Review of Management and Economic Engineering
Vol. 23, No. 3(93), September 2024, p. 188 - 198, ISSN (print): 1583-624X, ISSN (online): 2360-2155

ANALYSIS OF TOWING ACTIVITY IMPACT ON THE ENVIRONMENTAL PERFORMANCE IN CONSTANTA PORT

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Abstract: The shipping sector is under accelerating pressure to decarbonise, driven by regulation, customers and society. However, there are areas of the supply chain that are often overlooked, such as towing services, due to the small size of vessels. The world's major ports have set carbon reduction targets, which are also mobilizing towing service providers to decarbonise. This paper presents a first calculation of the CO_2 and N_2O emissions generated by the towing activity in the period 2019-2023 in Constanta Port. This service is provided permanently in the port, which makes it important to quantify the emissions generated, considering that the Port of Constanța is part of the European environmental initiatives and has concerns to become a green port. Also, the paper proposes solutions regarding the decarbonization of the towing service in Constanța Port, but also a perspective for future analyzes that will facilitate the decarbonization process of Constanța Port and neighboring regions.

Keywords: towing services, greenhouse gas emissions, decarbonization, eco-fuels, electro-fuels

1 INTRODUCTION

Reducing the carbon emissions in shipping is essential in the global fight against climate change. As a major source of greenhouse gas (GHG) emissions, the shipping industry faces high pressure to lower its carbon footprint.

Decarbonizing tugs, which are essential for maneuvering larger vessels in ports and harbors, is an important aspect of the broader effort to lower GHG emissions in the maritime sector (Ortega-Piris, Diaz-Ruiz-Navamuel, Martinez, Gutierrez & Lopez-Diaz, 2022).

The process of decarbonization involves several key strategies and initiatives:

1. Alternative Fuels (Lebedevas, Norkevičius & Zhou, 2021):
   - Liquefied Natural Gas (LNG): Although it is a fossil fuel, LNG produces fewer emissions compared to traditional marine fuels;
   - Biofuels: Derived from organic materials, biofuels can significantly reduce carbon emissions;
   - Hydrogen: Considered a clean fuel, it is suitable in fuel cells to power ships, emitting only water vapor;
   - Ammonia: Another potential zero-emission fuel that can be produced using renewable energy sources.
2. Energy Efficiency (Tadros, Ventura & Soares, 2023):
   - Hull Design: Improving the design of ship hulls to reduce drag and increase fuel efficiency;
   - Propulsion Systems: Developing more efficient engines and propulsion systems;
   - Speed Optimization: Adopting slow steaming practices in order to decrease fuel consumption and to lower emissions.
3. Electrification (Kolodziejski & Michalska-Pozoga, 2023):
   - Batteries: Using advanced battery technology for short-sea shipping and auxiliary power;
   - Hybrid Systems: Combining conventional engines with electric propulsion to reduce fuel use.
4. Renewable Energy Integration (Mimica, Perčić, Vladimir & Krajačić, 2022):
   - Wind Power: Utilizing sails, kites, or rotor sails to harness wind energy;
   - Solar Power: Installing solar panels on ships to generate electricity for onboard use.
5. Regulatory Measures (Risso, Cardona, Archetti, Lossani, Bosio & Bove, 2023):
   - International Maritime Organization: IMO has established goals to lower carbon intensity by 40% by 2030 and to cut overall GHG emissions by 50% by 2050, relative to 2008 levels;
   - Carbon Pricing: Implementing carbon pricing mechanisms to incentivize reductions in emissions;
   - Emission Control Areas (ECAs): Designating specific areas where stricter emission standards apply.
6. Port Infrastructure (Global Maritime Forum, 2023):
   - Onshore Power Supply (OPS): Enabling ships to connect to the electrical grid while docked, thereby reducing the need to run their auxiliary engines;
   - Green Ports: Developing ports with sustainable practices, such as renewable energy sources and efficient logistics;
   - Green shipping corridors: Specific maritime routes where sustainable practices and technologies are implemented to significantly reduce greenhouse gas emissions and minimize environmental impact. These corridors are established through collaborative efforts among ports, shipping companies, governments, and other stakeholders. The aim is to create cleaner, more efficient, and environmentally friendly shipping lanes.
7. Collaboration and Innovation (Hailemariam, Ivanovski & Dzhumashev, 2022):
   - Research and Development: Investing in R&D for new technologies and fuels;
   - Public-Private Partnerships: Collaborating between governments, industry stakeholders, and research institutions;
   - Digitalization: Using digital tools and data analytics to optimize routes, improve fuel efficiency, and manage emissions.

Safety services in ports and on inland waterways, integral to transport operations, encompass the piloting of maritime and river-sea ships during entry and exit of ports, movements between berths within the same port, and maneuvering towing within ports. These services fall under the jurisdiction of the state, specifically managed by the Ministry of Transport and Infrastructure. They are provided to all users consistently, without discrimination, and under equal conditions regarding quality, timing, and pricing (Consiliul de Supraveghere din Domeniul Naval, 2023).

Tug service refers to the operations and activities performed by tugboats, which are small but powerful vessels designed to assist larger ships in navigating confined or congested waters, such as ports, harbors, and canals. Tug service is essential for the safe and efficient operation of maritime transport, particularly in busy and constrained port environments. Tugboats' strength and maneuverability make them indispensable for ensuring the smooth movement and handling of large vessels (Consiliul de Supraveghere din Domeniul Naval, 2023).

Tugboats, although smaller than large cargo ships, can emit significant quantities of CO_2 due to their powerful engines designed for high maneuverability and towing capabilities.

General information about tugboat operations impact:

- A typical tugboat can consume between 250 to 500 liters of diesel per hour depending on its size and operation, leading to substantial CO_2 emissions. For instance, burning one liter of diesel fuel produces approximately 2.68 kilograms of CO_2. This means a tugboat could emit between 670 and 1,340 kilograms of CO_2 per hour of operation (Sapan, Putro, & Djari, 2019).
- Tugboats are also significant sources of NOx and SOx emissions because of the increased-sulfur matter in the marine diesel fuel. These pollutants contribute to air quality degradation and have adverse health effects (Webmaster, n.d.)
- NOx emissions from tugboats can range from 40 to 120 g/kWh depending on the engine type and operational conditions.
- Tugboats emit particulate matter (PM), which comprises microscopic elements capable of penetrating deep into the lungs and bloodstream, leading to health problems. PM emissions from tugboats are influenced by the quality of fuel used and the efficiency of the engine (Mousavi, Sowlat, Hasheminassab, Pikelnaya, Polidori, Ban-Weiss & Sioutas, 2018).

The International Maritime Organization (IMO) (Risso et al., 2023) and various national regulatory bodies are focusing on reducing emissions from all types of marine vessels, including tugboats. Measures include stricter emission standards, using engines that function with “cleaner” fuels, and the adoption of new technologies like hybrid and electric propulsion systems.

By focusing on these aspects, it becomes evident that while tugboats are essential for port operations, they also present a significant opportunity for emission reductions through technological and operational improvements.

Assessing the impact of towing operations on a country's carbon footprint is important, as these activities significantly contribute to the transport sector's overall carbon footprint. This effect is particularly pronounced in commercial seaports, which are vital for regional economic development. Despite their importance, tugboat operations often face scrutiny from local communities due to their environmental impact.

Concerns about port emissions are increasing, especially since major commercial ports (Ergüven, Bayirhan, Deniz, & Gazioglu, 2023) are usually situated in densely populated urban areas. This raises public awareness about the health implications of port activities on local residents and their broader environmental effects, which are significant public concerns. But we can observe that although in the port field studies regarding the carbon footprint are present, the impact analysis for the towing activity has been extremely little addressed.

In 2022, there were over 21,000 tugboats in operation worldwide, collectively emitting 40 million tons of CO_2 annually. While this represents just 4% of total shipping emissions, it is significant equivalent to the annual emissions of over 7 million automobiles. This highlights a substantial opportunity to decarbonize the maritime towage sector (Jameson, 2022).

Constanta Port is the largest one on the Black Sea and one of the most important maritime hubs in Eastern Europe (Constanta Port Business Association, n.d.), it is part of the European environmental initiatives and has concerns to become a green port. This paper presents a first calculation of the CO_2 and N_2O emissions generated by the towing activity in the period 2019-2023 in Constanta Port. This service is provided permanently in the port, which makes it important to quantify the emissions generated, considering that the Port of Constanța is part of the European environmental initiatives and has concerns to become a green port. Also, the paper proposes solutions regarding the decarbonization of the towing service in Constanța Port, but also a perspective for future analyzes that will facilitate the decarbonization process of Constanța Port and neighboring regions.

2 METHODOLOGY

This chapter presents the method used to conduct the research an also the data collection.

2.1 Port of Constanta maritime maneuvers

The Romanian Naval Authority is the central specialized authority under the Ministry of Transport and Infrastructure, in the field of navigation safety and ship security.

The data for maritime maneuvers used in this study are collected from the annual reports published by the Romanian Naval Authority that refer to the number of maneuvers carried out in the port of Constanta.

There are two management systems for the supervision, coordination and monitoring of maritime traffic in Constanta Port (Autoritatea Navala Romana, 2024):

- maritime traffic management through the VTS (Vessel Traffic System) Constanta service;
- ship traffic management through the RoRIS system (Information System and Traffic Management on the Romanian Sector of the Danube).

The Constanta VTMIS (Vessel Traffic Management and Information System – an extension of VTS) is an integrated maritime traffic management system that ensures the acquisition, processing, management, storage, consultation and presentation of system data and data from peripheral sensors.

The main task of the VTMIS Constanta service consists in the supervision of navigation and the management of naval traffic in the VTS area.

The VTS area of the VTMIS Constanta service includes the maritime area delimited by the circle sector with a radius of 12 NM (Nautical Mile, 1 NM=1852 meters) from the coordinate point: 44°10'.2 N - latitude and 028°39'.6 E - longitude (Autoritatea Navala Romana, n.d.).

RoRIS is a complex system for monitoring and managing ship traffic on the entire Romanian sector of the Danube.

Table 1 shows the number of maritime maneuvers in the last 5 years in Constanta Port. The information was retrieved from the annual activity reports of the Romanian Naval Authority generated from the two traffic management systems mentioned above.

Table 1. Number of maritime maneuvers in Constanta Port in the period 2019-2023 (Autoritatea Navala Romana, 2024).

Year	Number of maritime maneuvers
2019	10444
2020	10177
2021	16123
2022	16528
2023	11967

In Figure 1 it can be observed the trend of the maritime maneuvers in Constanta Port in the analyzed period. There is an increase in the last 4 years, followed by a sudden decrease in the last year, 2023. In the last 5 years, we can mention that an average number of approximately 13,048 maritime maneuvers have been registered. This will be taken as the average number of maritime maneuvers that will be the subject of the calculation of the quantity of emissions generated by the activity of tugboats. In this study we find only maritime maneuvers relevant because it is considered that the activity of tugboats is not necessary for river maneuvers.

Average operating time of a maritime maneuver is one hour, according to the information communicated by the The National Company "Administration of Maritime Ports" S.A. Constanta and the Romanian Naval Authority, as it results from the data invoiced by the Administration to the shipowners, and it is operationally confirmed by one of the authors of this work who was the General Director of The National Company "Administration of Maritime Ports" S.A. Constanta during 2019-2020.

Approximately half of this time can be considered the time for the tug to reach the place of maneuver, the rest of the time being allocated to the maneuver itself. In this load difference, it can be considered that during towing, the tug consumes approximately 40% more than when sailing freely. Considering that we do not have a concrete and accepted factor, we appreciate that the consumption per operating hour is constant.

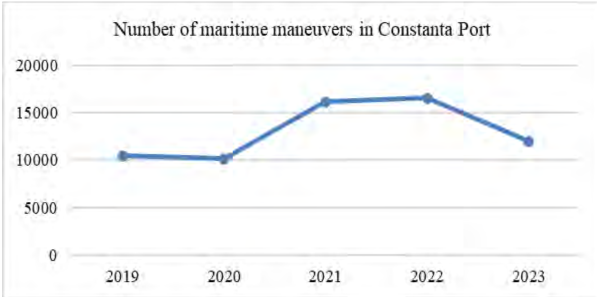

Figure 1. The trend of maritime maneuvers in Constanta Port in period 2019-2023 (Autoritatea Navala Romana, 2024)

Towing is a safety service, which ensures the safe conduct of navigation and port maneuvers and is carried out under state control, for all ships, regardless of their flag, in a non-discriminatory manner regarding the duration, quality and rates charged.

According to the provisions of OG no. 22/1999, the shunting towage of maritime and fluvio-maritime vessels in ports is ensured by the port administrations (Consiliul de Supraveghere din Domeniul Naval, 2023):

- directly, with tugboats and the administration's own staff;
- through specialized, authorized economic operators, based on a contract between the administration and the respective economic operators, based on the criteria imposed by the framework contract;
- by the concession of the towing service by the administration, in accordance with the law, to specialized, authorized economic operators.

As it is also mentioned in the literature review, the analysis of the impact for the towing activity has been extremely little addressed in the port field, therefore, this topic must be the subject of future research topics that will also contribute to new solutions for the establishment of an appropriate and official methodology for this type of studies.

2.2 Port of Constanta tugboat fleet

Currently, the maritime towing service in the ports is provided by three economic operators, under the auspices of The National Company "Administration of Maritime Ports" S.A. Constanta (named hereby CN APM SA) (Port of Constantza Homepage, n.d.).

Although the towing service market should be a competitive one, the three companies that provide this service work in rotation, according to the contract between the parties.

Regarding the technical equipment, in the first trimester of 2023, 14.3% of the 49 tugboats used by the three companies in the port of Constanța were built before 1980, 40.8% between 1980-1989, 18.4% after 1990 and 26,5% after the year 2000. Thus, the age of the tugboats ranges from 9 to 66 years, and 55.1% of them are equipped with a fire fighter system (Consiliul de Supraveghere din Domeniul Naval, 2023).

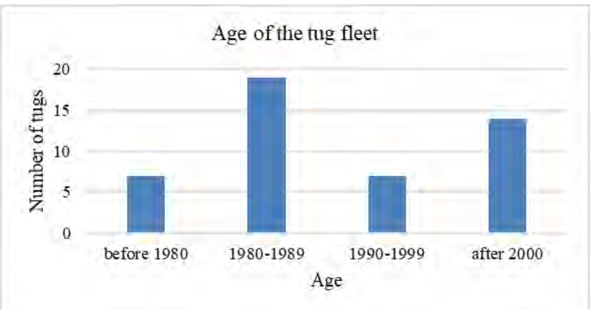

Figure 2. The age of the fleet of tugboats in the Port of Constanta

At this moment, 47 tugboats of the 3 companies are operating. Figure 2 shows the age of the tug fleet. As can be seen, most tugboats were produced between 1980-1989 and after 2000, and in smaller proportion are those produced before 1980 and between 1990-1999. This aspect shows that the fleet of tugboats in the Port of Constanta is quite old, with an average age of approximately 34 years. The fuel consumption of a tugboat is influenced by its age. Older tugboats typically have less efficient engines and outdated technology, leading to higher fuel consumption compared to newer models.

Regarding the hook pulling force of the tugs, 40.8% of the tugs of the 3 companies have more than 20 TF (ton-force), 26.5% have more than 40TF, 30.6% have more than 10TF and only one tug has >5 TF (Consiliul de Supraveghere din Domeniul Naval, 2023). Another essential aspect in the calculation of emissions is the power of the tugboat engines.

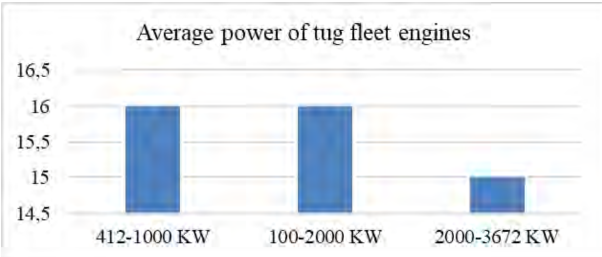

Figure 3. Average power of tugboats fleet engines of the Port of Constanta

In Figure 3 the average power of the tugboat engines can be observed. A proportion of the power of the tugboats is found. 1 third of these has a power between 412-1000 KW, 1 third - 100-2000 KW, and the last third +1 has a power between 2000-3672 KW. For calculation reasons, we will consider the average power of the fleet of tugboats as the arithmetic mean of all the power of the tugboats and obtain a power of 1787 KW.

Considering that we do not have information on the number of maneuvers performed by each tug in the studied period, but only the total number of maneuvers, we considered for the study that the tugs all operated constantly by rotation and depending on availability. Thus, it is difficult to achieve a weighted average to find out the average power of the tugboats depending on the hours of operation on the tugboat and thus, we resorted to an arithmetic average. For future studies when more information will be available for Constanta Port, an operational-mode-based method could be used (Chen, Meng, Jia & Kuang, 2021), starting by analyzing the fuel consumption for each individual tug depending on the number of maneuvers performed during the analyzed period (Murcia González, 2021; de Osés & González, 2020).

3 CALCULATION OF CO_2 AND NO_2 EMISSIONS GENERATED BY TOWING ACTIVITY

To calculate the emissions related to each type of gas, the next equations (The Intergovernmental Panel on Climate Change, 2023) will be used:

Emissions = Activity data × Emission factor (1)

Total emissions = Emissions × GWP (2)

where *Total emissions* or the carbon footprint refers to the total quantity of GHG emissions generated by the tug fleet during the time considered, measured in tones of CO_2-eq.

The GHG Emissions considered in this study are: CO_2, N_2O.

In order to succeed with the analysis carried out, the next aspects served as inputs:

- average consumption related to the fleet age. Given the advanced average age of the tugboat fleet (34 years old) and the average power of tug fleet of 1,787 KW, we will consider that the mean consumption per hour of operation is 150 gallons, that is, approximately 568 liters of diesel (Starcrest Consulting Group, 2023);
- the average annual number of maritime maneuvers. After analyzing the period 2019-2023 regarding the number of maritime maneuvers, we deduced an average of 13,048 maneuvers per year;
- estimated time per maneuver of one hour;
- Global Warming Potentials for CO_2– 1, for N_2O – 273 (Kirschbaum, 2014);
- the carbon footprint of Romania in 2022 was 107.3 Mt CO_2-eq (European Commission, 2023);
- For 1 liter of diesel the total emissions are considered:

2.52 kg CO_2-eq (from CO_2) + 0.04 kg CO_2-eq (from N_2O) = 2.56 kg CO_2-eq

To calculate the final quantity of emissions generated by the tug fleet, the following formula will be applied.

E = maneuvers × time per maneuver × consumption × emissions per liter (3)

Where *E* - Carbon footprint, *maneuvers* - number of maritime maneuvers, *consumption* - fuel consumption (liters/hour), *emissions per liter* - direct emissions for diesel (kg CO_2-eq).

4 RESULTS

Applying the equations from the previous chapter and using the collected data, we obtain the following:

E = 13,048 × 1 hour × 568 liters/hour × 2.56 kg CO_2-eq/liter = 18,972.84 kg CO_2-eq = approx. 19 t CO_2-eq

The total quantity of GHG emissions estimated per year (period 2019-2023) that was generated by the tug fleet of Constanta Port for maritime maneuvers is 19 t CO_2-eq. To make a comparison, Romania registered in 2022 a carbon footprint of 107.3 Mt (Million tons) CO_2-eq.

Of this value, 19% is owned by the transport sector (20.4 Mt CO_2-eq). If we include the towing service in the transport category, we understand that it contributes to less than 1% of the volume of emissions generated by this sector.

Even if the result does not seem alarming, it represents only a small part of the total quantity of emissions generated by all the registered maneuvers, in all the ports managed by CN APM SA. In order to achieve the objectives in the context of global warming, it is important that in any activity generating emissions, measures are taken to reduce them.

5 CURRENTLY EXISTING SOLUTIONS FOR EMISSIONS REDUCTION

Due to the global pressures to reduce the carbon footprint in all sectors, stakeholders in the logistics chain are also becoming very careful about their emissions. Thus, in addition to the global requirements and objectives regarding the green transition, there are pressures from the interested parties and clients of port services who want to decarbonize. Considering that part of the emissions generated by port services provided to port clients can be allocated to them, such as Scope 3 emissions, they force towing service providers to decarbonize as well. The world's major ports have set targets for halving emissions by 2030, such as Rotterdam, Singapore, Antwerp (Jameson, 2022).

The latest studies show that replacing diesel engines with new engines that consume cleaner fuels such as LNG, Biogas, Ammonia, or electric engines would significantly reduce the concentration of GHG emitted. But this action will not make it possible to reach Net Zero emissions as provided in the global objectives (Laursen, Barcarolo, Patel, Dowling, Penfold, Faber, Király, van der Ven, Pang, van Grinsven, 2022).

These also come with great challenges, the necessary investments have very high costs that will be amortized over a long period of time, being a more favorable option to design new prototypes that use "clean" fuels and be built from scratch.

The design of fully electric tugs would be the most favorable option, but given the need for high power, the batteries would also be oversized, which would make this modification only possible for larger tugs.

Also, the use of alternative fuels comes with challenges, they are very expensive and the energy efficiency is much lower than that of electric propulsion on batteries. Economic forecasts show that the demand for alternative fuels in the maritime field will increase significantly in the coming years, so much so that it will not be possible to cover this need with the existing production (Bouman, Lindstad, Rialland, Strømman, 2017).

The cleanest fuels at the moment addressed by shipping industry are electro-fuels, like e-methane, e-methanol, e-hydrogen, e-ammonia, that do not emit greenhouse gases neither when they are produced nor when they are burned, but there are still many discussions on this topic.

6 LIMITATIONS

As being among the first studies of this kind in Constanta Port, this work has limitations represented by the availability of public data regarding the activity of tugboats in the Port of Constanța, which required us to use the estimated consumption based on the number of vessels operated during the analyzed time period, the average number of maneuvers and the public information available from port authorities.

In order to simplify the calculations, the main 2 types of greenhouse gases generated by the activity of tugboats were taken into account, even if the activity of tugboats with a diesel engine also emits other types of emissions and particles that contribute to some extent to the final carbon footprint.

Also, all the values used were based on estimates and averages of real values. The concrete collected data have been processed for the purpose of this study. For instance, given the fact that we do not have concrete data on the exact consumption of the tugboats individually and also data regarding the operating time of each tugboat in the studied period, as these are not public data, we estimated the fuel consumption according to the average age of the tug fleet and the power of the fleet considering that all tugs operated in rotation.

7 CONCLUSIONS

Decarbonizing the shipping sector is a complex challenge that requires coordinated global efforts and substantial investment in technology and infrastructure. However, achieving these targets is essential to reduce the negative impact of the shipping sector on the environment and to contribute to the wider objective of mitigating climate change.

Decarbonizing tugs is a vital component of reducing overall emissions in the maritime sector, particularly in ports where tugs play a crucial role. By adopting cleaner technologies and practices, the industry can significantly mitigate its environmental impact while maintaining efficient port operations.

Even if the results of the calculations seem insignificant when we refer to the national carbon footprint, the footprint generated by the activity of tugboats is significant considering the concentration of emissions generated only from maritime maneuvers carried out per year.

For the Port of Constanta, to reduce emissions from tugboats, the solutions can be the redesign of ships to use cleaner fuels, increase operational efficiency and, last but not least, investments in new technologies such as alternative propulsion systems.

This study could continue further with a comprehensive analysis of the effects of the generation of emissions and harmful particles in the atmosphere on the health of citizens in the areas neighboring the port or even at a much greater distance, given the ability of these toxic elements to travel long distances and to remain in the atmosphere for a very long time. It can also represent the starting point for an economic impact analysis.

The fleet of tugboats of Constanta Port is aging, only 14 tugboats are produced after 2000, of which only 3 after 2010. Their age also implies a higher fuel consumption. The financing of investment projects would be a great opportunity for the Port of Constanta to renew its fleet of tugboats with newer, more energy efficient and environmentally friendly ones.

Retrofitting older vessels with more modern engines and technologies could reduce fuel consumption and emissions significantly, but newer tugboats inherently have the advantage of being designed with these efficiencies from the start.

The results of the work bring arguments and focus on a field that is today in the concerns of the Port of Constanta, taking into account the financing lines for new technologies and innovation in the field. In this sense, there are concerns regarding the measurement of the carbon footprint within the Port of Constanta in the ongoing projects (Pioneer, 2024).

The paper addressed the field of towing, as this is an activity carried out over short distances, it could be subject to technological changes regarding the propulsion or the fuel used.

Also, the work drew attention to the need for retechnology, taking into account the advanced average age of the fleet in the study addressed.

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