Determination of Carbon Footprint: Case Study of a Marine Company

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This study aims to establish a corporate carbon footprint by setting standards for carbon footprint assessment and reporting, identifying the necessary data for greenhouse gas (GHG) calculations, and defining appropriate calculation methods. The study examines the carbon emissions of a maritime technology company in Turkey, with a focus on 2023. The research identified Scope I, II, and III emission sources, following the GHG Protocol and ISO 14064 standards. Data from the company was used with emission factors from the Department for Environment, Food & Rural Affairs (DEFRA) to calculate emissions in carbon dioxide equivalent (CO$_2$e). The study revealed that 47.9% of the company's total CO2e emissions of 179,325 tons in 2023 resulted from Scope I direct emissions, 28.7% from Scope II indirect emissions, and 23.5% from Scope III other indirect emissions. The findings provide a comprehensive overview of the company's carbon emissions and identify key areas for potential GHG reductions. While previous studies have mostly focused on the carbon footprint of shipping and shipbuilding in the maritime sector, this study stands out as one of the first studies on the carbon footprint of maritime technology companies. It also serves as both an example and a guide for future research on conducting corporate carbon footprint assessment studies using current standards and emission factor inventories.

KEY WORDS
~ Carbon footprint
~ Environmental
~ GHG
~ Emissions
~ Marine
~ Ocean engineering

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1. INTRODUCTION

The United Nations (UN), with a target year of 2030, introduced a framework for assessing progress, monitoring developments, and reporting on environmental degradation and the sustainability of life through 17 Sustainable Development Goals (SDGs). In parallel, the European Union Green Deal (EUGD) established policy measures aimed at achieving net-zero greenhouse gas (GHG) emissions by 2050 and fostering economic growth decoupled from the consumption of natural resources. Together, the UN SDGs and the EUGD highlight a global commitment to sustainable development by aiming to reduce the environmental, social, and economic impacts of human activities.

Within this context, climate change has become one of the most critical global challenges. Earth's land and ocean temperatures are in constant flux, and the concentration of greenhouse gases (GHGs)—particularly carbon dioxide (CO_2)—in the atmosphere is rising rapidly (Demir, 2009). Human-induced GHG emissions are the primary driver of this increase in global temperatures. The contribution of each GHG to global warming varies depending on its atmospheric lifetime and radiative forcing potential. While gases such as methane (CH_4), nitrogen oxides (NO_x), sulfur oxides (SO_x), water vapor, ozone (O_3), and chlorofluorocarbons (CFCs) also contribute to warming, CO_2 remains the most influential due to its prevalence and long atmospheric lifetime (Andrew et al., 2023).

These emissions stem from a wide range of human activities. Transportation, energy consumption, heating, and food production have a significant impact on the carbon footprint of individuals, nations, and organizations, contributing to total CO_2 and other greenhouse gas emissions. Organizational emission levels are particularly influenced by factors such as land use, energy consumption, waste management practices, and the types of fuels used (Manzini, 2016).

In this broader context, the maritime sector is a significant contributor to global GHG emissions and climate change. Shipbuilding, maritime transportation, and marine technology production are critical areas for evaluating the sector's environmental impact (Berechman, 2014). In this context, carbon footprint analyses assess GHG emissions across the entire life cycle of maritime operations and identify opportunities for improvement. Such studies also promote the adoption of environmentally friendly practices and technologies, particularly within port operations.

Accurate calculation and assessment of the carbon footprint in Türkiye's maritime sector can support stakeholders in developing effective strategies to reduce GHG emissions. Achieving reductions in emissions related to maritime transport requires a detailed analysis of carbon footprints across processes such as shipbuilding, shipping operations, and marine technology production (Turkish Ministry of Environment, 2024). By evaluating emissions at each stage of the maritime transport life cycle, major sources can be identified and mitigation efforts can be prioritized to reduce environmental impacts (Turkish Shipyard Association, 2023).

Global regulatory and market dynamics further reinforce these needs. In recent years, sustainability has also emerged as a key policy priority in the global maritime sector. Environmentally driven regulations increasingly shape the dynamics of maritime industries (Önal, 2021). Numerous international environmental instruments and voluntary standards are being implemented, requiring the integration of new sustainability criteria into the design and construction of ships and maritime technologies. There is growing pressure within the industry to develop more energy-efficient and environmentally friendly vessels and systems. Current efforts include improving ship hydrodynamics, advancing energy-efficient engine technologies, developing low-carbon fuels, and establishing certification processes to support these innovations (UNCTAD, 2023).

As a result, maritime businesses and supply chains are expected to comply with global standards related to environmental protection, human rights, labor rights, transparency, and public reporting. These companies must work to minimize their negative impacts on the environment, society, and their workforce—particularly in contexts where national regulations may be insufficient. The UN has set the shipping sector a goal of reducing carbon emissions by between 50% and 70% by 2030, while also significantly increasing the number of zero-emission vessels. In line with this objective, the development and deployment of low- and zero-emission ships will help shipping companies achieve their sustainability targets while enhancing both operational efficiency and market competitiveness (Afiuddin et al., 2023).

In this evolving landscape, many shipping companies increasingly recognize the strong connection between environmental responsibility and commercial success, and are therefore prioritizing sustainability improvements across both environmental and social dimensions. Reducing waste and emissions during maritime operations offers technical, commercial, and ecological benefits. These companies frequently emphasize their environmental commitments through reports, websites, and presentations, often citing compliance with international environmental standards. Globally, many maritime businesses publish annual sustainability and corporate social responsibility (CSR) reports that outline their environmental strategies and initiatives (Xing et al., 2020).

For preparing such reports and calculating carbon emissions, internationally recognized standards and emission factor inventories are commonly used. An accurate carbon footprint assessment must take into account various factors, including the type of organization, service area, geographic location, and operational boundaries (Zhang et al., 2023). However, emission inventories developed for different purposes may necessitate the use of distinct standards and calculation methods. Therefore, selecting appropriate standards and inventories in the maritime sector is critical for ensuring both accuracy and international consistency.

While previous studies have primarily focused on the carbon footprint of shipping and shipbuilding within the maritime sector, this case study—conducted on a marine technology company in Türkiye that produces marine cleaning equipment—aims to serve as a reference for carbon footprint assessment. It seeks to contribute to the sector's sustainability performance by examining the environmental impacts of maritime companies and providing guidance for future research.

2. LITERATURE REVIEW

Numerous studies have examined greenhouse gas (GHG) emissions in the maritime sector, with a focus on emissions assessment methods, energy efficiency strategies, and the application of Life Cycle Assessment (LCA) frameworks.

Institutional and Regulatory Contributions:

In 2020, the International Maritime Organization (IMO) published its Fourth GHG Study, reporting that total maritime transport emissions increased by 9.6% between 2012 and 2018—from 977 million tonnes to 1,076 million tonnes. During the same period, the share of maritime emissions in global anthropogenic emissions rose slightly, from 2.76% to 2.89% (Kopela, 2020). Emissions from international maritime transport specifically increased by 5.6%, from 701 million tonnes to 740 million tonnes. While carbon intensity—defined as CO_2 emissions per unit of transport work—generally improved during this timeframe, indicating greater efficiency, some ship types experienced an increase in intensity. In 2018, carbon intensity was measured to be 21% to 29% lower than in 2008. Projections suggest that total emissions could rise to between 90% and 130% of 2008 levels by 2050. The impact of the COVID-19 pandemic on these projections is expected to be limited to temporary reductions in 2020 and 2021 (Crippa et al., 2024). These findings highlight the need for more consistent and sector-specific mitigation strategies.

Academic Studies on GHG Emissions and LCA:

Winebrake et al. (2007) focused on emissions resulting from fuel consumption in marine vessels and introduced a model for total energy and emissions analysis. The Total Energy & Emissions Analysis for Marine Systems (TEAMS) model was used to conduct a detailed life cycle assessment of fuel use in maritime operations. TEAMS evaluates emissions across the entire fuel supply chain, from extraction and processing to distribution and onboard consumption.

Fitzgerald et al. (2011) calculated the carbon emissions of international maritime transport in New Zealand using a cargo-based approach, which allocates emissions based on the quantity and type of cargo transported along specific routes. These results were then compared to values reported in New Zealand's official national GHG emissions inventory. The national inventory, which applies a limited scope based on fuel consumption, accounted for only one-seventh of the emissions estimated in the study. The findings underscore the importance of emission calculation boundaries and methodologies in accurately determining GHG emission levels.

Rehmatulla et al. (2017) examined technologies developed to enhance energy efficiency and reduce carbon emissions in the maritime sector. Their analysis revealed that while certain technologies—such as improved hull designs and engine modifications—offer substantial fuel savings and emission reductions, others are hindered by practical limitations, high costs, or limited applicability. These findings emphasize that not all innovations yield the same level of sustainability impact, highlighting the importance of carefully selecting and implementing the most effective measures.

While these works are valuable, they mainly address shipping operations and vessel construction rather than equipment manufacturing.

Bouman et al. (2017) conducted a comprehensive review of emission reduction technologies in the maritime sector and concluded that, although numerous options are available, their implementation is often constrained by economic, regulatory, and operational barriers.

Hilakari and Marianna (2019) conducted a study to quantify the carbon emissions associated with shipbuilding, using a cruise ship with 150,000 gross tons and 60,000 net tons as the case example. The analysis focused on seven primary materials used in the ship's construction—air conditioning ducts, windows, insulation, wiring, steel structures, and carpets—while also accounting for energy use and waste generation within the shipyard. The study estimated the total carbon footprint of the vessel at 101,097 tonnes of CO_2 equivalent (tCO_2e).

Wang, Watanabe, Hirata, and Toriumi (2021) developed an innovative method for real-time CO_2 emission management in ships using deep learning techniques. Their approach processes Automatic Identification System (AIS) data through cubic spline interpolation and Long Short-Term Memory (LSTM) neural networks to reconstruct vessel trajectories and estimate emissions. The results indicated that traditional methods tend to underestimate emissions, while their model offers a practical tool for real-time monitoring by capturing higher and more accurate CO_2 output per second.

Psaraftis and Zis (2022) offered a critical review of how LCA is applied in maritime transport, underscoring inconsistencies in functional units, boundary definitions, and data assumptions across studies. Their findings emphasize the need for standardized LCA practices to improve comparability and policy relevance.

Balcombe et al. (2019) conducted a life cycle comparison of marine fuels and propulsion systems in the UK, revealing how fuel type and technology significantly impact total emissions. Their results support the adoption of tailored LCA frameworks for evaluating fuel and engine alternatives in maritime applications.

Cucinotta et al. (2024) reviewed LCA applications in naval design and compared environmental performance across alternative fuels and ship types. Their study highlighted methodological gaps, particularly regarding CO_2e normalization and system boundary standardization, emphasizing the need for consistent LCA practices in ship design.

Adhikari, Li, and Gopalakrishnan (2025) conducted a bibliometric and systematic review of carbon footprint tracking in cross-sector industries, including transportation and shipping. They identified key frameworks (e.g., ISO 14064, PAS 2050), highlighted fragmentation in digital tools, and emphasized the need for scalable, integrated systems that combine artificial intelligence, the Internet of Things, and blockchain to improve data quality and transparency.

Sectoral and Applied Case Studies:

Balcombe et al. (2019) also contribute to this area, as their study includes applied LCA scenarios for real-world fuel use and propulsion system assessments, bridging academic and practical perspectives.

Ülker et al. (2021) compared road and maritime transport in the Marmara region of Türkiye by calculating direct emissions within defined system boundaries for each mode of transport. Their findings indicated that shifting freight from road to maritime transport during the specified years contributed significantly to reducing carbon emissions.

Andersson et al. (2021) conducted a full life cycle assessment (LCA) of a cruise ship and found that the majority of GHG emissions occur during the construction phase, particularly from the production of steel and engines. Their findings underscore the importance of including upstream material processes in Scope III emissions accounting.

Georgiev and Garbatov (2022) examined emissions generated by shipyard operations and their contribution to environmental pollution, with a focus on maintaining air quality at levels acceptable for human health. The study analyzed various shipyard production processes that emit air pollutants and assessed the concentration levels associated with specific activities. It also explored the correlation between these activities and established air pollution regulations within the shipbuilding and repair sector. The analysis was based on technologies currently in use at a specific shipyard.

Afiuddin et al. (2023) investigated the greenhouse gas impacts of fossil fuel combustion and energy use in the shipyard industry. The study quantified GHG emissions by first identifying the sources of CO_2 and other greenhouse gases, then applying the formulas and Global Warming Potential (GWP) factors specified in the IPCC 2006 Guidelines to convert them into carbon dioxide equivalent (CO_2e). The results showed that the shipyard's combined primary and secondary emissions totaled 358,693.723 tons of CO_2e annually.

Overall, the literature demonstrates extensive application of LCA and carbon assessment in shipping operations, shipbuilding, and fuel studies. However, most of these studies address vessels and operations rather than equipment manufacturing. Applications of ISO 14064, the GHG Protocol, and IPCC guidelines within shipyards and related facilities (e.g., Georgiev & Garbatov, 2022; Afiuddin et al., 2023) are particularly relevant, as they illustrate standardized methods in manufacturing environments. This provides a methodological foundation for the present study, which extends carbon footprint assessment to the case of a marine technology company in Türkiye that produces cleaning equipment—an area largely absent from current literature.

3. GREENHOUSE GASES AND CARBON FOOTPRINT

Greenhouse gases (GHGs), particularly carbon dioxide (CO_2), have long been identified as primary contributors to climate change due to their emission volume and persistence in the atmosphere (Jones, 2024; Güleç, 2004).

International climate agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement require participating states to establish and implement emission reduction targets (Climate Action Tracker, 2024; UNFCCC, 2023). These frameworks have also pushed industries to measure, report, and manage their carbon footprints as part of broader climate action initiatives. For maritime equipment manufacturers in Türkiye, these commitments intersect with the European Green Deal and its carbon border adjustment mechanism, which imposes carbon-related tariffs on imports and exports in energy-intensive sectors such as steel, aluminum, and cement (Republic of Türkiye Ministry of Foreign Affairs, 2024). Although maritime technologies are not directly listed among these priority sectors, their supply chains are increasingly influenced by these regulations.

Since the late 20th century, various carbon footprint assessment standards have been developed by governments and international organizations, including the World Resources Institute (WRI), the World Business Council for Sustainable Development (WBCSD), the British Standards Institution (BSI), and the International Organization for Standardization (ISO). Standards such as ISO 14064, the GHG Protocol, and guidelines from the Intergovernmental Panel on Climate Change (IPCC) aim to harmonize carbon emissions accounting practices, enabling comparability across organizations and products. The widespread adoption of these standards has played a critical role in supporting global carbon reduction efforts (WRI, 2011).

The GHG protocol is one of the most valid standards used in organizations' greenhouse gas inventory analyses. The GHG Protocol categorizes emissions into three scopes:

- Scope I includes direct emissions from sources that are owned or controlled by the reporting organization. These emissions typically result from the combustion of fossil fuels for heating, as well as from vehicle and machinery operation. Scope I emissions are generally considered to be within the organization’s direct control.
- Scope II covers indirect emissions associated with the consumption of purchased or acquired electricity, steam, heating, or cooling. Although these emissions occur off-site, they result from the organization’s operations. Calculating Scope II emissions allows organizations to better understand the environmental impact of their energy use.
- Scope III emissions encompass all other indirect emissions that occur throughout the reporting entity’s value chain, both upstream and downstream. These may include emissions from employee commuting, business travel, distribution and transportation, waste generation, and even the use and disposal of sold products. Due to the complexity of supply chains, Scope III emissions are often the most difficult to measure and control—yet they frequently represent the largest portion of an organization’s overall carbon footprint.

4. MATERIALS AND METHODOLOGY

A widely accepted principle in both national and international GHG emission management is that “what gets measured gets managed.” This approach identifies emission inventory research—covering sectors and institutions—as a critical first step in carbon management. Such inventories aim to present a clear, comprehensive, and transparent picture of current emissions. Conducting an inventory analysis using accurate and reliable measurements and estimations of present conditions enables the identification of appropriate emission reduction strategies, the implementation of necessary measures, and the achievement of meaningful outcomes. Based on the findings of the inventory study, a strategy and action plan should be developed to define the scope, timing, and prioritization of the actions to be taken (Gao et al., 2013).

The primary goal of a GHG inventory is to identify all direct and indirect greenhouse gas emissions from various sources. The inventory process applies Global Warming Potential (GWP) factors to convert different GHGs into carbon dioxide equivalents (CO_2e). Creating a GHG inventory involves a standardized process that includes three key components: defining inventory boundaries, measuring or calculating emissions, and reporting the results. The most widely used standards for conducting GHG inventory studies are the GHG Protocol—developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD)—and ISO 14064, which provides an internationally recognized framework for calculating and verifying GHG inventories. While ISO 14064 focuses on systematized calculation and verification, the GHG Protocol offers detailed guidance for emissions accounting and reporting (Oblitas-Romero, 2023). Table 4.1 summarizes key approaches and standards for GHG emission assessment.

Approach	Method/Standard
Greenhouse Gas Reduction Calculations	IPCC Calculations
Inventory Studies Institutions and Organizations	ISO 14064 - GHG Protocol - Carbon Trade
Life Cycle Assessments	ISO 14040 - PAS 2050 - PAS 2060
Carbon Trade and Carbon Tax	Mandatory Carbon Markets - Voluntary Carbon Markets

Table 4.1: GHG emission calculation standards

In this study, which focuses on a selected marine technology company, internationally recognized standards for carbon footprint assessment were applied. Although the ISO 14064 and GHG Protocol methodologies are based on similar principles, they differ in terminology and presentation of results. Methodological accuracy is critical in calculating CO_2 emissions, and different types of GHGs can be quantified using either computational methods or direct measurements.

The two primary approaches used to compute GHG emissions can be summarized as follows:

Estimation of GHG Emissions Using a Carbon Mass Balance Approach: This method relates CO_2 emissions to the amount of carbon-containing components at the input and output stages of a given process. The primary data used for emission calculations are the mass balances of carbonaceous materials entering and leaving the system (Vitalievich et al., 2023). For instance, in the limestone roasting process, CO_2 emissions can be estimated by accounting for the decomposition of calcium carbonate ($CaCO_3$) into carbon dioxide (CO_2) and calcium oxide (CaO), using the following formula:

$$E_{CO2} = \frac{44}{12} \times (CA_{stock,st} + CA_{input} - CA_{stock,end} - CA_{output}) \quad \text{...(1)}$$

where E_{CO2} – is the CO_2 emission,

CA_{input}, CA_{output} – is the amount of carbon entering and leaving the facility during the reporting period,

$CA_{stock,st}, CA_{stock,end}$ – is carbon stock at the end and beginning of the period.

The coefficient 44/12 in the formula is derived from the molar masses of carbon dioxide (44 g/mol) and carbon (12 g/mol).

Computation of GHG Emissions Using Emission Factors: This standardized approach calculates GHG emissions based on the organization’s activities and the quantity of fuel or energy consumed during the production of goods or services. Emissions are estimated using the following formula:

$$E_{CO2} = A \times EF \quad \text{...(2)}$$

where E_{CO2} – is the CO_2 emission,

A – quantitative characteristic refers to the numerical measurement of a calculated process or resource.

EF – refers to the emission factor associated with the specific process or resource.

In this study, the second method—calculation using emission factors—was employed. To calculate the corporate carbon footprint in accordance with the criteria outlined by the GHG Protocol and ISO 14064, organizational boundaries were first defined by evaluating data related to the company’s vehicles, energy sources, and waste generation. Emission sources were then categorized under Scope I, Scope II, and Scope III. After identifying these sources, the necessary activity data was collected from the production facility. Global Warming Potential (GWP) values were used to convert various GHGs into carbon dioxide equivalents (CO_2e), as shown in Table 4.2. Emission factors from the UK Department for Environment, Food & Rural Affairs (DEFRA) were applied to the collected data to calculate the total annual CO_2e emissions for the facility, with the entire site serving as the functional unit (DEFRA, 2023).

Activity	Emission	Unit	kg CO_2e
Kyoto protocol products	Carbon dioxide	kg	1
	Methane	kg	28
	Nitrous oxide	kg	265

Table 4.2: Global warming potentials for CO2, CH4 and N2O (DEFRA 2023)

4.1. Operation and Calculation Boundaries

The concept of an organisation's operational boundaries is crucial for carbon footprint assessments, as it defines the scope of emissions to be measured. This boundary outlines the operations and activities under the organization’s direct control, thereby guiding the identification and quantification of greenhouse gas emissions. Establishing a clearly defined operational boundary ensures that all relevant emission sources are accounted for, providing a comprehensive view of the organization’s environmental impact. The boundary should include all emissions from directly managed activities, such as combustion and industrial processes, as well as indirect emissions from purchased energy and related operations. Monitoring emissions within this framework enables organizations to assess their environmental performance and develop targeted strategies for emissions reduction and sustainability.

The principles of the GHG Protocol closely align with those of ISO 14064, which establishes standards for greenhouse gas accounting and verification. ISO 14064 emphasizes the importance of key principles such as completeness, accuracy, consistency, and transparency in GHG accounting and reporting. It also highlights the importance of stakeholder engagement and the use of appropriate methodologies and data quality management procedures to ensure the reliability of GHG inventories. Organizational boundaries are defined in accordance with the principles outlined in both the GHG Protocol and ISO 14064-1:2006. Together, these frameworks provide a structured approach for organizations to establish boundaries and ensure precise, consistent, and transparent reporting of emissions (Balçık, 2024).

Scope	Activity	Activity Detail
Scope I	Stationary combustion	Emissions from combustion processes occurring at stationary sources controlled by the organization
	Mobile combustion	Emissions from combustion processes occurring in mobile sources owned or controlled by the organization
Scope II	Purchased electricity	Emissions associated with the consumption of electricity purchased
	Purchased heating and cooling	Emissions associated with the consumption of heating or cooling purchased or acquired from external sources
Scope III	Fuel and energy-related activities not included in Scope I or Scope II	Emissions associated with fuel and energy use that are not directly owned or controlled by the organization, and are not included in Scope I or Scope II
	Waste generated in operations	Emissions associated with waste generated by the organization's operations
	Business travel	Emissions associated with employee travel for business purposes
	Employee commuting	Emissions associated with employee travel to and from work
	Capital goods	Emissions associated with the production of goods and equipment used by the organization

Table 4.3: Classification of emission sources according to their GHG scope (Ediz, 2023).

When defining the scope of carbon footprint calculations in a study, the characteristics of the analyzed institution and the quality of available data are critical. The type of data, measurement units, and level of detail provided by the organization are key factors in selecting appropriate standards and emission factors. In this study, the carbon footprint of a marine technology company was calculated using DEFRA emission factors in accordance with the GHG Protocol standard. Both direct and indirect emissions resulting from the company's operations were taken into account in the overall greenhouse gas assessment.

In the marine technology company examined in this study, emission sources included in the calculations were classified according to the GHG Protocol scopes and are presented in Table 4.3.

For this study, emission sources were identified based on data provided by the marine technology company and categorized according to the relevant GHG Protocol scopes. Scope I emissions include natural gas used for heating and production processes, as well as fuels consumed by industrial machinery such as generators and cranes. Mobile combustion from company-owned vehicles is also classified under Scope I. Scope II emissions consist of electricity consumed at the facility and purchased heating and cooling services. Scope III emissions—those not directly controlled by the company—encompass fuel and energy-related activities not included in Scopes I and II, waste generated from operations and production, business travel, employee commuting, and emissions from company-owned fixtures. Emission sources falling within the facility's defined operational and calculation boundaries will be analyzed, and carbon footprint calculations will be carried out in accordance with the GHG Protocol.

5. CASE STUDY

This study focuses on a maritime technology facility located in Istanbul, Türkiye, specializing in the production of marine cleaning equipment such as oil spill containment systems, skimmers, recovery units, and related support tools designed for spill response and port operations. While certain operational details are confidential due to proprietary considerations, the facility occupies a total area of 1,500 m² and employs 40 personnel. Its core activities include design, component fabrication, mechanical assembly, testing, and packaging of marine equipment. These operations serve as the foundation for the carbon footprint assessment conducted within the defined system boundaries. By specifying these product categories, the study provides reference points that may be reused in future LCA work addressing shipbuilding and maritime environmental technologies.

The facility's core operations involve the manufacturing of marine cleaning equipment, including oil spill containment systems and support tools. These processes consist of:

- Metal fabrication and assembly
- Use of forklifts and cranes for material handling
- Operation of generators and compressors
- Administrative and support activities consuming heat and electricity

These activities generate both direct and indirect GHG emissions, particularly from fuel use, electricity, transport, and waste generation.

To assess the carbon footprint of the marine technology company, a greenhouse gas (GHG) inventory was developed for the 2023 operational year in accordance with the GHG Protocol and ISO 14064-1 standards. Both organizational and operational boundaries were defined to encompass all relevant emission sources associated with the company's facility in Istanbul.

Activity data were collected from various departments and operations, including heating, electricity consumption, fuel usage, transportation, and waste management. Unit conversions were applied in accordance with the chosen calculation method. Emission sources were then categorized into Scope I (direct emissions), Scope II (indirect emissions from purchased electricity), and Scope III (other indirect emissions) as follows:

- Scope I included natural gas use for heating, diesel and fuel oil consumed by forklifts and generators, and vehicle use across cars, light trucks, and medium-heavy trucks.
- Scope II included electricity consumption totaling 180,000 kWh, mainly for lighting and production machinery.
- Scope III covered personnel transportation by personal vehicles and shuttle buses, annual water consumption, and multiple waste categories: domestic, plastic, wood, and metal. Fire extinguisher emissions were also included.

While this study includes several Scope III emission sources—such as employee commuting, business travel, waste generation, and upstream transportation—certain other indirect emissions were excluded due to data limitations or lack of access. Omitted categories include emissions from the production and maritime transport of purchased raw materials, the use and end-of-life treatment of sold products, and the procurement of capital goods.

The emission sources and corresponding activity data collected from the marine technology company are summarized in Table 5.1.

	Emission Source	Unit	Amount
SCOPE I	Natural Gas Combustion	m^3	1713
	Diesel Vehicles (Car-Light-Duty Truck)	lt	16966,7
	Gasoline Vehicles (Car-Light-Duty Truck)	lt	2145,5
	Forklift and Generators (Diesel)	lt	6082,04
	Forklift and Generators (Gasoline)	lt	5566,04
SCOPE II	Electricity Consumption	kWh	70696
SCOPE III	Business Travel (By Plane)	km	13296
	Business Travel (By Car)	km	3900
	Employee commuting (Car)	km	52272
	Employee commuting (Personnel Service)	km	36000
	Water Consumption	m^3	422,63
	Fire Extinguishers	kg	160
	Domestic Waste Generation	kg	1300
	Plastic Waste Generation	kg	720
	Metal Waste Generation	kg	200
	Wood Waste Generation	kg	250
	Transportation Used in Supply Processes (Plane)	km	2470
	Transportation Used in Supply Processes (Light-Duty Truck)	km	11500
	Transportation Used in Supply Processes (Heavy-Duty Truck)	km	8000

Table 5.1: Marine technology company data summary.

Emission values were calculated using the emission factor method. For each activity, the quantity of input—such as liters of fuel, kilometers traveled, or kilowatt-hours (kWh) of electricity consumed—was multiplied by the corresponding emission factor from the DEFRA (2023) database. Emissions from each source were then converted into carbon dioxide equivalents (CO_2e) using Global Warming Potential (GWP) values, allowing for standardized comparisons across different greenhouse gases.

Emissions were categorized under Scope I, II, and III in accordance with the GHG Protocol classification. The functional unit for the study was defined as the facility's total annual operational emissions for the year 2023. The inventory process prioritized completeness, transparency, and traceability by clearly linking each emission source to its corresponding industrial activity.

To establish a meaningful baseline for evaluating GHG emissions over time, the base year was set as 2023, aligning with the availability of comprehensive and verifiable data as well as the organization's current operational boundaries. This selection provides a reference point for future GHG inventory comparisons and complies with the requirements of ISO 14064-1.

The selection of 2023 as the base year is justified by the fact that the accuracy, completeness, and availability of relevant data. The base-year inventory was developed in accordance with the principles of consistency, transparency, and completeness outlined in ISO 14064-1, ensuring comparability with future inventory reports and compliance with the requirements of GHG reporting and reduction programs (ISO, 2006).

To enhance the transparency and reproducibility of the carbon footprint calculations, Table 5.2 presents the emission factors applied to each activity and emission source considered in the study. The majority of these factors were obtained from the DEFRA 2023 database, which provides standardized conversion values for various fuels, energy sources, and operational activities. For emission sources not directly covered in DEFRA, appropriate emission factors were derived using established conversion formulas and supplementary reference data. To ensure consistency in the calculation process, a unit has been assigned to each emission factor. This table illustrates how raw activity data were converted into carbon dioxide equivalents (CO$_2$e) and supports the interpretation of results in the subsequent sections.

	Emission Source	**Unit**	**Emission Factor (kg/CO$_2$e)**
SCOPE I	Natural Gas Combustion	m^3	2,04
	Diesel Vehicles (Car-Light-Duty Truck)	lt	2,51
	Gasoline Vehicles (Car-Light-Duty Truck)	lt	3,17
	Forklift and Generators (Diesel)	lt	2,51
	Forklift and Generators (Gasoline)	lt	3,17
SCOPE II	Electricity Consumption	kWh	0,7279
SCOPE III	Business Travel (By Plane)	km	0,27258
	Business Travel (By Car)	km	0,16983
	Employee commuting (Car)	km	0,16983
	Employee commuting (Personnel Service)	km	0,23128
	Water Consumption	m^3	0,177
	Fire Extinguishers	kg	1
	Domestic Waste Generation	kg	0,497
	Plastic Waste Generation	kg	0,00884
	Metal Waste Generation	kg	0,01264
	Wood Waste Generation	kg	0,02128
	Transportation Used in Supply Processes (Plane)	km	4,6734
	Transportation Used in Supply Processes (Light-Duty Truck)	km	0,23128
	Transportation Used in Supply Processes (Heavy-Duty Truck)	km	0,82313

Table 5.2: Emission factors for emission sources used in calculations

The outcome of this process was a detailed emissions profile of the facility, which serves as the basis for identifying major GHG contributors and informing mitigation opportunities discussed in the subsequent sections.

6. FINDINGS AND DISCUSSION

The percentage distribution of Scope I emissions for the maritime technology production facility was calculated based on 2023 data. The emissions attributed to each source are presented in Figure 6.1.

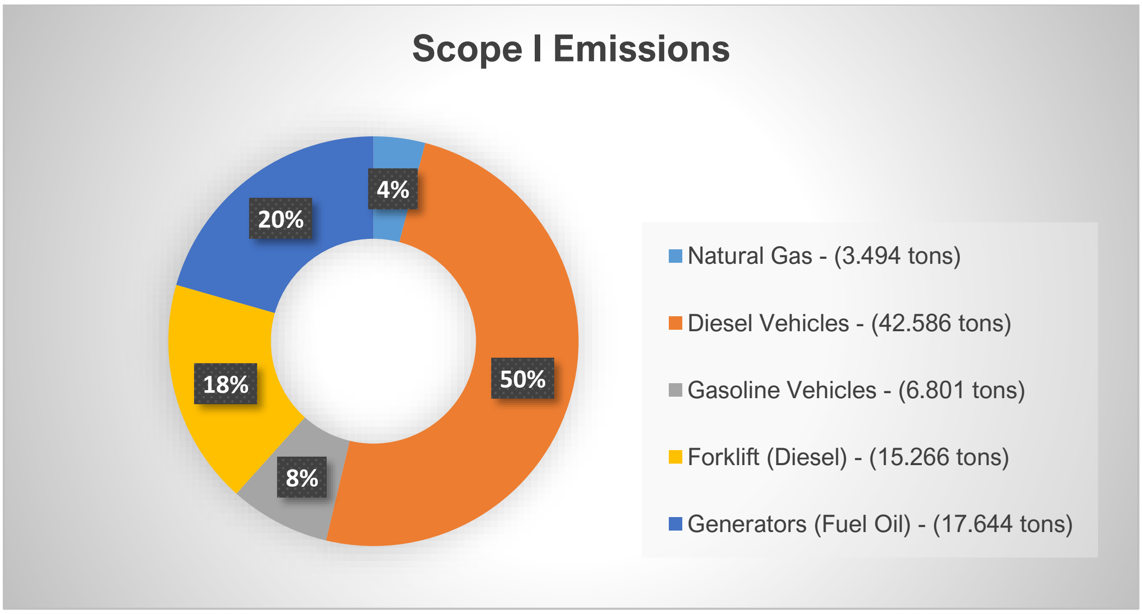

Figure 6.1 : CO2e (tons) values generated by scope I emission sources.

Based on the Scope I GHG emission calculations and corresponding consumption data, it was determined that 85,791 tons of CO_2e emissions were generated from fuel consumption in 2023. Emissions from mobile and stationary combustion sources were calculated directly using fuel consumption figures. An analysis of total Scope I fuel use at the facility shows that diesel consumption accounts for the largest share, at approximately 70.69%, followed by gasoline at 23.66% and natural gas at 5.63%. In calculating these proportions, the energy equivalent of 1,713 cubic meters of natural gas was converted based on an energy factor of 10.5 kWh per m^3. Using a conversion factor where 1 liter of diesel corresponds to approximately 9.8 kWh, the natural gas usage was equated to 1,834.34 liters of diesel fuel.

The distribution of calculated Scope I emissions across the three fossil fuel types is presented in Figure 6.2. Analysis of the emissions by fuel type shows that 67.44% of total Scope I emissions originated from diesel fuel, amounting to 57,852 tons of CO_2e. This is followed by gasoline, contributing 28.49% (24,445 tons CO_2e), and natural gas combustion, accounting for 4.07% (3,494 tons CO_2e).

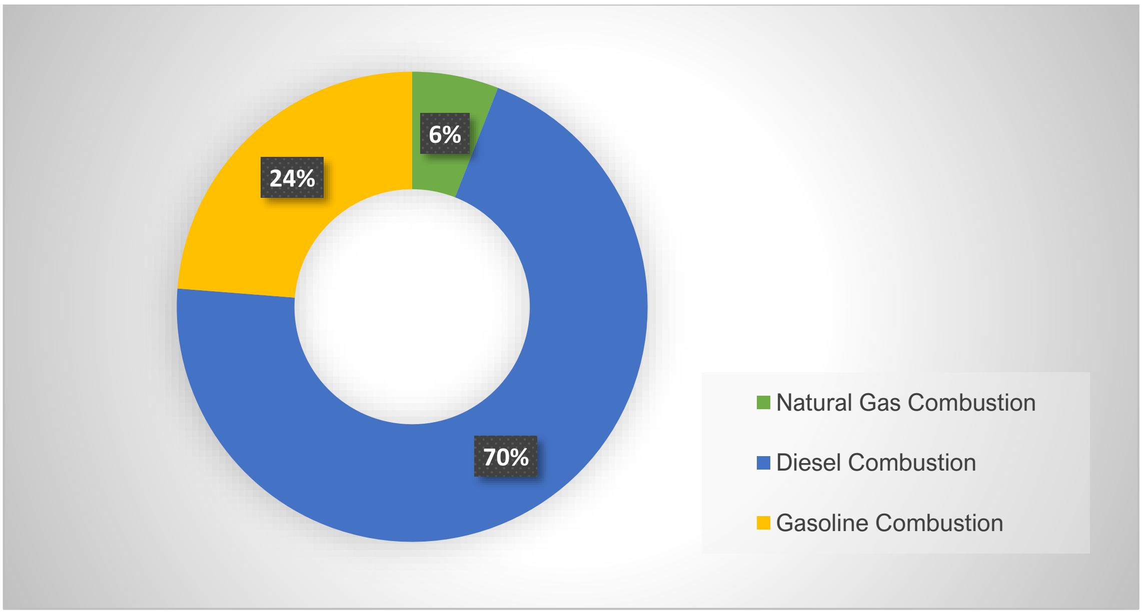

Figure 6.2 : Scope I emission groups.

The amounts of calculated Scope I and Scope II emissions without including other indirect emissions (Scope III) are given in percentage terms in Figure 6.3.

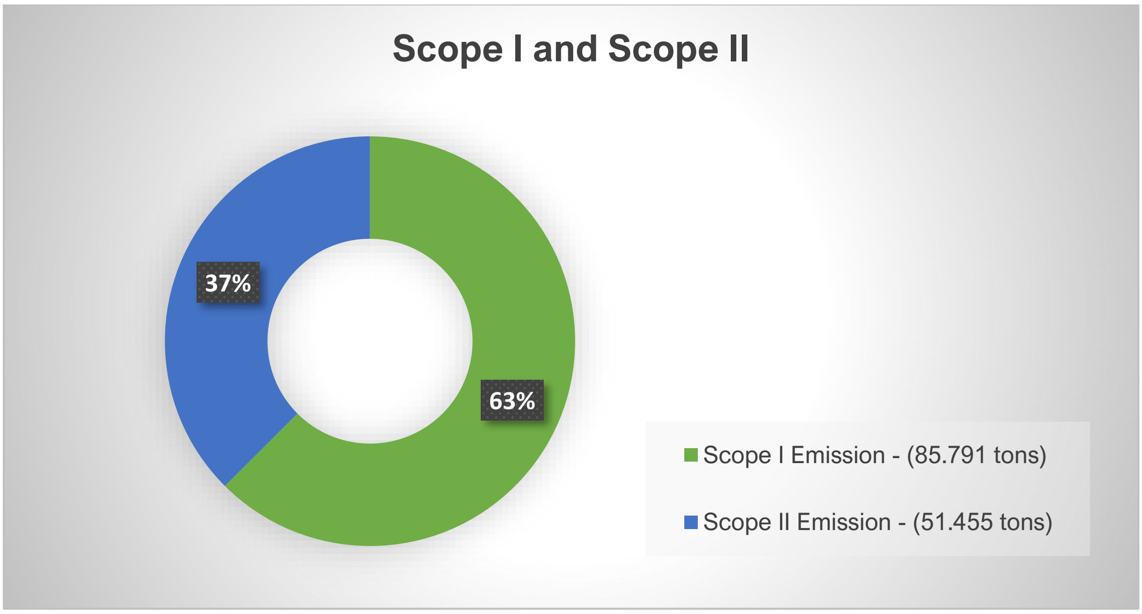

Figure 6.3 : Scope I and Scope II emission percentages (CO2e tons).

In this study, annual electricity consumption is the only source included under Scope II emissions. Heating and cooling processes at the facility are accounted for under natural gas consumption (classified within Scope I) and electricity consumption (Scope II). When energy-based greenhouse gas emissions for 2023 are calculated in carbon dioxide equivalents, electricity use results in 51,455 tons of CO_2e. Combined with the 85,791 tons of CO_2e calculated under Scope I, the total Scope I and Scope II emissions—which are mandatory for reporting—amount to 137,246 tons of CO_2e. Notably, electricity use accounts for 37.5% of total emissions from these two scopes.

The calculated Scope III emissions of the marine technology production facility are presented in Figure 6.4, categorized by emission sources.

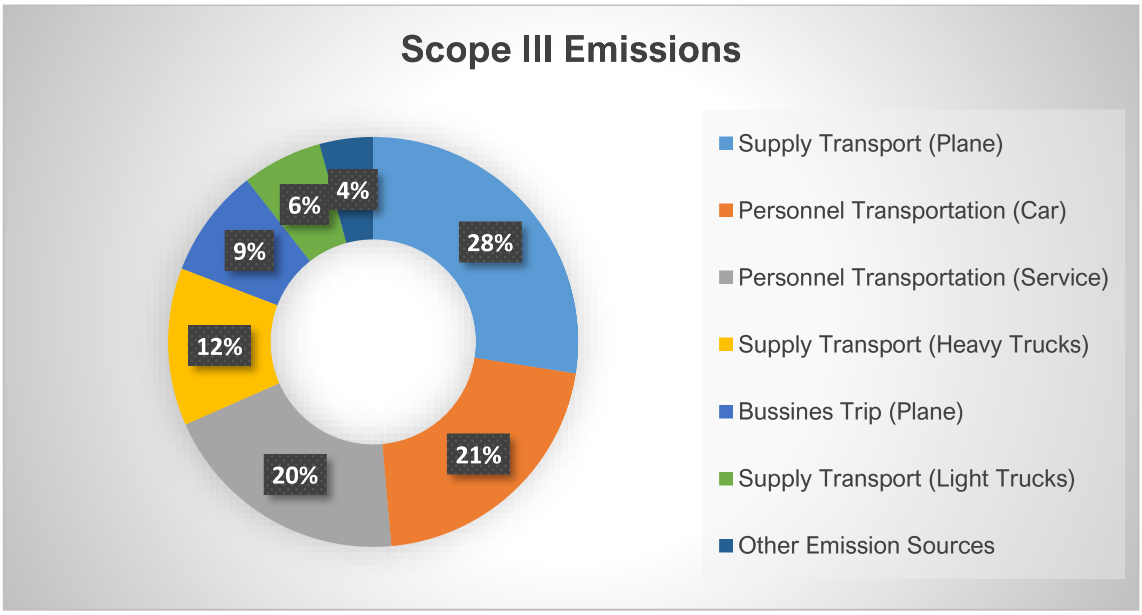

Figure 6.4 : CO2e (tons) values generated by scope III emission sources.

To calculate the indirect (Scope III) GHG emissions of the enterprise, measured values from emission sources within the defined operational boundaries were used. The results show that personnel transportation, combined with business travel, generated 21,489 tons of CO_2e, accounting for 54.05% of total Scope III emissions. The majority of these emissions resulted from employees commuting throughout the year. Although emissions from personal vehicle use are comparable to those from company-provided shuttle services, it is important to note that shuttles transport a significantly larger number of employees. In terms of business travel, air transportation was found to contribute substantially more GHG emissions than travel by car.

In carbon footprint calculations, carbon-based fire extinguishers are assumed to produce emissions equivalent to their weight. When emissions from carbon-based fire suppression systems, water consumption, and waste generation were calculated using 2023 emission factors, the total was found to be 1,121 tons of CO_2e, accounting for 2.66% of total Scope III emissions.

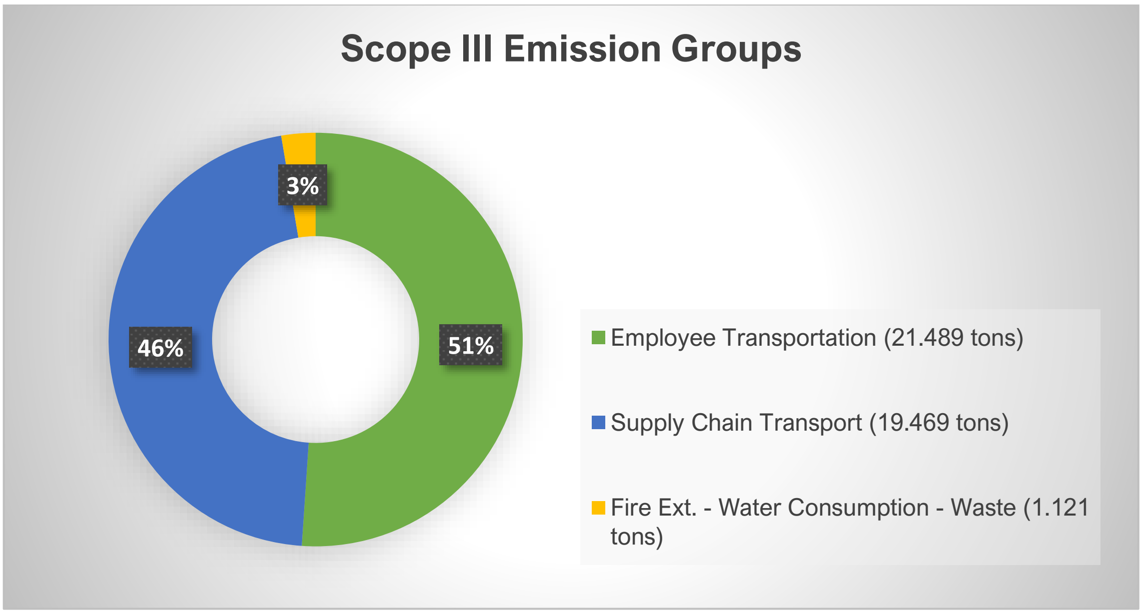

Figure 6.5 : Scope III emission percentages (CO2e tons).

The transportation methods used in the product and raw material procurement processes of the enterprise were evaluated under three categories: air transportation, light vans, and heavy trucks. It was calculated that these activities generated a total of 19,469 tons of CO_2e emissions in 2023, with more than half of this total attributed to air transport. Emissions from transportation related to procurement processes accounted for 46.29% of the total Scope III greenhouse gas emissions. The breakdown of Scope III emissions from these three transportation modes is illustrated in Figure 6.5.

When these three categories are combined, the total Scope III GHG emissions amount to 42,079 tons of CO_2e, representing 23.46% of the enterprise's total GHG emissions. Although Scope III emissions are not directly generated by the maritime technology company and are not mandatory for GHG reporting, they are essential for gaining a more accurate and comprehensive understanding of the organization's overall carbon footprint.

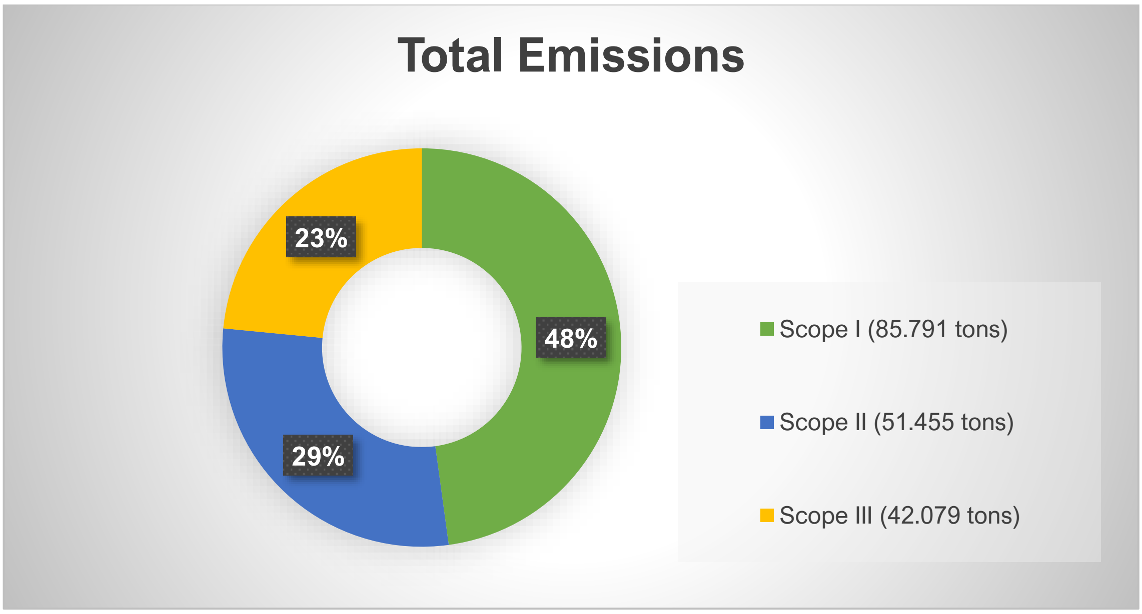

Figure 6.6: Total emission results of marine technology enterprise.

When calculating indirect emissions, the scope of the GHG inventory can be expanded by diversifying and detailing the emission sources included within the defined operational boundaries. The calculated GHG emissions of the maritime technology production facility are presented in Figure 6.6, showing the total amount and percentage distribution across each scope.

Scope I, Scope II, and Scope III emissions of the maritime technology company were calculated within the defined operational boundaries. The results show that Scope I emissions amounted to 85,791 tons of CO_2e, Scope II emissions to 51,455 tons of CO_2e, and Scope III emissions to 42,079 tons of CO_2e. Based on these figures, the total GHG emissions of the facility for the year 2023 were calculated as 179,325 tons of CO_2e. The distribution of emissions reveals that 47.86% originated from Scope I, 28.69% from Scope II, and 23.46% from Scope III.

7. CONCLUSION

The maritime industry, as an energy-intensive sector, contributes significantly to air pollution (particularly greenhouse gas (GHG) emissions) not only through shipping activities but also through shipbuilding, dismantling, maintenance and repair, and the production of marine technologies. Identifying and controlling these emissions, as well as implementing strategies to reduce them, is critical. A fundamental step toward mitigation in the maritime sector is the accurate calculation and analysis of enterprises' carbon footprints (Tantan & Akdağ, 2023). In recent years, sustainability has gained increasing prominence in shipbuilding, maritime technologies, and international maritime transport. In response to environmental regulations, the shipping, shipbuilding, and marine technology manufacturing sectors have begun to implement changes in both operational and organizational processes (Ölçer et al., 2022). While mitigation efforts have primarily focused on the operational phase of shipping, the environmental impact of ship construction, dismantling, and the manufacturing of maritime technologies is receiving growing attention as operational emissions decrease.

This study examined the carbon footprint of a maritime technology company in Türkiye specializing in the design and production of marine cleaning equipment, including oil spill containment systems, skimmers, and related support units. The facility's operations—mechanical assembly, component fabrication, equipment testing, and packaging—all contribute to its emissions profile. Based on 2023 operational data, Scope I, Scope II, and Scope III emissions were calculated, resulting in total annual greenhouse gas emissions of 179,325 tons of CO_2e. The distribution of emissions—47.9% from Scope I, 28.7% from Scope II, and 23.5% from Scope III—reflects the company's energy-intensive activities, including fuel combustion for material handling equipment, facility heating, and electricity use for production and assembly.

The majority of the company's Scope I emissions result from the use of fossil fuels in vehicles, forklifts, and generators. As these emissions fall under the facility's direct control, they represent a primary target for mitigation strategies. Transitioning to alternative fuels for vehicles and equipment (such as biodiesel, electricity, or hydrogen) along with improving fuel efficiency and optimizing logistics, could significantly reduce GHG emissions. Additionally, enhancing operational practices to lower natural gas consumption, including improved heating and insulation systems, offers further opportunities for emissions reduction.

When the company's total emissions are analyzed, electricity consumption accounts for a significant portion of indirect emissions. To reduce Scope II emissions, the facility can prioritize the use of energy-efficient machinery and lighting systems. Transitioning to electricity sourced from renewable energy (such as wind or solar) would substantially lower these emissions. Moreover, investing in solar energy panels presents a long-term strategy for reducing both greenhouse gas emissions and operational energy costs.

While other indirect emissions are not directly controlled by the facility, they offer valuable insight into the broader environmental impacts of its operations. Scope III emissions from employee commuting, business travel, waste management, and supply chain logistics highlight several areas where mitigation efforts can be implemented. Strategies such as promoting car sharing, encouraging the use of public transportation, and prioritizing sea or land travel over air travel for business trips can significantly reduce emissions. Similarly, optimizing supply chain logistics—by selecting more carbon-efficient transportation modes or sourcing from suppliers located closer to the facility—can help lower transport-related emissions. Although emissions from waste make up a smaller portion of the total carbon footprint, improving waste management practices through recycling and waste reduction initiatives can further reduce Scope III emissions.

However, it is important to note that certain high-impact Scope III categories – such as emissions from the production of purchased goods and services, product use and end-of-life treatment, and capital goods procurement – were not included in this study due to data limitations. As a result, the reported share of Scope III emissions may underrepresent the organization's total indirect carbon footprint.

These findings provide a detailed emissions baseline that the company can use to set measurable reduction targets and implement effective mitigation strategies—such as transitioning to cleaner fuels, enhancing energy efficiency, or sourcing electricity from renewable energy. Furthermore, this case study demonstrates the applicability of international GHG accounting standards, namely the GHG Protocol and ISO 14064-1, within maritime manufacturing operations. By establishing a replicable methodology and identifying key data limitations (particularly within Scope III) the study offers a practical framework for similar organizations seeking to evaluate and manage their environmental impact.

This study serves as a practical guide to support the sustainability efforts of the maritime technology company and can serve as a reference for future research. Continued investigation into greenhouse gas emissions and carbon reduction strategies (both within the maritime sector and across other industries) is essential in addressing the global climate crisis.

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CONFLICT OF INTEREST

Authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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