Mitigating the Effect of Port Electrification and Clean Fuels on Auxiliary Generator Emissions of an 8,000 TEU Container Ship

Hasan Yilmaz[1*]
[1]Dr. Mechanical Engineer., Giresun Municipality, Giresun, Türkiye,
(ORCID: 0000-0002-6942-734X),

Abstract: Maritime transport is a significant contributor to global emissions, with the auxiliary generators of container vessels representing a considerable, yet often overlooked, source of pollution. This study provides a thorough examination of the energy consumption and emissions characteristics of the auxiliary generators on a standard 8,000 TEU container vessel. Operational data and emission factors were used to evaluate the mitigating effects of Onshore Power Supply (OPS) and cleaner fuels like Marine Diesel Oil (MDO). The results show that auxiliary generators use more than 1,700 tons of fuel per trip and release about 5,441 tons of CO_2. The implementation of OPS in port can eliminate local air pollutants (NOx, SOx, PM) and reduce associated CO_2 emissions to nearly zero, representing a 69% reduction from auxiliary operations. While MDO use significantly curtails SOx and PM, it offers limited CO_2 benefits. Economic analysis confirms the long-term viability of OPS despite high initial infrastructure costs. The study concludes that a hybrid strategy that combines port electrification with the use of low-sulfur fuels at sea is essential for achieving the economic and environmental sustainability goals of the maritime sector.

Keywords: Auxiliary Generator on Ships, 8.000 TEU Container Ship, Shore Power, Marine Diesel Oil, Energy Consumption

* Corresponding Author

I. INTRODUCTION

While maritime transport accounts for over 80% of global trade, it is also a significant source of carbon emissions and air pollutants. Consequently, it represents a major focus for energy efficiency and emission control initiatives. Container ships, in particular, are notable sources of air pollution and greenhouse gases. For instance, international shipping emits approximately 1,000 million tons of CO_2 annually and contributes to 13% of total anthropogenic SO_x emissions [1]. According to data from the International Maritime Organization (IMO), it is reported that maritime transport is responsible for approximately 3% of global CO_2, NOx, SOx, and particulate matter emissions. The IMO indicates that about 15% of this value consists of NOx and 13% SOx, with the remainder being CO_2 [2]. This proportion is projected to increase significantly by 2050 if no preventive measures are taken. A substantial portion of these emissions originates from container ships. Container ships are among the highest power-consuming vessels in the maritime sector; in these ships, the propulsion system meets approximately 82% of the total energy demand, while electricity generation (auxiliary machinery) accounts for 17% [3,4]. In 8000 TEU (Twenty-Foot Equivalent Unit) class vessels, alongside the main propulsion system, auxiliary diesel generators fulfill the ship's electrical requirements and play a critical role during port maneuvers. A visual representation of an 8000 TEU class container ship is provided in Figure 1.

Fig. 1. A Typical 8,000 TEU Capacity Container Vessel [5].

On large container vessels, the total power of several large generators is reported to range between 30-50 MW. For instance, the total power output of the auxiliary generators aboard the *Emma Maersk* has been documented at approximately 30 MW [6]. This indicates that auxiliary generators hold a critical share in the vessel's overall energy consumption. In maritime operations, auxiliary generators are frequently required to operate under partial load conditions, a situation which elevates fuel consumption and consequently increases emissions.

Furthermore, environmental regulations within the maritime sector directly impact these auxiliary engines. For example, the IMO's MARPOL (International Convention for the Prevention of Pollution from Ships) Annex VI designates NOx Emission Control Areas (ECAs), which mandate the stringent Tier III standard for vessels operating in port regions surrounding Northern Europe and North America. The Tier III standard necessitates an approximate 80% reduction in NOx emissions compared to Tier I limits [7]. Figure 2 illustrates the NOx emission limits stipulated under MARPOL Annex VI. As shown in the figure, the Tier III implementation imposes significantly stricter limits, particularly for low-speed engines. Compliance with these limits is compulsory for vessels operating within Tier III designated areas, contingent upon their specific class [7,8].

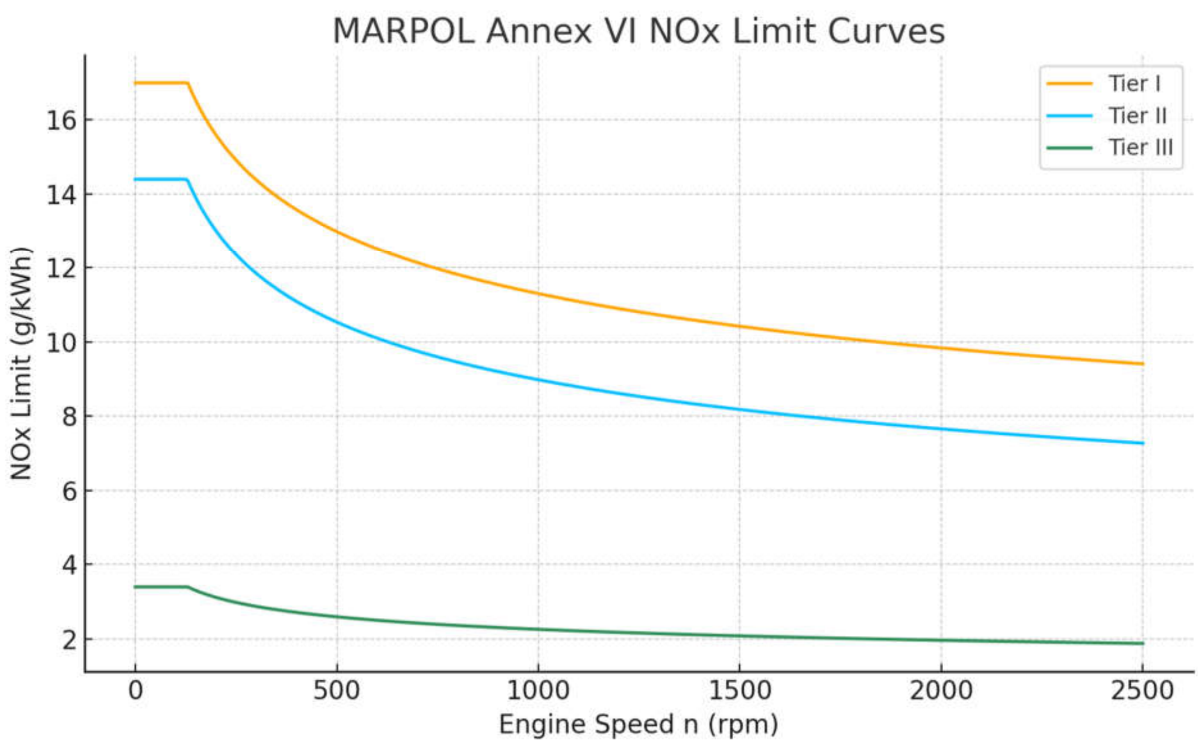

Fig. 2. NOx emission limit curves for ship main engines according to MARPOL Annex VI [7,8]

The graph in Figure 2 depicts the Tier I, II, and III standards established by the IMO, plotted against engine speed. Tier III imposes a mandatory requirement for up to an 80% reduction in NOx emissions compared to Tier I. The Tier III standard becomes particularly more stringent at lower engine speeds (1500 rpm and below) [9]. Similarly, the study by Pavlenko et al. (2020) highlighted that even alternative fuels such as LNG (Liquefied Natural Gas) may struggle to realize their full CO_2 advantages under these lifecycle constraints [10].

Fuel type significantly influences the emission profile. When cleaner marine diesel fuels like MDO (Marine Diesel Oil) / MGO (Marine Gas Oil) are used instead of Heavy Fuel Oil (HFO), SOx and NOx emissions decrease substantially. The literature indicates that switching from HFO to MDO in auxiliary diesel engines provides an approximate 25% reduction in NOx, while not significantly altering CO_2 emissions. Furthermore, due to its low sulfur content, MDO nearly eliminates SOx and reduces particulate matter (PM) emissions by up to approximately 70%. In this context, the use of low-sulfur fuels, combined with exhaust gas cleaning technologies such as Selective Catalytic Reduction (SCR) and Exhaust Gas Cleaning Systems (EGCS), significantly reduces emissions both in port and during voyages [11]. However, alternative fuels like LNG may not always deliver their full carbon advantages due to issues such as methane slip [9].

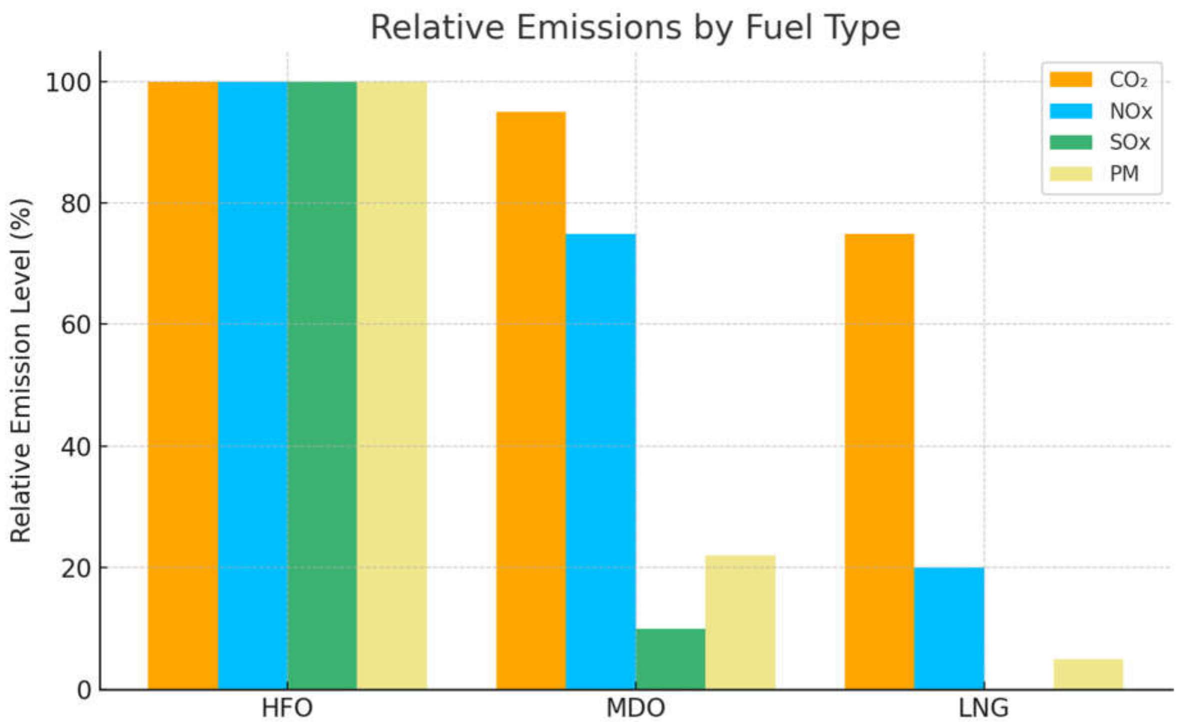

Fig. 3. Emission Comparison by Fuel Type [1].

Figure 3 provides a comparative analysis of the differences in NOx, SOx, and Particulate Matter (PM) emissions produced by Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO), and LNG. The emission values for HFO are normalized to 100 as a reference. The transition from HFO to MDO reduces NOx by up to 25% while also notably reducing particulate emissions. Although LNG achieves very high reductions in SOx and PM, its lifecycle emissions pose a risk due to the potential for methane slip. As illustrated in the figure, it is emphasized that MDO's low sulfur content enables SOx to approach practically zero, while also achieving an approximately 80% reduction in PM emissions. Despite the significant SOx/PM advantages offered by LNG, its overall carbon balance is more complex due to methane losses [1,9].

Shore power systems, also known as cold ironing, have gained prominence in recent years. Various analyses in the literature indicate that the use of Onshore Power Supply (OPS) can reduce CO_2 emissions during port stays by more than 50%. Furthermore, the utilization of shore power in ports outside Emission Control Areas (ECAs), such as those in the Black Sea and Baltic Sea, is projected to achieve CO_2 reductions of up to 57% [12]. Different organizations have reported the average shore power requirement for container ships to be between 549-725 kW [13].

A typical container vessel in the 8,000 TEU class has a deadweight tonnage (DWT) of approximately 100,000 tons and a length of about 334 meters. It is typically equipped with four auxiliary diesel generators, each with a power output of 3-3.5 MW [14]. These generators supply the vessel's electrical needs during voyages; consequently, they consume fuel and produce emissions. This study aims to contribute to sustainability efforts in the sector by analyzing the energy consumption, emission profiles, the impact of OPS utilization, and the operational reliability of these generators.

II. METHODOLOGY

This study examines a typical 8,000 TEU capacity container vessel. The ship's characteristics are as follows: approximately 100,000 DWT, a length of 334 meters, and is equipped with four auxiliary generators, each with a nominal power of 3.2 MW. A voyage scenario comprising 25 days at sea and 5 days in port (for loading/unloading operations) was assumed. During this period, the average load factor for the generators was set at a minimum of 25% at sea and 50% in port. The number of refrigerated containers and the durations of cargo operations were also incorporated into the calculations. For emission calculations, average values of ~700 gCO_2/kWh for HFO and ~690 gCO_2/kWh for MDO were used as baseline emission factors.

The MARPOL regulatory limits and the impact of SCR/EGCS systems were evaluated for NOx and SOx emissions.

2.1. Vessel and system description

The analysis was conducted on a typical 8,000 TEU container vessel characterized by the following specifications:

- Capacity : 8,000 TEU
- Deadweight Tonnage (Dwt) : ~100,000 tons
- Length : 334 meters
- Auxiliary Generators : 4 units, each with a nominal power of 3.2 MW

2.2. Operational scenario

- Voyage Duration : 25 days (Load Factor: 25%)
- Port Duration : 5 days (Load Factor: 50%)
- Annual Number of Voyages : 10

2.3. Emission calculation methodology

- Fuel Consumption: Calculated based on generator power, load factor, and operational duration.
- CO_2 Emissions: An emission factor of 690 gCO_2/kWh was applied for MDO.
- NOx and SOx Emissions: Calculations were based on IMO Tier II limits and a fuel sulfur content of 0.5%.

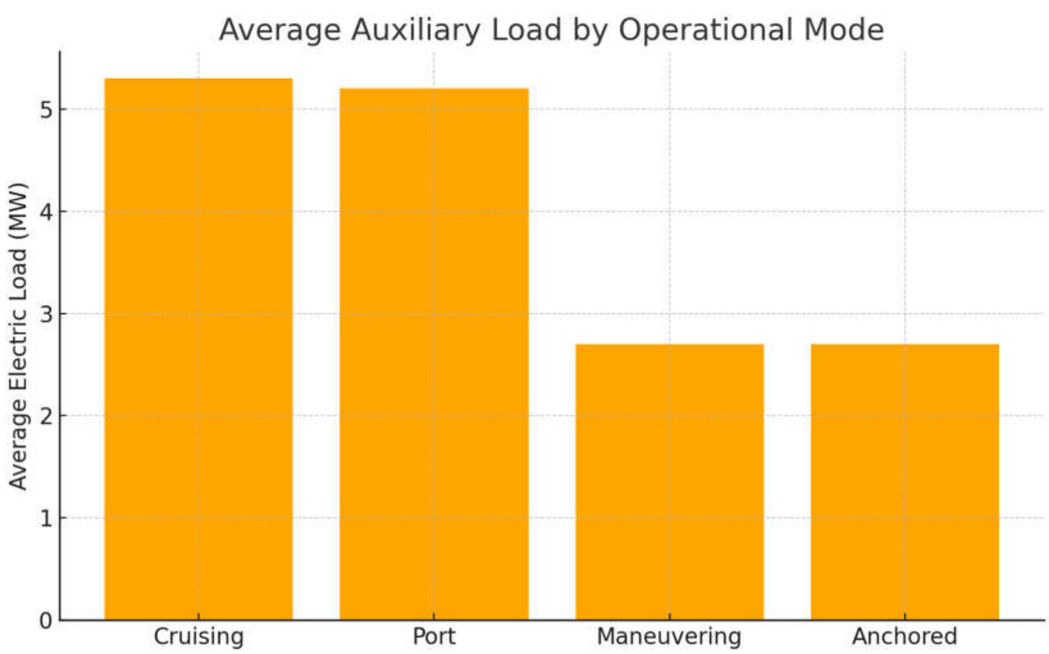

Fig. 4. Energy Load Distribution by Operational Modes [15]

The graph in Figure 4 illustrates the load distribution and electrical load sharing of the 8,000 TEU vessel during overseas voyage and port waiting modes. While the ship's propulsion load is dominant during open-sea voyages, the electrical demand from the auxiliary generators increases relatively in port. This scenario was adopted as a fundamental assumption for performing the calculations [15,16].

III. FINDINGS

3.1. Energy consumption and CO_2 emissions

The calculations revealed that the fuel consumption of the vessel's auxiliary generators during a single voyage (25 days at sea + 5 days in port) is substantial. In the presented scenario, approximately 1,344 tons of fuel were consumed at sea, with an additional 403 tons consumed in port (without OPS). The total fuel consumption was determined to be 1,747 tons of MDO. Consequently, the calculated CO_2 emissions were approximately 4,185 tons (at sea) and 1,256 tons (in port), respectively, resulting in a total CO_2 emission of approximately 5,441 tons per voyage. Utilizing shore power during port stays reduces the CO_2 emissions originating from the ship's auxiliary generators to nearly zero. Therefore, considering an annual average of 10 voyages, approximately 12,560 tons of CO_2 savings can be achieved. The calculated values are summarized in Table 1.

- Voyage Mode : ~1,344 tons fuel, ~4,185 tons CO_2
- Port Mode (without OPS) : ~403 tons fuel, ~1,256 tons CO_2

Table 1. Fuel Consumption and CO_2 Emissions of MDO-fueled Auxiliary Generators (Per Voyage Basis)

Mode of Operation	Duration (days)	Load Factor (%)	Fuel Consumption (tons)	CO_2 Emission (tons)
Voyage	25	25	1.344	4.185
Port (Without OPS)	5	50	403	1.256
Total	30	-	1.747	5.441

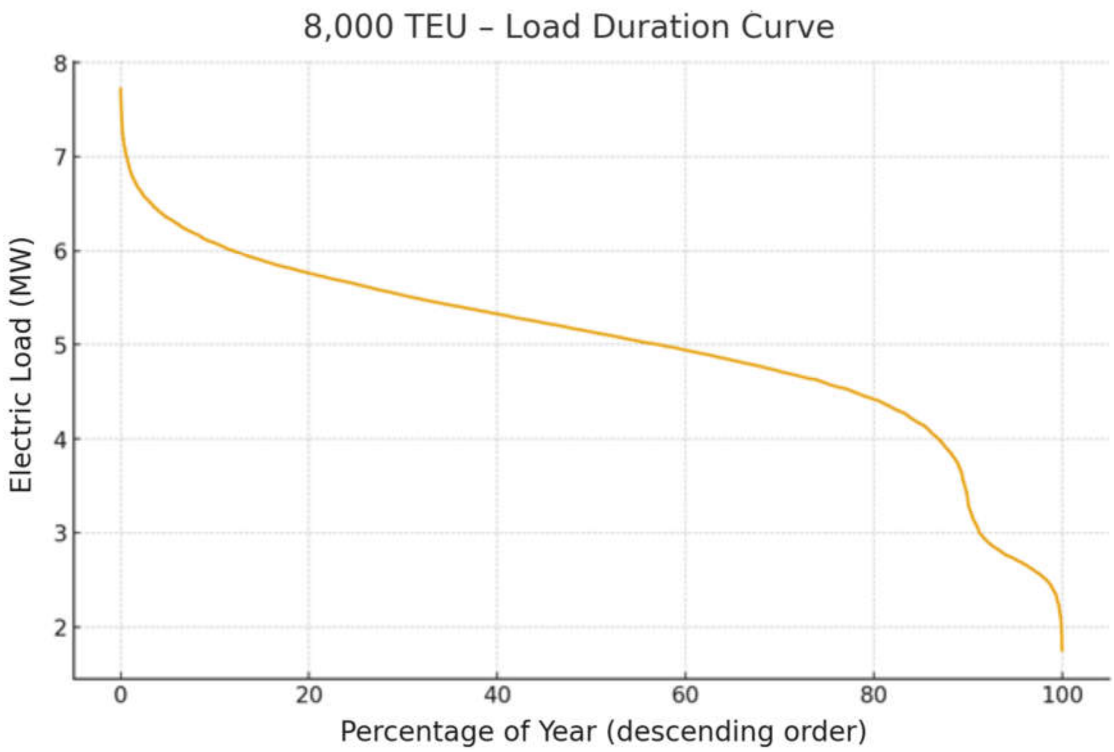

Fig. 5. Load-duration curve for the 8,000 TEU vessel [17,18].

Figure 5 illustrates the duration for which the ship's auxiliary generators operated under load at different power levels. The load-duration curve depicted in this graph summarizes the generators' power usage based on the simulation scenario. A tendency for prolonged operation at low load factors and relatively short operation at high loads is observed. This operational profile signifies decreased engine efficiency and increased specific fuel consumption under low-load conditions [17,18].

The impact of port electrification (shore power) is considerable. According to our simulation, the implementation of OPS eliminates generator fuel consumption in port and, consequently, reduces the associated CO_2 emissions to zero. This results in a 24% reduction in total CO_2 emissions per voyage. When considered specifically for the auxiliary engines, this reduction rate rises to 69%. Furthermore, literature indicates that a significant portion of the energy demand in ports originates from boilers (for heating and steam); for instance, in EU ports, approximately 44% of in-port CO_2 emissions are attributed to boilers [19]. This suggests that the application of cold ironing should be extended not only to generators but also to boiler systems. As also observed in Figure 3, emission control in existing low NOx/SOx areas is shaping power source choices and technology adoption. It should be noted that while OPS eliminate local ship emissions, the net carbon reduction depends on the carbon intensity of the local electrical grid supplying the power.

3.2. NOx, SOx, and PM emissions

NOx, SOx, and particulate matter (PM) emissions also decrease correspondingly; particularly with the use of shore power, SOx emissions approach zero, and NOx emissions are significantly reduced. Due to the use of MDO and the 0.5% sulfur limit, SOx emissions are at very low levels compared to HFO. NOx emissions are constrained by IMO Tier II limits. The utilization of OPS eliminates all local emissions (NOx, SOx, PM) in port [20,21].

The obtained results demonstrate that the energy consumption and emissions of auxiliary generators must not be overlooked. Auxiliary systems contribute significantly to the total energy consumption, especially in container vessels [3,22]. Our study confirmed that using MDO reduces NOx by up to ~25% and substantially decreases SOx. However, it was observed that changing the fuel type alone does not significantly reduce CO_2, whereas exhaust gas treatment technologies can further lower NOx and particulate emissions. For instance, the deterioration of engine efficiency at low loads increases specific fuel consumption [3,11].

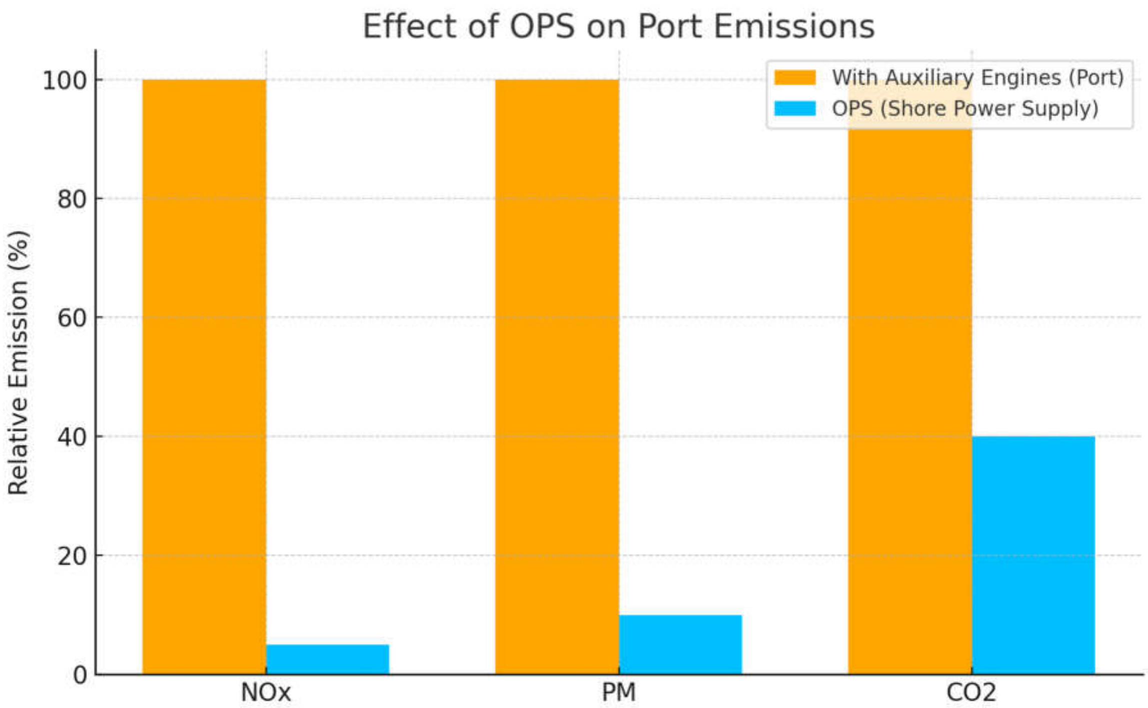

Fig. 6. Impact of OPS Implementation on Emissions [20,21]

Figure 6 illustrates the emission reduction achieved when utilizing shore power at the berth. With the switch to the Onboard Power System (OPS), electrical energy is sourced from the land-based grid, allowing the ship's generators to be shut down. Consequently, NO_x and PM emissions are reduced to approximately 5% and 10% of their original levels, respectively. From a CO_2 emissions perspective, absolute zero emissions should not be expected upon transitioning to OPS. When accounting for the carbon dioxide release associated with the energy sources used for grid electricity production (e.g., natural gas, coal, or a renewable energy mix), the CO_2 emissions attributable to OPS usage remain at approximately 40% of the original level. This value represents a significant reduction compared to the direct fuel combustion of the generators. However, since emissions are not entirely eliminated, the carbon neutrality of port electrification is directly dependent on the energy generation mix of the grid. Increasing the share of renewable energy sources will enable this percentage to be further reduced [20,23].

These findings carry significant importance for promoting sustainable port operations within the international maritime sector. The widespread adoption of Onboard Power Systems (OPS) plays a critical role in achieving port emission reduction targets outlined in MARPOL Annex VI. The use of OPS leads to a marked decrease in CO_2 emissions in port. Similarly, significant reductions in NOx and PM emissions are also observed. These results are consistent with the projected 50-69% CO_2 reduction reported in the literature.

3.3. Economic analysis

The conducted economic analyses demonstrate the significant impact of fuel costs. Assuming an MDO fuel price of 900 USD/ton, the annual expenditure for auxiliary systems consuming thousands of tons of fuel annually is substantial. In contrast, meeting the energy demand in port with shore power at a unit price of approximately 0.05 USD/kWh can significantly reduce the cost for the same amount of energy. However, the investment cost for OPS infrastructure (converters, cables, adaptors) is considerably high, and the payback period extends over the long term.

For example, consider an 8,000 TEU vessel with an annual electricity consumption in port of 2,400,000 kWh.

The cost for energy using OPS would be:2,400,000 kWh * 0.05 USD/kWh = 120,000 USD

Using marine diesel fuel (MDO), the calculations are as follows:

Fuel energy required to generate 2,400,000 kWh of electricity (assuming 50% generator efficiency):

2,400,000 kWh / 0.5 = 4,800,000 kWh.

Conversion of this energy to MDO mass (using an energy content of ~11.9 kWh/kg for MDO):

4,800,000 kWh / 11.9 kWh/kg = 403,36 kg ≈ 403 tons MDO.

Cost of 403 tons of MDO:

403 tons * 900 USD/ton = 362.700 USD ≈ 360.000 USD

The calculated values are presented collectively in Table 2. In this example, the cost of using the generators is approximately three times higher than that of cold ironing. The economic analysis indicates that the OPS system yields an annual cost saving of approximately 265,000 USD. Although the initial investment cost for OPS infrastructure (1-2 million USD) is high, it can provide an economic advantage in the long term by reducing energy costs in port. Furthermore, while LNG fuel appears attractive, the risk of methane slips and the costs associated with its physical infrastructure must be considered. As methanol and ammonia are not yet commercially widespread, decisions regarding transitioning to these fuels require careful analysis. In summary, a combined approach—investing in shore-side electricity infrastructure in ports to lower fuel costs while utilizing low-sulfur liquid fuels at sea—achieves an economic and environmental balance.

Table 2. Economic Comparison of OPS and Traditional System (Annual Basis)

Parameter	Conventional System (MDO)	OPS System	Unit
Energy Consumption (Port)	2.400.000	2.400.000	kWh
Fuel/Electricity Cost	360.000	120.000	USD
CO_2 Emissions (Port)	12.560	-	ton
Maintenance Cost	50.000	25.000	USD
Total Annual Cost	410.000	145.000	USD

3.4. Reliability and maintenance

Auxiliary diesel generators can operate for tens of thousands of hours without failure when subjected to regular maintenance. This typically involves oil and filter changes approximately every 500-1000 operating hours, coupled with an annual comprehensive overhaul. Neglect of maintenance can degrade fuel efficiency and precipitate failures. For instance, under irregular maintenance schedules, significant increases in NOx and particulate emissions have been observed, alongside a 5-10% rise in fuel consumption [11,24]. The maintenance schedule and its impacts for auxiliary generators are detailed in Table 4.

Redundancy strategies, which involve installing multiple generators on a vessel, significantly enhance operational reliability. In the event of a single generator failure, others can be brought online to ensure energy continuity. Additional measures to boost reliability include oil analysis, performance monitoring via vibration and emission sensors, and stringent fuel filtration control. Overall, appropriate maintenance and continuous monitoring are paramount for preserving auxiliary generator performance and maintaining high levels of energy efficiency [24,25].

Table 3. Auxiliary Generator Maintenance Schedule and Effects [26].

Maintenance Activity	Frequency	Effect	Risks if Maintenance not Performed
Oil and Filter Change	Every 500-1000 hours	Maintains fuel efficiency, emission control.	5-10% increase in fuel consumption; rising emissions.
Fuel Filter Check	Every 250 hours	Protects fuel injection system.	Engine failures; performance degradation.
General Overhaul	Annually	Ensures system reliability.	Unexpected failures; operational downtime.
Vibration Analysis	Semi-annually	Predictive Maintenance.	Major repair costs, potential catastrophic failure.

IV. Conclusions

This study comprehensively evaluated the auxiliary generators of an 8,000 TEU class container vessel. The analysis revealed that the energy consumption of the auxiliary machinery is substantial and cannot be overlooked, and the emissions associated with this consumption constitute a significant portion of the vessel's total emission load.

The principal findings are as follows:

- Auxiliary generators consume over 1,700 tons of fuel per voyage, resulting in thousands of tons of CO_2 emissions.
- Shore power (OPS) has the potential to eliminate port-originated emissions entirely, offering annual CO_2 savings exceeding 12,000 tons. Economically, while the infrastructure investment for shore power is costly, the fuel savings provide a net advantage in the long term.
- Low-sulfur fuels, such as MDO, substantially reduce SOx and PM emissions.
- Regular maintenance directly enhances both operational reliability and environmental performance.

V. Recommendations

Short-Term:

- The use of MGO/MDO in existing vessels should be expanded, and exhaust gas treatment systems such as SCR/EGCS should be evaluated.
- A hybrid strategy should be implemented. Fuel costs should be reduced by establishing electrification infrastructure in ports, while low-sulfur liquid fuels (MDO/MGO or biofuel blends) should be utilized on the open sea. This combination achieves both economic and environmental balance.
- Collaboration with fuel suppliers should be initiated to research biofuel and low-emission fuel options.

Medium-Term:

- OPS infrastructure investments in ports should be incentivized, and OPS connection capabilities should be made mandatory in new vessel designs.
- OPS lines and plug-in infrastructure should be developed. OPS connections and plug-in features for auxiliary engines must be pre-planned in new vessel designs.

Long-Term:

- Research, development, and infrastructure projects for zero-carbon fuels—namely methanol, ammonia, and green hydrogen—should be accelerated.
- Maintenance efficiency should be enhanced by integrating sensors and monitoring systems for predictive maintenance. Implementing these steps will significantly contribute to the sustainability of maritime transport and play a key role in achieving the IMO's 2050 greenhouse gas reduction targets.

The implementation of these measures will increase energy efficiency and significantly reduce emissions in 8,000 TEU and similar large container vessels. This study has clearly demonstrated that the energy consumption and emissions of auxiliary generators on an 8,000 TEU container vessel constitute a significant component of the ship's total environmental footprint. The obtained results are consistent with the literature and provide guiding insights for enhancing environmental effectiveness in ship operations.

REFERENCES

1. Sui, C., De Vos, P., Stapersma, D., Visser, K., & Ding, Y. (2020). Fuel Consumption and Emissions of Ocean-Going Cargo Ship with Hybrid Propulsion and Different Fuels over Voyage. *JMSE,* 8(8), 588.

2. IEA- International energy agency (2025, Ekim). *International shipping*. https://www.iea.org/energy-system/transport/international-shipping

3. Aijjou, A., Bahatti, L., & Raihani, A. (2019). Study on container ship energy consumption. WIT Press Energy and Sustainability WIII, 237, 25-36.

4. Çelik, Y., & Yorulmaz, M. (2023). Türkiye'deki konteyner terminallerinin performans incelemesi ve Mersin Limanı için performans gelişim önerileri. *Journal of Turkish Operations Management*, *7*(1), 1531-1549.

5. Baird Maritime. (2025, Ekim). *CMA CGM takes delivery of LNG-powered 8,000TEU ship*. https://www.bairdmaritime.com/shipping/boxships/cma-cgm-takes-delivery-of-lng-powered-8000teu-ship

6. Diesel Services of America (DSOA). (2025, Ekim). *Auxiliary Engines Explained: Powering Your Marine Adventures*. https://dieselservicesofamerica.com/auxiliary-engine/

7. DieselNet. (2025, Ekim). *IMO Marine Engine Regulations- Emission Standarts.* https://dieselnet.com/standards/inter/imo.php

8. Mathur, A. (2020). Selective Catalytic Reduction (SCR) Reactors For Ships – Types, Working Principle, Advantages And Disadvantages. *Marine Technology.* https://www.marineinsight.com/tech/selective-catalytic-reduction-scr-reactors-for-ships-types-working-principle-advantages-and-disadvantages/

9. Anderson M., Salo K., & Fridell E. (2015). Particle- and Gaseous Emissions from an LNG Powered Ship. *Environ Sci Technol.*, 49(20), 12568-12575.

10. Pavlenko, N., Comer, B., Zhou, Y., Clark, N., & Rutherford, D. (2020). The climate implications of using LNG as a marine fuel. International Council on Clean Transportation (ICCT). *Stockholm, Sweden: Swedish Environmental Protection Agency.*

11. Jayaram, MV., Miller, JW., Nigam, A., Welch, MWA., & Crocker, D. (2009, April) Measurement of Criteria and Greenhouse Gas Emissions from Auxiliary Engines on Ocean-Going Vessels Operating on Heavy Fuel Oil and Marine Diesel Oil. *University of California, Riverside College of Engineering-Center for Environmental Research and Technology.* Contract 03-345.

12. Marineinsight, (2025, Feb). *Understanding Onshore Power Supply* https://www.marineinsight.com/green-shipping/understanding-onshore-power-supply/

13. Sustainable Ships. (2025). Containership Shore Power Demand. https://www.sustainable-ships.org/stories/2024/average-shore-power-demand-containership

14. Sustainable Ships. (2024). *Average Shore Power Demand Guide* pp:56. https://static1.squarespace.com/static/6155b5bdada6ea1708c2c74d/t/67359caf6af15a7228675eae/1731566769571/Average+Shore+Power+Demand+Guide+1.12.pdf

15. Baldi, F., Johnson H., Gabrielii C.,Andersson, K. (2015). Energy and Exergy Analysis of Ship Energy Systems – The Case study of a Chemical Tanker. *International Journal of Thermodynamics.* 18(2), 82-93.

16. Trozzi, C., (2010). Emission estimate methodology for maritime navigation. *Techne Consulting, Rome, 780.* https://gaftp.epa.gov/air/nei/ei_conference/EI19/session10/trozzi.pdf

17. Baldi, F., Ahlgren, F., Nguyen, T. V., Thern, M., & Andersson, K. (2018). Energy and exergy analysis of a cruise ship. *Energies*, *11*(10), 2508.

18. Lee, J. H., Oh, J. H., & Oh, J. S. (2022). Application of generator capacity design technique considering the operational characteristics of container ships. *Electronics*, 11(11), 1703.

19. Osipova, L., & Camilla Carraro C. (2023). Shore power needs and CO2 emissions reductions of ships in European Union ports: Meeting the ambitions of the FuelEU Maritime and AFIR.

20. Bailey, D., & Solomon, G. (2004). Pollution prevention at ports: clearing the air. *Environmental impact assessment review*, *24*(7-8), 749-774.

21. Winkel, R., Weddige, U., Johnsen, D., Hoen, V., & Papaefthimiou, S. (2016). Shore side electricity in Europe: potential and environmental benefits. *Energy Policy*, *88*, 584-593.

22. Yeh, CK., Lin, C., Shen, HC., Cheriyo, NK., Nguyen, DH., & Chang, CC. (2022). Real-time energy consumption and air pollution emission during the transpacific crossing of a container ship. *Scientific Reports*, 12(1), 15272.

23. Corbett, J. J., Wang, H., & Winebrake, J. J. (2009). The effectiveness and costs of speed reductions on emissions from international shipping. *Transportation Research Part D: Transport and Environment*, *14*(8), 593-598.

24. Daya, A.A., ve Lazakis I. (2024) Systems Reliability and Data Driven Analysis for Marine Machinery Maintenance Planning and Decision Making. *Machines*, 12(5), 294.

25. Güçlü, K., & Yorulmaz, M. (2023). Konteyner Terminallerindeki İş Kazalarının Bulanık Dematel ve Topsis Yöntemleri ile İncelenmesi: Kocaeli Liman Bölgesinde Bir Uygulama. *İstanbul Ticaret Üniversitesi Fen Bilimleri Dergisi*, *22*(44), 310-339.

26. Eyit, B., & Yorulmaz, M. (2025). Konteyner Terminallerinde Yük Operasyonlarının Verimliliğini Etkileyen Faktörlerin Dematel Yöntemiyle İncelenmesi. *Ekonomi Maliye İşletme Dergisi*, *8*(1), 30-45.