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An Evaluation of the Environmental Impact of Logistics Activities: A Case Study of a Logistics Centre

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Abstract: Lately, the logistics sector has seen accelerated development, which has led to general economic growth, but, at the same time, it has caused considerable environmental damage due to the excessive consumption and emissions that are currently affecting society at large. Since logistics activities are considered some of the most polluting economic activities, this present article aims to present the advantages of implementing the green logistics concept. To this purpose, the activity of a logistics centre in Romania was analysed, with a focus on the greenhouse gases (GHGs) produced as a consequence of this economic activity, and its carbon footprint was calculated according to the GHG Protocol. Although this global standard is based on an integrated approach to how GHG emissions are calculated, there is limited evidence about its degree of implementation by companies. The results of the analysis revealed that the consumption of energy and fuel by the logistics sector has a significant impact on the environment. This impact is maintained, albeit at a smaller scale, even if the technology is replaced and the equipment used by companies to carry out their activities is increasingly performant.

Keywords: green logistics; greenhouse gases; emissions; sustainable supply chain development

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1. Introduction

The boom of online commerce during the past few years has contributed to the rapid growth of the logistics industry, implicitly contributing to environmental pollution caused by this activity. The logistics sector ensures the management of the flux of products, materials and information. Although it is often considered to be exclusively about transport, logistics in fact comprises a wide range of activities, including the acquisition of products (supplier management), storage (stock and warehouse management) and distribution and transport (delivery). Among these, transport is an essential component, which produces a high percentage of greenhouse gases. According to the European Parliament [1] and to the European Environment Agency [2], in 2019, transport generated about one quarter of the total CO_2 emissions in the European Union, 71.7% of which came from road transport. The European Parliament [2] has also highlighted that the transportation sector is the only one where GHGs have seen a steady increase over the past three decades, thus making it necessary to cut the CO_2 emissions resulting from this activity. In a report released in 2022, the European Environment Agency stated that the GHGs produced by the transport sector represented 25% of total GHGs in the European Union.

The increasing concerns about the negative effects of transportation on the environment have led to the appearance of the green logistics concept, which is considered a future development trends within the context of a sustainable economy. Green logistics is connected with environmental objectives; it promotes the sustainable development of the transportation sector and the reduction in CO_2 emissions. In an attempt to reduce the environmental impact of this activity, the transportation industry through the European Shippers' Council has created the Green Freight Europe programme, by means of which it promotes efficient, sustainable and digital freight transportation inside and outside Europe [3]. This programme aims to support companies in the process of improving the environmental performances of European freight transportation, as well as to implement sustainable policies for a significant reduction in black carbon, carbon emissions and other environment pollutants that are directly connected with the transportation sector. The idea of green transport has been taking shape and is on the rise, with logistics companies permanently identifying problems and looking for solutions such as replacing polluting vehicles and optimising ecological processes, etc. [4]. By assessing the sustainability of the supply chain and analysing innovative strategies, some of the polluting elements have been eliminated.

Within this context, logistics has become increasingly digitalised, making it possible to fulfil sustainability criteria. Thus, among the essential technological components of such activities, one can mention artificial intelligence, automatic learning, robots, Industrial Internet of Things (IIoT), and blockchain.

In the modern logistics industry, a significant part of the process involves the Industrial Internet of Things (IIoT) technology. This technology plays an important role in information development, being indispensable in the industry [5–7]. Likewise, robots are essential since they optimise the processes of every logistics centre. The major problem is that there is no unitary approach in the circular economy process regarding the degree to which they are collected and recycled, although they contain electrical and electronic components [8]. This is why we cannot refer to the logistics industry without considering electrical and electronic equipment. Ever since 2003, the European Union has insisted on accelerating the process of reduction and elimination of electrical and electronic waste, as well as on preventing the production of more types of this waste. The emerging technologies, especially 5G and virtual reality, accelerate the depreciation rate of electronic items and generate new fluxes of electronic waste. It is expected that the new generations of electrical and electronic equipment will increase the global quantity of electrical and electronic waste up to 74.7 Mt by 2030 [9]. In order to be able to speak about a circular economy in the case of logistics activities, policies should be developed to mitigate the environmental impact of both the current activities carried out in logistics centres and the degree of recuperation and valorisation of the waste they produce [10].

Managing the ecological supply chain improves economic efficiency and competitiveness. An ecological supply chain framework is based on three integrated factors, social, economic and environmental, which facilitate better management of ecological processes [11]. Two elements that can contribute to generating policies for the sustainable management of the supply chain are risk management and sustainable product design. They both stimulate the ecological supply chain development within a sustainable framework [12].

Many political and operational challenges related to the transformation of the logistics industry should be rapidly tackled. Ecological development is different from the traditional development concept in terms of how it operates and how it is standardised. Traditional logistics has many disadvantages, such as the low efficiency of the labour force, the slow information flow and its obvious financial flaws. Green logistics has its advantages because it is based on elements that lead to a reduction in the impact on the environment.

Starting from this approach of the green logistics concept, through this article, we intended to present the environmental impact caused by the consumption of energy and fuel and, implicitly, of the carbon footprint of the logistics sector. To calculate this, we used the GHG Protocol as the only standardised document in this respect. In our research, we focused on electrical energy and fuel consumption because we considered them as having a major impact on the quantity of GHGs generated by a company in the logistics sector. Through this model, we also intended to reduce the negative impact of logistics activities on the environment and to contribute to balanced economic development.

2. Literature Review

At the moment, climate change represents a major challenge for all the countries in the world. Commercial activities are leaving deep traces and have a major impact on the environment. The logistics sector is developing and becoming increasingly difficult to manage, which has led to the need for new, sustainable concepts. Since logistics is a complex activity including operations all along the supply chain and the green logistics concept has a significant impact not only on the company but also on society at large, the activities related to this concept should aim to measure and minimise the impact of logistics activities on the environment [13].

Due to the complexity of logistics activities, numerous definitions have been given in different times to the concept of green logistics. Thus, various authors have different views regarding green logistics. Some consider it a process that has an environmentally friendly approach and comprises activities in the field of distribution, storage, transport and recycling, including the processing and elimination of waste [14]. Other authors see green logistics as an extension of traditional logistics, focusing on performance, but only in an environmentally friendly manner, with a view to preserving resources [14,15]. The most comprehensive approach to green logistics is the one that takes into consideration the trends implemented by companies within their operations in order to increase economic efficiency while protecting the environment at the same time. This is the most complex definition, considering the fact that green logistics is a field of activity that influences the whole supply chain (transport, delivery, storage, recycling and reduction in waste and emissions) [16,17].

Implementing green logistics in a distribution centre not only requires good knowledge of the processes within the respective centre but also within the industry as a whole. Because there are no integrated tools that would indicate how industrial logistic concepts can be best implemented, each company chooses its own methods and tools depending on their own needs and knowledge [18]. Thus, one can state that the absence of an integrated, standardised instrument is a major problem that prevents companies from increasing the performance and efficiency of the supply chain [19]. Even if there is a stringent need for such an instrument, the importance of taking action in this sense is not yet understood. Most authors who are considering the introduction of green logistics concepts into this economic activity focus on evaluating and optimising the logistics processes from the point of view of companies [20–22], without focusing on a circular economy, which offers a way of dealing with climate change and makes society more sustainable and resilient [23].

Within this context, in order for logistics to offer services that are effective from the point of view of resources and energy, it is crucial to identify relevant evaluation and control instruments. Therefore, a standardised, comprehensive method that is connected to the need for evaluating logistics processes is necessary in order to define the requirements of green logistics [20].

During the next few decades, logistics companies will have to deal with intense pressure to reduce their GHGs as part of an effort to reach very ambitious goals of reducing carbon emissions at a global level [22]. The importance of good logistics performance for low-emissions/no-fossil-fuel economies is widely recognised, especially because the transportation sector, which represents a considerable part of logistics, is responsible for a substantial part of GHGs at the global level.

Green logistics and the circular economy have been recognised as essential concepts for achieving good long-lasting economic and environmental performance. In spite of this, there is a lack of understanding of the combined effects of the two concepts on reducing CO_2 emissions. While the circular economy focuses on minimising environmental impacts, making effective use of resources and increasing economies' environmental performance at the same time [24], green logistics aims to reduce the amount of GHGs [25]. Integrating these two concepts would mean a change of paradigm, since companies feel the critical need to separate economic growth from the increase in carbon emissions [25,26]. However, in spite of the added value of integrating these two transforming concepts, little assessment has been carried out of the actual effectiveness of these concepts in controlling carbon emissions.

At the global level, there are two tools that can be used to standardise the calculation methods of the carbon footprint, namely the GHG Protocol [27,28] and the ISO Standards. The two ISO Standards that are relevant for this purpose are the following: ISO14064-1 Greenhouse gases—Part 1: Specification with guidance at the organisation level for the quantification and reporting of greenhouse gas emissions and removals [27,29] and ISO14064-3 Greenhouse gases—Part 3: Specification with guidance for the verification and validation of greenhouse gas statements [27,30].

By applying only one of the two instruments, the amount of GHGs reported can vary substantially, which represents a conflict from the point of view of sustainability [31]. It would be ideal if an integrated approach to the two tools existed, but in its absence, the most comprehensive one that can be used is the GHG Protocol. Unfortunately, the specialised literature does not make reference to the use of the GHG Protocol by companies. The only study we identified is limited because it only uses data from European companies in the year 2019 [32]. Therefore, we believe that there is a major need to develop a generally accepted framework in order to be able to analyse the environmental impact of logistics activities. Briefly, it can be stated that designing an integrated approach that would reduce the impact of carbon emissions on the environment would bring added value to logistics activities.

The element of novelty brought by this present paper is that it ensures an integrated and unitary approach to the environmental impact of logistics activities, thus completing the previous studies carried out in this domain.

3. Materials and Methods

3.1. Description of the Proposed Methodology

The methodology proposed for this paper is described in what follows and it aims to set objectives, identify limitations, map the processes and analyse the carbon footprint.

By using the GHG Protocol, we propose a unitary approach to a stringent issue regarding the carbon emissions resulting from logistics activities. Since logistics activities are fairly complex, the methodology proposed will hopefully help us not only reveal the developed algorithm but also the major impact on the environment caused by energy and fuel consumption in logistics centres.

Through this study, we intend to establish an algorithm that can determine how to calculate the carbon footprint in real conditions.

The stages proposed for the present methodology are the following:

Stage 1: setting the objectives and accepted limitations within the model;

Stage 2: developing a process map in order to understand the processes within the logistics centre;

Stage 3: calculating the carbon footprint according to the GHG Protocol;

Stage 4: collecting and analysing the data regarding consumption;

Stage 5: creating simulations regarding the increase in energy efficiency and reduction in greenhouse gases.

The accepted objectives within the present model refer to reducing the energy consumption needed for the activities carried out in a logistics centre, thus increasing the effectiveness of the centre.

One of the study's limitations consists of the fact that we only analysed the energy consumption of the equipment and means of transport used. In other words, we calculated their carbon footprint, taking into account the energy and fuel they consumed. Another limitation is that this study only considered emission factors in Romania. Despite this, in a logistics centre, there are many more elements that have an impact on the environment, among which new equipment and technologies are used, which are not associated with electrical and electronic waste, even though their components may be. We consider this to be an area that can be the object of further studies.

Mapping the processes is essential for the analysis. With the use of this method, we will know which processes are taking place in the logistics centre and how to quantify them so that we can calculate the emissions corresponding to each activity later on.

According to the definition of a process, the reason for an organisation to exist is to transform an input into an output through coordinated activities while also bringing some kind of added value [33]. A general process model is presented in Figure 1 below.

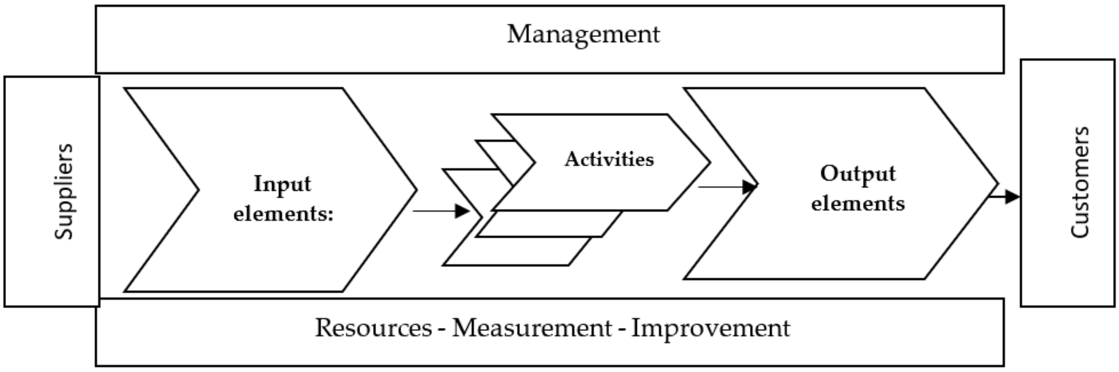

Figure 1. Process map created using the SR EN ISO 9001:2015 standard—Quality management systems. Requirements [33].

In accordance with the generic process map above, the processes in a logistics centre are illustrated in Table 1.

Table 1. General processes in the logistics centre.

Suppliers	Activities	Customers
Input elements: Raw materials Finished products	Storage Communication of orders Processing of orders Entering of orders Transport	The customers are the ones who establish the input elements because these depend on their needs. The clients also keep track of the output elements, i.e., the distribution of raw materials or finished products.

In logistics, these general processes can be subdivided into sub-processes. For the present methodology, the analysis was restricted to the processes above.

To calculate the carbon footprint, we used the GHG Protocol. According to this protocol, the GHGs produced by a company are classified into three Scopes. Scopes 1 and 2 are compulsory to report, whereas Scope 3 is voluntary and the most difficult to monitor. For the purpose of this study, the carbon footprint was calculated for all 3 Scopes.

The emissions included in Scope 1 are direct emissions generated by the sources owned or controlled by the logistics centre. Thus, Scope 1 covers the emissions from sources directly owned or controlled by the analysed centre. These emissions include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are produced by stationary and mobile combustion and by involuntary fugitive emissions. Fugitive emissions may also include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), ssulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

In order to calculate the emissions, because the fuel heat content was unknown, the following formula was used:

$$E_c = \mathrm{C} \times \mathrm{F_e} \tag{1}$$

where

E_c = Emissions;

C = Fuel (fuel mass or volume);

F_e = Emission factor.

The emissions falling into Scope 2 are indirect ones, coming from the generation of acquired energy. The emissions generated indirectly by the logistics centre are included here, and they have their origin in the place where the energy that they acquire and use is produced. To calculate the emissions, two methods can be used—the location method and the market method.

The emissions in Scope 2 are calculated by multiplying the data of each operation by the emission factor for the respective activity. One should take into account the fact that some sets of electrical energy emission factors may include emission rates for CO_2, CH_4 and N_2O, whereas others may only provide CO_2 emission rates.

$$E_{\mathrm{ci}} = \sum_{i=1}^{n} C_{\mathrm{i}} \times F_{\mathrm{i}} \tag{2}$$

where

E_{ci} = Emissions;

C_{i} = Fuel (fuel mass or volume);

F_{i} = Emission factor.

The emissions in Scope 3 are the ones produced in the value chain of the logistics centre, and the reporting relates to both upstream and downstream emission sources. Thus, Scope 3 includes the emissions that are not produced by the company itself and do not result from the activity of the assets it owns or controls but from the ones it is indirectly responsible for, situated upstream and downstream on the value chain. In the particular case analysed, these are products acquired from suppliers in order to be further sold.

To calculate the emissions in Scope 3, the logistics centre can use several methods. The first two methods—specific to the supplier and the hybrid method—require that the centre should collect data from suppliers, whereas the next two methods—based on average data and costs—use secondary data, meaning the average data of the industry.

For this study, the hybrid method was used in order to calculate the emissions generated by the energy used, the sold equipment and the waste resulting from returned equipment.

$$\mathrm{ECO}_{2\mathrm{e}} = \sum_{i=1}^{n} E_{\mathrm{ci}} \tag{3}$$

where

ECO_{2e}= CO_2 emissions;

E_{ci} = Emissions.

This analysis continued with a simulation of the processes in the logistics centre that may lead to the highest reduction possible in environmental impact. This can be referred to as green logistics.

The data quality is assessed by calculating the 95% confidence interval for a 5% deviation, in agreement with the methodology in the guide of the GHG Protocol's Measurement and Estimation Uncertainty of the GHG Emissions tool.

The confidence interval for the mean of an X variable that follows the normal rule $N(\mu, \sigma^2)$ with $\mu \in R$ and $\sigma^2 > 0$ known has the following form:

$$\overline{x} - z_{1-\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}} < \mu < \overline{x} + z_{1-\frac{\alpha}{2}} \frac{\sigma}{\sqrt{n}} \tag{4}$$

According to the distribution table, the 95% probability is defined in the interval (−1.96; +1.96).

The confidence interval with the probability $P(-1.96 < z < 1.96) = 0.95$.

From this, we obtain the following interval limits:

$$\overline{x} - 1.96 \frac{\sigma}{\sqrt{n}} < \mu < \overline{x} + 1.96 \frac{\sigma}{\sqrt{n}} \tag{5}$$

In this way, the theoretical mean is constructed for the 95% confidence interval.

3.2. Presentation of the Logistics Centre

For this study, an average-sized logistics centre was analysed.

In the selected logistics centre, we took into consideration the equipment used for the logistic operations, as well as the means by which these operations are performed. The centre is divided into 3 areas, as can be seen in Figure 2.

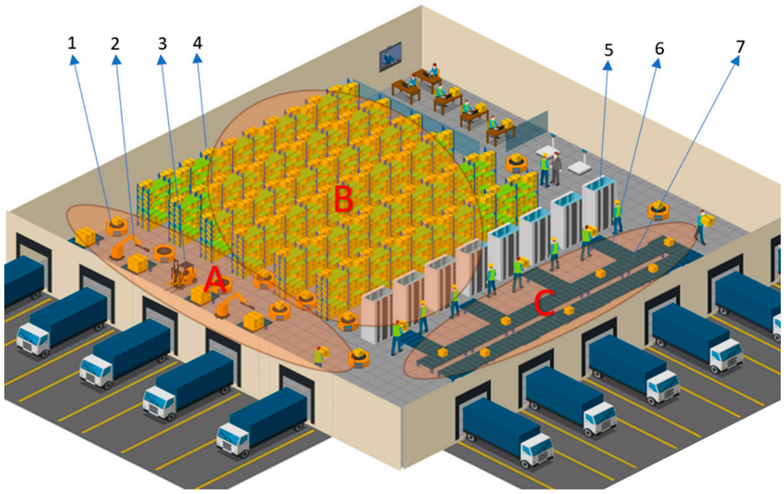

Figure 2. General structure of the distribution centre (figure created by the authors).

From a functional viewpoint, the previously mentioned areas are as follows:

Area A—this is the area where the goods come into the warehouse through 5 gates, and it comprises the following systems:

- ➢ A total of 2 electric forklifts (identifiable as no. 3, Figure 2) with the role of transporting the loaded pallets to the depalletization area;
- ➢ A total of 2 joint-arm industrial robots (identifiable as no. 2, Figure 2) with the role of depalletizing goods;
- ➢ A total of 12 mobile robots (identifiable as no.1, Figure 2) with the role of transporting the goods from area A to area B (storage area) and from area B to area C (preparation area, sorting and directing parcels to the exit gates).

Area B—this storage area includes the following two sectors:

- ➢ The sector with classic storage structures (identifiable as no. 4, Figure 2), where the storing of goods and their retrieval is done manually by human operators;
- ➢ The sector with automated storage lift systems (identifable as no. 5, Figure 2), which facilitates the automatic storage and retrieval of a certain product type on demand, with the retrieval operation being performed by the human operator in the specific retrieval area of the vertical lift. There are 8 vertical lifts.

Area C—the area where the goods leave the warehouse through 6 gates and which contains 9 S1 type conveyors (identifiable as no. 6, Figure 2) and 4 S2 type conveyors (identifiable as no. 7, Figure 2) with the role of transporting the packaged goods to the exit gates.

The flow of materials highlighting the main operations performed by automated technical systems (conveyors, mobile robots, joint-arm robots and vertical lift storage systems) is as follows: the pallets with products are unloaded from the lorries using electric forklifts and then transported inside the warehouse in the area of the joint-arm robots, which perform the depalletizing operation. The depalletized products are positioned on autonomous mobile robots, which have the role of transporting them to storage area B, in the two sectors specific to manual storage and by means of vertical lifts, respectively, depending on their type.

In the manual storage sector, the goods are placed on the shelves by human operators, while in the vertical lifts sector, the human operators perform simple operations of positioning the products at the same level to be automatically stored.

The taking over of the products in order to ready the parcels for shipment to the customers is carried out in a similar way to the storage operation. In the manual storage sector, there are 50 human operators per shift, working in two shifts. Thus, there are 100 human operators in total who take over the goods that will be transported by the mobile robots to area C on sorting conveyors, directing the parcels towards the exit gates to be loaded into lorries.

In the storage sector with vertical lifts, the product pick-up operation is semi-automated; operators performing simple operations take over operations from the storage structures situated at the same height when the goods are brought to the pick-up area by the transport/transfer system. After the parcels have been readied, they are placed on the sorting conveyors and directed towards the exit gates to be loaded into lorries.

The energy consumed by the electric forks, joint-arm robots, mobile robots and vertical lifts that facilitate the flow of materials within the storage centre was taken from their technical data sheets, and for the conveyors, it was calculated depending on their type and specific load.

Electric forks are used in warehouses to unload and load goods from/into lorries and to transport them to pre-established locations. In the logistics centre analysed, the forklifts (Figure 3) are used to unload pallets from lorries and to transport them to the depalletization area. The main specifications of this type of equipment are loading capacity/load—1500 kg, travel speed with load/without load—16/16 km/h, lifting speed with load/without load—0.51/0.74 m/s and energy consumption according to the EN cycle—3.7 kWh/h, resulting in a consumption of 29.6 kWh for 8 h of operation/day for each forklift (a working day with two shifts).

Figure 3. Electric forklift (figure made by the authors).

Palletizing robots are generally used for palletizing operations, but they can also be used for depalletizing products from the pallet. In most cases, this happens in the goods reception area of logistics centres. For the case study in this present paper, palletizing robots (Figure 4) with the following technical specifications were used: load capacity—50 kg, controlled axes—5, Voltage 50/60 Hz 3phase—350 V and power consumption—2.5 kW. Considering an average operation of 8 h per day, the resulting energy consumption per robot per day (a working day with two shifts) is 20 kWh.

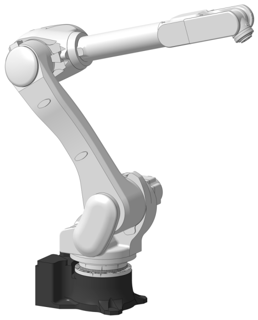

Figure 4. Joint-arm robot (figure made by the authors).

Autonomous mobile robots used in warehouses have the role of transporting products from one point to another on a flexible route, depending on the specifics of the application. In the analysed case, the C-MATIC 06 mobile robots (Figure 5) had the role of transporting products from area A, where depalletization takes place, to storage area B and from there, to parcel exit area C. These robots have the following technical specifications: load capacity—600 kg, travel speed, with/without load—5.4/7.2 km/h, lifting speed, with/without load: 0.29 m/s, lowering speed, with/without load: 0.21 m/s, drive motor power: 750 W, lifting motor power: 480 W and rotating motor power: 400 W. Taking these technical characteristics into account, as well as the operating cycle of a mobile robot of 16 h per day, the result is an approximate consumption of 16 kWh per day per robot (a working day with two shifts).

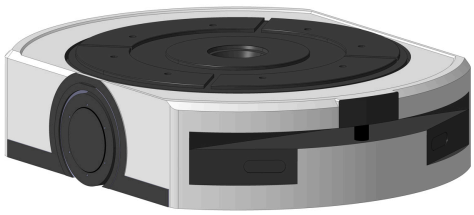

Figure 5. Autonomous mobile robot (figure made by the authors).

The automated vertical lift storage systems allow the products to be stored in an orderly and rapid manner, reducing the number of movements the operator must make to handle the goods. The pick-up area can be customised for different configurations, depending on the customers' requirements. The vertical lift storage system (Figure 6) used for this study has the following specifications: maximum throughput: 190 picks per hour, total payload: 25,000 kg, single-tray payload: 350 kg, picking bay height: 835 mm, tray side height: 45 mm, maximum depth of each tray: 425 mm and power consumption: 1.2 kW. Therefore, for a vertical lift storage system to operate at full capacity for 16 h per day (a working day with two shifts), 19.2 kWh are needed in total.

Conveyors are used in logistics to transport products from one work point to another on a rigid route. In the logistics centre analysed, there are two types of conveyors: a belt conveyor with a length of 3 m and another one with a length of 9 m, the width of both conveyors being 0.6 m.

For the belt conveyors, the following calculation method was used to determine the required power and, implicitly, energy consumption:

$$\text{Required Power} = \text{Belt Pull} \times \text{Belt Speed} \tag{6}$$

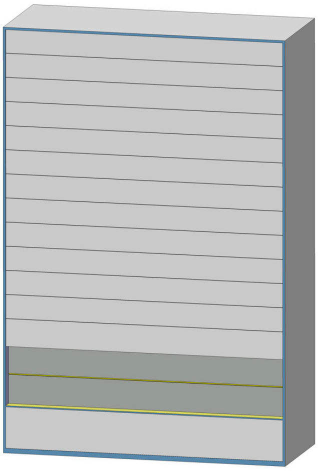

Figure 6. Vertical lift storage system (figure made by the authors).

Thus, the traction force required to move the products on a conveyor belt is equal to the total weight of all the packages plus the weight of the belt, multiplied by the friction coefficient between the lower part of the conveyor belt and the upper part of the support plate that supports the band (Figure 7).

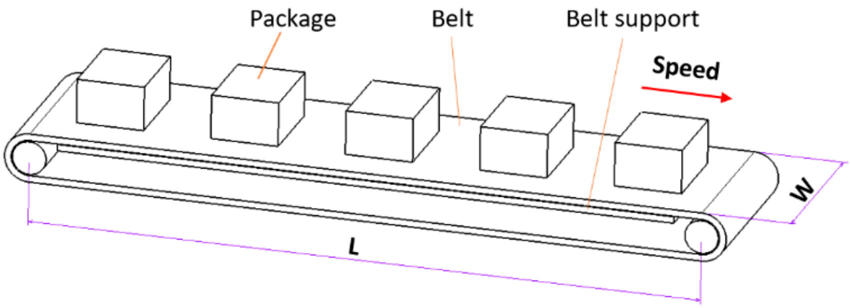

Figure 7. Simplified representation of the belt conveyor (figure made by the authors).

A conveyor belt has PVC and Polyester Canvas in its structure, being made of 3 layers: soft material, high strength material and gripping material. The thickness of the belt is 2.1 mm, the density is 2.3 kg/m^2 and the friction coefficient between the lower part of the conveyor belt and the upper part of the support plate that supports the belt is 0.2.

Six products with an average weight of 50 kg can be transported simultaneously on the S2 conveyor with a belt length of 3 m. The transport speed of the products on the conveyor belt was considered to be 0.5 m/s. Following the calculations, a required power of 320 W resulted; therefore, for an average operation of 8 h per day, there was an energy consumption of 2.5 kWh (a working day with two shifts).

On the S3 conveyor with a belt length of 9 m, 18 products with an average weight of 50 kg can be transported simultaneously. Considering the same transport speed of the products on the conveyor belt of 0.5 m/s, the calculations resulted in a required power of 907 W; therefore, for an average operation of 8 h a day, the energy consumption equals 7.3 kWh (a working day with two shifts).

In addition to the energy consumption of the equipment that ensures the logistics operations specific to the flow of materials, the consumption of the support equipment such as the lighting system, the calculation/surveyance system, the ventilation system, the heating/cooling system and other sources was added to the total consumption.

In order to calculate the impact that this activity has on the environment, an overall analysis of the processes that take place within the logistics centre is necessary. In this paper, both the activity within the centre and external connections with customers and suppliers were taken into account.

4. Results

4.1. Technical Information Related to the Logistics Centre Analysed

In order to be able to calculate the environmental impact of the carbon footprint, we have centralised the technical information regarding consumption in Table 2. For the calculation of energy and fuel consumption, we considered 21 working days in a month.

Table 2. Monthly consumption by the equipment used.

Equipment	Quantity	Consumption/Equipment/Month	Consumption/Total Equipment/Month
Joint-arm robots	2	420 kWh	840 kWh
Mobile robots	12	336 kWh	4032 kWh
Vertical lift storage systems	8	404 kWh	3232 kWh
Type S1 Conveyors	9	53 kWh	477 kWh
Type S2 Conveyors	4	154 kWh	616 kWh
Electric forklifts	2	622 kWh	1244 kWh
Support equipment	-	5000 kWh	5000 kWh
Vehicle fleet	11	1680 L	18,480 L

By adding up the energy consumption values for each equipment used, the total monthly consumption was calculated. Thus, the following formula was applied:

$$C_t = \sum_{i=1}^{8} a_j \tag{7}$$

where a_j is the total energy used in a month by each equipment.

As mentioned above, the total monthly energy consumption of the equipment used, as per Table 1, was 10,441 kWh. The support equipment related to the activity performed had a monthly consumption of 5000 kWh.

One should also mention that the logistics centre uses diesel for its vehicle fleet that includes 11 lorries—the total quantity used being 18,480 L.

The activity of the logistics centre consists of selling electrical and electronic equipment such as medium-sized AC units, small AC units, portable computers, monitors, desktops, LCDs and heat pumps. We took a monthly average of these products that are to be sold into consideration.

4.2. Calculation of the Emissions Related to the Analysed Logistics Centre

a. As mentioned above, the emissions in Scope 1 are direct emissions from resources controlled or owned by the logistics centre. In other words, these are emissions released into the atmosphere as a direct result of an activity performed by the company. For example, all the fuels that produce GHG emissions should be included in Scope 1.

Mobile combustion is related to all the vehicles that burn fuel that are owned or controlled by the logistics centre. The calculation of the emission factors in Scope 1 can be seen in Table 3.

Table 3. Calculation of the emission factors for Scope 1.

Activity	Fuel Quantity	Standard Emission Factor	Total Emissions
Fuel used by the vehicle fleet (diesel)	18,480 L	0.267	4934.16 kg CO_{2e}
Energy consumption of the electrical and electronic equipment used, including the support equipment	15,441 kWh	0.701	10,824.141 kg CO_{2e}

Thus, it can be seen that the logistics centre had a total of 15758.301 kg CO_{2e} emissions. Electricity is a vital resource for company operations. However, this resource presents risks related to GHG emissions. These emission factors can be diminished by replacing energy and fuel technology and by striking a balance between the sector objectives on the one hand and low carbon emissions and other environmental objectives on the other hand.

b. Reporting the greenhouse gas emissions in scope 2 necessitates the following algorithm:

➢ The data for each operation are multiplied by the emission factor for the respective activity.
➢ The values of the global warming potential (GWP) are multiplied by the total GHG emissions in order to calculate the total emissions CO_2 equivalent (CO_{2e});
➢ Scope 2 is reported using the market-based method. The calculation of the emission factors in scope 2 can be seen in Table 4.

Table 4. Calculation for Scope 2 using the market-based method.

Activity	Total Energy Consumed	Emission Factors	Emissions Calculated
Total emissions corresponding to total energy consumption (standard supplier contract)	15,441 kWh	0.61	9419.01 kg CO_{2e}

The calculation was made only for the emissions related to the total consumption of electricity in the situation of a standard contract with the supplier. The supplier emission factor in the contract was 0.61.

c. For Scope 3, a hybrid method was used due to the complex nature of the processes in the logistics centre.

Since data collection directly from supplier emissions is a time-consuming and costly activity, we assumed that the suppliers of the logistics centre were exclusively from Romania. The total emissions represented the sum of all the calculated intermediary emissions, as can be seen in the following figure:

$$CO_{2e} \text{ emissions} = \sum_{i=1}^{n} E_{\mathrm{ci}} \quad (8)$$

Table 5 shows the emissions by category of purchased goods. Here, the returned non-compliant equipment was also included, which, in the present analysis, was represented by the heat pumps.

Table 5. Calculation of emissions of the goods acquired using the hybrid method.

Equipment/Electricity/Fuel	Total Energy Consumed	Emission Factors	Calculated Emissions
Electricity	15,441 kWh	0.701	10,824.141 kg CO_{2e}
Fuel used by the vehicle fleet (diesel)	18,480 L	0.267	12,954.48 kg CO_{2e}
Average AC units	2000 × 25 kg/item = 50,000 kg/item	1.770	35,050 kg CO_{2e}
Small AC units	2000 × 15 kg/item = 30,000 kg/item	1.70	21,030 kg CO_{2e}
Portable PCs	2000 × 4 kg/item = 8000 kg/buc	1.770	5608 kg CO_{2e}
Monitors	2000 × 8 kg/item = 16,000 kg/item	1.770	11,216 kg CO_{2e}
Desktops	2000 × 15 kg/item = 30,000 kg/item	1.770	21,030 kg CO_{2e}
LCDs	2000 × 10 kg/item = 20,000 kg/item	1.770	14,020 kg CO_2e
Heat pumps	1000 × 50 kg/item = 50,000 kg/item	1.725	35,050 kg CO_{2e}
Returned non-compliant equipment—heat pumps	1000 × 2 kg/item = 2000 kg/item	1.725	1402 kg CO_{2e}

The impact of each activity taking place in the logistics centre is illustrated in Figure 8.

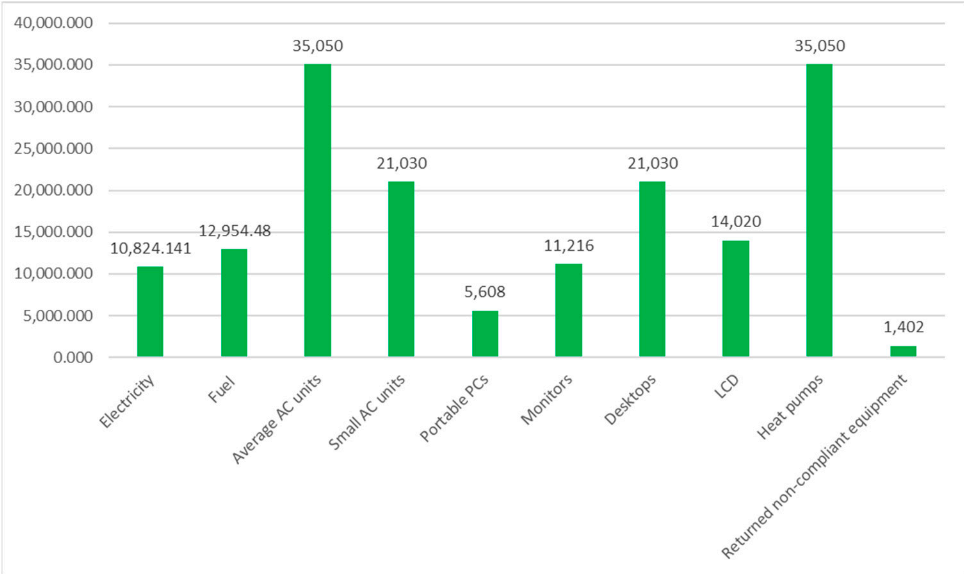

Figure 8. Evolution of emissions calculated according to Table 5.

The total value of the emissions calculated for Scope 3 comprises the sum of emissions for each activity, and it amounted to 168,184.621 kg CO_{2e}.

However, the activity of the logistics centre is much more complex. Since at some point electrical and electronic equipment is also likely to become waste, for the transition to a circular economy, it is imperative for companies to invest in electrical and electronic equipment with a longer average operating time and to provide periodic maintenance so that it can function for a longer period of time.

Since Scope 1 and 2 are not so difficult to manage and fall within the regulated area, Scope 3 was further analysed. It can thus be noticed that according to Scope 3, the contribution of electricity to the total calculated emissions reached 6.43%, and transport accounted for 7.7%, both making, therefore, a significant contribution to total emissions.

In case the logistics centre used only electric means of transport, the calculated emissions for the vehicle fleet would be 4897.2 kg CO_{2e}, the impact being 3.15%. Another significant reduction that is up to the company may come from using renewable energy sources (photo-voltaic). Such a change would result in 7720.5 kg CO_{2e} generated, representing a decrease of 4.9% of total emissions.

The evaluation of data quality was made by calculating the 95% confidence interval for a 5% deviation, in agreement with the methodology of the GHG Protocol's Measurement and Estimation Uncertainty of the GHG Emissions tool. The evaluation was made for one year.

We used the working hypothesis that, starting from the beginning of the year, the logistic centre would purchase an electric car every month so that by the end of the year, the entire vehicle fleet would be electric. Also, from the seventh month, they would have renewable energy sources installed (photo-voltaic). For this simulation, the equipment was considered to maintain its characteristics and, implicitly, its emissions. This hypothesis was used because the specifications of this equipment do not depend on the degree of involvement of the logistics centre. Only end consumers can request for companies that supply such equipment to make it more environmentally friendly. Table 6 showcases the evolution of the previously mentioned elements.

Table 6. Emissions calculated for the electricity and fuel used.

Months in One Year	Emissions
1.	24,223.82
2.	23,491.34
3.	22,758.86
4.	22,026.38
5.	21,293.9
6.	20,561.42
7.	16,725.3
8.	15,992.82
9.	15,260.34
10.	14,527.86
11.	13,795.38
12.	13,062.9

Figure 9 illustrates the evolution of the calculated emissions for the electricity and fuel used.

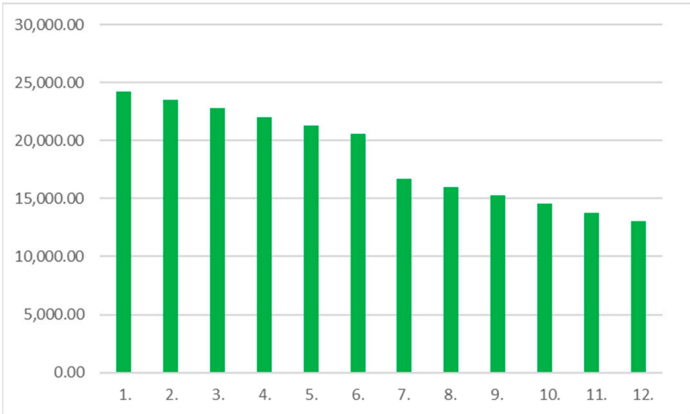

Figure 9. Evolution of emissions calculated for electricity and fuel used over a period of one year according to Table 6.

To assess the quality of the data, the first indicators to be calculated were the arithmetic mean of the values in Table 5, the result being 18,643.4, as well as the variation, which was 3952.4.

Next, the confidence interval was calculated for the average of the resulting emissions of the analysed population, from which a sample with the significance threshold of $\alpha = 0.05$ was extracted. It was assumed that the emissions were normally distributed, and $Z = 1.96$. The general form of the confidence interval is the following:

$$\left[x_j - z_\alpha \frac{\sigma}{\sqrt{n_j}} < \mu < x_j + z_\alpha \frac{\sigma}{\sqrt{n_j}}\right] \quad (9)$$

In the analysed situation, the confidence interval was [16,407.05; 20,879.67]. It can be noticed that it was wider, but in spite of this, the confidence interval helps us understand the variations in the carbon emissions and the range within which these variations can influence the total value of the carbon emissions.

The objective of this study is to optimise the energy consumption in the logistics sector by minimising the amount of carbon emissions. Using the data in Table 7, simple regression was performed to establish the degree of dependence of the total emissions on the emissions related to the consumption of energy and fuel. For this analysis, the same emissions produced by sold and returned equipment were considered.

Table 7. Emissions calculated for the electricity and fuel used and total yearly emissions.

Yearly Electricity and Fuel Emissions	Total Yearly Emissions
24,223.82	168,629.8
23,491.34	167,897.3
22,758.86	167,164.9
22,026.38	166,432.4
21,293.9	165,699.9
20,561.42	164,967.4
16,725.3	161,131.3
15,992.82	160,398.8
15,260.34	159,666.3
14,527.86	158,933.9
13,795.38	158,201.4
13,062.9	157,468.9

Using simple regression to visualize the degree of dependence between electricity and fuel emissions and the total emissions produced in one year, we produced the graph in Figure 10.

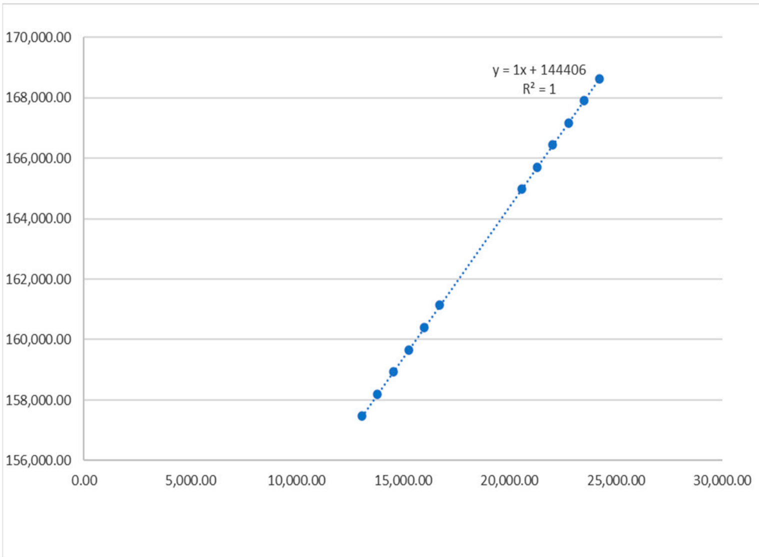

Figure 10. Regression calculated using the data in Table 7.

The general form of the regression line is y = ax + b. Since the regression coefficient b in the analysed case had positive values, it can be concluded that there was a direct correlation. According to Figure 10, the coefficient of determination reinforces the statement regarding the influence of emissions generated by energy and fuel consumption on total emissions. Thus, value 1 of the coefficient of determination indicates a linear functional dependence between the analysed variables.

Nevertheless, the activity of a logistics centre is not only about the impact it has on the environment due to the energy and fuel it uses for the means of transport it operates. Due to its high activity complexity, a logistics centre produces a more significant impact on the environment.

5. Discussion

During the past few years, the ecological initiatives aiming to reduce carbon emissions have become increasingly popular, and numerous authors have developed cost models to achieve this goal. In the logistics field, the focus is on transport activity, even if all activities result in a high amount of emissions. From the point of view of the analysed industry (i.e., logistics), its high levels of energy consumption call for measures to reduce carbon emissions. Certain authors have developed a model for streamlining logistics activities at various levels, taking into account the carbon emissions coefficient and integrating it into the objective function in order to numerically analyse the benefits and thus analyse whether carbon emissions are taken into account or not in a logistics network [31,34]. The results indicated that streamlining logistics activities, taking into account carbon emissions, has a significant impact but not a sufficient one. Other authors have focused on developing models for the streamlining of the supply chain in the logistics sector so that there would be a balance between economic benefits and environmental impact [32,34].

Calculating the carbon footprint is also a complex process that takes numerous aspects related to logistics activities into consideration, such as transport, storage, packaging and administrative activities [35–37]. This study aimed to calculate the carbon footprint for the consumption of energy and fuel in particular, but there are more issues to be considered. The equipment and technologies used in the logistics sector may become waste, with their own impact on the environment. It is important to recycle electrical and electronic waste not only in order to dispose of it but also to recuperate valuable materials. For example, from a joint-arm robot used in the logistics sector, it is possible to recuperate the following elements: steel, aluminium, plastic, batteries and cables. Consequently, all used equipment should comply with the European Directives regarding electrical and electronic equipment and the way in which it should be collected and recycled [38].

The 2030 Agenda of the United Nations Organisation [39] and the European Green Deal [40] aim to channel capital flows towards a sustainable economy, and reporting GHGs is part of these sustainability efforts.

This study is one of the few to have analysed green logistics in light of the GHG Protocol, and it contributes to the research in this field by offering a consolidated approach to the respective protocol.

Reporting GHG emissions is highly important nowadays, and it has a direct impact on assessing the sustainability of companies [41,42]. Within this context, in order to properly compare companies in terms of their GHG emissions, unitary approaches are essential. Although the GHG Protocol is a relatively widely used tool at the moment to measure GHG emissions, it is not generally accepted. This is why there is no real evidence that companies use a consolidated approach. Some companies are using the GHG Protocol, whereas others certify their management system by referring to the ISO standards. Although the two directions are similar, there is no unitary approach [43].

In this sense, this paper intends to form the basis for further discussion that may lead to the development of integrated approaches related to GHG reporting, with the final objective being that of achieving environmental sustainability and mitigating climate change.

6. Conclusions

By implementing environmentally friendly strategies, logistics companies can develop new, innovative processes with a major impact. It is already a commonplace idea that, along the logistics chain, there should be objectives such as cutting costs, reducing carbon emissions and implicitly increasing energy efficiency.

Through this present paper, the authors intended to develop a model based on the GHG Protocol that would lead to a reduction in carbon emissions. The initial hypothesis of this paper—that energy and fuel consumption are essential factors in terms of GHG emissions—was confirmed by the findings of this research. However, the major limitation of this paper is that because there are few studies on the implementation of the GHG Protocol by companies, it was difficult to carry out a pertinent analysis of how this tool is currently used at a global level.

The results of this research have revealed the impact of energy and fuel consumption of a logistics company on the environment. In order to reduce the environmental effects of economic activities in this particular case regarding logistics activities, it is necessary to develop tools for analysis and simulation, which should be incorporated in current environmental policies.

The model described will support the eventual management decisions of any company as far as investing in reduction in energy consumption is concerned. By means of this paper, the authors also intend to issue a warning about the need to develop a unanimously accepted, integrated standard for calculating the carbon footprint.

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