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**Master of Science
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Master's thesis

Organization Greenhouse Gases (GHG) emissions inventory for SFC Solutions according to GHG Protocol and ISO14064- 1:2018



**Politecnico
di Torino**

Supervisor

prof. Claudio Comoglio

Candidate

Edoardo De Bortoli

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Italian version follows

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Abstract

This master's thesis analyses the quantification and reporting of greenhouse gas (GHG) emissions for SFC Solutions, in line with the Greenhouse Gas Protocol and ISO 14064-1:2018. SFC Solutions is a group composed of five manufacturing sites in Europe and one in Morocco, and operates in the automotive sector, producing sealing and Fluid Transfer Systems (FTS). SFC Solutions is integrated in an international network composed of companies, distributed over 30 countries. Particularly, GHG inventory activity proposed by this thesis' work include data from 2024 of three plants located in Cirie (Italy), Borja (Spain) and Pitesti (Romania). The first chapter frames GHG emissions within the historical and political context, with a focus on the main international climate treaties (Kyoto Protocol and Paris Agreement) and EU initiatives, such as the European Green Deal, the Corporate Sustainability Reporting Directive (CSRD), and the EU Taxonomy. The chapter also includes a brief explanation of the status of EU automotive sector in relation with the European Green Deal. After the description of the main principles of the reference standards, the study applies them to three company plants (Italy, Spain, Romania), defining organizational and operational boundaries and the methodology used to quantify Scope 1, Scope 2, and Scope 3 emissions. Scope 1 categories include direct emissions from stationary and mobile combustion, and direct fugitive emissions from the release of GHGs in anthropogenic systems, such as air-conditioning and cooling systems. Scope 2 emissions take are indirect emissions from purchased electricity. Scope 3, which is the broadest and most impacting Scope, include indirect emissions from: transport of people (employee commuting, business trips, customers and visitors going to the facility), transport of goods (upstream and downstream distribution), purchased goods and services, capital goods and waste disposal. Results show that indirect emissions included in Scope 3, particularly from purchased goods and services, dominate the overall footprint, accounting for more than 80% of total emissions, while direct emissions and purchased electricity play a secondary role. The analysis also includes a qualitative assessment of the uncertainty of emission factors and data. These results set the year 2024 as baseline, used to establish reduction strategies and targets, aligned with SFC Solutions' carbon neutrality commitment by 2050. The study underlines the importance of GHG inventory activity as both an environmental responsibility and a competitive advantage in the automotive industry.

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1. Greenhouse gases

This chapter focuses on Greenhouse Gases (GHGs) and details the significant contribution of automotive industry to their release into the atmosphere. Firstly, there will be a general definition of greenhouse gases and an overview of those included in GHG emissions inventory; secondly, a subchapter will be focused on highlighting the most important milestones in the history of how countries have become aware of human activities effects on planet Earth and how current mitigation, and adaption policies have come about.

Afterwards, the focus will be on EU, with emphasis on European Green Deal, the ambitious plan, started in 2019, agreed by European countries to face climate change and reach carbon neutrality by 2050.

Eventually, as stated at the beginning, automotive industry GHGs emissions contribution will be analysed, with particular attention to road transport, which is the largest contributor in percentage terms, outlining also types of vehicles contribute the most to this situation.

1.1 Greenhouse gases definition

Greenhouse gases are those present in the atmosphere—both natural and anthropogenic—that absorb and emit radiation at specific wavelengths within the infrared spectrum emitted by the Earth's surface, the atmosphere, and clouds (British Standards Institution, 2019). Over the decades, their concentration has increased, following the growth of human activities, leading to climate alteration and a series of consequent effects as rising temperatures and sea level, desertification, and extreme weather events.

The GHGs officially cited by Kyoto protocol and Paris Agreement are:

- Carbon dioxide (CO₂), naturally produced by animals during respiration and through the decay of biomass. It also enters the atmosphere through fossil fuel combustion and chemical reactions. It is responsible of 79.2% of EU GHG emissions in 2021.
- Methane (CH₄), a colourless gas that is the main constituent of natural gas. Its emissions result from the production and transport of coal, natural gas and oil, as well as from livestock and other agricultural practices, land use and by the decay

of organic waste in municipal solid waste landfills. It is responsible of 13.1% of EU GHG emissions in 2021.

- Nitrous oxide (N_2O). This gas is emitted in agricultural and industrial activities as well as in land use. It is mainly produced as a result of microbial action in the soil, the use of fertilisers containing nitrogen, the burning of timber, chemical production, the combustion of fossil fuels and solid waste, and the treatment of wastewater. It is responsible of 5.7% of EU GHG emissions in 2021.
- Hydrofluorocarbons (HFCs). They are a group of gases that serve as refrigerant fluids, to absorb heat in refrigerators, freezers, air conditioners and heat pumps. Other fields of application include their use as propellants in asthma sprays and technical aerosol spray cans; as blowing agents for, and in fire extinguishers. They are responsible of 1.78% of EU GHG emissions in 2021.
- Perfluorocarbons (PFCs) are a group of man-made compounds commonly used during industrial manufacturing processes. They are responsible of 0.05% of EU GHG emissions in 2021.
- Sulphur hexafluoride (SF_6), commonly employed in power line insulation.
- Nitrogen trifluoride (NF_3), used as a chamber-cleaning gas in production processes to clean unwanted build-ups on microprocessor and circuit parts as they are being constructed. Combined with SF_6 , they are responsible of 0.17% of EU GHG emissions in 2021 (European Parliament, 2023).

Each gas contributes differently to greenhouse effect; therefore, an index which relates its dangerousness to CO_2 's was introduced. This index is called Global Warming Potential (GWP), and it is based on measuring the total radiative force caused by a unit mass of a given greenhouse gas over a specific period (Joint Research Centre, 2023). Because CO_2 is the most present gas in the atmosphere, it serves as the baseline for comparison, with GWP expressed in kilograms of CO_2 equivalent. GWP is calculated over several time horizons (20, 100 and 500 years), but GHG protocol and ISO14064 commonly use the one referring to 100 year-period (GWP100). The table below presents several examples of GHGs and their GWP100 values, based on the most recent data from the IPCC Sixth Assessment (World Resources Institute, 2024).

Table 1. GWP100 for principal Greenhouse gases (World Resources Institute, 2024).

Gas	Formula	GWP100 (kgCO ₂ e)
Carbon dioxide	CO ₂	1
Methane (non-fossil)	CH ₄	27
Methane (fossil)	CH ₄	29.8
Nitrous oxide	N ₂ O	273
Nitrogen trifluoride	NF ₃	17,400
Sulfur hexafluoride	SF ₆	24,300

1.2 Greenhouse gases: historical context

Starting from the 1970s, scientists began to look for evidence of environmental impacts of human activities by recording the increase in CO₂ concentration in the atmosphere, in order to show its correlation with climate change. This research activity led to the publication of scientific reports that brought the issue into political discussions, demonstrating the need for dialogue and knowledge sharing. The first official meetings are the United Nations Conference in Stockholm (1972), and the conference organized by World Meteorological Organization (WMO), in Geneva (1979). These two events preceded the creation of the major institutions dealing with climate change: Conference of Parties (COP) and International Panel on Climate Change (IPCC).

The IPCC was created in 1988, following the United Nations conference held in the same year, in response to the need for an intergovernmental authority able to provide certified and reliable information, given the increasing number of publications. The IPCC periodically updates the current state of climate change by publishing assessment reports, which also highlights its negative social and economic effects, in addition to strategies to tackle the phenomenon. These reports serve as official sources of information for United Nations Framework Convention on Climate Change (UNFCCC), governments, and international organizations. The first report dates to 1990 and the latest is the sixth, published in 2023. It is important to mention that the second assessment, published in 1995, served as basis for Kyoto Protocol, released in 1997, and the fifth, published 2014, was fundamental for drafting the Paris agreement in 2015 (Intergovernmental Panel on Climate Change, s.d.).

Similarly to what happened among scientists, politicians also came to understand the importance of meeting to agree on joint action plans to tackle climate change. This led,

starting in the 1990s, to the decision to establish regular official meetings known as the Conference of the Parties (COP). Formally, the first COP was held in Berlin in 1995, but the process began with the Rio de Janeiro Conference in 1992, where 154 states signed the United Nations Framework Convention on Climate Change (UNFCCC). Among all editions of this Conference, which is approaching to the thirtieth and will be held in Belem, Brazil, two are particularly relevant: COP3, held in Tokyo in 1997, and COP21, which took place in Paris in 2015.

Each of these conferences will have a dedicated subsection to follow, along with one focused on the most recent Conferences, in order to discuss the current state of climate change.

1.2.1 COP 3 – the Kyoto Protocol

The third Conference of Parties (COP3), held in Kyoto in December 1997, played a significant role in drafting the first international treaty focused on the reduction and containment of GHGs emissions. The Kyoto Protocol entered into force on 16 February 2005, classifying participant countries into two categories: developed countries and developing countries. By signing the treaty, developed countries agreed to reduce their overall emissions of GHGs by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012 (United Nations Framework Convention on Climate Change, 1997).

Figure 1.1 below presents the specific reduction targets assigned to each country.

Annex I Parties ^a	Emission limitation or reduction (expressed in relation to total GHG emissions in the base year or period inscribed in Annex B to the Kyoto Protocol) ^b
Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland	-8 %
United States of America ^c	-7 %
Canada, Hungary, Japan, Poland	-6 %
Croatia	-5 %
New Zealand, Russian Federation, Ukraine	0
Norway	+1 %
Australia	+8 %
Iceland	+10 %

Figure 1. Emission limitation and reduction for Annex I countries (United Nations Framework Convention on Climate Change, 2008).

Each Annex I Party's initial assigned amount is expressed in individual units, named assigned amount units (AAUs), each of which represents an allowance to emit one metric

tonne of carbon dioxide equivalent (tCO₂e) (United Nations Framework Convention on Climate Change, 2008). The Kyoto Protocol authorizes Parties to modify their initial amount, by adding or subtracting AAU, resulting from participation in the Kyoto mechanisms. Parties can also change their level of allowed emissions through Land Use, Land-Use Change and Forestry (LULUCF) activities, which consist of forest land, cropland and grazing land management.

The Kyoto mechanisms are innovative solutions that allow Annex I Parties to exchange AAU, also known as Kyoto units, by: Emissions Trading, Joint Implementation (JI) and Clean Development Mechanism (CDM).

Under Emissions Trading an Annex I Party may acquire or cede Kyoto units with another Annex I Party. This does not change the total number of units assigned to Annex I Parties; it redistributes them among the Parties. Each Party is allowed to obtain an unlimited number of units, with a limitation in transferring units to other Parties: a minimum level, called the Commitment Period Reserve (CPR), must be held in the national registry.

Joint Implementation is a mechanism that allows an Annex Party to reduce emissions by investing in projects carried out in another Annex I Country. Each project corresponds to a specific number of emission reduction unit (ERU), which is the conversion from existing AAUs. ERUs may be assigned by two possible verification processes: JI Track 1 and JI Track 2. JI Track 1 is the assessment made by a host Party that meets the eligibility requirements, whereas JI Track 2 is the assessment made by an accredited independent body.

While the first two mechanisms only redistribute Kyoto units, CDM is project-based mechanism and generates new credits, called Certified Emission Reductions (CERs), from projects in non-Annex I Parties. Therefore, by this mechanism the collective assigned amount for Annex I Parties and the individual amount for the Party acquiring these new units, are increased. This mechanism addresses particular importance to reforestation and afforestation projects. CERs may be temporary and long term.

In addition, the Protocol identifies several fields of application for emission reduction such as energy efficiency improvement, renewable sources usage increase, CO₂ sequestration techniques and promoting sustainable agriculture. A special committee was established as a vigilant body to ensure compliance with the objectives.

1.2.2 COP 21 – the Paris Agreement

The other important Conference of Parties that resulted in the draft of a treaty is COP 21, held in Paris (2015). The treaty, known as the Paris Agreement, entered into force on 4 November 2016 and represents the most comprehensive and ambitious international treaty on climate change, thanks to the direct participation of 195 countries. Based on the principle of common but differentiated responsibilities and respective capabilities, the Paris Agreement aims to reach three main goals:

- 1) To keep the global average temperature increase “well below 2°C above pre-industrial levels”, with the limit of being below 1.5 °C (United Nations Framework Convention on Climate Change, 2015).
- 2) To increase the ability to adapt to the negative effects of climate change, while supporting climate resilience and low-emission development, without compromising food production.
- 3) To align economies with low-GHG-emission and climate-resilient development (United Nations Framework Convention on Climate Change, 2015).

These three objectives should be viewed in the context of achieving carbon neutrality by the second half of the century. Under this treaty, developed country Parties still are the leaders, but all countries must contribute to meeting the targets. The treaty sets a common baseline, to which self-determined national contributions are added. These contributions must be updated every five years, showing progression over time, when compared to the previous targets.

Parties, both singularly and collectively, are required to report their emissions and progress in encountering the declared targets. The common assessment is known as the Global Stocktake and its first draft was completed during COP28 (Dubai, 2023).

1.2.3 Recent COP Outcomes and the current climate situation

This subchapter provides an overview of the current situation by summarizing the key outcomes of the latest Conferences of Parties (COPs) and introducing data from the IPCC Sixth Assessment Report.

At COP26 in Glasgow (2021), Parties discussed about a gradual separation from fossil fuel subsidies, particularly coal. In addition, Parties discussed over the institution of a fund for damages and losses due to climate change, which became a reality the next year,

during COP27, held in Sharm El-Sheik. During COP28 (Dubai, 2023) the first Global Stocktake was released, while the latest COP (Baku, 2024) reviewed several financial aspects for carbon trading market and set the target of at least USD 1.3 trillion per year to be invested for climate action by 2035 (United Nations Framework Convention on Climate Change, 2024).

Despite these developments in international negotiations, scientific assessments indicate that current efforts remain largely insufficient to meet global climate objectives. According to IPCC Sixth Assessment Report, between 2011 and 2020, the average global surface temperature increase is 1.09 °C, with a higher rise in urban areas (1.59 °C), compared to the oceans (0.88 °C).

The image below (Figure 2) displays different GHGs emissions scenarios for different situations:

- 1) current implemented policies and mitigation strategies (red band)
- 2) if the limit of 1.5 °C is respected (blue band)
- 3) if the limit of 2 °C is respected (green band)

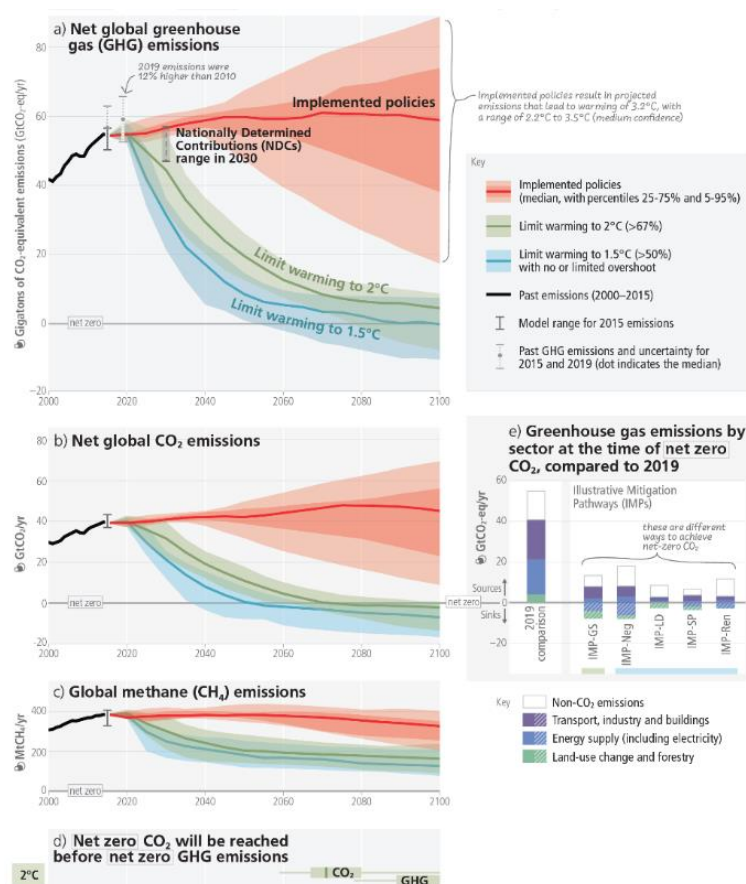


Figure 2. GHG, net CO₂ and CH₄ emission scenarios (Intergovernmental Panel on Climate Change, 2023)

Panels (a, b, c) in Figure 2 show that global GHGs emissions pathways that limit warming to 1.5°C (blue band) with no or limited overshoot, and those that limit warming to 2°C (green band), require rapid, deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors to reach the net-zero targets. Considering the actual rate of reduction (red band), the forecast highlights a global average temperature increase in the range between 2.2 and 3.5 °C (Intergovernmental Panel on Climate Change, 2023).

When compared to graph a, the graphs for net CO₂ and CH₄ emissions (b and c) show similar trends, differing only in the timeframe for reaching net-zero emissions (between 2080 and 2100 for net GHG emissions, between 2040 and 2060 for net CO₂ and CH₄ emissions). Net zero-emissions year possible scenarios are also framed in panel d: particularly, considering limit warming to 1.5 °C and 2 °C, net-zero CO₂ occurs several decades earlier than net-zero GHGs. Panel (e) shows the sectoral contributions of CO₂ and non-CO₂ emissions sources and sinks at the time when net-zero CO₂ emissions are reached, under different ways:

- carbon removal (IMP-Neg)
- with high resource efficiency (IMP-LD)
- sustainable development focus (IMP-SP)
- renewable energy focus (IMP-Ren).

Across these solutions, even in net-zero CO₂ emissions, the common factor is the difficulty of total abatement of other GHGs, like methane and nitrous oxide, deriving from crucial sectors: transport, industry and building (purple band) and energy supply (light blue band).

The IPCC Report also outlines that approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change.

Increasing weather and climate extreme events, like floods, droughts and storms, have exposed millions of people to acute food and water insecurity, with the largest adverse impacts observed in Africa, Asia, Central and South America. Between 2010 and 2020, human mortality in these regions was 15 times higher, compared to regions with very low vulnerability (Intergovernmental Panel on Climate Change, 2023).

1.3 The European Green Deal

The EU's response to Paris Agreement concretized in the European Green Deal, presented by the European Commission on 11 December 2019. This policy initiative represents a set of actions that aims to modernise the EU economy and strengthen its competitiveness with the other global economic powers, adhering to the principles of a sustainable, resilient and carbon-neutral development. Carbon neutrality is the key point of the plan, with the EU aiming to reach it by 2050, passing through an intermediate step of at least 55% reduction by 2030 (considering 1990 levels), as stated by the European Climate Law (European Union, 2021). This intermediate step includes a specific set of regulations, known as Fit for 55, which defines the objectives to be achieved.

The European Green Deal is based on several pillars, covering the most important aspects of the EU economy. The main ones include:

- 1) Circular Economy Action Plan (CEAP). This is a set of measures, including packaging, waste and eco-design regulations with the aim of reducing resource use, waste, and environmental impact across the product lifecycle.
- 2) Energy transition. The goal is to decarbonize energy production and consumption. Directives in this sector are oriented towards improving efficiency, increasing production from renewable sources (at least 40%, including hydrogen and offshore wind), and modernization of infrastructures, for creating a more integrated system (European Environment Agency, 2023).
- 3) Zero Pollution Action Plan (ZPAP). This plan describes concrete targets for different environmental domains: soil (reduce nutrient and pesticide losses by 50%), water (reduce the presence of plastic and microplastics in the oceans), air (reduce the number of premature deaths caused by air pollution by 55%), noise and waste (reduce of 50% of municipal waste) (European Commission, s.d.).
- 4) Sustainable and smart mobility. This pillar enhances the importance of shifting freight transport, which is currently carried by road, towards rail and inland waterways. It also promotes the digitalization of traffic management systems, along with new sustainable mobility services (including new fuels), to reduce congestion and pollution, especially in urban areas (European Commission, 2019).
- 5) Preserving and restoring ecosystems and biodiversity. The EU is committed to preventing biodiversity from a drastic decline, which is ongoing due to natural

resources, land and sea overexploitation. Measures include expanding protected areas and restoring damaged ecosystems, with a focus on those most stressed by climate change, like forests and oceans.

To ensure the achievement of climate targets and to sustain financially the Green Deal, the European Commission drafted the Sustainable Europe Investment Plan (SEIP) (European Parliament, s.d.). This plan promises to mobilize at least €1 trillion over the next ten years towards sustainable development, focusing on climate and environment, to incentivize the green and carbon-neutral economic transition. The plan is based on three aspects:

- from the economic point of view, it will allocate a significant share (€1,000 billion) to environment and climate, using incentives to attract private funding, prioritizing the most affected regions.
- developing a regulatory framework, which will include the EU taxonomy, to guarantee the necessary tools to public and private investors, to properly identify sustainable investments.
- providing support and creating connections between public administrations and private project promoters.

This overview is necessary to introduce the next subchapter, which will focus on the Corporate Sustainable Reporting Directive (CSRD) and the EU Taxonomy, within which GHGs inventory activity is included.

1.3.1 The EU Taxonomy and Corporate Sustainable Reporting Directive (CSRD)

As previously stated, the EU, with the release of the Green Deal and the Sustainable Europe Investment Plan, took a significant step towards sustainable development. Two relevant initiatives arisen from this commitment and designed for assessing companies' environmental impact, are the Corporate Sustainability Reporting Directive (CSRD) and the EU Taxonomy for sustainable activities.

The EU Taxonomy (European Union, 2020) is a framework establishing a common classification system for environmentally sustainable economic activities, and entered into force on 12 July 2020, with the publication of the Taxonomy Regulation (EU) 2020/852. The document declares six environmental objectives:

- 1) Climate change mitigation
- 2) Climate change adaptation
- 3) Sustainable use and protection of water and marine resources
- 4) Transition to a circular economy
- 5) Pollution prevention and control
- 6) Protection and restoration of biodiversity and ecosystems

For an economic activity to be listed in the EU Taxonomy, it must make a substantial contribution to at least one of these six objectives and must not harm none of them. Moreover, it must respect other two conditions: compliance with minimum safeguards and alignment with the specific technical screening criteria set by the EU for that activity. The Taxonomy Regulation does not force companies to convert their activities into the standard, but it provides a common reference framework for comparing activities with the best practices in the sector. In addition, starting from the Taxonomy Regulation, the EU introduced laws for large companies to report a new form of accounting, not related to their financial performance, but to their environmental performance and commitment. This is the case of the CSRD.

The CSRD (European Union, 2022) is a revision of the 2014 Non-Financial Reporting Directive (NFRD), which required certain large public-interest companies to report on environmental, social, and governance (ESG) aspects. It entered into force in January 2023, and its first version was expected to involve nearly 50,000 companies in the EU. Companies meeting at least two of the following characteristics, which are now under discussion in the ‘Omnibus’ package, must comply with the law:

- €40 million in turnover
- €20 million in assets
- 250 employees

The Directive initially established a four-step timeline that defined when the different categories of companies would be required to comply, with the first stage referring to those companies already subject to the NFRD (companies with more than 500 employees). However, the so-called Omnibus package, with the ‘Stop the Clock Directive’ (EU Directive) 2025/794), postponed the entry into force by two years (from 2024 to 2026) for in categories 2 and 3 (large companies not included in NFRD and small-

medium enterprises). The fourth stage is for non-EU companies with more than €150 million turnover within the EU.

The CSRD requires companies to include several mandatory elements in their reports, which embrace a broad range of ESG topics (e.g., greenhouse gas emissions, energy use, workforce diversity, human rights, and impacts on local community). The reports must be prepared using the European Sustainability Reporting Standards (ESRS, with the first set released in July 2023) and following the principle of “double materiality”, which is the analysis of how sustainability issues affect the company’s financial position and performance, and how the company’s activities impact people and the environment. Moreover, sustainability reports must be included in the companies’ annual management reports, published digitally and subjected to mandatory verification.

1.4 Automotive industry context

This final subchapter serves to provide the context in which the company used as case study operates: an important part of its revenues comes from the automotive sector, thanks to its commercial relationships with car and trucks manufacturers. The automotive industry, especially the passenger car segment, is a crucial sector of EU economy, providing 13.8 million jobs and contributing 7% of the EU’s GDP (Gross Domestic Product) (European Commission, s.d.) (European Parliamentary Research Service, 2024). It directly involves 255 manufacturing plants for assembling vehicles, which contributed to put in the market in 2023 14.8 million vehicles (12.2 million passenger cars). In addition, this sector leads the economies of several countries, like Romania, Sweden, and Germany, as well as cities like Turin. More importantly, the automotive sector consists of a complex network of cross-border supply chains, including specialised small and medium-sized enterprises (SMEs) engaged in different manufacturing activities, like basic metals and rubber and plastics products, whose gross value added depends on the automotive sector by more than 10% (OECD, s.d.).

Nowadays, this sector is facing a crisis, as testified by a reduction of 18.3% of registered cars between August 2023 and August 2024. This situation is linkable to two interdependent factors: the Green Deal emissions reduction targets, specifically the ‘Fit for 55’ package, and the growth of non-EU competitors, especially China. Since transport has a significant impact on GHGs emissions, the initial version of ‘Fit for 55’ required a 55% reduction in average CO₂ emissions for new cars by 2030 (50% for vans) relative to

2021 levels, and a 100% CO₂ reduction for all new cars and vans from 2035, except for cars powered by e-fuels. The reduction also affects heavy vehicles, like trucks and buses: for example, in urban areas, all new buses should be zero-emission by 2030, and new heavy trucks must cut emissions by 90% by 2040. These targets are meant to be achieved primarily through electrification. However, this transition requires the modernization of infrastructures and industries, in terms of technologies, equipment and reorganization of production lines. To meet these requirements, manufacturers, historically based on internal combustion engine (ICE) vehicles, have lost ground to their competitors, especially Chinese manufacturers, which, have long invested in electric vehicles. Thanks to the availability of the necessary resources, these companies have been able to seize these market opportunities to enter the European market, as testified by the following graph shown in Figure 3 (European Automobile Manufacturers' Association (ACEA), 2024).

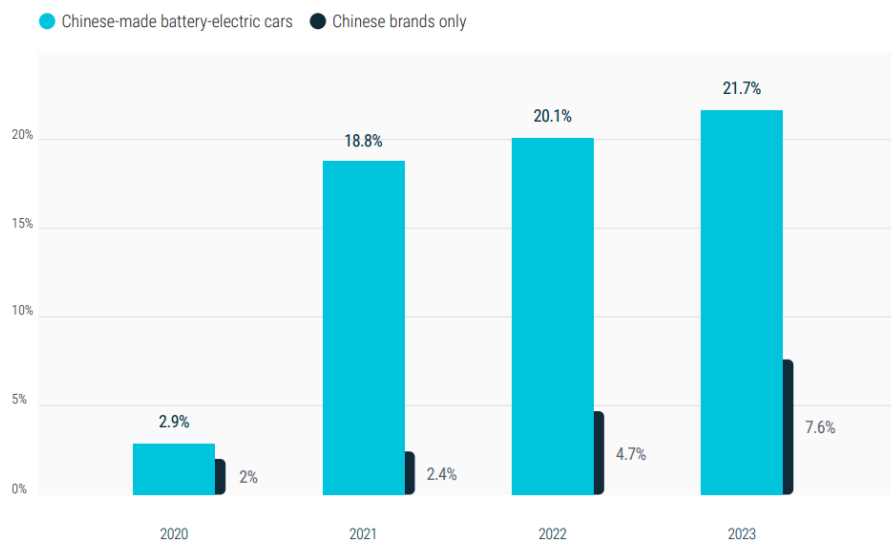


Figure 3. Market share of Chinese-made cars in EU electric car sales (European Automobile Manufacturers' Association (ACEA), 2024).

The graph displays the number of electric cars produced in China, for both EU and Chinese brands, sold in the EU. They are both facing a steep increase, with the Chinese brand cars passing from 0% in 2020, to almost 8% in 2023 and the Chinese-made cars passing from 2.9% to 21.7% in the same period.

In conclusion, the Green Deal not only reshaped the regulatory environment of the automotive sector but also redefined its competitive landscape, creating both urgent challenges and long-term opportunities for companies operating within it.

2. Protocols

2.1 The Greenhouse Gas Protocol

The Greenhouse Gas Protocol (GHG Protocol), A Corporate Accounting and Reporting Standard (World Resources Institute, & World Business Council for Sustainable Development, 2004), is a document developed for companies to provide reporting standard for GHG emissions. It was created by the Greenhouse Gas Protocol Initiative, established in 1998, under the control of World Resources Institute (WRI)—an environmental NGO based in the United States—and the World Business Council for Sustainable Development (WBCSD), an international coalition of 170 companies. The Initiative actively involved both public and private stakeholders, such as non-governmental organizations, governments and companies.

This joint-venture resulted into, as anticipated, GHG Protocol Corporate Accounting and Reporting Standard, which is analysed throughout this chapter. First released in September 2001 and extended in 2004, the document still represents the most widely used international standard for GHG emission quantification and reporting. It shows a rigorous approach throughout the entire process of collecting and processing, enabling companies and organizations to evaluate the environmental impact of their activities in terms of GHGs release in the atmosphere.

Companies and organizations may approach the GHG inventory to achieve different objectives, such as public reporting, participation in GHG reporting programs and managing climate-related risks. To achieve these goals, several important principles, set by GHG Protocol, must be shared, which are:

- Relevance, to ensure that the data and results shown in the report objectively reflect the company's situation.
- Completeness, to guarantee that the reporting activity considers all contributions from GHG releases emitted within the defined organization boundaries.
- Consistency, to ensure a uniform and coherent methodology, so that the results obtained over time can be compared both among the same organization and with others.
- Transparency, so that everything related to the report (methodology, assumptions, operational boundaries, etc) is based on appropriate references and sources.

- Accuracy, to ensure the credibility of the report, by minimizing uncertainties and avoiding over- or underestimation of emissions.

Having introduced the topic briefly, it is now possible to move on with the explanation of reporting activity.

Chapter 3 and 4 of the Protocol define the first step for the inventory, which is defining the boundaries of the system under analysis. They represent the maximum limits to be considered when addressing GHG emissions and they may be different from the physical boundaries of the plant.

When these boundaries exceed the physical perimeter of the plant, emissions sources considered are not only related to company's direct activities, like production processes, heating or electricity consumption, but they are also associated with indirect operations, such as the production of incoming raw materials, the transportation of goods and products, employee commuting and the disposal of waste.

It is important to note that the more complete and comprehensive report a company wants its report to be, the more difficult it will be to collect information with high precision and reliability, especially because it very often requires collaboration with other companies which are not always interested in sharing this kind of information. Knowing that, the GHG Protocol shows flexibility, and requires that, assumptions and exclusions made due to lack of information are clearly stated, in accordance with the transparency principle.

The GHG reporting activity and the choice of boundaries extension depend both on the organization's purposes, and on external factors. For instance, a company can voluntarily start this kind of activity to achieve environmental certifications, or as mentioned in the previous chapter, like it happened when New Green Deal and CSRD law were published, laws can force companies with a certain size to gather and report these data. Eventually, estimating GHG emissions performance can be necessary even for staying competitive in the market, both among companies of the same sector when applying for businesses with large companies, and to build a positive image to customers' eyes.

The GHG Protocol identifies two types of boundaries: organizational boundaries and operational boundaries. Organizational boundaries define the perimeter of the organization under analysis and include all emission-generating activities for which the organization is directly responsible. These boundaries can be defined according to two possible approaches, which bring to the same result:

- The Equity Share Approach considers the company responsible for emissions in proportion to its share of equity in a given activity.
- The Control Approach considers 100% of the emissions from activities over which the company exercises control, which may be either financial, for the activities which directly bring economic benefits for the organization; or operational, where the company oversees the management of emission-generating activities.

As before, the decision between the two approaches to choose is not universal and driven by the objectives the company wants to aim. What matters is that, once the method is chosen, it is applied consistently throughout the report.

Operational boundaries extend beyond the organizational boundaries and include activities that are not directly controlled by the company but are connected to its operations. Defining these boundaries is a crucial step, as it determines which emission sources will be faced in the report.

The combination of organizational and operational boundaries defines the perimeter of the emissions inventory.

After the definition of operational and organizational boundaries, the next step in the inventory reporting procedure consists of dividing emissions into two categories: direct and indirect.

Direct emissions are those released from sources owned or controlled by the company, whereas indirect emissions are those resulting from the company's activities but released by sources not owned or controlled by the organization.

Furthermore, emissions can be classified into three Scopes, which are macro-categories designed to help organize data, calculate emissions, and present results in a clear and consistent manner.

Scope 1 includes all direct emissions, whose sources vary widely depending on the company's operations. For instance, they can be generated during specific production processes, from heating systems, or by company-owned transport vehicles.

Scope 2 is the category which includes indirect emissions from the generation of purchased electricity or other forms of energy (e.g., steam, heating, cooling or compressed air). Reporting them separately facilitates the evaluation of potential cost and benefit

trade-offs related to reducing energy consumption—both from an environmental perspective (GHG emissions reduction) and an economic one (e.g., investments in energy efficiency or switching to renewable energy sources).

Scope 3 is optional and represents the most difficult Scope for collecting data, as it includes all other indirect emissions, not already covered in Scope 2.

This category embraces a wide range of possible sources, like upstream and downstream freight distribution, business travel, purchased goods and services, product use, waste disposal. Scope 3 also includes emissions from outsourced activities, as well as secondary aspects of energy generation, such as emissions from fuel extraction or transportation, and losses during transmission and distribution.

The following figure summarizes the three Scopes.

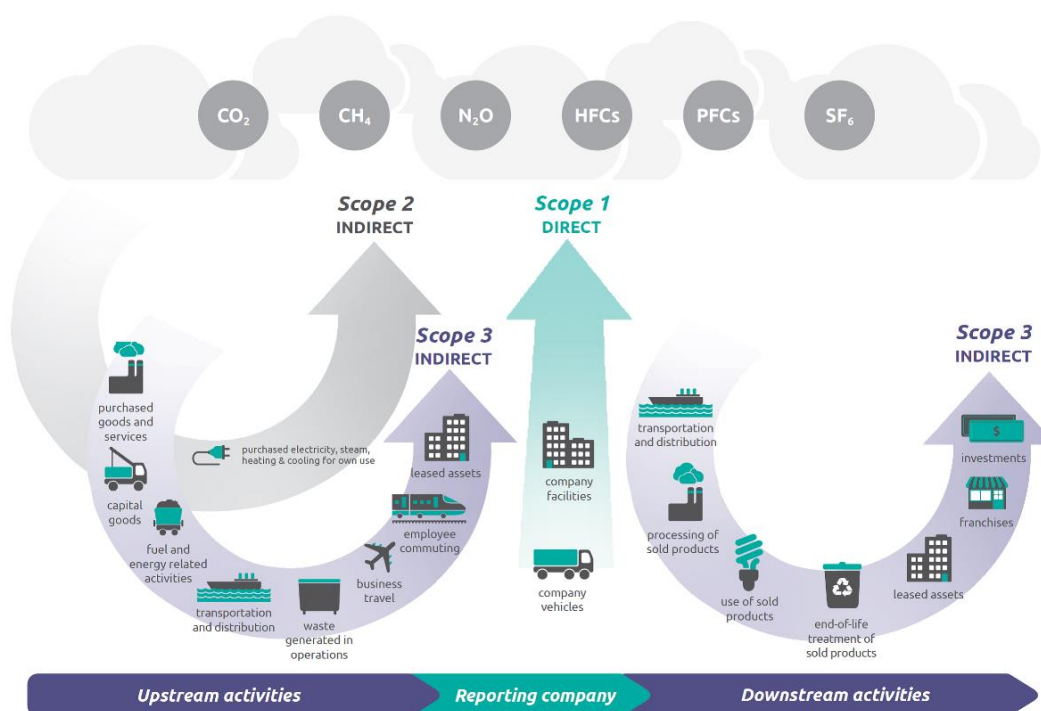


Figure 4. Scope 1, 2, 3 according to GHG Protocol (U.S. Environmental Protection Agency, 2023).

Having categorized the emissions according to the three Scopes, the next step involves choosing which sources should be included in the report.

For the first year of reporting, it is suggested to start data collection for all categories and only afterward identify the most relevant contributors and run a more in-depth analysis. The most important contributors can be selected considering their weight percentage

relative to the total emissions, but also considering their emission reduction potential, and the public perception of their severity.

GHG reporting must not be treated as a one-time exercise and the analysis should be repeated annually to assess whether the emission reduction progress meets the targets, when compared with the base year used as reference. This exercise is also useful to provide an up-to-date overview of the organization's environmental impact and sustainability performance, which is fundamental to maintain competitiveness in the market.

The base year selected, as suggested by the Protocol in chapter 5, must be representative of the structure and operations of the organization and its emissions data must be reliable. It can refer to a single calendar year or multi-average, and its emissions must be recalculated in the case of:

- significant structural changes in the organization, like mergers or outsourcing
- change or improvement in the calculation methodology
- when significant errors are discovered.

Once the general rules for GHG reporting have been presented, the GHG Protocol provides guidance on how emissions should be practically calculated.

Emissions must first be divided into categories, as each one requires specific methodologies to convert available data into quantities of carbon dioxide equivalent (CO₂e). Each category corresponds to a particular type of emission source.

The emissions calculation process consists of five steps:

- 1) identify the emission sources
- 2) choose a calculation approach
- 3) collect data and select an appropriate emission factor
- 4) calculate the emissions for each source and category
- 5) calculate data at the corporate level.

Starting with Scope 1, direct emission sources depend on the type of activity carried out by the company. However, they can generally be grouped into four categories:

- stationary combustion, such as from boilers, engines, burners, incinerators
- mobile combustion, such as from cars, trucks, buses, airplanes, ships
- process emissions, released from physical or chemical industrial processes

- fugitive emissions, meaning intentional or unintentional releases into the atmosphere due to leaks (e.g., air conditioning units) or uncontrolled sources (e.g., cooling towers, wastewater treatment systems, landfills, or safety valves). This category also includes methane emissions from coal mines.

Once Scope 1 has been completed, the next step is to assess indirect sources emissions (Scope 2 and 3).

These can derive from the generation of purchased energy, such as electricity or heat (Scope 2), or from indirect upstream and downstream activities within company's value chain (Scope 3). Scope 3 emissions are optional, but they can provide relevant information of company's emissions outside its physical boundaries.

After defining the sources of direct and indirect emissions, the next step is to choose a calculation approach. This can be based on direct measurements, mostly for Scope 1 sources, but they are very often expensive and impractical. For this reason, there are two main alternative methods: Mass balance or stoichiometric calculations, and calculation using emission factors.

The choice between the two methods depends on the type of emissions source and the availability of data, and if both are feasible, the most accurate one should be preferred. Mass balance methods may be more suitable for specific activities (e.g. chemical processes or fuel combustion), while emission factor methods are more appropriate when only general data are available, which is the most common situation. In the case of calculation approach based on emission factors, the selection of the most appropriate one is necessary to determine the reliability of results.

After the definition of the calculation approach, the third step is to collect data for each emission source. This can be done by cooperating with different departments/offices inside and outside the company, or by using reasonable assumptions and approximations.

Following data collection phase, the final step is the calculation of emissions, which can be performed in a spreadsheet or with calculation tools provided by the Greenhouse Gas Protocol. Firstly, the calculation is run for each individual GHG, then results are converted into CO₂ equivalents, by multiplying the collected values by their Global Warming Potential (GWP) value. By summing all emissions converted into CO₂e, the total CO₂ equivalent emissions can be obtained.

In the case of companies with multiple sites or facilities, emissions can be calculated either centrally, with all data collected and processed at the corporate level, or decentrally, where data is processed at each site and only the final emissions figures are communicated to the person or team responsible for compiling the organization's overall emissions inventory. Throughout the entire process, it is fundamental to guarantee the quality standards specified by the GHG Protocol in Chapter 7, in order to meet the required level of accuracy and credibility for the results achieved.

Eventually, when the data and results are defined, a report must be compiled, to describe the approach and all the assumptions made and to summarize what has been obtained, as described in chapter 9 of the Protocol. The structure must reflect the steps followed during the reporting process. The report begins with the organizational and operational boundaries, specifying the approach used to set them, and the reporting period on which the analysis is based. Secondly, the report presents emissions for Scope 1 and Scope 2 separately, categorized by type of greenhouse gas, and expressed both in tonnes and in tonnes of CO₂e. Moreover, the report must also specify the base year chosen for reference and the methodology used to calculate or measure the emissions, with specific explanations for those sources which were excluded.

In addition to these mandatory elements the report may include other voluntary disclosures (e.g. emissions covered under Scope 3 and of greenhouse gases not listed in the Kyoto Protocol, a results analysis and the definition of reduction targets).

2.2 ISO14064-1:2018

After the publication of the GHG Protocol, many others organization decided to draft their own document for GHG emissions inventory activity.

In 2006, the International Organization for Standardization (ISO) introduced the first version of its own standard for the assessment and reporting of GHG emissions. This standard, titled *UNI EN ISO 14064-1 – Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals*, was approved at the European level on September 8, 2018, and a year later, was integrated into the Italian national regulatory framework on April 11, 2019.

The ISO 14064-1:2018 (British Standards Institution, 2019) is included in the ISO 14060 family, which provides guidance for estimating, monitoring, reporting and validating GHG emissions and removals, both for specific processes and organizations. ISO 14064-1 and the GHG Protocol share the same principles (relevance, completeness, consistency, accuracy, and transparency) and structure, differing in terminology and classification.

Like GHG Protocol, The ISO standard, initially defines the concepts of organizational boundaries and reporting boundaries (named ‘operational’ in the GHG Protocol). Organizational boundaries can be determined using either the control approach or the equity share approach, as defined in the GHG Protocol subchapter.

Reporting boundaries and operational boundaries are different in terms of the definition of macro-categories: while the GHG Protocol divides them in Scope 1, Scope 2 and Scope 3, the ISO standard simply distinguishes direct and indirect emissions.

The first distinction between direct and indirect emissions, described in detail in Annex B of the ISO document, is the organization’s control and ownership of the emissions sources.

Direct GHG emissions derive from sources owned or controlled by the organization and located within its organizational boundaries. As described in the GHG protocol, they may originate from:

- stationary fuel combustion, such as in boilers or gas turbines
- mobile fuel combustion like company-owned vehicles
- industrial activities and processes
- fugitive emissions, such as leaks in refrigerant systems or emissions from waste fermentation.
- land use, land-use change, and forestry (LULUCF)

On the other hand, indirect emissions, derive from sources not owned or directly controlled by the organization and are divided as:

- indirect emissions from imported energy, such as electricity, steam, or compressed air, produced from fossil fuels
- indirect emissions from transportation of goods (upstream and downstream distribution) and people (employee commuting, customers and visitors and business travel). In this category, depending on the approach chosen, attention should be paid to avoid double counting

- indirect GHG emissions from products and services used by the organization, including raw material extraction and fuel production not covered in energy purchases. The ISO standard particularly emphasize the explanation for capital goods, which are goods used and purchased by the organization, with an extended lifetime. Two methods can be followed to estimate these emissions: reporting them entirely in the year of acquisition or amortizing them over the useful life of the asset, similarly to the financial depreciation. Services purchased by the organization, such as waste treatment, outsourced maintenance, or consultancy, fall in this category.
- indirect emissions from the use of products from the organization. This category often presents significant uncertainty due to the variability of product usage and their field of application. Emissions from leased goods and activities owned or by the organization, as in the GHG Protocol, during the reporting period fall under this category.
- indirect emissions from other sources

Unlike the GHG Protocol, The ISO standard suggests separating data by facility for a better understanding. It also introduces three groups of emissions for each category: biogenic (carbon derived from biomass), anthropogenic biogenic (carbon derived by anthropogenic activities), or non-anthropogenic biogenic (carbon from natural phenomena), according to their definition in section 3 of the document.

After defining the types of emissions, Section 6 the ISO standard explain the process of obtaining data and estimating emissions for the reporting boundaries. There are two main methodological approaches: direct measurements and quantification models. A quantification model converts data from a physical process into emissions or removals expressed in CO₂ equivalents. For this purpose, ISO requires the use of 100-year Global Warming Potential (GWP) values provided by the Intergovernmental Panel on Climate Change (IPCC). Other inputs, such as emission factors, usually expressed as tCO₂e/quantity of activity data, or monetary values (amounts spent on certain products, services or materials) are allowed, as stated in Annex C.

The organization, considering the type of emission source, data availability, the level of accuracy and the purpose of the inventory activity, should select a method, which must be used throughout the entire inventory. When explaining the chosen method, it is

necessary to document any assumptions made, limitations, data sources and calculation formulas.

Collected data must be clearly divide as primary or secondary and as site-specific or general, depending on the origin of the source. Emissions must be quantified on an annual basis, and the organization is encouraged to establish a base year to serve as a reference point for tracking trends over time. This base year can be a specific year, an average of multiple years, or the year of the first inventory if historical data are unavailable. Regardless, the base year must be representative of actual organization's emissions. Recalculations, as explained also in the GHG Protocol, are required whenever there are significant changes in organizational or reporting boundaries, calculation methodologies, or significant errors.

Section 7 and 8 also suggest actions for GHG emissions reduction and how to ensure a certain level of quality, like GHG Protocol.

Finally, Section 9 provides detailed guidance on reporting. Differently from the GHG Protocol, the ISO standard include in the mandatory elements of the report a clear statement explaining:

- the report's purpose and how it aligns with the company's overall emissions strategy
- an explanation of the intended audience and use of the report
- the identification of those responsible for the quantification and reporting process.

The report must reflect the structure of the inventory, including descriptions of the company, its goals, the defined organizational and reporting boundaries, the methods and results, and any emissions reduction initiatives and performance monitoring activities.

3. Case study: introduction

The historical-political framework outlined in the first chapter, in addition to the regulatory context developed in the second chapter—focused on the theoretical explanation of the protocols—has proven useful in defining the context in which the case study was analysed and used as a practical example for greenhouse gas reporting. The case study presented in this thesis is related to the SFC Solutions group operating in the automotive sector in Europe and Morocco, with the pilot project focused on SFC Solutions Italy, located in Ciriè (Turin). Later, methodology has been applied to the other five manufacturing locations. In addition to SFC Solutions Italy, this thesis shows results for SFC Solutions Spain and SFC Solutions Romania.

After a brief organizational introduction to the group to which it belongs, the discussion continues with an overview of its production processes and the sustainability practices in which the company is involved.

3.1 SFC Solutions Group: the companies and the industrial processes

SFC Solutions Italy Srl is a part of the SFC Solutions group, owned by the international private equity investor Mutares and included in the Amaneos group, a family of companies operating in the automotive sector and the industrial & specialty vehicle market. The Amaneos group offers several categories of products and services, including interior and exterior vehicle systems, high-performance plastic components, and rubber compounds and sealing systems, which is the SFC Solutions' area of expertise. Particularly:

- high-performing Fluid Transfer Systems (FTS) solutions are produced in Morocco, Poland, Romania and Spain.
- Sealing business is carried out by the plants in France, Italy, Morocco and Romania.
- Compounds are produced in France and Italy.

Focusing on Ciriè facility, it expands over an area of 33.500 m² and in 2024 employed more than 300 people. It serves 270 customers, delivering more than 2000 items for different sectors, like automotive, trucks, and commercial vehicles.

The plant is equipped with two mixing lines and nine extrusion lines, several finishing stations, a laboratory, an engineering tooling shop and a quality control office.

The two mixing lines have a maximum capacity of 36 tonnes per day over three shifts and are able to produce more than 180 compound recipes. One of the two implements on-line straining, a filtering process performed during the mixing process. 90% of compound recipes include EPDM (Ethylene Propylene Diene Monomer) and the remaining 10% consists of other polymers, fillers and additives, such as SBR (Styrene Butadiene Rubber), NBR (Nitrile Butadiene Rubber), NR (Natural rubber).

After the mixing stage in the mixing room, rubber compounds are filtered to remove impurities and then moved to the batch off stage, divided in:

- 1) Anti-tack section, where the rubber is coated with an anti-tack agent (usually a water-based solution) to prevent the rubber sheets from sticking to each other when stored.
- 2) Drying section, where rubber moves through fans and ventilators to reduce water content and cool down.
- 3) 'Flic-flac' section, where rubber is folded and then packed in plastic boxes.

Later, the rubber compounds are ready to be sent to one of the extrusion lines to obtain one of the profile available in the SFC catalogue. In the extrusion line, along with the metal carrier and the unextendible wire, compounds pass through the die, to define the specific shape of the extruded profile. Later, that, the profile enters the vulcanisation stage. This process serves to cross-link the polymer chains of the rubber and can be carried out in three different ways: with hot air, microwaves, or salt bath. The final phase of the production process consists of the finishing process, in which extruded profiles are cut and treated with anti-corrosion, coatings or other products.

The internal laboratory and the engineering tooling shop guarantee research and development on new dies and compounds in line with the client's needs, while the quality control office checks if the products can be released in the market.

3.2 SFC Solutions Group: carbon neutrality and circular economy

With the commitment to achieve carbon neutrality by 2050, SFC Solutions has started its path for fighting climate change and becoming more sustainable, with several practices that help to reduce the environmental impact of its products and processes. Particularly, these projects focus on finding new ingredients to substitute the traditional ones and introducing circularity in the facility.

Three examples are reported below:

- AGR DEVULPRENE, is a recycled rubber material made from in-house production scraps. These rubber waste materials, collected from the plant's own processes, undergo devulcanization — a process that breaks the sulphur cross-links created during vulcanization. This transforms vulcanized rubber back into a processable, softer form, which is then converted into granules or masterbatch for reuse. This recycled material can be reused in new compounds in a proportion of 5–40% by weight. This example helps reduce waste and improve material circularity.
- UPM 4000 RFF, is a renewable functional filler made from hardwood. It can replace the traditional fossil-derived carbon black 30% by weight in the compound.
- CARBIO is a bio-based alternative to traditional calcium carbonate, developed using waste eggshells. It is part of a circular economy initiative led by the company Circul'egg, which recycles eggshells that would otherwise be discarded by the food industry. This innovative material can entirely replace CaCO_3 , which is conventionally mined for rubber compounds use. If implemented, CARBIO can increase the renewable content in rubber by up to 20%, making the compound more sustainable and reducing fossil-based content.

In addition to these circular economy projects, SFC Solutions has already obtained ISO14001 certifications for all facilities (Ciriè, Borja, Czestochowa, Pitesti, Tangier and Charleval).

4. Case study: analysis of categories and methodology

This chapter is focused on the explanation of the methodology used for the inventory. It begins with the definition of the operational and reporting boundaries considered for the case study. Next, an introductory paragraph presents the two main sources used for emission factor data: the UK Government GHG Conversion Factors for Company Reporting and the Climatiq database. Finally, the methodology applied for emissions quantification is outlined. This methodology is structured according to the three Scopes of the GHG Protocol and further subdivided in the categories illustrated in the ISO14064-1 standard. Within each subparagraph, based on data availability, the necessary assumptions made to develop the reporting for each category are explained.

4.1 Operational and organizational boundaries

For the organizational boundaries, the operational/financial control approach was chosen. This approach considers the emissions associated with sources over which each plant has economic control. Therefore, for reporting purposes, all emissions released within the group's boundaries—which currently include a total of three production plants—will fall under direct emissions (Scope 1). Additionally, all emissions resulting from purchased and consumed energy by these facilities will be reported under Scope 2. Regarding the reporting boundaries for indirect emissions (Scope 3), since this is the company's first year of GHG reporting, it has been decided to calculate all the categories in line with the company's sector of activity. The boundaries were extended upstream to include the company's direct suppliers, and downstream they were limited to the point at which the product reaches the customers' facilities. The categories excluded - consistently across all production sites – are:

- direct emissions and removals from industrial process (analysed further in Section 4.3.3)
- direct emissions and removals from land use, land use change and forestry (LULUCF)
- indirect emissions from purchased energy (heating, steam, cooling, compressed air)
- indirect emissions from the use of assets
- indirect emissions from the use stage of the product
- indirect emissions from downstream lease assets

- indirect emissions from end-of-life stage of product
- indirect emissions from investments

While category for direct emissions and removals is analysed in detail in Section 4.3.3, direct emissions from land use, land use change and forestry (LULUCF) were not taken into account as the facility activities are not directly involved with the use of land, forests and CO₂ reservoirs. Moreover, no activities have been carried out that may have impacted the surrounding area.

Indirect emissions from imported energy were not taken into account as SFC Solutions facilities only purchase electricity.

Categories related to the use of assets and leased assets were excluded because the companies of the group are not involved in. Particularly, companies of SFC Solutions Group do not have neither any asset used inside the plant nor do not own any asset which was leased to other companies during the reporting year. The category of emissions from investments were excluded because they usually are related to private or public financial institutions.

The others were excluded mainly due to the difficulty of obtaining reliable and accurate information. These include the categories of product use and end-of-life. The reason is as follows: the plastic and rubber components produced by the company are later integrated into much larger and more complex final products, such as cars or trucks. The emissions associated with the use phase of those vehicles are not only difficult to track and attribute, but also, they are difficult to estimate, as they depend on several variables, such as the country, and the ways and purposes with which the customer chooses to use them. Moreover, considering that the main source of pollution during the use phase of these products is fuel consumption, it can be said that the impact of seals and gaskets on this aspect is virtually negligible.

Similar considerations apply to the end-of-life phase: the components produced by SFC Solutions, when compared to the final products they are part of, are very limited in both weight and volume. Additionally, disposal processes vary greatly between countries, making it difficult to access consistent and sufficient data.

Once the boundaries have been defined, it is now possible to proceed with the analysis of the sources within the three Scopes and the calculation of emissions.

4.2 Emission factors: UK government for company reporting database and Climatiq

The methodology approach chosen to run the GHG inventory activity for this case study is based on emission factors, which represents the most feasible approach for managing a huge amount of data, particularly for indirect emissions (Scope 2 and 3). As explained in Chapter 2, emission factors are numerical values that allow the conversion of real data deriving from company activities, such as kilometres travelled by employees, litres of fuel consumed, or kilowatt-hours of electricity used, into emissions expressed in carbon dioxide equivalents (CO₂e). For this case study, since it was not possible to use any fee-based database, all the emission factors were derived from free access sources, widely recognized and aligned with the requirements of GHG Protocol and ISO14064-1:2018. These sources are Climatiq and UK Government conversion factors for company reporting of greenhouse gas emissions data sheets. Climatiq is a digital tool that offers several premium services for carbon accounting, but it also serves as a collection of datasets from official sources, which can be:

- free-access (e.g., EPA – Environmental Protection Agency (USA), EEA - European Environment Agency (EU) and CAEP - Chinese Academy of Environmental Planning (China) and UK Government conversion factors)
- fee-based (e.g., ecoinvent and EXIOBASE)

To ensure transparency and traceability, Climatiq for each factor also indicates the source, region of applicability, methodological notes, and scope classification (Scope 1, 2, or 3).

The other main source of emission factors, as anticipated, is the UK Government conversion factors for company reporting of greenhouse gas emissions. The file is published annually, and it is developed by BEIS (Department for Business, Energy & Industrial Strategy), in collaboration with DEFRA (Department for Environment, Food & Rural Affairs). It is one of the most respected and cited internationally and is often used as a reference even outside the UK.

The file is divided in multiple Excel sheets, each representing specific category, which are:

- energy and fuel use (e.g., natural gas, diesel, petrol)
- transportation (passenger and delivery vehicles, freighting goods)
- water supply and treatment

- materials (use and waste disposal)

Each factor is expressed as kg CO₂e per unit of activity, usually representing three GHGs (CO₂, CH₄, and N₂O). Particularly, given that coefficients for CH₄ and N₂O are already provided as CO₂e, by dividing for their own GWP100 (28 for CH₄, 265 for N₂O), the coefficient kgCH₄ per unit of activity and kg N₂O per unit of activity were obtained. To be consistent with the dataset, GWP values considered are from IPCC Fifth Assessment, even if IPCC has already released the Sixth.

4.3 Scope 1

As anticipated in the previous chapters, Scope 1 includes the company's direct emissions from owned or controlled sources, which are divided as follows:

- direct emissions from stationary combustion
- direct emissions from mobile combustion
- direct process emissions and removals from industrial processes
- direct fugitive emissions from the release of GHGs in anthropogenic systems

The following subchapters will explain in detail the assumptions, data and formulas used for calculation of this Scope.

4.3.1 Direct emissions from stationary combustion

Direct emissions from stationary combustion in the case of SFC Solutions facilities are related to the following fuels:

- natural gas and industrial diesel at Ciriè facility
- natural gas at Borja facility
- liquefied petroleum gas (LPG) at Pitesti facility

Natural gas and LPG are employed for machineries operating in the production line, as well as for boilers and other secondary equipment. For both facilities, fuel consumption is collected by monthly-based invoices.

Industrial diesel is used at Ciriè facility to power a forklift truck (the only non-electric one in the company) and the emergency generator that supports the fire protection system. It is stored in a tank, and in 2024 it was purchased a total of 3,500 litres, divided in three times as follows:

- 1,000 litres in March
- 1,000 litres in June
- 1,500 litres in November

According to the two reference documents used for the case study, emissions from the forklift truck should fall under category of mobile combustion emissions. However, no precise data for the quantity of diesel used by the forklift compared to the total purchased were available, for this reason it was assumed that all diesel acquired in 2024 was consumed by the emergency generator. Consequently, the entire quantity is attributed to stationary combustion. The tables below summarize the fuel consumption values for each fuel and the conversion factors used in the emissions calculation.

Table 2. Emission factors used for stationary combustion emission calculations. Source: UK government for company reporting 2025.

	Natural gas (Sm ³)		Diesel (l)	LPG (l)
EF CO ₂ (kgCO ₂ /Sm ³)	2.0627	EF CO ₂ (kgCO ₂ /l)	2.62818	1.55491
EF CH ₄ (kgCH ₄ /Sm ³)	0.0001096	EF CH ₄ (kgCH ₄ /l)	1.0357*10 ⁻⁵	4.85714*10 ⁻⁵
EF N ₂ O (kgN ₂ O/Sm ³)	3.585*10 ⁻⁶	EF N ₂ O (kgN ₂ O/l)	0.0001248	3.2452*10 ⁻⁶

Table 3. Fuel consumption for each SFC Solutions facility

	SFC FACILITIES		
FUEL	ITALY	SPAIN	ROMANIA
Diesel (l)	3,500	-	-
Natural gas (Sm ³)	1,363,135	421,671	-
LPG (l)	-	-	212,690

The following formula was used to obtain the amount of each GHG due to fuel stationary combustion:

$$tGHG_{combustion} = \frac{\sum consumption_{fuel} * EF_{fuel}}{1000}$$

4.3.2 Direct emissions from mobile combustion

This category considers emissions from the mobile combustion sources owned/controlled by the company, which are, for this case study, only company cars. As previously mentioned, since it is not known the exact diesel consumption from the forklift truck, it has been decided to assume that all diesel purchased in 2024 is included in stationary combustion category. SFC Solutions also has several electric forklifts, which fall under category of imported electricity, as their electricity consumption is included in the invoices.

To determine the total fuel consumption for each type of vehicle, all fuel purchase receipts were collected and summed, using data gathered from the fuel provider's online portal. The tables 4 and 5 below summarizes fuel consumption by type and the corresponding conversion factor.

Table 4. Emission factors used for mobile combustion emission calculations. Source: UK Government for company reporting 2025.

Petrol	EF CO₂ (kgCO₂/l)	2.05523	Diesel (average biofuel blend)	EF CO₂ (kgCO₂/l)	2.53763
	EF CH₄ (kgCH₄/l)	0.0002878		EF CH₄ (kgCH₄/l)	1.0357*10 ⁻⁵
	EF N₂O (kgN₂O/l)	2.215*10 ⁻⁵		EF N₂O (kgN₂O/l)	0.0001241

Table 5. Number of company cars and fuel consumption for each SFC Solutions facility.

SFC SOLUTIONS FACILITIES						
ITALY			SPAIN		ROMANIA	
FUEL	CARS	CONSUMPTION (l)	CARS	CONSUMPTION (l)	CARS	CONSUMPTION (l)
Diesel	7	15,788.34	1	2,577	4	4,415.2
Petrol	5	2,337.65	-	-	7	4,959.36

By multiplying fuel consumption by the corresponding conversion factor, as shown by the formula in Section 4.3.1, the total amount of emissions for CO₂, CH₄ and N₂O, related to company cars, was calculated.

4.3.3 Direct process emissions and removals from industrial processes

According to both Greenhouse Gas Protocol and ISO:14064-1 standard, Category 1.3 (or "direct emissions from industrial processes") includes greenhouse gas emissions that arise from chemical or physical processes occurring during manufacturing processes. In the case study considered, no direct CO₂ measurements from industrial processes are available. However, the three facilities are legally required to monitor Total Organic Carbon (TOC), every three years in the case of Ciriè site. TOC is not a direct measure of greenhouse gas emissions, but it may include direct GHG emissions under certain assumptions, like assuming full oxidation of organic carbon to CO₂, only if a documented conversion methodology is implemented. For this case study, neither one of these methodologies, nor emission factor specific to the process under consideration were available, and so TOC values alone were considered not sufficient to quantify direct GHG emissions. Therefore, in this inventory, Category 1.3 is not applicable, due to lack of reliable and suitable conversion factors.

4.3.4 Direct fugitive emissions from the release of GHGs in anthropogenic systems

This category includes the calculation of emissions resulting from leakage and the unintentional release of gases. Particularly, for the purposes of this case study, emissions from fluids used in cooling and air conditioning systems have been included. The data on the quantity released is based on maintenance reports—conducted either semi-annually or annually in accordance with legal requirements—for each machine. These reports indicate the amount of fluid that was refilled, which has been assumed as the quantity that was dispersed into the environment during 2024. The table below shows for each facility and each fluid: the number of machines, the total amount refilled in 2024 (expressed in kg), and the GWP, given by maintenance reports.

Table 6. For each SFC Solutions facility, the refrigerant fluids, their reload in the equipment, expressed in kilograms, and the GWP provided by the maintenance reports.

SFC SOLUTIONS FACILITIES	REFRIGERANT FLUID	TOTAL LOAD (kg)	GWP
ITALY	R404A	0.35	3922
	R407C	2	1774
	R410A	0.5	2088
SPAIN	R410A	116.07	2088

	R-22	7	1600
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To obtain the equivalent CO₂ emissions, the total load was multiplied by the corresponding GWP value. It can be noticed that, by comparing these GWP values with the ones for CH₄ and N₂O (28 and 265 kgCO₂e), the impact of these refrigerant fluids, even if the amount injected is small, except for fluid R410A in Spain, makes this category relevant in terms of CO₂e emissions. None of the fluids are used at Pitesti site.

4.4 Scope 2

Scope 2 is the macro-category of the GHG Protocol that includes indirect GHG emissions from purchased energy. Particularly, Scope 2 is divided in:

- indirect emissions from imported electricity
- indirect emissions from imported energy (steam, heating, cooling and compressed air)

For this case study, only electricity consumption is included in the inventory, as the company does not purchase other forms of energy.

4.4.1 Indirect emissions from imported electricity

For calculating GHG emissions from purchased electricity, the GHG protocol presents two methods: the location-based method and the market-based method.

The location-based method represents the average emissions intensity of a specific region electricity grid (e.g. country), considering the overall mix of energy sources, both renewable and non-renewable, used to generate electricity regardless consumer's purchasing decisions. This method uses statistical emission factors provided by national or regional authorities.

The market-based method, on the other hand, accounts for the emissions associated with the specific contractual agreements defined between the company and the electricity provider. Renewable energy certificates (RECs), power purchase agreements (PPAs), or supplier-specific emission rates are necessary if this method is implemented. Moreover, by choosing this approach, the company can show its commitment in reducing electricity emissions. For the share not covered by any contractual instrument, a residual mix

emission factor, which represents the part of purchased electricity coming from unknown origin, shall be used.

For both facilities, market-based method was used. In the case of Ciriè site, the contractual instrument is a declaration by GSE (Gestore dei Servizi Energetici – Electricity Service Manager) of 5,600 MWh produced by renewable sources. It represents the 50.1% of the total amount of electricity purchased in 2024. As suggested by both protocols, electricity from renewable sources have zero GHG emissions, and so, excluded by the calculation. The remaining part (49.9%) was multiplied by the residual mix emissions factor for Italy. The same approach was used for Pitesti and Borja facilities; in the latter case, only 84,719 kWh were not supplied by renewable sources.

Table 7 in the following page shows annual consumption, the part certified as produced by renewable sources, the residual part and the emission factor.

Table 7. For each SFC Solutions facility, the emission factor (Source: Climatiq) for the electricity residual mix and: the annual consumption, the amount of electricity from renewable sources and the residual from fossil sources

	SFC SOLUTIONS FACILITIES		
	ITALY	SPAIN	ROMANIA
EF electricity – residual mix (kgCO2/kWh)	0.5006	0.2824	0.2125
Total annual electricity consumption (kWh)	11,177,123	1,013,999	7,098,021
Certified electricity from renewable sources (kWh)	5,600,000	929,280	-
Residual electricity from fossil sources (kWh)	5,577,123	84,719	7,098,021

4.5 Scope 3

Scope 3 is the broadest and most complex category to account for, due to the wide range of considerations that must be taken into account. For the purposes of this case study, the calculation will focus on the following categories:

- emissions from transportation, including upstream and downstream transport of goods, employee commuting, business travel, waste and travel by customers and visitors to the facility

- emissions from products used by the organization, including purchased goods and services, capital goods, and losses occurring during the distribution of electricity and fuels
- emissions from waste generated by the organization.

4.5.1 Indirect emissions from upstream distribution of goods

This category covers the entire supply chain of the plant (incoming raw materials) and the delivery of the company's products to customers, when the transportation is under company control (under Incoterms DDP/DAP). The source data consists of summary files of all incoming deliveries in 2024 and outgoing shipments for the same year.

Before proceeding with the methodology adopted for this category, it is important to define better the meaning of Incoterms, which is an important information also for downstream distribution category. The Incoterms® are a set of 11 individual rules issued by the International Chamber of Commerce (ICC) that define the responsibilities, costs and risks of sellers and buyers during the sale of goods (International Chamber of Commerce (ICC) Italia, 2020).

In the case study, four Incoterms are considered:

- 1) EXW – Ex Works: This means the seller delivers the goods by placing them at the buyer's disposal at the seller's premises or another named place (factory, warehouse, etc.).
- 2) FCA – Free Carrier: This term means the seller delivers the goods to the carrier or another person nominated by the buyer at the seller's premises or another named place, such as a customs point in the country of export. FCA requires the seller to clear the goods for export (if applicable), but not for import at the destination country. The buyer is responsible for import customs clearance and any applicable duties.
- 3) DAP – Delivered at Place: This means the seller delivers the goods when they are placed at the disposal of the buyer on the arriving means of transport, ready for unloading at the named destination. The seller has all risks associated with transporting the goods to the agreed location.
- 4) DDP – Delivered Duty Paid: Under this term, the seller delivers the goods, cleared for import, on the arriving means of transport and ready for unloading at the

agreed destination. The seller has all costs and risks involved in delivering the goods.

For the purposes of this case study, in order to simplify calculations, FCA was treated as equivalent to EXW, and DAP was treated as equivalent to DDP.

After this brief necessary definition, it is now possible to introduce the methodology. Regarding the emissions from inbound goods and raw materials, the data was grouped as follows:

- supplier name and code
- total mass received (in tonnes)
- production sites (which can be more than one for the same supplier)
- intermediate distribution centres or warehouses
- kilometres by truck
- kilometres by ship (container ship and Ro-Ro ferry)
- kilometres by train

In order to accurately map the route followed by the goods and products delivered, data collection on the shipping plans for the facilities was carried out by directly contacting the suppliers with whom the company had commercial relations in 2024. The request included the following information:

- production site
- means of transport used during delivery stages
- intermediate stops (logistics hubs, etc.)
- frequency of restocking at intermediate warehouses

Not all suppliers gave their response were received, with varying levels of detail—particularly regarding the frequency of restocking at warehouses and the means of transport used for moving goods. However, the production site was shared by most suppliers. In cases where a full shipping plan was not provided, it was assumed that the product was shipped directly from the production site to the Ciriè facility. Additionally, it was assumed that orders dispatched on the same day were transported using the same vehicle.

Another key challenge within this category is the selection of the appropriate emission factor for the calculation. Since the available data varies in terms of detail and content, it was necessary to make a series of assumptions in order to define a consistent methodology

applicable across all possible delivery scenarios. The GHG Protocol and ISO14064-1 propose different calculation approaches:

- the fuel-based method, which involves determining the amount of fuel consumed and applying the emission factor for that fuel
- the distance-based method, which needs the mass, distance, and mode of each shipment, for choosing the appropriate mass-distance emission factor for the vehicle used
- the spend-based method, which applies emission factors money-based, considering the amount spent on each transport

For this case study, it was decided to apply distance-based method, assuming four types of possible means of transport:

- for land shipments by road, the emission factor for an articulated truck with average laden, which can carry from 3.5 to 33 tonnes of goods
- for maritime routes, the emission factor for average container ship or Roll-on/Roll-off Ferry (Ro-Ro), decided case by case, according to the distance between the two locations
- for land shipments by railway, the emission factor for freight train

Figure 5 shows the production site of all the suppliers that delivered raw materials/products to SFC Solutions Italy.



Figure 5. Map with the location of the supplier production sites for SFC Solutions Italy (Source: Kepler.gl)

As it is visible, the company received in 2024 a total of 1,631.8 tonnes as raw materials and products from 115 production sites across four continents, with more than 18 countries. Most of them (97) are in Europe and 48 in Italy. The average trip by truck is of 776 km and by ship is 11,531 km.

In the same year, Borja manufacturing site received 1196.1 tonnes of raw materials and products, from 82 suppliers, distributed in 14 countries, 3 of which are non-european. only one shipment arrived by ship, from Shanghai (China). Differently from Ciriè plant, which has 41.7% of suppliers from Italy, Borja plant has only 19 suppliers from Spain, corresponding to 23.1%. The average trip by truck is longer (1,188.9 km).

Pitesti plant is the only one that receive goods and raw materials (5188.7 tonnes in 2024) from all European suppliers (11 countries represented), with an average trip of 1,346.8 kilometres. The total number of companies delivering to Pitesti is 32, and 7 are from Romania.

Moving to the calculation, by applying the distance-based method, first it is necessary to multiply the total km travelled by each means of transport, by the amount of mass that travelled with. In the same way, the part of emissions related to deliveries of products sold by the company, under DDP/DAP Incoterms responsibility, was calculated.

The results of this calculation, including upstream shipments and DDP/DAP deliveries, are shown in Table 8 below.

Table 8. Results from the multiplication of tonnes received by the km travelled during upstream distribution and DAP/DDP downstream distribution by each means of transport, for each SFC Solutions facility.

	SFC SOLUTIONS FACILITIES		
	ITALY (tonnes*km)	SPAIN (tonnes*km)	ROMANIA (tonnes*km)
HGV – diesel – articulated (3.5 – 33 t) average laden	13,070,580	1,500,761	1,826,496,24
Average Ro-Ro ferry	28	-	-
Freight train	55.766	-	-
Average container ship	14,870,008.37	394,097.4	-

Later, the quantity ‘tonnes*km’ obtained is multiply by the corresponding emission factor, shown in Table 9.

Table 9. Emission factors used for goods transport emission calculations. Source: UK Government for company reporting 2025.

Means of transport	EF CO ₂ (kgCO ₂ /tonne*km)	EF CH ₄ (kgCH ₄ /tonne*km)	EF N ₂ O (kgN ₂ O/tonne*km)
HGV – diesel – articulated (3.5 – 33 t) average laden	0.12432	7.143*10 ⁻⁷	7.4717*10 ⁻⁶
Average Ro-Ro ferry	0.05095	7.143*10 ⁻⁷	2.3396*10 ⁻⁶
Freight train	0.02749	7.143*10 ⁻⁷	1.0566*10 ⁻⁶
Average container ship	0.01592	3.571*10 ⁻⁷	7.1698*10 ⁻⁷

Eventually, the total contribution of the category is given by the following formula:

$$tGHG_{up,tot} = tGHG_{upstream} + tGHG_{downstream,DDP/DAP}$$

4.5.2 Indirect emissions from downstream distribution of goods

This category includes emissions that occur in the reporting year from transportation and distribution of sold by means not owned or controlled by the company. This category share with the previous one the same possible approaches, and, as before, to be consistent, Distance-based method, with the same emission factors, was implemented.

The table used to group all deliveries includes the following information:

- supplier name and code
- delivery site (location, address and postal code)
- total mass delivered
- Incoterms definition.

Since both reference protocols establish that deliveries made under DAP/DDP commercial terms are to be included in upstream distribution category, downstream distribution category only consists of shipments classified as EXW. As in the previous section, land distances were obtained using Google Maps, while maritime distances were calculated through EcoTransit, considering departure and arrival ports based on the shortest possible route. Therefore, these assumptions may not reflect the actual routes taken and do not account for possible changes caused by current geopolitical conditions.

Table 10 below shows ‘tonnes*km’ for downstream distribution.

Table 10. Results from the multiplication of tonnes received by the km travelled by each means of transport, for each SFC Solutions facility.

	SFC SOLUTIONS FACILITIES	
	ITALY (tonnes*km)	SPAIN (tonnes*km)
HGV – diesel – articulated (3.5 – 33 t) average laden	11,518,007	1,948,945
Average Ro-Ro ferry	16,520	-
Freight train	10,218	-
Average container ship	14,059,904	-

At Ciriè facility situation is more complex, in terms of tonnes of products (18,032) and delivery sites (306). In this case, countries represented are more than 32 countries, including 10 different US states, Australia, Japan, Brazil, China, Thailand and India. Nearly a third of the delivery sites are located in Italy. 174 delivery sites have been considered as EXW Incoterms, meaning that the remaining 132 have been included in the upstream distribution of goods (Section 4.5.1) calculation. The average trip by sea is 6926 km, while the average trip by truck is 861 km, much lower than Borja facility. Figure 6 below shows the map including the delivery sites mentioned.



Figure 6. Map with the location of the client delivery sites for SFC Solutions Italy (Source: Kepler.gl)

Borja facility delivered a total mass of 2,195.9 tonnes of products in six countries (France, Portugal, Germany, Morocco, Turkey and Spain) divided in 21 delivery sites (5 in Spain). The means of transport used is only truck (except for the route to cross the sea to land in Morocco and United Kingdom), with 1,766,143 kilometres travelled and an average trip of 1,178 kilometres. Only with for one customer, Peugeot Citroen Automotive, deliveries were with DDP/DAP Incoterms, which have been included in the previous category calculation.

At Pitesti plant, data from this category are still under collection.

For this category, the same approach and emission factors of upstream distribution of goods (Subchapter 4.5.2) were used to calculate GHG emissions.

4.5.3 Indirect emissions from employee commuting

This category includes emissions from the transportation of employees between their homes and their workplace. They may arise from:

- Car
- Bus
- Train
- Other modes of transportation (e.g., bicycling and walking).

There are three possible options to evaluate emissions:

- Fuel-based method, which involves determining the amount of fuel consumed
- Distance-based method, which involves collecting data directly from employees on commuting method
- Average-data method, which is based on average (e.g., national) data

The first step of the approach chose to assess the impact of this category was to collect data about employee commuting at each facility. For all facilities it has been decided to apply the distance-based method, as follows: at Borja and Pitesti sites, the managers decided to collect data manually, by asking directly to the employees and then aggregate in an Excel sheet, while at Ciriè plant, information was gathered by a Microsoft Forms online questionnaire. It was composed of five questions:

- 1) Employee identification number
- 2) Mode of transportation used (car, motorbike, bus, train, by walk, bicycle, other)

- 3) For car and motorbike, the type of power source (diesel, petrol, LPG, CNG, electric, hybrid)
- 4) Kilometres travelled in a day (round-trip)
- 5) If car sharing is implemented (yes/no)

Although the response rate was not 100%, the 206 responses received allow to take some observations. First, the car is the means of transport used by 96.6% of employees, 20 of whom (9.7%) regularly share their commute with colleagues through car sharing. Only one person commutes by bicycle, and two people use a motorcycle. Among the cars, petrol is the most used fuel type, accounting for 44.8%, followed by diesel at 35.5%, and LPG at 13.1%. 56.2% of employees commute in less than 30 km round-trip, highlighting the company's positive impact by actively engaging hundreds of families living in the surrounding area. Only 17.7% travel more than 60 km per day. The average commuting distance is 32.23 km, equivalent to approximately 16 km per trip. The following charts illustrate the percentages mentioned above. For the calculation of emissions for Ciriè facility, the value of 215 working days was set and applied for all the employees, which was then multiplied by the daily commuting distance of each employee. Since there were 320 employees in 2024, but only 206 replies were collected, to assess a valid estimation for the missing replies, it has been decided to multiply the average distance (32.23 km), by the number of people, employed in 2024, that did not reply to the questionnaire (106). The assumption uses the emission factor for average car diesel.

At Borja site, considering 133 employees, only one person does not use the car to go the workplace, and people using car sharing are more than double, compared to Ciriè facility situation: 44. In this case, the most used power source is diesel (104 cars) and none of the cars are powered by electricity.

At Pitesti site, 212 people regularly commute by bus, 7 people by walk and the remaining 52 by car (44 diesel cars, 8 petrol cars).

The resulting total kilometres, calculated as the sum of the kilometres travelled by each employee who does not use car sharing, plus the total kilometres travelled by those who do, divided by two, were then grouped by mode of transport, as shown in the Table 11 below, and multiplied by the corresponding emission factor.

Table 11. Emission factors used for employee commuting emissions calculation (Source: UK Government for company reporting 2025) and kilometres travelled for each SFC Solutions facility.

				SFC SOLUTIONS FACILITIES		
Means of transport	EF CO ₂ (kgCO ₂ /km)	EF CH ₄ (kgCH ₄ /km)	EF N ₂ O (kgN ₂ O/km)	ITALY (km)	SPAIN (km)	ROMANIA (km)
Average petrol car	0.16204	1.2857*10 ⁻⁵	1.2075*10 ⁻⁶	450,425	115,646	65,400
Average diesel car	0.17136	1.656*10 ⁻⁷	6.3019*10 ⁻⁶	1,334,909	372,568	289,504
Average LPG car	0.19557	2.1429*10 ⁻⁶	1.3585*10 ⁻⁶	198,983	-	-
Average hybrid car	0.12708	6.7857*10 ⁻⁶	3.6981*10 ⁻⁶	101,400	23,155	-
Average CNG car	0.17201	6.3214*10 ⁻⁵	1.3585*10 ⁻⁶	14,190	-	-
Average Electric car	-	-	-	2,150	-	-
Average Motorbike	0.17925	0.000101	3.1698*10 ⁻⁶	6,450	-	-
By walk	-	-	-	-	-	1,744
Bus	0.10311	3.57143*10 ⁻⁷	2.75472*10 ⁻⁶	-	-	1,724,380

The total amount of emissions for this category is given by the formula below, which include also the contribution of the assumption made for the missing replies at Ciriè facility:

$$tGHG_{commuting} = \frac{\sum(km_{tot,means} * EF_{means})}{1000} + \frac{106*32.23*EF_{diesel}}{1000}$$

4.5.4 Indirect emissions from customer and visitor transport to the facility

This category is clearly defined only in ISO14064 and considers the emissions associated with the transportation of visitors and clients who travelled to the facility. The following table, based on the company's 2024 presence register, reports the visits of customers or guests who entered more than 10 times during the year 2024.

To be consistent, it has been decided to apply the same approach of employee commuting, which is the distance-based method. Since it was not provided any information about the mode of transport used by customers or visitors to reach the facility, nor the number of days spent in Turin for each visit, the headquarters of the visitor's company was assumed as the point of departure and no hotel nights were considered. The total distance in kilometres was calculated as follows (factor 2 represents the round-trip):

$$km_{tot,visitor} = entrances * 2 * distance\ from\ SFC\ facility$$

Once the total kilometres travelled by each visitor were obtained, average diesel car emission factor, for car trips and plane emission factor were used for calculating the total contribution of the category, as expressed by the formula below:

$$tGHG_{c\&v} = \frac{km_{tot,car} * EF_{car} + km_{tot,plane} * EF_{plane}}{1000}$$

Table 12. Kilometres travelled by customers for each SFC Solutions facility.

	SFC SOLUTIONS FACILITIES		
	ITALY	SPAIN	ROMANIA
	Total km	Total km	Total km
Car – diesel (average biofuel blend)	54,332	505	1,752
Plane	61,884	-	-

Table 13. Emission factors used for customer transport emissions calculation

Means of transport	EF CO ₂ (kgCO ₂ /km)	EF CH ₄ (kgCH ₄ /km)	EF N ₂ O (kgN ₂ O/km)
Plane	0.12693	3.57143*10 ⁻⁷	3.4717*10 ⁻⁶
Average diesel car	0.17136	1.656*10 ⁻⁷	6.3019*10 ⁻⁶

4.5.5 Indirect emissions from business travel

Business trips are often necessary to ease collaboration between companies within the same group, as well as to establish new commercial relationships with clients and suppliers or to strengthen existing ones. However, their environmental impact must be taken into consideration, due to the use of airplanes, cars, and other means of transport. In addition to fuel-based and distance-based methods, expressed in the employee commuting subchapter, the spend-based method, which needs the amount of money spent for each business travel, can be applied for this category. As for employee commuting, distance-based method was considered, but several assumptions were needed.

First, to organize business travel data, SFC Solutions utilizes TravelPerk software, which records all business trips, specifying the departure and arrival airports, the number of nights spent in hotels, and whether a rental car was used. Thanks to this tool, it was possible to aggregate the data by number of hotel nights per country, as well as all train and air travel. As for car rentals, information is available on the pick-up and drop-off locations, and thus the distance travelled is based on an estimate. The table below summarizes the kilometres travelled and the number of trips for each means of transport, organized by each facility.

Table 14. Emission factors used for transport emissions calculation for business travels

Means of transport	Total km	EF CO ₂ (kgCO ₂ /km)	EF CH ₄ (kgCH ₄ /km)	EF N ₂ O (kgN ₂ O/km)
Plane	106,969	0.12693	3.57143*10 ⁻⁷	3.4717*10 ⁻⁶
Average petrol car	6,000	0.16204	1.2857*10 ⁻⁵	1.2075*10 ⁻⁶
Train	691	0.0351	2.85714*10 ⁻⁶	1.0566*10 ⁻⁶

Moving to the calculation, the contribution from the transport is given by the formula:

$$tGHG_{travel} = \frac{EF_{car} * km_{car} + EF_{plane} * km_{plane} + EF_{train} * km_{train}}{1000}$$

The emissions for the hotel nights were already available in the report released by the software TravelPerk, which were estimated taking into account the type of hotel and the country. The following table lists this information.

Table 15. Hotel nights during business trips for each SFC Solutions facility

SFC SOLUTIONS FACILITIES			
ITALY		SPAIN	
Country	Hotel nights	Country	Hotel nights
DE	21	PT	4
ES	4	PL	1
FI	1	MA	6
FR	45	SE	2
IT	13		
PL	12		
RO	12		
SE	6		

For Ciriè facility employees France is the country with the highest number of nights, while for Borja employees is Morocco, which is the only non-European country visited. No business trips were done by employees at Pitesti site.

Before summing the two contributions, it is necessary to convert CH₄ and N₂O emissions in tonnes of CO₂e, by using GWP100 from IPCC Fifth Assessment.

Eventually, it is possible to obtain the total emissions from this category, as expressed by the formula below:

$$tCO2e_{total,travel} = tCO2_{hotel} + tCO2e_{travel}$$

4.5.6 Indirect emissions from purchased goods and services

Purchased goods and services are one of the most impacting categories in the case study GHG inventory, mainly because of the type and the quantity purchased, which are mostly chemical and fossil derived products. Specifically, this category considers four sections:

- 1) emissions from purchased goods
- 2) emissions from purchased services
- 3) losses during fuel transport (Well to Tank – WTT)
- 4) losses during electricity distribution (T&D)

This category is calculated only for Ciriè manufacturing site. Considering the initial amount of material received, the quantity coming from five suppliers, located in the Turin area that are in charge of final processes before delivering to clients, were excluded from

the calculation of this category, as there was no information provided by them about their impact on emissions. They were included only in logistics-related categories.

Before proceeding with the calculation of the contribution from purchased goods, it was necessary to divide them by commodity in order to ease the search for conversion factors for products where suppliers did not provide information. Out of 457 products, data were received from suppliers for only 107, while the remaining items were all calculated using factors from Climatiq, based on their respective categories.

Climatiq also provided data regarding losses associated with fuel and electricity, the latter being country-specific. To obtain these two contributions, the annual amount of material, fuel, or electricity received was multiplied by the respective emission factor.

With regard to purchased services, the only available data concerned the transportation of employees from the various service providers visiting the company.

Emission factors and kilometres travelled by service providers are shown in the tables in Appendix.

This contribution was calculated in the same way as the category for customers and visitors (Section 4.5.4), and was subsequently converted into CO₂ equivalents to be aggregated with the other contributions, resulting in the total emissions from this category, calculated using the following formula:

$$tCO2e_{g\&s} = tCO2_{goods} + tCO2e_{services} + tCO2e_{WTT} + tCO2e_{T\&D}$$

4.5.7 Indirect emissions from capital goods

This category includes the upstream emissions related to company-owned goods used to manufacture a product. They differ from purchased goods due to the extended lifetime and because they are neither transformed nor sold to other companies or organizations. GHG Protocol suggests calculating the total emissions in the year of their acquisition, with four possible methods:

- supplier-specific method, by using data provided by the supplier
- hybrid method, which includes a combination of supplier data (as available) and secondary data for the remaining information
- average-product method, which involves estimating emissions by multiplying by relevant secondary emission factors, based on unit of product

- average spend-based method, which involves estimating emissions for goods by collecting data on the economic value of goods purchased and multiplying by emission factors, expressed as kg of emissions per monetary value of goods.

ISO14064-1 allows to assess capital goods emissions in accordance with their depreciation time, similarly to what accounting department does. For this case study, since many of the capital goods were purchased several years ago, when GHG emissions estimation were still not considered, and due to the lack of specific information, it has been decided to apply the average spend-based method, considering the depreciation time of each asset. The formula represents the method used.

$$tCO2e_{assets} = \frac{\sum(EF_{asset\ class} * economic\ value_{asset\ class})}{1000}$$

Eventually, the table below lists the assets, along with the corresponding emission factor, grouped by category, that still had a residual economic value as of 2024.

Table 16. Capital goods and the corresponding emission factors for each SFC Solutions facility

Asset class	EF (kgCO ₂ e/eur)	Residual economic value (eur)	
		SFC SOLUTIONS ITALY	SFC SOLUTIONS SPAIN
Software	0.082	9,693.8	79,431
Buildings	0.0579	328,188.79	81,957
Machineries	0.2888	749,531.42	990,301
Machineries and equipment (<5000 euros)		362.44	-
Machine tools		70.58	-
Office furniture	0.2007	780.28	23,999
Computer equipment		12,870.91	-

4.5.8 Indirect emissions from waste disposal

This category accounts for emissions associated with the transportation and treatment of waste, which can be obtained by three different methods:

- Supplier-specific method, which uses emissions data directly from waste treatment companies (e.g., for incineration, recovery for recycling)
- Waste-type-specific method, which uses emission factors for specific waste types and waste treatment methods

- Average-data method, which estimates emissions based on total waste going to each disposal method (e.g., landfill) and their specific average emission factors.

Without any precise information from the waste treatment plants, waste-type-specific method was implemented. In addition to the contribution of emissions from the waste treatment, emissions from waste transportation phase must be taken into account. For Ciriè site, CO₂e emissions related to transport were provided directly by the software system in which, according to current Italian regulations, all movements of each waste must be recorded. The total amount is 8.046 tonnes of CO₂e.

At the Borja and Pitesti production sites, the calculation was carried out manually, with the same approach as with upstream and downstream distribution of goods (distance-based method). Knowing the amount of waste transported and the number of trips:

- average van diesel <3.5 t emission factor was used for Borja site
- HGV – diesel – articulated (3.5 – 33 t) average laden was used for Pitesti site.

Moving to the disposal contribution to the emissions, all waste generated for each facility, presented in the Appendix, was organized by:

- Name
- European Waste Code (EWC)
- Quantity in tonnes
- Hazardousness classification
- Type of treatment (landfill, recycling, recovery, incineration, chemical-physical treatment)

The total amount of waste produced at Ciriè production site is 2,117 tonnes, of which 554.1 are classified as hazardous.

Among these, 478.5 tonnes are in liquid form and undergo additional physical-chemical treatment. 47 tonnes are sent to landfill, while 291 tonnes undergo recycling processes. 32.51 tonnes are entirely allocated to a recovery phase.

Borja facility produced 132.93 tonnes of waste, with just 7.21 tonnes of hazardous waste. All of them were sent to landfill, except for paper and cardboard boxes, which were sent to recycle treatment.

Pitesti facility produced 752.08 tonnes of waste in 2024, of which 32.1 are hazardous. 61.215 tonnes (household waste) were sent to landfill, while 644.74 (rubber shrinkage

waste) are sent to combustion plants. The remaining part (46.125) undergoes chemical-physical treatment or recycle processes.

To calculate the emissions from waste disposal, the following emission factor were applied in the formula:

$$tCO2e_{disposal} = \frac{\sum(EF_{waste} * mass_{waste})}{1000}$$

Table 17. Emission factors used for waste disposal emissions calculation

Waste treatment	Emission factor	Unit
Incineration (non-hazardous waste)	0.1115	kgCO ₂ e/kg
Incineration (hazardous waste)	844	kgCO ₂ e/t
Recycle (closed/open loop)	4.68568	kgCO ₂ e/t
Incineration (only for waste rubber)	2.076	kgCO ₂ e/kg
Chemical-physical treatment and landfill for liquid waste	520.5327	kgCO ₂ e/t
Landfill (only for rubber and plastics)	8.98311	kgCO ₂ e/t
Landfill (hazardous industrial waste)	128	kgCO ₂ e/t
Landfill (only for empty sprays)	128	kgCO ₂ e/t
Landfill for residual household waste	497.2	kgCO ₂ e/t
Chemical-physical treatment for industrial waste	0.588	kgCO ₂ e/kg

Eventually, by summing the two parts of emissions, the total contribution was calculated:

$$tCO2e_{waste} = tCO2e_{disposal} + tCO2e_{waste\ transport}$$

4.6 Data uncertainty assessment

This chapter introduces the concepts of quality and uncertainty associated with the data and emission factors used. Both reference protocols underline the importance of assessing these aspects, preferably quantitatively, or qualitatively, if the other is not possible. Before proceeding with the analysis, it is necessary to introduce some terminology:

- Data quality refers to the reliability of the data. They can originate from primary sources, which include data calculated directly by suppliers and are specific to their activities, or from secondary sources, which are not derived from specific

activities but more representative of a category or sector, as for example industry-average data from database (New Zealand External Reporting Board, 2023).

- Uncertainty is defined as a parameter associated with the result of a quantification that characterises the dispersion of the values that could reasonably be attributed to a particular quantity (British Standards Institution, 2019).

A quantitative analysis of uncertainty involves assigning numerical confidence intervals or probability distributions to data, whereas a qualitative analysis provides a description of the possible sources of error and their implications. For the purposes of this case study, a qualitative analysis has been selected, as it better reflects the limitations of available data and the reliance on assumptions in several categories.

Starting with Scope 1 and Scope 2, all activity data can be considered of high quality since they derive from direct measurements reported by provider. The only possible error can be linked to measurement inaccuracies. The situation slightly differs when emission factors are considered:

- The emission factors uncertainty of combustion process and refrigerants is relatively low to medium, since they are provided by UK Government for company reporting 2025 and IPCC databases, which are widely recognized.
- For electricity consumption, the emission factor is from Climatiq database. In this case, a higher uncertainty must be considered, as the factor is based on residual national grid-mix assumptions that may not fully represent the current status of the energy sources mix.

Regarding Scope 3, before analysing specific cases, some general considerations on data quality can be mentioned:

- 1) Mass data, which are required for transportation, purchased goods, and waste categories, can be considered of high quality because they are directly measured.
- 2) Distance data, used for the transportation of goods and people, are of medium quality. This is because data are collected from online sources such as EcoTransit for maritime routes and Google Maps for land transport, which may not accurately reflect the real number of kilometres travelled. These distances depend on factors such as traffic conditions or economical and geopolitical constraints.
- 3) Emission factors are generally assigned a medium-high level of uncertainty. This is because they represent standardized values that often refer to technological or

geographical contexts different from the company's ones, and because they are based on assumptions that tend to generalize categories. For example, in transportation, a single type of truck has been chosen to represent an entire logistics flow, even though in reality other vehicle types and laden conditions may be different. Uncertainty is even higher for waste disposal category, as the free-access database did not provide suitable values for all types of treatments, resulting in an even greater degree of generalization.

Focusing on specific cases, the employee commuting calculation for Ciriè facility highlights significant variability. This arises from the assumptions needed to apply to the whom that did not respond to the questionnaire. Generalising both the means of transport (average diesel car) and the commuting distance (the resulting average of the other 200 replies) introduces a level of uncertainty that deviates from the actual situation. Also, for categories related to external visitors of the company, such as purchased services and customers/visitors, uncertainty is high. This is mainly related to the distance data (for many people the company headquarters were assumed as their starting point, although this was likely not the actual case) and from the number of visits, which was considerably filtered due to ambiguities in the records.

5. Results

This chapter presents the results obtained from the calculation of the categories considered within the inventory. As stated by both the GHG Protocol and ISO 14064, results must be reported for each greenhouse gas and subsequently converted into tonnes of CO₂ equivalent. The GWP values used for the conversion are sourced from the IPCC Fifth Assessment (World Resources Institute, 2024). Tables 16, 17 and 18 illustrate the results obtained for the three plants under consideration: Italy, Spain, and Romania. The latter two cannot be fully compared with the Italian site, as data collection could not be completed at the time of the thesis conclusion. However, considering the differences in plant size and geographical location, some meaningful observations can still be drawn. The Figure 7 shows the percentage distribution of Scope 1, 2, and 3 emissions for the Italian plant, which is the only one that includes all the categories described in the methodology.

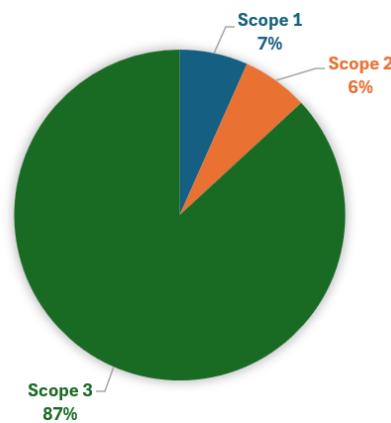


Figure 7. Percentage distribution for Scope 1, 2, 3 for SFC Solutions Italy.

The total value is 43,177.86 tonnes, 87% of which are Scope 3 emissions. In particular, the most impactful category is purchased goods, representing 70.3% of total emissions. The second largest contribution comes from waste (2,932.561 tonnes), while stationary combustion and purchased electricity present similar values (2,877.92 and 2,971.92 tonnes). Logistics also play a significant role, with upstream and downstream transport together accounting for 3,590 tonnes, highlighting the considerable impact of goods movement within a highly globalized manufacturing context.

Afterwards, it is possible to provide a brief comparative analysis of the three plants, whose percentage distribution is illustrated in the graphs shown in Figures 8 and 9, while the totals for each are reported in Table 19.

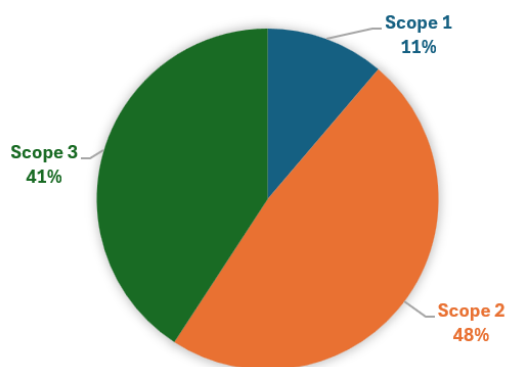


Figure 8. Percentage distribution for Scope 1, 2, 3 for SFC Solutions Romania.

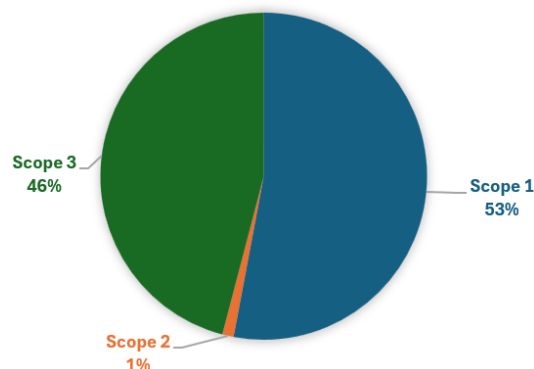


Figure 9. Percentage distribution for Scope 1, 2, 3 for SFC Solutions Spain.

Starting with Scope 1. For all three plants, the stationary combustion category is the most significant, with the Italian site reporting the highest value, mainly due to the greater consumption of natural gas required to operate the facility. This is followed by Spain and then Romania, which, due to different volumes and types of fuels used, emit a considerably lower amount. It is worth noting the high value of fugitive emissions in Spain, caused by extensive maintenance work on refrigeration equipment carried out during 2024.

With regard to Scope 2, all three plants purchase only electricity. The Italian site records the highest level of emissions, even though Romania is the one with the highest consumption. However, Romania emits roughly half as much because of its lower emission factor. Spain, thanks to renewable energy accounting for 98% of its electricity production, shows an extremely low value for Scope 2.

Turning to Scope 3, when considering the categories common to all three plants, it can be observed that upstream logistics depend on both the incoming volumes and their geographical origin. The transportation of raw materials for the Italian site, which frequently sources from a large number of suppliers located on other continents, often requires long-distance sea freight and therefore results in the highest emissions among the three plants. Finally, employee commuting can be analysed in terms of both the number of employees and the means of transport used. Romania, where a large share of employees commute by bus, generates lower emissions compared to the Ciriè site, even though both have a similar workforce of around 300 employees. Spain, despite employing a lower number of people (126), shows higher commuting emissions, as all employees travel by private car without car sharing. Considering emissions from the three manufacturing locations, Scope 1 is 4,364.5 tonnes of CO₂e (9% of the total), Scope 2 is

4,324.17 tonnes of CO₂e (8.9% of the total) and Scope 3 (not complete among the categories for Borja and Pitesti sites) is 39,773.54 tonnes of CO₂e (82.1% of the total).

Table 18. Summary of GHGs emissions for SFC Solutions Italy.

	SFC SOLUTIONS ITALY EMISSIONS					
	(tonnes)					
	Total CO₂e	CO₂	CH₄	N₂O	CO₂e (CH₄)	CO₂e (N₂O)
Scope 1						
Direct emissions from stationary combustion	2,826.534	2,820.937	0.149	0.005	4.186	1.411
Direct emissions from mobile combustion	45.426	44.869	0.001	0.002	0.023	0.533
Direct fugitive emissions from anthropogenic systems	5.965	-	-	-	-	-
Scope 2						
Indirect missions from purchased electricity	2,791.908	-	-	-	-	-
Scope 3						
Indirect emissions from upstream distribution of goods	1,907.395	1,864.262	0.015	0.161	0.411	42.722
Indirect emissions from downstream distribution of goods	1,682.736	1,658.875	0.013	0.096	0.371	25.490
Indirect emissions from employee commuting	359.943	357.145	0.009	0.010	0.243	2.555
Indirect emissions from customers and visitors transport	17.310	17.165	0.00003	0.001	0.001	0.144
Indirect emissions from business travel	18.810	14.760	0.00004	0.0004	0.001	0.110
Indirect emissions from purchased goods and services	30,350.148	-	-	-	-	-
Indirect emissions from capital goods	239.127	-	-	-	-	-
Indirect emissions from waste disposal	2,940.607	-	-	-	-	-

Table 19. Summary of GHGs emissions for SFC Solutions Spain

	SFC SOLUTIONS SPAIN EMISSIONS (tonnes)					
	Total CO₂e	CO₂	CH₄	N₂O	CO₂e (CH₄)	CO₂e (N₂O)
Scope 1						
Direct emissions from stationary combustion	871.476	869.781	0.046	0.002	1.295	0.401
Direct emissions from mobile combustion	6.624	6.538	0.000027	0.00032	0.00075	0.085
Direct fugitive emissions from anthropogenic systems	255.684	-	-	-	-	-
Scope 2						
Indirect missions from purchased electricity	23.925	-	-	-	-	-
Scope 3						
Indirect emissions from upstream distribution of goods	195.895	192.849	0.001	0.011	0.034	3.046
Indirect emissions from downstream distribution of goods	221.968	218.454	0.001	0.013	0.035	3.479
Indirect emissions from employee commuting	87.823	87.111	0.002	0.003	0.045	0.668
Indirect emissions from customers and visitors transport	0.08735	0.08650	0.0000001	0.000003	0.000002	0.00084
Indirect emissions from business travel	4.415	3.779	0.00007	0.0001	0.002	0.029
Indirect emissions from purchased goods and services	-	-	-	-	-	-
Indirect emissions from capital goods	302.074	-	-	-	-	-
Indirect emissions from waste disposal	16.442	-	-	-	-	-

Table 20. Summary of GHGs emissions for SFC Solutions Romania

	SFC SOLUTIONS ROMANIA EMISSIONS (tonnes)					
	Total CO₂e	CO₂	CH₄	N₂O	CO₂e (CH₄)	CO₂e (N₂O)
Scope 1						
Direct emissions from stationary combustion	331.186	330.714	0.010	0.001	0.289	0.183
Direct emissions from mobile combustion	21.612	44.869	0.001	0.002	0.023	0.533
Direct fugitive emissions from anthropogenic systems	-	-	-	-	-	-
Scope 2						
Indirect missions from purchased electricity	1,508.329	-	-	-	-	-
Scope 3						
Indirect emissions from upstream distribution of goods	230.723	227.070	0.00130	0.014	0.037	3.616
Indirect emissions from downstream distribution of goods	-	-	-	-	-	-
Indirect emissions from employee commuting	87.823	87.111	0.002	0.003	0.045	0.668
Indirect emissions from customers and visitors transport	239.849	238.008	0.001	0.00023	0.017	0.005
Indirect emissions from business travel	17.310	17.165	0.00003	0.001	0.001	0.144
Indirect emissions from purchased goods and services	-	-	-	-	-	-
Indirect emissions from capital goods	-	-	-	-	-	-
Indirect emissions from waste disposal	794.876	-	-	-	-	-

Table 21. Summary of tonnes of CO₂ equivalents for Scope 1, 2, 3 and their percentage distribution for each SFC Solutions facility.

	SFC SOLUTIONS FACILITIES EMISSIONS							
	ITALY		SPAIN		ROMANIA		TOTAL (tCO ₂ e)	%
	tCO ₂ e	%	tCO ₂ e	%	tCO ₂ e	%		
Scope 1	2,877.92	7	1,133.78	53	352.80	11	4,364.5	9
Scope 2	2,791.92	6	23.92	1	1,508.33	48	4,324.17	8.9
Scope 3	37516.08	87	982.75	46	1,282.76	41	39,781.59	82.1
TOTAL	43,185.91		2,140.46		3,143.89		48,470.26	

6. Strategies and targets for emissions reduction

After emissions calculation, the next step consists of analysing the results, in order to elaborate strategies and establish targets for emissions reduction. Figure 10 below shows the path towards carbon neutrality decided by SFC Solutions Group.



Figure 10. Target of emissions reduction for SFC Solutions Group.

Considering the results of this master's thesis as the baseline year (2024), the first stage of reduction is to Scope 1 and 2 by 30% by 2030. The next one is to reduce Scope 3 of the same amount five year later (2035) and before the total neutrality in 2050, the third target of 80% reduction is set in 2040. To these objectives, it is important to start improving performance in every category included in the inventory, with particular focus on the most impacting.

For Scope 1, in order to completely eliminate the emissions of mobile combustion, a fleet of full electric company cars should be considered. Also, the replacement of cooling systems with more up-to-date equipment using low-emission gases to reduce direct fugitive emissions.

Scope 2 emissions, only related to purchased electricity, can be eliminated either by buying 100% only from certified renewable sources, or by combining the production by solar panels systems installed on the plant's rooftops and with the purchasing of the remaining electricity from certified renewable sources. Moreover, to reduce electricity consumption, it could be possible to update lighting systems, by LED technology, and improve machineries efficiency, optimizing their usage.

Regarding Scope 3, which includes all other indirect emissions, the next step, is to run Life Cycle Assessment and Product Carbon Footprint activities to have a more in-depth understanding. These two activities can be useful also from the economic point of view, as automotive manufacturers request are requesting this information to the suppliers. Specific actions for raw materials and products include:

- investing on sustainable design projects, optimizing the quantity of material needed without compromising performance, and by using recycled/recovered materials to substitute partially or entirely high-impact raw materials. This activity has been already implemented in the past at Ciriè facility, as discussed in chapter 3.
- For upstream and downstream distribution of goods, collaborating with logistics suppliers that use low-emissions vehicles and optimizing the procurement and delivery plan.
- Applying green procurement practices when purchasing raw materials, prioritizing alternatives with the lowest environmental impact.

Moreover, actions for the other Scope 3 categories are:

- Reduce at minimum business trips and introduce company buses in the other facilities for employee commuting, as already done at the Pitesti site.
- Minimize geographical distance of business partner to limit transport-related emissions.

7. Conclusion

In view of the Inventory activity carried for this master's thesis, it is possible to draw several final remarks. Several years after the release of institutional plans (such as the European Green Deal) and specific laws (such as the EU Taxonomy and CSRD), the level of awareness of environmental sustainability within the automotive industry has significantly increased. Particularly, thanks to the collaboration with SFC Solutions Group, it was possible to evaluate the state of art of GHG quantification in a complex network involving companies of different size and sectors.

First, GHG Protocol and ISO14064-1 provide a theoretical point of view the appropriate orientations to correctly run the activity, offering flexibility among the possible methodologies that can be adopted depending on data availability. However, when applying them, many difficulties may be faced.

Proceeding step by step, Scope 1 and 2 emissions, which account for 4,364.5 and 4,324.17 tonnes of CO₂e across the three plants, proved to be easily to collect and calculate. Providers share accurate information, both regarding consumption/releases and their impact on GHG emissions (e.g. tonnes of CO₂e or the emission factor of their energy mix already indicated in the invoice). Moreover, when it is necessary to find secondary data from databases, it is usually easy to find reliable emission factors suitable for calculation.

Scope 3 (48,470.26 tonnes of CO₂e) presents a totally different scenario, which represents the part of the study with the main difficulties. For these categories data are barely available and their emission factors are more general, increasing the uncertainty. The first aspect can be explained considering purchased goods and services category, while the second with the upstream and downstream distribution of goods.

During data collection for purchased goods category it was noticed that at the moment, very few suppliers, although automotive sector is various, spanning multiple countries, have carried out LCA activities or possess PCF certificates. However, although the data obtained show a high level of uncertainty, they represent well the impact of the category. This is visible from the comparison between the Ciriè plant, which includes purchased goods in its inventory, and the other two plants that do not: the percentage balance shifts considerably.

On the other hand, the transport of goods categories shows that without complete information about the usual routes travelled and type of mode on transportation used, it is difficult to predict precisely.

Finally, the chapter about strategies and targets raised the importance of a well-organized long-term program and investments, as improvements and updates for the plants require time and resources to be implemented. In this perspective, benefits will be both in terms of environmental performance, and to remain competitive in the market.

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Appendix

	Type of Waste	Hazardous / Non-hazardous	EWC (European Waste Code)	Quantity (tonnes)	Treatment
SFC SOLUTIONS Pitesti	Household garbage	Non-hazardous	200301	61.215	Landfill
	Rubber shrinkage waste	Non-hazardous	070299	644.74	Incineration
	Paper, cardboard boxes	Non-hazardous	150101	7.25	Recycle
	Plastic packaging	Non-hazardous	150102	6.775	Recycle
	Used oil	Hazardous	130113*	0.66	Chemical-physical treatment
	Adhesive	Hazardous	080409*	0.45	Chemical-physical treatment
	Salt residuals	Hazardous	070211*	29.02	Chemical-physical treatment
	Contaminated packaging	Hazardous	150110*	1.97	Chemical-physical treatment
SFC SOLUTIONS Ciriè	Rubber shrinkage waste	Non-hazardous	070299	1166.03	Recovery
	Toner cartridge	Non-hazardous	080318	0.08	Incineration
	Paper, cardboard boxes	Non-hazardous	150101	108.48	Recycle
	Nylon, plastics	Non-hazardous	150102	24.6	Recycle
	Wooden platform	Non-hazardous	150103	157.96	Recycle
	Compactor	Non-hazardous	150106	21.14	Landfill
	Out of order devices	Non-hazardous	160214	8.9	Recovery
	Ferrous residuals	Non-hazardous	170405	23.52	Recovery
	Water with glycole residuals	Non-hazardous	161002	6.7	Chemical-physical treatment
	Groundwater from skimmer and purge operations	Non-hazardous	161002	19.6	Chemical-physical treatment
	HCl	Hazardous	080102	0.46	Chemical-physical treatment
	Salts	Hazardous	060313	2.631	Chemical-physical treatment
	Water from floor cleaning operation	Hazardous	070201	130.12	Chemical-physical treatment
	Salty solutions	Hazardous	070201	31.92	Chemical-physical treatment
	Varnish residuals	Hazardous	080111	8.62	Incineration
	Sealant for Line 8, 2	Hazardous	080409	16.62	Incineration
	Hydraulic oils	Hazardous	130110	0.6	Preliminary collection
	Water and oil from oily emulsions	Hazardous	130802	168.62	Chemical-physical treatment
	Other solvents and solvent mixtures	Hazardous	140603	0.0125	Incineration
	Empty glue drums	Hazardous	150110	1.457	Incineration
	Spray cans	Hazardous	160504	0.09	Recovery
	Dirty shreds and paper (special waste)	Hazardous	150202	50.29	Incineration
	Out of order devices	Hazardous	160213	1.33	Chemical-physical treatment
	Raw materials residuals	Hazardous	160305	19.021	Incineration
	Industrial sweeper	Hazardous	160305	3.86	Incineration
	Oily deposits	Hazardous	160708	12.54	Chemical-physical treatment
	Water from adhesive cleaning operation	Hazardous	161001	105.91	Chemical-physical treatment
SFC SOLUTIONS Borja	Rubber and plastic	Non-hazardous	070213	106.1	Landfill
	Paper, cardboard boxes	Non-hazardous	200101	19.62	Recycling
	Getrén	Non-hazardous	160199	6.4	Landfill
	Used oil	Hazardous	130205	0.45	Landfill
	Contaminated plastic packaging	Hazardous	150110	0.04	Landfill
	Contaminated material	Hazardous	150202	0.28	Landfill
	Empty sprays	Hazardous	160504	0.04	Landfill

SERVICE	TOTAL KM TRAVELLED (round-trip)
canteen	365590
cleaning service	912
coffee machines	4010
consulting	47300
food	20196
human resources	27424
hydraulic plant	1150
industrial vehicles	418
maintenance	150648
measurements	5120
office printer	3872

Goods	Emission Factor	Unit	Source	Notes
Natural gas	0.3366	[kgCO ₂ eq/m ³]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic film
Diesel - electricity generator and forklift trucks	0.62409	[kgCO ₂ eq/l]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic film
Petrol - company cars	0.58094	[kgCO ₂ eq/l]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic film
Diesel - company cars	0.61101	[kgCO ₂ eq/l]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic film
Electricity	0.003367	[kCO ₂ eq/MWh]	https://www.climatq.io/data/explorer?sector=Energy&region=IT&search=1%26D&data_version=%5E20	
Carbon black	4	[kgCO ₂ eq/kg]	from Orion Engineered Carbons GmbH	
Coating	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	paint waterborne
Coating	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	inorganic compounds and basic chemicals
Coating	1	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=coating&access_type=public&data_version=%5E23	application coating - silicon resin
Deminerallized water	0.0003	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?access_type=public&search=water&data_version=%5E20	deionized / technical water
Ethylene glycol	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E20	organic compounds
Gasket	4	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=plastic&profile&data_version=%5E20	plastic profile
Glass cord	8.5	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=glass+fiber&data_version=%5E24	glass fiber reinforced plastic
Glue	2.68	[kgCO ₂ eq/kg]	from Henkel Spa	
Glue	6.3	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=chemicals&page=4&data_version=%5E20	glue / adhesives
Heslane	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E20	organic compounds
Metal carrier	0.029	[kgCO ₂ eq/kg]	from STG Standtechnik Gesellschaft	
Metal carrier	1.3545	[kgCO ₂ eq/kg]	from Marcegaglia Carbon Steel Spa	
Metal staples	4.68	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=aluminium+-+nails&unit_type=Weight&access_type=public&data_version=%5E23	aluminium - nails ecc - total EU
Mineral oil	1.401	[kgCO ₂ eq/kg]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - mineral oil
Mix of wax and accelerator	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E20	organic compounds
Paper	1.3	[kgCO ₂ eq/kg]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - paper
Paperboard	0.62	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=cardboard&unit_type=Weight&access_type=public&data_version=%5E24	card board
Plastic bags	8.21	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=plastic+bag&data_version=%5E20	plastic bags and film
Plastic film	2.916	[kgCO ₂ eq/kg]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic film
Plastic pin	3.354	[kgCO ₂ eq/kg]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic rigid
Plastic profile	2.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=rubber+Synthetic&unit_type=Weight&access_type=public&data_version=%5E23	synthetic rubber
Plastic pultrab	2.916	[kgCO ₂ eq/kg]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic film
Plastic strip	3.354	[kgCO ₂ eq/kg]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - average plastic rigid
Plastic tape	6.032	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?access_type=public&unit_type=Weight&search=joint+sealing&data_version=%5E23	joint sealing butyl tapes
Plastic trim	2.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=rubber+Synthetic&unit_type=Weight&access_type=public&data_version=%5E23	synthetic rubber
Polymer - AEM acrylic	3.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=rubber+Synthetic&unit_type=Weight&access_type=public&data_version=%5E24	synthetic rubber
Polymer - chlorobutadiene	4.057	[kgCO ₂ eq/kg]	from Arlameo Deutschland GmbH	
Polymer - EPDM	2.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=rubber+Synthetic&unit_type=Weight&access_type=public&data_version=%5E24	synthetic rubber
Polymer - epichlorohydrin	2.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=rubber+Synthetic&unit_type=Weight&access_type=public&data_version=%5E25	synthetic rubber
Polymer - natural rubber	2.7	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=natural+rubber&unit_type=Weight&access_type=public&data_version=%5E23	natural rubber
Polymer - NBR	2.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=rubber+Synthetic&unit_type=Weight&access_type=public&data_version=%5E24	synthetic rubber
Polymer - PVC	2.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=rubber&data_version=%5E20	synthetic rubber
Polymer - styrene-butadiene	2.898	[kgCO ₂ eq/kg]	from Versalis Spa	
Polymer - thermoplastic	2.547	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=rubber+Synthetic&unit_type=Weight&access_type=public&data_version=%5E24	synthetic rubber
Salts	0.92	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=nitrate&data_version=%5E23	potassium nitrate
Sealant	6.032	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?access_type=public&unit_type=Weight&search=butyl&data_version=%5E23	joint sealing tape butyl
Sealant	0.032	[kgCO ₂ eq/kg]	from Di Ver Service Srl	
Silicon plastic profile	6.858	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?access_type=public&unit_type=Weight&search=plastic+profile&data_version=%5E20	silicone plastic profile
small chemicals - accelerator	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E18	organic compounds
small chemicals - activator	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E19	organic compounds
small chemicals - anti-aging agent	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E20	organic compounds
small chemicals - anti-aging agent	2.8	[kgCO ₂ eq/kg]	from Lanxess Srl	
small chemicals - anti-aging agent	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	inorganic compounds and basic chemicals
small chemicals - blowing agent	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E19	organic compounds
small chemicals - CaCO ₃	0.01	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=calcium&unit_type=Weight&access_type=public&data_version=%5E20	calcium carbonate
small chemicals - cellulose fibers in EPDM	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E19	organic compounds
small chemicals - functionalizer	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E20	organic compounds
small chemicals - MgO	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	inorganic compounds and basic chemicals
small chemicals - peroxide	3.58	[kgCO ₂ eq/kg]	from Nouryon Functional Chemicals B.V.	
small chemicals - peroxide	1.13	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=peroxide&data_version=%5E20	hydrogen peroxide
small chemicals - plasticizing agent	1.7	[kgCO ₂ eq/kg]	from Lanxess Srl	
small chemicals - plasticizing agent	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E17	organic compounds
small chemicals - processing aid	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E18	organic compounds
small chemicals - retarder	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E19	organic compounds
small chemicals - siliceous powder	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	inorganic compounds and basic chemicals
small chemicals - siliceous white filler	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	inorganic compounds and basic chemicals
small chemicals - vulcanizing agent	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E19	organic compounds
small chemicals - wax	1.9	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?unit_type=Weight&access_type=public&search=organic&data_version=%5E20	organic compounds
small chemicals - white filler	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	inorganic compounds and basic chemicals
small chemicals - ZnO	5.9	[kgCO ₂ eq/kg]	from Lanxess Srl	
Sodium hypochloride	2	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?search=chemicals&unit_type=Weight&access_type=public&data_version=%5E23	inorganic compounds and basic chemicals
Tape	6.032	[kgCO ₂ eq/kg]	https://www.climatq.io/data/explorer?access_type=public&unit_type=Weight&search=joint+sealing&data_version=%5E23	joint sealing butyl tapes
Wooden pallet	0.269	[kgCO ₂ eq/kg]	UK Government GHG Conversion Factors for Company Reporting 2025	sheet 'Material use' - construction wood

Supplier name	Material name	Emission factor (kgCO ₂ e/kg)
ARANIA S.A	LAMIERINO GREZZO mm.61 x 0,47	2.707
ARANIA S.A	LAMIERINO GREZZO FE 50 mm.33 x 0,55	2.707
ARANIA S.A	LAMIERINO GREZZO FE 50 mm.66 x 0,55	2.707
Arlanxeo Deutschland GmbH	BAYPREN 215 (44/56)	4.057
Arlanxeo Deutschland GmbH	BAYPREN 510 MV 45/55	4.057
Arlanxeo Netherlands B.V.	KELTAN 3973	3.24
Arlanxeo Netherlands B.V.	KELTAN 4869C	2.583
Arlanxeo Netherlands B.V.	KELTAN 6160 D	3.319
Arlanxeo Netherlands B.V.	KELTAN 6471	3.513
Arlanxeo Netherlands B.V.	KELTAN 7752C	2.704
Arlanxeo Netherlands B.V.	KELTAN 8570C	2.995
BFC Fahrzeugteile GmbH	LAM.ACCIAIO DC04 C590MARL 1P BFC	0.2548
BFC Fahrzeugteile GmbH	LAMIERINO 32x0,55 mm BFC	0.21303
BFC Fahrzeugteile GmbH	LAMIERINO FERRO STIRATO 37x0,50 BFC	0.20728
BFC Fahrzeugteile GmbH	LAMIERINO FLEX BAND 34x0,47 - VOLVO	0.25155
Cabot Switzerland GmbH	CARBON BLACK SPHERON 6000 SILO	3.27
Cabot Switzerland GmbH	PUREX LS 35 - SPHERON 4000	3.27
Cooper Standard Automotive Italy	KELTAN 7752C	2.704
DI.Ver.Service S.R.L.	SIGILLANTE GRIGIO 645010Q(non inf.)F.Blu	0.032
FILMAR SRL	LAM Filo[33x0,76][Pick31 2+7+2F]Hope	0.14
FILMAR SRL	LAM Filo[40x0,75][Pick27 2F+6+2F]Mabiel	0.14
FILMAR SRL	LAM Filo[40x0,76][Pick31 3+6+3F]Mabiel	0.14
FILMAR SRL	LAM.FILO PAR.MM.26X0,76 SCHLEGEL	0.14
FILMAR SRL	LAMIERINO FILO 26MM TRATT.PLASMA FILMAR	0.14
FILMAR SRL	LAMIERINO FILO PARALL. MM 29x0,76	0.14
FILMAR SRL	LAMIERINO SAIFLEX MM.18 X 0,75	0.14
FILMAR SRL	LAMIERINO SCHLEGEL mm.31X0,76 - 8 FILI	0.14
FILMAR SRL	LAMIERINO SCHLEGEL mm.37 X 0,76 LATEX	0.14
Interbusiness S.r.l.	INTERCURE n.1 DF/CURATIVE HDMC DF 25 kg	8.8
KETTLITZ-CHEMIE GMBH und CO. K	KEZADOL GR - INNOVOX FG - KG 5	0.0221
KETTLITZ-CHEMIE GMBH und CO. K	KEZADOL GR-INNOVOX FG-CALOXOL CP2 - 2kg	0.0221
Lanxess S r l	AFLUX 42 S (possibile utilizzo anche M)	1.7
Lanxess S r l	NAUGARD Q-VULKANOX HS/LG (AGERITE-TMQ)	2.8

Lanxess S r l	ZnO AKTIV	5.9
Marcegaglia Carbon Steel Spa	LAMIERINO GREZZO mm.52 x 0,47	1.3545
Marcegaglia Carbon Steel Spa	LAMIERINO GREZZO mm.61 x 0,47	1.3545
Marcegaglia Carbon Steel Spa	LAMIERINO GREZZO FE 50 mm.33 x 0,55	1.3545
Marcegaglia Carbon Steel Spa	LAMIERINO GREZZO FE 50 mm.66 x 0,55	1.3545
Momentive Performance Material	coating WSC 1042 monocomp.art. nr. 94446	2.38
Momentive Performance Material	COATING WSC 4029 AC	2.89
Momentive Performance Material	WSC 4029 component B Reticolante	7.81
Momentive Performance Material	WSC 4029 component D	10.3
Nouryon Functional Chemicals B.V.	RETIC BIS 40CC	3.58
Orion Engineered Carbons GmbH	CARBON BLACK N550/HS45/SSO SILO	4.079
Orion Engineered Carbons GmbH	CARBON BLACK N772 SRF CORAX REGAL SILO	4.079
Orion Engineered Carbons GmbH	CARBON BLACK SPH.5000A / HS25 SILO	4.079
Orion Engineered Carbons GmbH	CARBON BLACK SPHERON 6000 SILO	4.079
Sojitz Europe GmbH – Milan bra	CSM TS-530	6.14
STG Stanztechnik Gesellschaft	LAM. 37 X 0,5 MM DC01 C390 EN10139	0.029
STG Stanztechnik Gesellschaft	LAM.ASYM. MM.35X0,47 D40235047C	0.029
STG Stanztechnik Gesellschaft	LAMIERINO FLEX A051 35x0,50	0.029
Ver Plast srl	NEW EVASIL 1K NERO 18216 V2 (x520)	15.03
VERSALIS SPA	DUTRAL CO 054 - C/D	2.898
VERSALIS SPA	DUTRAL TER 4033 C/D	2.898
VERSALIS SPA	DUTRAL TER 4038	2.898
VERSALIS SPA	DUTRAL TER 4044 C/D	2.898
VERSALIS SPA	DUTRAL TER 4049	2.898
VERSALIS SPA	DUTRAL TER 4535 C/D	2.898
VERSALIS SPA	DUTRAL TER 6537 C/D (EX537 E2)	2.898
VERSALIS SPA	EUOPRENE 3360 - C/D PED.KG. 1200	2.898
VERSALIS SPA	EUOPRENE N 3345 GRN C/D (EX FC)	2.898
VERSALIS SPA	SBR 1502 - POLIMERI EUROPA / PETROFLEX	2.898
VERSALIS SPA	SBR-EUOPRENE HS 630 (ex hs 65)	2.898
ZINCOL OSSIDI S.p.A.	ZnO NEIGE A	0.5958
ZINCOL OSSIDI S.p.A.	ZNO Verde	0.6002