

32nd CIRP Conference on Life Cycle Engineering (LCE 2025)

LCA studies to support a waste treatment company in the context of the circular economy

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Abstract

Starting from 2022, the RMB S.p.A. company has decided to use the Life Cycle Assessment (LCA) methodology to quantify the environmental impacts associated with its activities. The company is active in the circular economy, since it treats different types of waste (e.g. end-of-life vehicles and bottom ash from waste-to-energy plants) with the main objective of extracting ferrous and non-ferrous metals for their subsequent recycling. The company first requested to analyze its carbon footprint for the years 2022 and 2023 in order to undertake short and long-term greenhouse gases reduction commitments. The assessment was carried out in accordance with the ISO 14064-1:2018 standard, including direct and indirect emissions resulting from imported energy consumption. Some improvement actions were then suggested (i.e. the purchase of certified renewable electricity and an optimization of energy consumption) and their impact reduction in terms of carbon footprint was estimated. The company also requested a product LCA to understand the impacts associated with one of its most representative products, i.e. the so-called *Ferro Proler* produced from end-of-life vehicles, which is used as a raw material in steel mills. The paper will describe the studies conducted for the company to support its path towards improved circularity and environmental sustainability.

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Peer-review under responsibility of the scientific committee of the International Academy for Production Engineering (CIRP)

Keywords: Ferrous metals recovery; product Life Cycle Assessment (LCA); organizational Carbon Footprint; Proler

1. Introduction

Waste management is a complex matter, with a wide range of consequences that involve stakeholders and the society. In the last decades, the Life Cycle Assessment (LCA) methodology has gained wide acceptance as a tool to support waste management planning and policy-making from the environmental point of view, at the local, national and international level [1,2].

This paper presents an application of the LCA methodology to representative products and services provided by RMB S.p.A., a company located in Northern Italy (Brescia, Lombardy region) specialized in the treatment and the recovery of hazardous and non-hazardous waste such as hulks of end-of-life vehicles and engines, materials containing metals from urban waste sorting, bottom ash from waste-to-energy (WTE) plants, and inert materials from the excavation of earth and

rocks. In recent years, the company has been continuously striving to improve its role in the circular economy and in the conservation of natural resources. In this context, the LCA methodology was selected by RMB to understand its overall impact both on-site and across the value chain and to promote the compatibility between productivity and environmental protection. To this purpose, an Organizational Carbon Footprint has been set to quantify the current direct and indirect greenhouse gases (GHGs) emissions of the company, aiming at defining a reduction plan. In parallel, LCAs on the most representative products of the company are ongoing with the aim to identify the main hotspots across their production and to communicate their impacts profile to the customers.

This paper presents the first results of the Organizational Carbon Footprint and the product LCA performed for one of the main products, the so-called *Ferro Proler*.

2. Materials and methods

2.1. LCA of Ferro Proler

In the year 2021, 1.17 million Italian vehicles got de-registered becoming waste (end-of-life vehicles - ELVs), with a rate of reuse/recycling equal to 84.3% of the average weight of the vehicles [3,4].

In the ELVs recycling process, the recovered metallic fractions represent more than 70% of the total weight of the ELV waste [5]. They are classified as secondary raw products, ceasing to be waste, when they fulfil the criteria of the 333/2011/EC Regulation. Among these metallic fractions, the *Ferro Proler* (a fraction of ferrous metals with a typical size of single pieces ranging from 5 to 150 mm) is particularly relevant in terms of weight.

The environmental performances of the *Ferro Proler* are analyzed in this study with a life cycle perspective.

Differently from recent LCAs [5,6,7,8] focusing on the quantification of environmental impacts related the overall management of the ELVs and its potential improvement (waste perspective), this LCA is performed on a specific product obtained from the ELVs treatment. To the authors' knowledge, this is the first LCA focused on the ferrous metals recovered from ELVs. Previous works about the ferrous fraction from ELVs evaluated some aspects of the circular economy, such as quality issues and perspective in metals recycling, without performing a life cycle assessment [9,10,11].

This LCA can be useful for RMB but also for steel mills that use *Ferro Proler* as secondary raw material, in order to correctly evaluate the performance of their final products.

The *Ferro Proler* production process performed by RMB (Figure 1) starts with a first step of volumetric reduction by means of shredders, followed by a grinding stage with hammer mills. The waste is then divided into two main fractions (the

heavy and the light one), by means of an aeraulic separation, and both fractions are subjected to a magnetic separation for the recovery of the *Ferro Proler*. After that, the light fraction, mainly composed of plastics and rubbers, classified as a waste, is partly sent to landfill and partly to energy recovery in an Italian cement kiln or in a WTE plant after a mechanical pretreatment performed in Italy or in Austria. The heavy fraction, classified as a co-product with a positive economic value considering that the company typically sells it, is sent to other sections inside the facility for the recovery of the non-ferrous metals still contained. An air treatment line equipped with cyclones, scrubbers, bag filters, and a treatment with activated carbon completes the analyzed section.

The LCA performed on this product is a partial LCA since it excludes its transportation from RMB to the steel mills, and its use stage and end-of-life. The impacts of the product were calculated considering 1 tonne of *Ferro Proler* as the declared unit (DU).

Since *Ferro Proler* is produced from a waste (ELVs), according to the LCA modelling guidelines of the International EPD® System, version 4.0 [12], based on the *polluter pays* principle, the stages included in the system boundary (Figure 2) are the ones occurring from the moment the ELVs acquires a positive economic market value, i.e. after the depollution stage at the car wreckers in the current Italian context. On the contrary, the environmental loads of the previous processes shall be attributed to the product system generating the waste (out of the scope of this analysis). The boundary of the analyzed system therefore starts from the gate of the car wreckers and ends at the gate of the RMB facility (Figure 2).

The stages of ELVs transportation from the car wreckers to the RMB facility and their treatment carried out there were described with primary data, collected for the year 2023 and reported in Table 1.

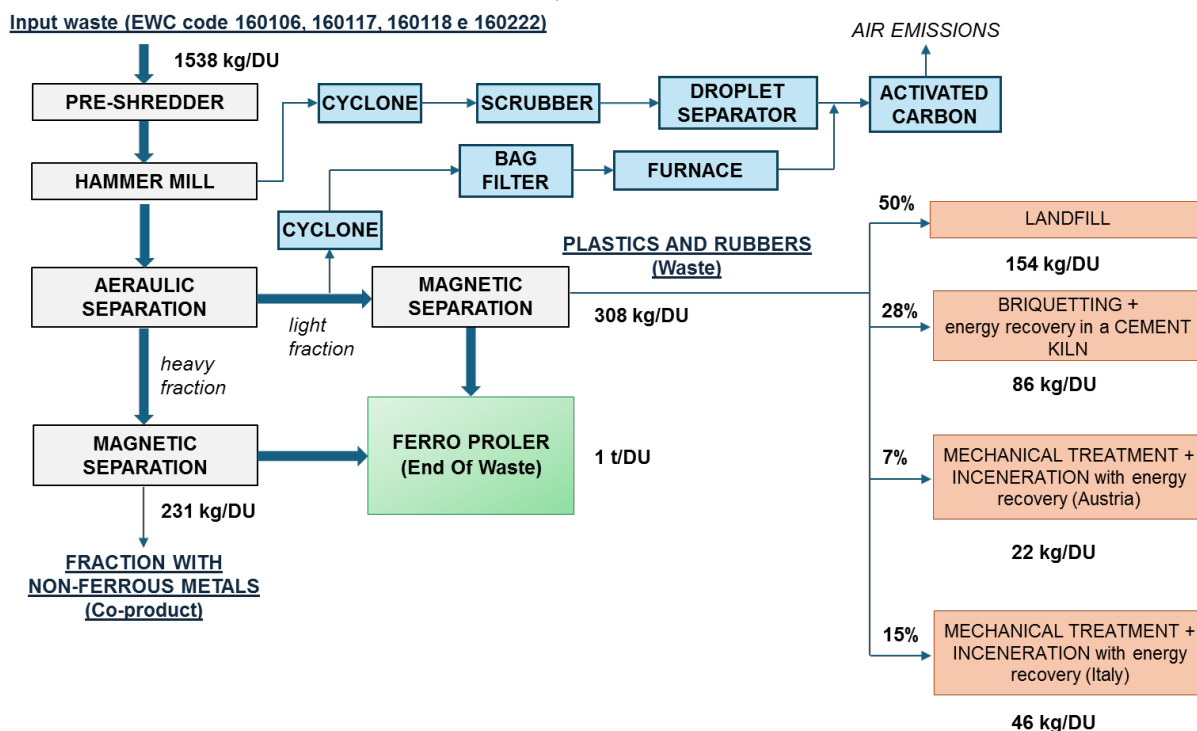


Fig. 1. Process scheme and mass balance related to the production of 1 tonne of *Ferro Proler* by RMB. DU = declared unit; EWC = European waste catalogue.

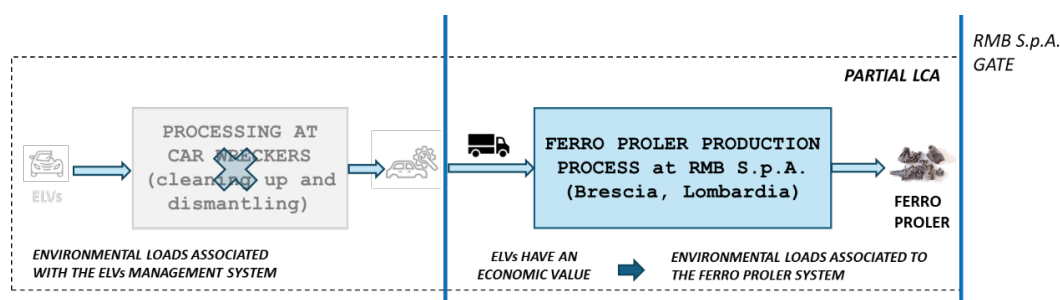


Fig. 2. System boundary for the partial LCA associated to the *Ferro Proler* according to the International EPD® System guidelines (version 4.0). ELVs = end-of-life vehicles.

Table 1. Main inventory data (primary data related to the year 2023) used in the LCA describing the production of 1 tonne of *Ferro Proler*. DU = declared unit; EF = emission factor; ELVs = end-of-life vehicles; WTE = waste-to-energy.

Transportation of ELVs to RMB facility	Amount per DU
By lorry (> 32t; 49% Euro≤3, 4% Euro4, 3% Euro5, 44% Euro6; [13])	444 km×0.98 t
By freight ship	15 km×0.98 t
Treatment at RMB	Amount per DU
Electricity (95.6% Italian grid, 4.4% self-production by a photovoltaic plant)	22.4 kWh
Activated carbon (90% regenerated, 10% virgin)	227.9 g
Liquefied petroleum gas (supply and combustion)	Amount of fuel: 224.2 g Fossil CO ₂ : 674.4 g (EF: 65.6 g/MJ) [14] Fossil CH ₄ : 10.3 mg (EF: 1.0 mg/MJ) [14] N ₂ O: 20.6 mg (EF: 2.0 mg/MJ) [14]
Diesel (supply and combustion)	Amount of fuel: 174.1 g Fossil CO ₂ : 552.0 g (EF: 73.5 g/MJ) [15] Fossil CH ₄ : 225.0 mg (EF: 30.0 mg/MJ) [15] N ₂ O: 28.2 mg (EF: 3.75 mg/MJ) [15]
Tap water	8 L
Shredder hammers (primary steel, produced in China)	147.2 g
Wastewater to an external treatment plant	2.5 L
Waste fraction of plastics and rubbers	198.4 kg of which: 50% to landfill (260 km); 28% to cement plant for energy recovery (110 km); 22% to mechanical pretreatment (196 km) and then to WTE plant (166 km)

Primary data in Table 1 were obtained after applying an economic allocation to subdivide the impact of the ELVs supplying and treatment between the main product, *Ferro Proler* (64% of the load), and the co-product (36% of the load), represented by the heavy fraction with non-ferrous metals inside. The allocation was performed according to the average price of the two products calculated over a period of five years (2018-2023).

The plastics and rubbers fraction (198 kg/DU) is instead classified as waste considering that RMB pays for its management regardless of the final destination and, for this reason, the environmental loads associated to its treatment

were included in the assessment, according to the *polluter pays* principle [12]. In detail, each treatment of this fraction (landfilling, combustion in a cement kiln or in a WTE plant after a mechanical pretreatment) was modelled according to:

- the specific waste composition (84% plastics and 16% rubbers), the average proximate analysis, and the average elemental analysis provided by RMB for the year 2023 in relation to the generated waste;
- the operating procedures of the treatment plants which generally manage the plastics and rubbers industrial waste in Northern Italy.

Background production processes (e.g. production of electricity or production of fuels) were modeled using datasets from the LCA ecoinvent database, version 3.9.1 (allocation cut-off classification approach).

For the impact assessment, the 16 impact categories from the Environmental Footprint (EF) Life Cycle Impact Assessment Method, version 3.1 were selected [16,17]: acidification (A), climate change (CC), freshwater ecotoxicity (FEC), particulate matter (PM), marine eutrophication (ME), freshwater eutrophication (FE), terrestrial eutrophication (TE), human toxicity, cancer (HTC), human toxicity, non-cancer (HTNC), ionizing radiation, human health (IR), land use (LU), ozone depletion (OD), photochemical ozone formation (POF), resource use, fossils (RUF), resource use, minerals and metals (RUMM), and water use (WU). Results were calculated both just after the characterization step and after the application of the normalization and weighting factors of the EF method [18,19]. The SimaPro software (version 9.5, PRé Sustainability, Amersfoort, The Netherlands) supported the data processing.

2.2. Organizational Carbon Footprint

The Organizational Carbon Footprint consisted in the quantification and reporting of the GHGs emission at the organization level related to the main facility of the company, located in Brescia (Lombardy, Italy). The analysis was performed according to the principles and the requirements of the standard ISO 14064-1:2018 [20] and included the following types of GHGs emissions:

- direct GHGs emissions (also known as category 1 emissions). They consist of: i) emissions from stationary combustion (office heating with diesel boilers, operation of diesel generators, combustion of liquefied petroleum

gas for a drying process involved in some waste treatment sections); ii) emissions from mobile combustion from vehicles and trucks owned by the company or leased; iii) fugitive emissions due to leakage of refrigeration gases by heat pumps and air conditioners; iv) emissions due to self-production of electricity by an owned photovoltaic (PV) plant;

- indirect GHGs emissions from imported energy (also known as category 2 emissions). They are due to the consumption of electricity imported from the Italian grid. The quantification was performed according to both the location-based approach and the market-based approach. The location-based approach reflects the average emission intensity of the grid on which the energy consumption occurs using mostly national-grid emission factor data; the market-based approach reflects emissions from electricity that companies have purposefully chosen from contractual instruments.

The quantification was performed for the reference year 2023 and included GHGs emissions of CO₂ (fossil and biogenic), CH₄ (fossil and biogenic), N₂O, and some HFCs (hydrofluorocarbons) and HFOs (hydrofluoroolefins) involved as fugitive emissions from the refrigeration equipment. For each GHG, the value of the Global Warming Potential (GWP) over a period of 100 years was used, based on the Sixth Intergovernmental Panel on Climate Change (IPCC) report [21]. For each source of emission, emission factors provided by ISPRA (the Italian Superior Institute for the Protection and the Research on the Environment) were selected [22], in order to be aligned with the current Italian context, where the facility is located.

3. Results and discussion

3.1. LCA of *Ferro Proler*

Table 2 reports the indicator values associated to the production of 1 tonne of *Ferro Proler* from the treatment of ELVs for each analyzed impact category, while Figure 3 shows the corresponding contribution analysis.

The most important environmental loads of the *Ferro Proler* production are generally associated to stages performed outside the RMB facility. In 6 impact categories (FEC, PM, LU, OD, RUF, and RUMM), the most important contribution is in fact the road transportation of the ELVs from the car wreckers to the treatment facility (average trip of 444 km). This contribution ranges from 65% to 77% and it is due to: i) the consumption of diesel as fuel (for FEC, OD, and RUF impact categories); ii) the road production and maintenance (for LU); iii) the particulate air emission from tires and brakes (for PM); iv) the lorry production and maintenance (for RUMM). Moreover, in 9 impact categories (A, CC, ME, FE, TE, HTC, HTNC, POF, and WU) the most important contribution (36%-82%) is the final treatment of the plastics and rubbers waste fraction. Most of the impact is attributable to the air emissions of its combustion in the cement kiln and in the WTE plant (especially fossil CO₂, NO_x, Cd, and Hg) that play an important role in all the cited categories except for ME, FE, and WU. In ME, the

environmental load is mainly due to the leachate production and treatment during landfilling. In FE, the most relevant contribution is related to the final landfilling of the solid residues (fly ash and air pollution control residues) from the WTE plant. The consumption of water for the operation of the WTE plant results the main burden in WU.

Only in the IR impact category, 42% of the environmental load is associated to the production process of *Ferro Proler* at RMB facility, mainly due to the consumption of electricity from the Italian grid. A non-negligible contribution is also visible in FE (24%) and WU (37%), always due to the electricity demand of the process.

Table 2. Results of the characterization step given per declared unit (1 tonne of *Ferro Proler*).

Impact category	Unit	Impact
Acidification (A)	mol H ⁺ eq.	5.03E-01
Climate change (CC)	kg CO ₂ eq.	3.12E+02
Freshwater ecotoxicity (FEC)	CTUe	4.60E+02
Particulate matter (PM)	disease incidence	6.70E-06
Marine eutrophication (ME)	kg N eq.	4.22E-01
Freshwater eutrophication (FE)	kg P eq.	9.26E-03
Terrestrial eutrophication (TE)	mol N eq.	2.31E+00
Human toxicity, cancer (HTC)	CTUh	6.48E-08
Human toxicity, non-cancer (HTNC)	CTUh	2.13E-06
Ionizing radiation (IR)	kBq U-235 eq.	2.17E+00
Land use (LU)	Pt	8.77E+02
Ozone depletion (OD)	kg CFC11 eq.	1.54E-06
Photochemical ozone formation (POF)	kg NMVOC eq.	7.08E-01
Resource use, fossils (RUF)	MJ	1.01E+03
Resource use, minerals and metals (RUMM)	kg Sb eq.	1.84E-04
Water use (WU)	m ³ deprived	1.18E+01

The normalization and weighting stages return a single impact score of 14.6 milli Point (mPt) per DU. In terms of process contribution, 66% of the overall score is due to the final treatment of the plastics and rubbers waste fraction, 29% to the ELVs transportation phase, and the remaining 5% is associated to the treatment at RMB. Concerning the impact categories contribution, the burden is mainly associated to CC (59% of the single score), followed by RUF (9%), PM (7%), and POF (6%).

The burden of the transportation can be reduced by optimizing the logistics in terms of transported load, number of travels, way of transport, fuel type, and travelled distance.

For the management of plastics and rubbers waste, the major challenge is the identification of a more sustainable treatment. Developing new technologies at the commercial scale to perform a material recovery in place of energy recovery is of strict importance. Some studies in the existing literature explored pilot-scale processes to convert such waste into aggregates for asphalt or concrete used in non-structural applications [23, 24] or to separate the mixture into the individual plastic polymers by using a sinking floatation

technique [25]. In this context, RMB is testing a treatment of the plastics and rubbers waste for the production of a secondary reduction agent, which can substitute metallurgic coke in electric arc furnaces.

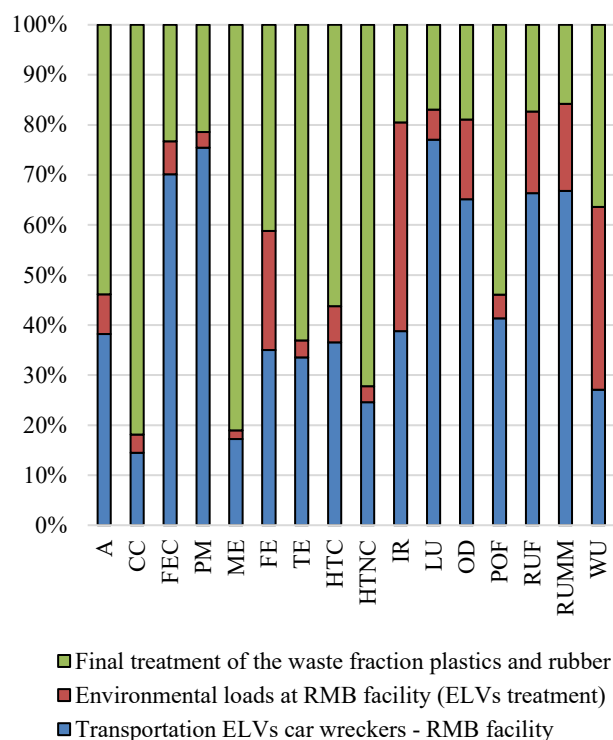


Fig.3. Contribution analysis of the LCA results for the production of 1 tonne of *Ferro Proler*.

3.2. Organizational Carbon Footprint

According to the Organizational Carbon Footprint analysis, the overall GHGs emission, intended as the sum of the category 1 and category 2 emissions, is equal to 15.24 kgCO₂ eq. per tonne of treated waste if the location-based approach is applied (Table 3). The market-based approach results in a 52% increase in the emission (23.12 kgCO₂ eq. per tonne of treated waste), since the company is currently not purchasing any amount of certified renewable energy.

Regarding the emission sources (Table 3), the most important contribution (68% of the total emission for the location-based approach and 79% for the market-based approach) is the indirect emission from the imported electricity (emission of category 2). The contribution of the mobile combustion is also relevant, being between 19% and 29% of the total emission.

Starting from this assessment, a further analysis was performed to support the company in the definition of specific actions for the reduction of its GHGs emission in the long-term period. The focus was on the consumption of electricity, whose purchase from the Italian grid resulted the most important contribution to the impact (Table 3). The effect of a prevention measure was firstly investigated. By reducing the electricity consumption in the facility (goal achievable implementing an optimization and renewal of the waste treatment equipment and staff training), the overall

GHGs emission (sum of categories 1 and 2) would be reduced by 6.8% (location-based approach) or 7.9% (market-based approach) for every 10% reduction of the electric request. As a second step, an alternative way of electricity production was investigated. Since no more place is available for the installation of additional photovoltaic power on site, the purchase of certified renewable energy was investigated. It is important to underline that this action influences only the calculation performed when applying the market-based approach. The final outcome is that for each 10% increase in the purchase of certified renewable electricity, the overall GHGs emission (sum of categories 1 and 2, market-based approach) would be reduced by 8.0%. With a 100% purchase, the final GHGs emission would be equal to 4.91 kg CO₂ eq. per tonne of treated waste (i.e. -79% compared to the current value in Table 3).

Table 3. Accounting of the GHGs emissions (total value and value subdivided by category 1 and category 2) for the RMB company (facility of Brescia) in the year 2023 according to the location and market-based approaches. C = category; GHGs = greenhouse gases.

GHGs emission category	Location-based	Market-based
C1: stationary combustion	0.39 kg CO ₂ eq./t (2.5%)	0.39 kg CO ₂ eq./t (1.7%)
C1: mobile combustion	4.43 kg CO ₂ eq./t (29.1%)	4.43 kg CO ₂ eq./t (19.2%)
C1: refrigerant leakage	0.09 kg CO ₂ eq./t (0.6%)	0.09 kg CO ₂ eq./t (0.4%)
C1: self-production of PV electricity	0 kg CO ₂ eq./t	0 kg CO ₂ eq./t
C2: imported electricity (Italian grid)	10.33 kg CO ₂ eq./t (67.8%)	18.21 kg CO ₂ eq./t (78.8%)
Total (C1+C2)	15.24 kg CO₂ eq./t	23.12 kg CO₂ eq./t

4. Conclusions

This paper reports the main outcomes of the first life cycle assessments commissioned by RMB S.p.A., a company specialized in the treatment and the recovery of hazardous and non-hazardous waste in Northern Italy. The main goal of these analyses was to make the company conscious of its environmental impacts and then being able to define a plan to improve its performance from an environmental point of view.

The first analysis was a product LCA, focused on one of the main representative products of the company, i.e. the *Ferro Proler* produced by the treatment of ELVs. It was a partial LCA where the system boundary was defined as cradle-to-company gate and the evaluation was based on a wide spectrum of impacts categories on the environment, on the human health, and on resources consumption. The results show that the main contributions to the impacts are the activities performed in the system but outside the RMB facility. In detail, depending on the impact category, the most relevant contribution results either the transportation of ELVs from car wreckers to the treatment facility or the final treatment of the plastics and rubbers waste fraction generated during the *Ferro Proler* production process. An optimization of the logistics and the implementation of new treatment technologies for the recycling of the plastics and rubbers fraction are of paramount importance.

The second analysis consisted of an Organizational Carbon Footprint. It was performed accordingly to the ISO 14064:2018 standard and it included the direct GHGs emissions (category 1) and the indirect GHGs emissions from imported energy (category 2). The resulting overall GHGs emission, for year 2023, was 15.24 kgCO₂ eq. per tonne of treated waste when applying the location-based approach, and 23.12 kgCO₂ eq. per tonne of treated waste when applying the market-based approach. Since the consumption of electricity from the Italian grid plays a crucial role, different prevention and reduction strategies were defined and tested, such as the reduction of the consumption at the source and the purchase of certified renewable energy.

This study is part of a wider research activity related to an environmental assessment of the RMB waste treatment processes according to the principles of circular economy and to the life cycle approach. New LCAs on other representative products of the company, for example the recovered non-ferrous metals, will be implemented by applying a similar modeling approach.

Acknowledgments

The study was financially supported by the RMB S.p.A. company.

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