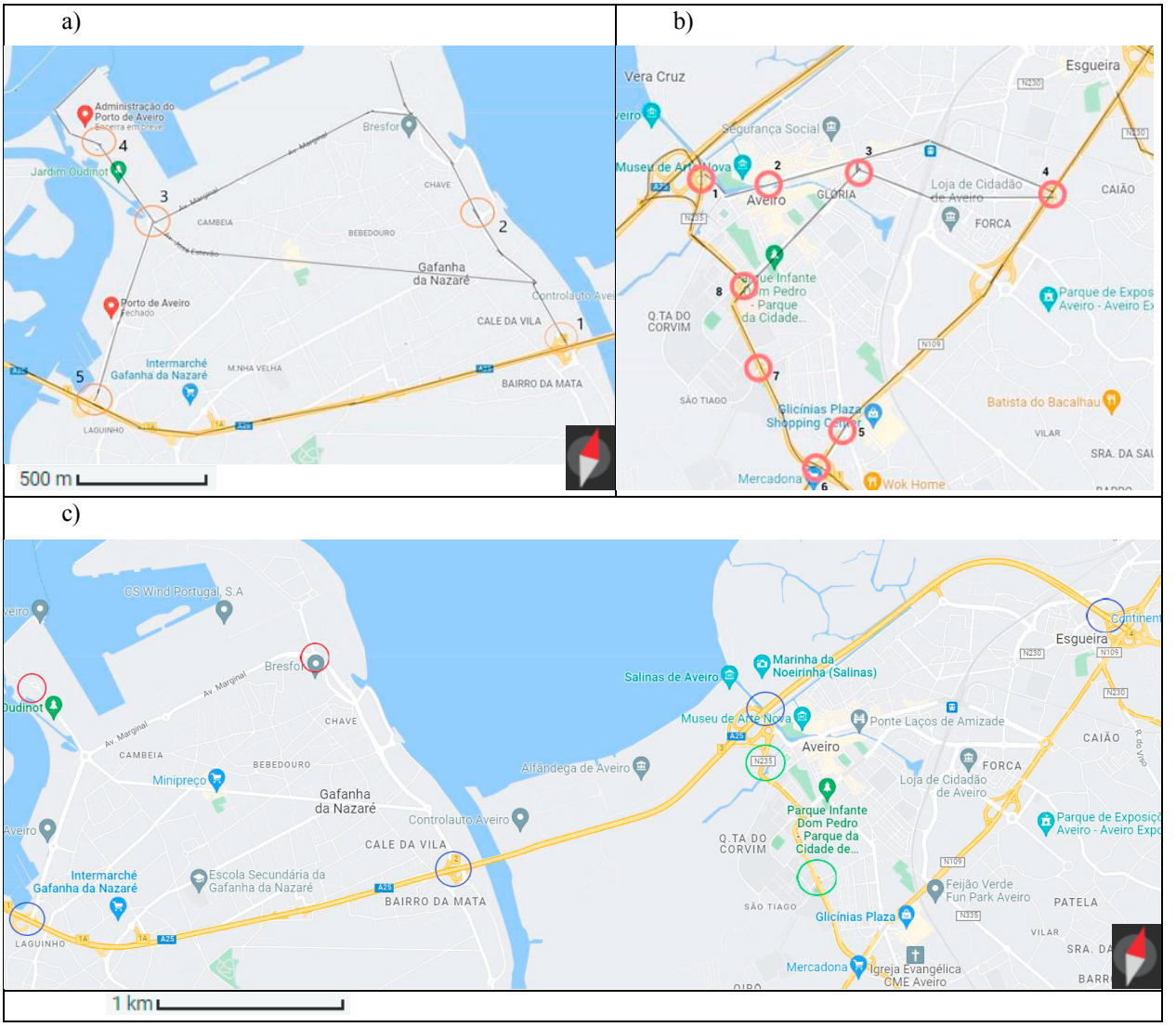

Fig. 1. Overview of the monitoring sites within the vicinity of the city and the Aveiro Port area: a) Port of Aveiro area; b) Aveiro city centre; c) Region of interest area.

2.4. Scenario definition

Two online surveys were developed to gather precise information about mobility strategies and habits (actual habits and receptiveness to alternative ones, such as remote work) that would support the development of alternative scenarios for decarbonising mobility in a port city. The surveys were disseminated among the Administration of the Port of Aveiro (survey 1) and employees of the port community companies (survey 2) and 54 completed responses were obtained. Each online survey included nine questions focused on information regarding: the origin of the daily journey, the most frequently used mode of transport, the interest in working remotely, and the potential uptake of a mobility-as-a-service (MaaS) subscription plan, by questioning the interest in using public transport and shared mobility solutions if these were available.

The proposed scenarios involve: baseline - current modal choice (home-work trips) and scenarios of declared interest in using new mobility solutions and practices, such as i) electric mobility, ii) remote work (digitalisation), or

iii) MaaS packages. The base case scenario simulates the road conditions of the case study between 08:30 and 09:30 AM, the morning rush hour. All scenarios developed were created for the same time period.

3. Results and discussion

From the results obtained, we concluded that, for the baseline scenario, in the defined simulation period (1h) and considering all vehicles present in the network, 11.8 tons of CO_2, 17.1 kg of CO, 36.9 kg of NOx and 1.7 kg of HC were emitted. In the baseline scenario, the average CO_2 emission was 153.8 gCO_2/veh.km. Based on the responses to the survey, it was found that 93% of all respondents use a private car on their daily trips.

Regarding the scenario focused on electric mobility implementation, and considering that the environmental burden involved in an electric vehicle is mainly associated with its production, Fig. 2 shows the comparison of CO_2 emissions evolution over time for an electric vehicle (EV) versus the use of an internal combustion engine vehicle (ICEV). To tackle decarbonisation goals, the highest advantage, from a medium-long term perspective, is to have EVs circulating from origins distancing from the port more than 15 km per trip. Regarding electric buses implementation from the city and the port (and vice-versa): the monthly CO_2 emissions would be approx. 24 kg, which represents an emission reduction of more than 90% (compared to the baseline scenario, with a diesel bus). These results depend on the electricity production source.

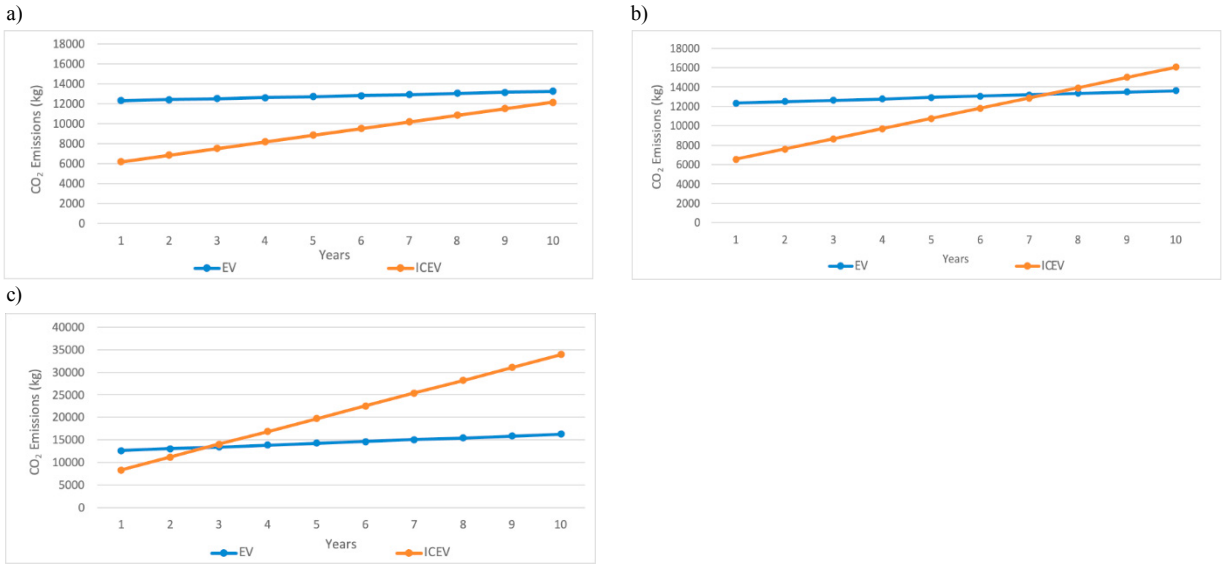

Fig. 2. Comparison of CO_2 emissions impact from the use of ICEV vs. EV in different routes to the Port: (a) <5km ; (b) 5-15km; (c) >15km.

Concerning digitalisation, the impact of remote work on exhaust emissions was studied. It was found that approximately 95% of employees go to the port at least 5 days a week and almost half of them would be interested in working remotely if that option would be feasible. It is important to refer that based on the nature of some professional activities (e.g., cargo handling activities), there is a significant part of port employees that requires physical presence to perform their work (52%). The results of the survey show that 43% of the respondents were interested in working remotely and only 5% had no interest in doing it. Table 1 presents the percentage of the port employees interested in working remotely as a function of the number of days per week. The results reveal that more than 77% of them are interested in working remotely 2 or 3 days per week.

Table 1. Respondents' interest in working remotely as a function of the number of days per week.

Number of Days Working Remotely	1	2	3	4	5
Percentage of employees interested (%)	3.7	48.1	29.6	11.2	7.4

With these assumptions, the scenario was simulated considering a new class of vehicles representing the trips made by the port employees using their own cars. This allowed to determine the CO_2 emissions resulting from these trips, to subsequently estimate the savings related to remote work as a function of the number of days per week it occurs. These results are illustrated in Table 2. From the simulation model, it was possible to estimate that on average the CO_2 emissions associated with a commuting trip is 2.3 kg CO_2 per vehicle per day.

Table 2. CO_2 Emissions savings considering the digitalisation scenario.

Number of Days Working Remotely	1	2	3	4	5	Total
CO_2 Emissions savings (%)	0.3	8.3	7.6	3.9	3.2	23.3

The results obtained considering the implementation of remote work allowed to conclude that by avoiding some trips to the office/port, a reduction of around 23% in CO_2 emissions would be expected.

Finally, a MaaS impacts scenario was assessed. From the survey results, it was found that almost 60% of workers in the port community would be interested in using alternatives to private transport, if these would be available in the region. Considering that the key concept of MaaS is to enable subscription to different mobility solutions based on travellers' needs, three different types of subscription packages were proposed, involving different transport options such as micromobility, electric buses and trains. For workers from remote areas, an additional option of subscribing to an EV leasing service was also included. This scenario was simulated assuming that is possible to have a sustainable mobility solution for all the port employees provided by a MaaS system. With this assumption, the MaaS scenario reveals that there is the potential for at least 95% savings in CO_2 emissions. Considering only those employees who have expressed willingness to use more sustainable mobility solutions, it can be concluded that the savings are around 57%.

4. Conclusions and future work

This paper analyses the mobility challenges of a port city and associated CO_2 emissions. Decarbonisation scenarios focused on electrification and digitalisation-based solutions were established. Traffic and emissions microscopic models (PTV VISSIM and VSP) were used to understand vehicle movements between the city and the port (and vice-versa) and the CO_2 emissions involved. Two surveys were developed, one for the administration of the Port and another for employees of companies in the port community.

The traffic performance and emissions analysis revealed that:

- There is an interest in the port community to work remotely 2 or 3 times a week. If this could be implemented, an emission reduction of 23% could be achieved.
- 93% of all respondents use a private car. However, 58% would be interested in using public transport in their displacements, which shows the feasibility of a scenario based on MaaS.
- The studied scenarios can be complementary and applied together, which would potentially improve the environmental impacts by lessening CO_2 emissions.
- The mobility between a city and its neighbouring port should be studied in a holistic manner, involving every single stakeholder, since passenger and freight transport and the coexistence of different modes should be considered together for more sustainable development strategies.

Future work will be focused on developing a decarbonisation plan for Port mobility, which will involve the quantification of greenhouse gas (GHG) emissions generated by all the mobility activities in 1990 and 2022 (considered as reference cases to fulfil the European Union's targets) as well as study of alternative scenarios, namely: alternative fuels (incorporation of hydrogen, methanol, biofuels), electrification (onshore power supply, e-vehicle, e-non road, e-ferry), and intermodality (increase of modal share from road to rail).

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