Environment and Ecology Research 12(1): 86-95, 2024 http://www.hrpub.org
DOI: 10.13189/eer.2024.120109

Action Plan for the Mitigation of Greenhouse Gas Emissions in the Manufacturing Sector of the Hellenic Army

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Received November 28, 2023; Revised January 11, 2024; Accepted February 26, 2024

Cite This Paper in the Following Citation Styles

***(a):** [1] Iraklis Karaiskos, Vasileios Bozoudis, Ioannis Sebos , "Action Plan for the Mitigation of Greenhouse Gas Emissions in the Manufacturing Sector of the Hellenic Army," Environment and Ecology Research, Vol. 12, No. 1, pp. 86 - 95, 2024. DOI: 10.13189/eer.2024.120109.*

***(b):** Iraklis Karaiskos, Vasileios Bozoudis, Ioannis Sebos (2024). Action Plan for the Mitigation of Greenhouse Gas Emissions in the Manufacturing Sector of the Hellenic Army. Environment and Ecology Research, 12(1), 86 - 95. DOI: 10.13189/eer.2024.120109.*

Abstract This study conducts a thorough examination of the carbon footprint in the Hellenic Army's manufacturing sector, scrutinizing both stationary and transport-related emissions. It advances prior investigations into the Hellenic Army's emissions by introducing a comprehensive action plan designed to substantially reduce greenhouse gas (GHG) emissions in military production. The plan integrates Key Performance Indicators (KPIs) and a precise carbon footprint timeline as essential instruments for continuous monitoring and efficacy assessment. The method for calculating emissions, utilizing 2021 data, adheres to the guidance of the Intergovernmental Panel on Climate Change (IPCC) and aligns with Greece's national reporting, ensuring observance of global standards such as ISO 14064. This adherence guarantees the reliability and validity of the study's conclusions. The analysis identifies electricity usage as the primary emission source, contributing 83.7% to the sector's carbon footprint, underscoring the significant environmental influence of energy utilization in military manufacturing. While recognizing the sector's considerable environmental footprint, the research also notes the beneficial impact of Greece's shift to renewable energy, which has led to a notable decrease in emissions. The study underscores the need for precise, industry-specific mitigation tactics, highlighting the military manufacturing sector's capacity for environmental impact reduction. The research not only illuminates the present GHG emission status in the Hellenic Army's manufacturing operations but also charts a definitive, sustainable course of action. The proposed strategic plan, reinforced by KPIs and an emission timeline, represents a balanced approach to ecological responsibility without compromising military production efficiency. This study stands as an exemplar for other industries aiming to reconcile with climate change mitigation objectives effectively.

Keywords Carbon Footprint, Climate Change, Mitigation Action Plan, Greenhouse Gas Emissions, Industrial Sector, Emission Sources, Key Performance Indicators

1. Introduction

Caused by human activities, the emission of greenhouse gases (GHGs) is driving climate change, which poses the most significant threat to humanity in the present time [1], and is expected to exacerbate in the future [2]. Scientists and analysts have issued warnings about the potential of global warming to become a national security concern for the world. The primary GHGs present in the Earth's atmosphere include carbon dioxide (CO_2), methane (CH_4), ozone (O_3), water vapor, nitrous oxide (N_2O), and fluorinated gases. These gaseous compounds have the capacity to absorb and emit infrared radiation, leading to the retention of heat in the lower atmosphere while allowing some of the heat to escape back into space.

To mitigate the emissions of the seven greenhouse gases (GHGs) identified by the United Nations Framework Convention on Climate Change (UNFCCC) as the primary human-induced contributors to global climate change, every nation must establish environmentally conscious policies and regulations. These measures are designed to restrict the rise in the global average temperature to 1.5ºC, in accordance with the goal of limiting climate change [3, 4]. Significant advancements have been achieved in terms of national mitigation commitments through the adoption and signing of various international treaties, such as the Kyoto Protocol and the Paris Agreement. These agreements have played a crucial role in facilitating tangible progress in addressing climate change on a global scale, but are also considered insufficient in achieving the global target [5-7]. Mitigation strategies, along with action plans, are not solely confined to addressing climate change; they are also applicable to various other potential hazards, including industrial safety. The primary objective of these strategies is to minimize risk and bolster resilience in the face of diverse hazards [8, 9].

The carbon footprint (CF) serves as a crucial metric for assessing greenhouse gas (GHG) emissions and is instrumental in the development and implementation of action plans aimed at mitigating these emissions [10]. It refers to the collective GHG emissions generated by a country, individual, organization, etc., within a specific time frame, measured in terms of carbon dioxide equivalent (CO_{2eq}) [11, 12]. In this context, the terms “carbon footprint” and “greenhouse gas emissions” are used interchangeably, as both represent the total emissions of gases that contribute to the greenhouse effect. CF is critical to consider sustainability aspects such as global warming, energy consumption, user waste output, and advancements in manufacturing and recycling procedures [13]. Decarbonization of the industrial sector, especially in power generation, is vital for achieving carbon neutrality [14]. Given the ongoing escalation of the greenhouse effect, nations prioritize industries characterized by high energy consumption and substantial carbon emissions [15]. The carbon emissions associated with manufacturing exhibit complexities such as multiple sources, indistinct evaluation boundaries, and challenges in accurate quantification.

The emissions from the sector Industrial Processes and Product Use contributing 10% to total EU GHG emissions in 2021, 318 Mt in 2021, decreased by 29 % from 445 Mt in 1990 [16]. The most important GHGs from this sector are CO_2 (7% of total GHG emissions), HFCs (2.1%). Mineral industry has the greatest share in this sector with 33% of the emissions, followed by metal industry with 23% and refrigeration and air conditioning with 20%. Moreover, manufacturing industries and construction generate large quantities of GHG emissions by the energy consumed. This category contributed to 439,540 kt CO_{2eq} in the EU. This sector in Greece produces 4,825 kt CO_{2eq}, about 1.1% of the EU [17].

In Greece over the year 2021, GHG emissions amounted to 77.50 Mt CO_{2eq} showing a decrease of 25.5% compared to 1990 levels. Carbon dioxide emissions accounted for 74.3% of total GHG emissions in 2021, methane emissions accounted for 14.6% and nitrous oxide emissions for 4.9% [17]. The majority of GHG emissions (48.5%) in 2021 derived from energy industries, while the contribution of transport, manufacturing industries and construction and other sectors is estimated at 31.4%, 9.1% and 10.9% respectively.

2. Case Study

In this study, the CF of the transport activities and stationary emission sources of the Army Industrial Factory (AIF, Greece) was estimated. The purpose of this estimation is to allow the Hellenic Army to expand the action to mitigate GHG emissions, starting from the most polluting units. By combining this estimation with the previously studied CF of the 401 Military General Hospital of Athens (401 MGHA) for the year 2018, as conducted by the authors [18, 19], a clear insight of the GHG emission among the Hellenic Army is provided and a path to decreased CF.

The analysis of GHG emissions was done using the available data from 2021 combined with the emission factors proposed by the National Inventory Report of Greece [17]. From this analysis, Key Performance Indicators (KPIs) have been identified as specific metrics to evaluate the factory’s performance, accompanied by an action plan to meet its low carbon and sustainability objectives.

2.1. The Army Industrial Factory (AIF)

The Army Industrial Factory constitutes the chemical industry of the Hellenic (Greek) Army. Its main mission is to cover the maintenance needs of the Hellenic Army and other branches of the Armed Forces. It produces a variety of products, such as medical and industrial oxygen and nitrogen, paints of various types (common oil paints and Anti-IR, acrylic and plastic paints in all shades, epoxy floor paints, roof insulators, etc.), cleaning agents (dishwashing detergent, floor cleaners and hand soap), plastic items like water containers, soap boxes and buttons as well as metal paint packaging boxes and shoe polishes. It is located in Avlonas, Greece, about 50 km north of Athens city center. Since its foundation in 1986, the collaborations with domestic education institutions stand out, conducting research into the manufactured products [20].

To quantify the factory’s carbon footprint of both from its stationary emission sources and the transport activities, the annual GHG emissions were calculated for the years 2019 to 2021, by applying methods consistent with the IPCC guidance and the national inventory report of Greece [17]. The methods applied are described in the following sections.

2.2. Carbon Footprint Calculations

In order to assess the environmental impact of the factory's energy processes and transportation activities, data from the year 2021 was utilized. The measurement unit employed to quantify various greenhouse gases was "carbon dioxide equivalent" (CO_{2eq}). This unit allows for the expression of the quantity and type of greenhouse gas in terms of the equivalent amount of carbon dioxide that would produce the same Global Warming Potential (GWP). GWP represents the extent to which gas contributes to global warming over a specified period, typically 100 years. The analysis relied on the most recent GWPs provided by the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [2]. These GWPs are currently adopted for reporting national greenhouse gas inventories to the UNFCCC. This technique is also in line with international standards such as ISO 14064, which is widely used to quantify and report GHG emissions [21].

2.2.1. Energy Consumption

The most important sector in terms of GHG emissions in EU is energy (i.e., combustion and fugitive emissions), which accounted for 80% of total emissions including LULUCF and international aviation in 2021 [22].

2.2.1.1. Electricity

The manufacturing sector consumes significant quantities of energy [23]. The electricity consumption in the factory is estimated to be one of the highest in the Hellenic Army. The total of about 2,400,000 kWh purchased electricity in year 2021, has accounted for the greater portion of the factory’s energy cost. This consumption is mainly due to the operational needs of the factory to produce liquid oxygen and nitrogen for medical and industrial use. Additionally, the use of industrial equipment, air conditioners and daily usage of light bulbs for the artificial lightning of the buildings contribute to electricity consumption. The GHG conversion factor, for the year 2021, was 371.68 gCO_{2eq}/kWh [17], so the total GHG emissions were 892.0 tCO_{2eq}.

2.2.1.2. Fossil Fuels

The only fossil fuel used for central heating and other internal needs is diesel oil. Its consumption for the year 2021 was 2,600 lt. The GHG conversion factor for diesel oil is 73.78 tCO_{2eq}/TJ and the net calorific value is 42.80 TJ/kt [17]. As a result, the GHG emissions linked to diesel oil usage, and consequently to fossil fuels, totaled 6.90 tCO_{2eq}.

2.2.2. Transport Activities

2.2.2.1. Staff

The factory staff are about 50 employees, working either an 8-hour or 24-hour shift per day. To calculate the kilometers traveled per mode of transport, all staff members completed an identical questionnaire about:

a) The means of transport that they used to reach the factory (private car, bus, minibus, railway, or any combination of these).
b) An estimation of the distance they covered in order to arrive at the factory.
c) Whether they arrived at the factory using their personal vehicle, and if so, whether they came alone or with co-workers (through carpooling/car sharing), along with specifying the type of fuel used by their vehicle.

Regarding the means of transport, by analysing the sample, the conclusion was that:

a) 32.5% (13 persons) used private cars.
b) 15% (6 persons) used military buses.
c) 45.5% (19 persons) used military minibuses.
d) 5% (2 persons) used railway.

Additionally, 14 out of 27 persons that did not use their private cars also used metro (the subway) to reach their destination. It was concluded that 4 of the 13 private cars (30.8%) were equipped with diesel engine. The distance travelled in 2021 is distributed to the respective mode of transport, in units of passenger-kilometer (pkm), as follows:

a) 27.5% (296,400 pkm) by private cars of which, 205,200 pkm were traveled with gasoline-engine cars and 91,200 pkm with diesel-engine cars.
b) 15.0% (162,000 pkm) by military buses.
c) 49.4% (532,000 pkm) by military minibuses.
d) 4.2% (44,800 pkm) by railway.
e) 3.9% (42,000 pkm) by metro.

The GHG emissions resulting from transportation activities are determined by multiplying the distance traveled by the GHG conversion factor specific to each mode of transport. These emissions are measured in tonnes of CO_{2eq}, while the distance traveled is measured in kilometers. The GHG conversion factor represents the emissions factors that estimate the combined GHG impact (including CO_2, CH_4, and N_2O) per passenger-kilometer based on the distance traveled. In this study, the GHG conversion factors used are provided in Table 1, along with their respective sources. To calculate the GHG emissions for the metro, the GHG conversion factor is derived from electricity consumption data provided by Urban Rail Transport S.A., combined with the 2021 grid electricity CO_2 emission factor for Greece, which is 371.68 gCO_{2eq}/kWh [17]. The conversion factor of railway was assumed to be equal to the average conversion factor of railway in the European Union [24].

Table 1. GHG conversion factors in kgCO_{2eq} per passenger-km (pkm) per mode of transport

Mode of transport	Private car	Private car	Minibus	Bus	Truck (<7,5 t)	Metro	Railway	Source
Fuel	gasoline	diesel	diesel	diesel	diesel	Electricity	Electricity	
EF CO_2 (t/TJ)	73.26	73.23	73.23	73.23	73.23	-	-	[17]
EF CH_4 (kg/TJ)	9.52	0.03	0.53	6.65	6.65	-	-	[17]
EF N_2O (kg/TJ)	1.4	2.99	2.07	1.83	1.83	-	-	[17]
NCV (TJ/kt)	42.79	42.8	42.8	42.8	42.8	-	-	[17]
Fuel Consumption (g/km)*	70	60	95	300	110	-	-	
EF CO_2 (kgCO_2/km)	0.219	0.188	0.298	0.940	0.345	-	-	-
EF CH_4 (kgCH_4/km)	2.85E-05	7.70E-08	2.15E-06	8.54E-05	3.13E-05	-	-	-
EF N_2O (kgN_2O/km)	4.19E-06	7.68E-06	8.42E-06	2.35E-05	8.62E-06	-	-	-
Number of passengers**	1	1	12	25	1	-	-	
EF GHG (kg CO_{2eq}/pkm)	0.221	0.190	0.025	0.038	0.348	0.005	0.033***	

Abbreviations: EF = emission factor, NCV = net calorific value, TJ = tera joule, kt = thousand tonnes, kg = kilogramme, g = gram, km = kilometre, GHG = greenhouse gas

*Average fuel consumption assumed for each mode of transport

**Average number of passengers per mode of transport

***[24]

Table 2. GHG emissions per mode of transport by staff

Mode of transport	Distance travelled (pkm)	GHG conversion factor (kgCO_{2eq}/pkm)	GHG emissions (tCO_{2eq})	Share (%)
Private car (gasoline)	205,200	0.221	45.41	54.10
Private car (diesel)	91,200	0.190	17.35	20.67
Minibus (diesel)	532,000	0.025	13.30	15.85
Military Bus (diesel)	162,000	0.038	6.16	7.33
Metro	42,000	0.005	0.23	0.29
Railway	44,800	0.033	1.48	1.76
Total	**1,077,200**		**83.92**	**100**

The GHG emissions for each mode of transport resulting from the transportation activities of the factory's staff are provided in Table 2. The dominant mode of transport is the use of private cars, accounting for approximately 74.77% of the total GHG emissions generated by the staff's commuting to and from the factory (as indicated in Table 2).

2.2.2.2. Factory Vehicles

In 2021, factory vehicles, including light and heavy-duty vehicles for transportation of goods and tankers for the transportation of liquid oxygen mainly to military hospitals consumed 10,800 lt of diesel. By using Table 1, the fuel consumption is converted to GHG emissions, which are estimated to be 28.61 tCO_{2eq}.

2.2.2.3. Suppliers

In 2021, the factory was supplied with raw materials, mechanical equipment, food, fuels and other supplies. Most of these came from suppliers located near Athens. Based on the estimated total mileage of 45,000 kilometers traveled by the suppliers' trucks and utilizing the GHG conversion factors from Table 1, the calculated GHG emissions from the suppliers' trucks amount to approximately 15.66 tCO_{2eq}.

2.2.2.4. Waste Disposal Vehicles

In 2021, the total distance covered by the vehicles involved in the disposal of the factory's waste was estimated to be approximately 15,600 kilometers. By applying the GHG conversion factors from Table 1, the

GHG emissions from this source are calculated approximately 5.43 tCO_{2eq}.

In total, the CF of the transport activities is 133.6 tCO_{2eq} (Table 3). The greatest part is coming from staff's movement, which includes personal car and military bus usage.

Table 3. The carbon footprint of the transport activities

Transportation activity	GHG emissions (tCO_{2eq})	Share (%)
Staff's movement	83.9	62.8
Factory vehicles	28.6	21.4
Suppliers	15.7	11.7
Waste disposal vehicles	5.4	4.1
Total	**133.6**	**100**

2.2.3. Solid Waste Disposal

Methane emissions are generated through the anaerobic decomposition of organic waste in land-based solid waste disposal sites, making solid waste disposal a significant contributor. Additionally, carbon dioxide emissions occur when biogas produced from waste decomposition is flared. However, it's important to note that these emissions of biogenic origin should not be accounted for in the GHG emissions of the sector. The calculation of methane emissions involves utilizing the First Order Decay (FOD) method [25], which necessitates historical data spanning several decades, including information on waste generation, waste composition, and the waste management practices implemented [17].

In 2021, the factory produced and disposed about 30 tonnes (t) municipal solid waste. The CH_4 emissions from SWDS for a single year can be estimated using the equation below [17]:

$$\text{CH}_4\text{ emissions} = W_T \times DOC \times DOC_f \times MCF \times F \times 16/12 \times (1 - OX_t) \times (1 - R) \quad (1)$$

where:

W_T = mass of waste disposed (disaggregated for paper, food waste and non-food waste) in the reference year (kt/year)

DOC = degradable organic carbon. Based on the NIR of Greece, the following DOC values were used: 0.4 for paper, 0.15 for food waste, 0.2 for non-food waste.

DOC_f = fraction of DOC that can decompose. It is assumed that it is 0.5.

MCF = methane correction factor. MCF for aerobic decomposition is 1 for managed SWDS.

F = fraction of CH_4 in landfill gas. It is assumed to be 50%.

16/12 = molecular weight ratio CH_4/C

OX_T = oxidation factor. It is assumed to be 0.1.

R = recovered CH_4 (kt/year). Based on the NIR of Greece, it is 43% for year 2021.

The composition by mass of the produced waste is about 18% paper, 12% food waste and 70% non-food waste. Considering the aforementioned parameters, we can make the following calculations:

- CH_4 emissions (by paper) = 0.369 t/year.
- CH_4 emissions (by food waste) = 0.092 t/year.
- CH_4 emissions (by non-food waste) = 0.718 t/year.

The total CH_4 emissions of the factory's solid wastes in 2021 were 1.18 tonnes. Multiplying this number with the GWP of CH_4, the total GHG emissions from solid waste were 33.0 tCO_{2eq}.

2.2.4. Fluorinated Gases

2.2.4.1. Residential/Domestic Refrigerators

The factory has approximately 10 domestic refrigerators (small capacity, lower than 150lt). According to the National Inventory Report (NIR) of Greece for GHG and other Gases [17], 47% of domestic refrigerators contain HFC-134a (1,1,1,2-tetrafluoroethane, CH_2FCF_3), with a GWP of 1,530 $kgCO_{2eq}$/kgHFC134a. The remaining 53% contain R600a (isobutene, $CH(CH_3)_2\ CH_3$) with a GWP equal to 3 $kgCO_{2eq}$/kgR600a. The assumption is made that out of the 10 domestic refrigerators, 5 units contain HFC-134a, and the other 5 units contain R600a. The estimation GHG emissions associated with the operation and servicing of these domestic refrigerators can be determined using the following equation:

$$\text{GHG Emissions } (tCO_{2eq}) = (\text{number of refrigerators}) \times M \times x \times GWP/1{,}000 \quad (2)$$

where:

GWP: 1,530 $kgCO_{2eq}$/kgHFC134a, and 3 $kgCO_{2eq}$/kgR600a,

x: emission factor or product life factor (% of initial charge per year), and

M: initial charge.

Based on the NIR of Greece, the emission factor x is considered to be 0.25% of initial charge per year and the initial charge M=0.225kg [17].

Therefore:

1. Calculation of the HFC-134a Emissions (tCO_{2eq}) = 5 units * 0.225 kgHFC134α / unit * 0.25% * 1,530 ($kgCO_{2eq}$/kgHFC134a) = 4.3 $kgCO_{2eq}$

and

2. Calculation of the R600a Emissions (tCO_{2eq}) = 5 units * 0.225 kgR600α/unit * 0.25% * 3 ($kgCO_{2eq}$/kgR600a) = 0.008 $kgCO_{2eq}$

The cumulative emissions from the domestic refrigerators in 2021 amounted to 4.3 $kgCO_{2eq}$, which is equivalent to 0.0043 metric tons of CO_{2eq}.

2.2.4.2. Residential and Commercial Air-conditioning

The factory is equipped with 15 split type air conditioning 12,000 btu units. These air conditioners contain a refrigerant called R-407C, which is a blend consisting of HFC-32, HFC-125, and HFC-134a in a proportion of 23%, 25%, and 52% respectively. These individual HFCs have different GWPs, with HFC-32 having a GWP of 771, HFC-125 having a GWP of 3,740, and HFC-134a having a GWP of 1,530. Considering the composition of the refrigerant blend and the GWPs of each gas, the overall GWP of R-407C is estimated to be 1,907.9 $kgCO_{2eq}$ per kilogram of R-407C.

The average initial charge and emission factor were obtained from the NIR of Greece. The initial charge is M=1.5kg, and the emission factor x=5% [17].

Based on the above information, the air conditioners in the factory contribute an estimated GHG emission of 0.21 tCO_{2eq}, by the application of equation (1).

2.2.4.3. Industrial Cooler

The factory produces liquid nitrogen and oxygen for industrial and medical applications in Greek Army. An industrial refrigerant is used in the production process which contains about 50kg of HFC -134a. The GWP HFC - 134a is 1,530.

The emission factor x (% of initial charge/year), according to the NIR of Greece, is 0.5% initial charge/year [17]. Taking into consideration the above parameters, the GHG emissions of the industrial cooler were estimated to be 0.38 tCO_{2eq}, by the application of equation (1).

2.3. Carbon Footprint Timeline

Using available data from the beginning of 2019, factory's carbon footprint as calculated for every year though the analysis is presented above (Table 4). The objective of this analysis was to gain insights into the environmental impact of the factory and to track the trajectory of its carbon footprint over time. Carbon footprint from waste disposal has remained about the same since there was no significant change in municipal solid waste production or the handling of such waste. Also, the lack of any changes in the refrigeration and cooling system resulted in keeping the carbon footprint associated with fluorinated gas emissions steady. A reduction in the size of staff from about 55 to 40, as well as the reduced travel due to Covid-19 has resulted in a decrease in the carbon footprint associated with transportation and consequently to the overall footprint. However, there were significant changes in energy usage over the years which is the main contributor.

The electricity EF for Greece showed a significant decline, about 40%, over the last 5 years. This drop is directly related to CF from electricity usage. Over the 3 years that had been studied, electricity consumption decreased by 4% and the produced CF decreased over 36.7%. Diesel consumption and its carbon footprint decreased by 63.9%, as a result of the electrification progress and the energy saving plan of the factory. In total, the CF was decreased by 33.7% from 1.61 to 1.07 $ktCO_{2eq}$ per year, with the CF from each category presented in Table 5 and Figure 1.

Table 4. Carbon Footprint from energy usage between 2019 and 2021

Energy usage		2019	2020	2021
Electricity	consumption (kWh)	2,500,000	2,600,000	2,400,000
	EF ($kgCO_{2eq}$/kWh)	0.5642	0.4200	0.3717
	emissions (tCO_{2eq})	1,410.4	1,092.1	892.0
Diesel	consumption (lt)	7,200	4,600	2,600
	emissions (tCO_{2eq})	19.1	12.2	6.9

Table 5. Carbon Footprint of the factory between 2019 and 2021

Emissions sources	GHG emissions (tCO_{2eq})		
	2019	2020	2021
Electricity	1410.4	1092.1	892.0
Diesel	19.1	12.3	6.9
Transportation	146.1	140.3	133.6
Wastes	33.0	32.2	33.0
Fluorinated gases	0.6	0.6	0.6
Total	**1,609.1**	**1,277.5**	**1,066.1**

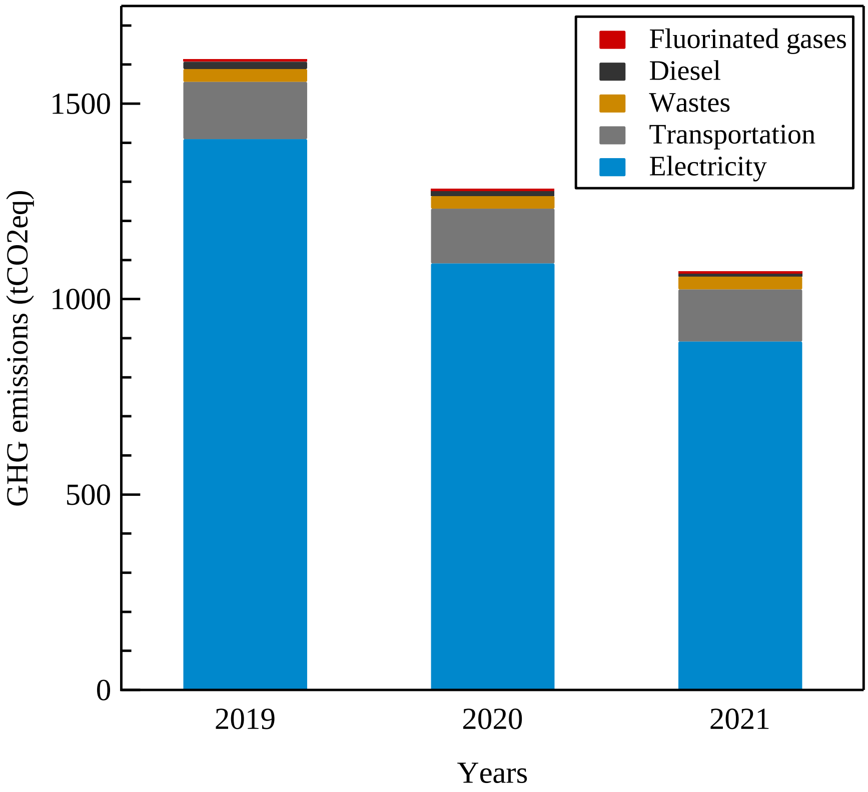

Figure 1. Factory's Carbon Footprint per category between 2019 and 2021

3. Results and Discussion

The carbon footprint of the stationary and transport emission sources of the factory is presented in Table 6.

The electricity consumption constituted the category with the highest contribution (83.7%) to the factory's carbon footprint, followed by the emissions from transportation with 12.5%.

Table 6. The carbon footprint of the factory in 2021

Emissions sources	GHG emissions (tCO_{2eq})	Share (%)
Electricity	892.0	83.7
Diesel	6.9	0.6
Transportation	133.6	12.5
Wastes	33.0	3.1
Fluorinated gases	0.6	0.1
Total	**1,066.1**	**100**

Industrial sector is estimated to have the second largest CF, after the hospital-based healthcare among the Hellenic Army. For comparison, according to previous papers by the authors [18] the total carbon footprint of the 401 MGHA in year 2018 was 9,791.2 tCO_{2eq}, while in 2021 it is estimated to be about 7400 tCO_{2eq}. The contribution of Electricity and fossil fuel is about 90% of the total emissions of the Hospital, relatively close to the factory's contribution.

3.1. Factory Key Performance Indicator (KPI)

According to the most recent EU climate law, the goal of reducing EU emissions by at least 55% by 2030, compared to 1990 levels and by 40% compared to 2005 levels is a legal obligation [26]. This is the first step to achieve the goal of making the EU climate-neutral by 2050. At the same time, Greece as a member of the Union, has the obligation to reduce its emissions by 23% by 2030 compared to 2005. In 2021, GHG emissions in Greece (without LULUCF) amounted to 77.50 Mt CO_{2eq} showing a decrease of 25.5% compared to 1990 levels [17].

Factories necessitate significant energy consumption to maintain continuous operations throughout the year. Additionally, the transportation activities associated with the movement of staff, visitors, and suppliers to and from factories contribute substantially to GHG emissions. Determining the amount of GHG emissions serves as a starting point for devising action plans aimed at reducing energy usage and operational expenses.

The management of the factory can address the substantial energy requirements and yearly GHG emissions of the factory by formulating and executing a range of initiatives focused on energy conservation and emission reduction. This approach aims to facilitate a gradual shift towards utilizing low-carbon energy sources and transportation methods.

To effectively track and assess the progress in reducing the factory's carbon footprint, it is recommended to establish specific Key Performance Indicators (KPIs) as measurable metrics. By utilizing these metrics, the factory's "Energy Management Team" can enforce policies and procedures that target GHG emission reduction, determining appropriate mitigation measures to be implemented. One potential comprehensive KPI, encompassing all mitigation actions and emission sources, could be expressed as "tCO_{2eq} per t of product", while more specific KPIs such as "tCO_{2eq} from staff transportation per person" can be used for specific mitigation action.

3.2. Action Plan

In this section, we introduce a carefully developed action plan, tailored to substantially curtail the GHG emissions originating from the manufacturing sector of the Hellenic Army. This approach involves a comprehensive set of strategies that target various aspects of the manufacturing process, from optimizing energy usage to implementing more sustainable manufacturing practices. Additionally, it involves regular assessments and audits to monitor progress and ensure the effective implementation of these strategies, by the use and monitoring of the KPIs discussed in the previous section. Through this action plan, we are committed to actively contributing to the global efforts in combating climate change, while maintaining the operational efficiency of the Hellenic Army's manufacturing sector.

The electricity consumption is the main contributor to the factory's total GHG emissions. In 2021 about 2,400,000 kWh were consumed, responsible for 892.0 tCO_{2eq}, 83.7% of the factory's total emissions. It is estimated that in 2005 the respective number was 2,900,000 kWh and combined with the much higher emission factor, 0.8996 $kgCO_{2eq}/kWh$ [17], the emissions from electricity consumption were 2,610 tCO_{2eq}. As a result, the emissions from electricity were decreased by 66% and the total GHG emissions by about 60%, assuming that the rest of the emission categories remained the same. This is more than enough to reach the goal set by the EU.

Table 7. Proposed GHG emission reductions by the year 2030

Emissions sources	GHG emissions (tCO_{2eq}) in 2021	Estimated GHG emissions reduction by 2030	GHG reduction (tCO_{2eq}) by 2030
Electricity	892.0	-35%	-312.2
Diesel	6.9	-35%	-2.4
Transportation	133.6	-30%	-40.1
Wastes	33.0	-25%	-8.3
Fluorinated gases	0.6	-10%	-0.1
Total	**1,066.1**	**-34%**	**-363.0**

Although, a more ambitious goal can be set, for example the reduction of the factory's emissions by 75% by 2030 compared to 2005. In this case, the emission by 2030 should be reduced by 34% (360 tCO_{2eq}) compared to 2021 (Table 7).

3.2.1. Electricity

Electrification has reduced the factory's GHG emissions in the past. The European Union is currently focused on decarbonizing the electricity generation sector, and Greece is making significant progress in this regard by increasing the proportion of electricity generated from low-carbon fuels and renewable resources [19].

The implementation of measures such as the expansion of renewable energy sources and the introduction of gas-fired plants, along with the planned phase-out of lignite-fired power plants in the country by 2028 [27], will contribute significantly to the reduction of GHG emissions resulting from electricity consumption. These initiatives are expected to have a positive impact on minimizing the environmental footprint associated with electricity generation and consumption, thus helping to mitigate GHG emissions. The conversion factor of electricity has shown a great decrease over the last decade, from 0.8486 $kgCO_{2eq}/kWh$ in 2011 to 0.3717 in year 2021 [17]. As a result, the annual GHG emissions are derived from the electricity consumption overall in the country, but also for the factory that has significantly reduced electricity consumption emissions are going to decrease further over the next years. The combination of a power-saving policy along with the decreasing conversion factors can achieve the goals set for the future.

The factory's "Energy Management Team" can employ a straightforward Key Performance Indicator (KPI) to track their progress in energy savings and the corresponding reduction in GHG emissions. The extensive use of electricity for the industrial equipment makes the research for new energy saving technologies necessary. Various energy efficient appliances and investments, like installing roof-mounted solar PV energy systems, should be considered in the next annual budgets in order to lead to net zero goals. At this moment, solar PV is leading the expansion of the energy market along with wind, setting the largest annual increase ever [28]. Manufacturing sector can take advantage of this huge potential, by upgrading its infrastructures.

3.2.2. Transportation of Staff to and from the Factory

As mentioned before, in 2021 factory's manpower was 40 person per day. The total GHG emissions caused by the staff movement were 83.9 tCO_{2eq} and 75% of them came from private car usage, despite the existence of the factory's buses. The proposed KPI to monitor this is transportation of GHG emissions per person. This KPI could be reduced by adding another minibus route connecting the factory and the city of Thiva, which is about 40 km away, and by encouraging car-pooling techniques.

3.2.3. Other Mitigation Actions

The National Energy and Climate Plan (NECP) of the Greek Government, as outlined by Ministry of Energy and Environment, incorporates targeted measures for improved waste management [27]. A major problem is the disposal of solid waste since there is a great amount of industrial and municipal waste produced daily. To address this issue, the factory's administration should actively encourage practices such as composting of food waste, recycling, and reusing materials, with the aim of minimizing the quantity of solid waste that needs to be disposed of. By promoting these initiatives, the factory can contribute to the reduction of waste and its environmental impact while aligning with the objectives outlined in the NECP.

The implementation of an ISO environmental management standard from the ISO 14000 series can bring several benefits to the factory. These standards provide comprehensive guidelines for developing an effective environmental management strategy and offer a practical framework for the team to follow [29].

4. Conclusions

This study estimates the carbon footprint (CF) of the Hellenic Army's industrial sector, building on prior research into transport activities and stationary emissions in healthcare. This comprehensive analysis forms a base for strategizing GHG emissions reduction, optimizing energy use, and managing the Army's annual budget. The study reveals that the factory's CF is primarily driven by indirect emissions from electricity consumption (83.7%), with transportation activities (12.5%) also being a significant factor. Notably, the shift from lignite-fired power plants to renewable energy in Greece has resulted in a 36.7% reduction in the factory's emissions from 2019 to 2021.

The implementation of Key Performance Indicators (KPIs) is recommended for tracking and assessing emission reductions. These KPIs range from broad metrics like “tCO_{2eq} per ton of product” to specific ones such as “tCO_{2eq} from staff transportation per person”, aiding in monitoring and evaluating the effectiveness of various mitigation measures. These targeted KPIs offer insights into particular areas of emission reduction and help in assessing the overall progress in minimizing the factory's CF.

In the broader context, the EU aims for net zero GHG emissions by 2050, in line with the Paris Agreement. Greece targets a 23% emission reduction by 2030 from 2005 levels. The factory has already achieved a 60% reduction in emissions compared to 2005, surpassing this goal. The proposed mitigation actions in this study are projected to yield an annual reduction of over 360 tCO_{2eq} by 2030, exceeding national targets and reflecting the Hellenic Army's commitment to environmental stewardship within its Corporate Social Responsibility framework.

Statements and Declarations

Ethical Responsibilities of Authors

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Competing Interests

The author declares no competing interests.

Funding

No funding was received for conducting this study.

Authors' Contributions

Conceptualization, Vasileios Bozoudis (V.B.) and Ioannis Sebos (I.S).; methodology, Iraklis Karaiskos (I.K.), V.B. and I.S.; validation, I.S.; formal analysis, I.K. and V.B.; investigation, I.K. and V.B.; data curation, I.K. and V.B.; writing—original draft preparation, I.K. and V.B.; writing—review and editing, V.B. and I.S.; visualization, I.K. and V.B.; supervision, I.S. All authors have read and agreed to the published version of the manuscript.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article.

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