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The economic assessment of the environmental and social impacts generated by a light packaging and bulky waste sorting and treatment facility in Spain: a circular economy example

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Abstract

Background: The waste sorting and treatment facilities play an important role in the management of Municipal Solid Waste (MSW), as they permit the materials to be prepared for their later reuse and recycling. The aim of this work is to carry out a technical–economic analysis of a sorting and treatment facility (STF) of light packaging and bulky waste in Gavà-Viladecans, Barcelona, Spain, by means of a methodology based on a social Cost–Benefit Analysis (sCBA), as it studies the private impacts and externalities (impacts related with environmental and social aspects) to determine the Total Benefit (the difference between revenues and costs) generated by the facility to decide whether it is operationally and economically profitable.

Results: The key point of the case study is the identification, frequency, quantification and monetary valuation of the impacts generated by the facility, as well as the sale of materials, the CO_2 emissions and the increase in the availability of materials, among others. By applying the methodology, it has been possible to show that this facility is operationally ($B_P = 7.06$ €/ton) as well as economically ($B_T = 55.72$ €/ton) profitable.

Conclusions: The plant is highly profitable from a social and environmental perspective, as can be seen from the monetary valuation of the externalities. The STF fulfils a primordial function for the city of Barcelona and its environs, as it treats waste for later reuse and recycling, preventing waste from being sent to landfills and reducing the CO_2 emissions from the extraction of virgin raw materials, thereby helping to reach the objectives set by the European Commission. Finally, this paper provides a guide for future researchers and decision makers interested in the economic analysis of MSW management systems.

Keywords: Technical–economic analysis, Recycling, Municipal Solid Waste, Externalities, Social cost–benefit analysis, Circular economy

Background

The circular economy emerges as an alternative to the current linear economy model, where materials and products are used for a short time and then are discarded, generally ending up in landfills, generating negative impacts (environmental and social) [1]. The circular economy is a production and consumption model that

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seeks to ensure that materials remain in the economy longer, reducing the use of virgin raw materials and the generation of waste and consequently reducing damage to society and the environment [2]. The circular economy is based on the durable design, maintenance, repair, reuse, remanufacturing, restoration and recycling of products [3].

In general, recycling is considered beneficial for the environment and the economy [4]. It mitigates the lack of resources by reducing the consumption of raw materials, reducing the amount of waste sent to landfills, and extending their useful working life. In addition, a decrease in the amount of waste sent to landfills and incinerators reduces ground, water and air pollution [5, 6]. Some countries suffer from a serious lack of raw materials and, in their case, waste represents a sure supply of materials, which in turn reduces their dependence on imported materials, leads to substantial energy savings and contributes to conserving the environment [7]. On the other hand, recycling allows significant economic savings, since it prevents that a large percentage of the value of the materials is lost to the economy after a short use, as in the case of plastic packaging materials, where it is estimated that approximately 95% of value is lost, that is, USD 80–120 billion annually, because these materials are discarded after a short time [8]. In addition, recycling avoids costs due to the extraction and production of new raw materials and costs due to landfilling or incineration of waste (i.e., payment of gate fees, environmental and public health damage costs).

The waste sorting plants play an essential role in MSW management, as they allow the materials to be prepared for their later reuse and recycling. On the other hand, these facilities promote the circular economy, and they allow to keep the resources in use for as long as possible, the maximum value extracted from them while in use by recycling products into the same or similar quality application, and product recovery and regeneration at the end of life [8, 9].

MSW management and material recovery in Barcelona

This article focusses on carrying out a technical–economic analysis of a waste sorting and treatment facility (STF), located in Gavà-Viladecans, Barcelona, Spain. The facility provides a waste management service to the metropolitan area of Barcelona (AMB) and promotes the circular economy. The AMB with an area of 636 km^2 and more than 3.2 million inhabitants is one of the largest metropolitan areas in Europe [10]; it is composed of 36 municipalities, including Barcelona city, Badalona and Sant Adrià de Besòs. In 2017, 1,452,414 tons of MSW were generated by the AMB, corresponding to 1.22 kg/day per inhabitant. Specifically, 43,488 tons of light packaging waste were collected through the yellow containers and 71,469 tons of bulky waste were collected through the green points.

This facility analyzed is composed of two plants, one for light packaging waste treatment and the other for bulky waste treatment, as can be seen in Fig. 1. This facility is one of the three light packaging waste sorting and treatment facilities and the only bulky waste sorting and treatment facility in the AMB. This facility is managed by a public company belonging to the Ajuntament de Barcelona (Barcelona City Council), and it was established in 1992 and built on industrial-zoned land, with a surface

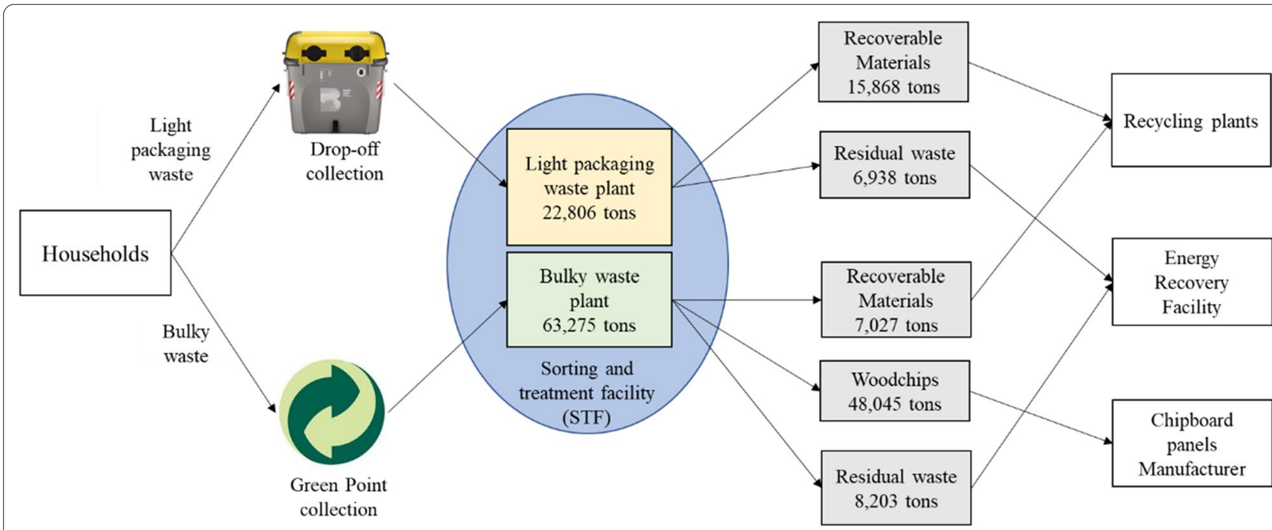

Fig. 1 Flowchart of the MSW treated at the STF in 2017. Source: authors' elaboration

area of 58,600 m^2, and is surrounded by a mixture of industrial plants and agricultural areas [11].

The light packaging waste plant carries out the sorting and treatment of light packaging waste obtained from the yellow containers, dealing with approximately 22,000 tons/year. This plant sorts different types of light packaging, such as plastic packaging (HDPE, PET, LDPE), metal packaging (aluminium and steel) and carton packaging for food and drink. These materials are then sold to authorised recycling companies for the later manufacture of new packaging and materials [12]. The bulky waste plant carries out the treatment of bulky waste and wood recovered from the green points around the AMB. This plant deals with approximately 60,000 tons/year, recovering and sorting different types of waste such as wood, scrap, mattresses, plastic furniture, pressurised cans, among others. The wood is triturated to obtain chips, used mainly in the manufacture of chipboard for the furniture industry. Once separated, the rest of the waste is sold to authorised companies, always prioritising its recovery. The waste that cannot be materially recovered is sent to the Energy Recovery Facility for energy generation [12]. Figure 1 shows the amount of waste that was treated in 2017, as well as the amount of waste that was sold to different companies or sent to other facilities.

Literature review

In general, when waste management systems are evaluated, only the private or internal impacts such as costs and revenues related to the investment, operation and maintenance of the treatment plants are considered [13]. This may cause a bias against other options such as recycling, which from a purely financial point of view may be more expensive than dumping [14]. However, if we include the external costs and revenues or externalities (impacts related to environmental and social aspects) the results may change, favouring the adoption of options such as recycling, which has greater social and environmental advantages. Recycling waste means reducing the consumption of raw materials, leading to considerable energy savings and contributes to protecting the environment, as well as reducing the amount of waste sent to landfills, thereby increasing their useful life [6, 7].

There are several studies that focus on the economic analysis of recycling systems, generally concentrating on comparing them with the landfills. Some studies carry out the analysis by focussing on the private costs, as in Tonjes and Mallikarjun [15], who present a model of systems to determine whether the recycling programmes are cost-effective. This paper considers primarily the private costs (personnel, financial and fuel costs, among others). Lavee [16] studies whether the recycling systems are economically efficient, considering the cost savings from reducing the amount of waste sent to landfills as well as the private costs associated with the adoption of recycling systems. The results show that, for 51% of municipalities, adopting recycling would be efficient, even without taking the externalities into account. Da Cruz et al. [6] present the costs and benefits of recycling packaging waste in Portugal, studying the profitability of the invested capital (debt and equity) with respect to the financing of the assets destined to the recycling process and the cost savings from redirecting waste from refuse collection activities and relying less on landfills. The unit cost of selective waste collection and sorting is calculated as 204 €/ton collected.

Gradus et al. [17] compare the cost-effectiveness of two different treatment options, recycling and incineration, for plastic waste in the Netherlands, focussing mainly on the environmental impact of the CO_2 emissions. They show that the main benefit of recycling plastic is that it avoids the CO_2 which would otherwise be produced during incineration and the production of the virgin plastic material. Craighill and Powell [5] compare the environmental impacts of a recycling system with a system for dumping in landfills using the Life Cycle Evaluation (a combination of the Life Cycle Assessment and economic evaluation) and considering the costs relating to gas emissions, traffic accidents and congested roads. The results show that the recycling system generally works better than the landfills in terms of contribution to climate change, the effects of acidification and the nutrition of surface water.

Although several economic analyses have been carried out regarding different recycling systems in terms of the collection and sorting of waste, generally, the focus is on economic valuation of one specific impact or only some impacts of those systems; for example, studying the costs relating to the environmental impact of the CO_2 emissions. In general, these studies consider only private impacts or environmental impacts, without including social aspects such as the impact on quality of life, physical risks, and education. Furthermore, no previous studies have presented a model that considers and integrates various impacts generated by recycling systems.

The methodology used also allows researchers and decision makers to evaluate, in a simple way, the operational and economic profitability of a specific treatment facility while considering the most relevant impacts related to economic, social, and environmental aspects of recycling systems, allowing the evaluation of MSW management systems considering the sustainability principles and their three pillars. In addition, have a more complete vision of these systems and their effects on society, environment, and economy. It is considered that the current economic system does not take into account environmental and social costs to maximise profits. In general, while economic indicators such as investment or production are positive, environmental and social indicators are increasingly negative [18]. That is why it is important to change the traditional focus of profit-making companies and find a balance between economic, social and environmental aspects. Some authors note that environmental, social, and economic concerns must be integrated throughout decision-making processes to move towards development that is truly sustainable [19].

This article aims to determine and analyse several private and external impacts (positive and negative), thus providing a guide for future researchers and policy makers interested in the economic analysis of any MSW management system. This article addresses the issue of costs and revenues involved in a MSW sorting facility, which is a highly debated issue in terms of environmental impact but has the difference of considering and quantifying social costs such as physical risks, education, and quality of life, which makes the work have a novel contribution, with the potential to constitute a consultation document to establish a standard methodology on this topic.

Previously, Medina-Mijangos et al. [20] presented a methodology for the economic analysis of any kind of MSW's management system, where several impacts were listed and described. In addition, a case study was briefly presented to verify the applicability of the methodology; however, only a few impacts were valued monetarily. In the present paper, impacts related to environmental and social aspects are described in detail, quantified and valued monetarily for a specific context. The main aim of this case study is to determine the Total Benefit generated by the plant, taking several private and external impacts into account, which will then be identified, quantified and valuated monetarily; this will determine whether the plant is operationally and economically profitable.

The rest of the document is structured as follows: "Methods" section describes the methodology and how the data has been obtained and used. Then the results of the case study are presented and discussed in "Results and discussion". Finally, "Conclusions" contains the conclusions, as well as suggestions for future research.

Methods

The data used in this case study was obtained from public information available on the website of the company's group, which contains documents such as auditor's reports, annual accounts, sustainability reports and production data, as well as environmental studies carried out by the company and other bodies. The SABI database, which contains the financial information of Spanish and Portuguese companies, was also consulted [21]. The present case study focusses on the costs and revenues generated by the treatment facility in 2017.

The methodology conducted by [20] was adopted in this study. This research followed a method for the technical–economic analysis of MSW management systems based on a social Cost–Benefit Analysis (sCBA), as it evaluated the waste management systems and plants from the perspective of society as a whole, where the private and external costs and revenues (caused by environmental and social impacts) were considered [22]. The methodology is composed of seven steps which should be fulfilled, as shown in Fig. 2: (1) objective definition; (2) definition of scope study; (3) impacts of the project; (4) identification of the stakeholders; (5) study of the needs and financial possibilities; (6) aggregation of costs and revenues; and (7) sensitivity analysis.

Objective definition

The aim of this case study is to evaluate whether the STF is operationally and economically profitable, by determining if the Private Benefit (B_P) and Total Benefit (B_T) are greater than 0. The objective function to be optimised is shown in Eqs. (1) and (2):

$$B_P = \sum_{n=0}^{N} [(AVW_n{}^*SP) - (IC_n + OMC_n + FC_n + T_n)] \tag{1}$$

$$B_T = \sum_{n=0}^{N} [(AVW_n{}^*SP) - (IC_n + OMC_n + FC_n + T_n) + (PE_n - NE_n) - OC_n] \tag{2}$$

where AVW is the annual volume sold; FC is the financial costs; IC is the investment costs; N is the total project duration; n is the project year index ($n = 0, \ldots, N$); NE is the negative externalities; OC is the opportunity cost; OMC is the operational and maintenance costs; PE is the positive externalities; SP is the price of sale per volume unit; T is the taxes. Definitions about the elements of equations can be found in the supplementary material (Additional file 1: Table S1).

Definition of scope study

The STF is a public company which is part of a group belonging to the Ajuntament de Barcelona [24]. Its main activity is the sorting and treatment of the MSW of the AMB. This case study focusses on analysing the treatment of MSW at the STF, taking both the light packaging and bulky waste treatment processes into account, without considering the collection and transport of the waste, because these processes are realised by other companies. Only the processes and impacts

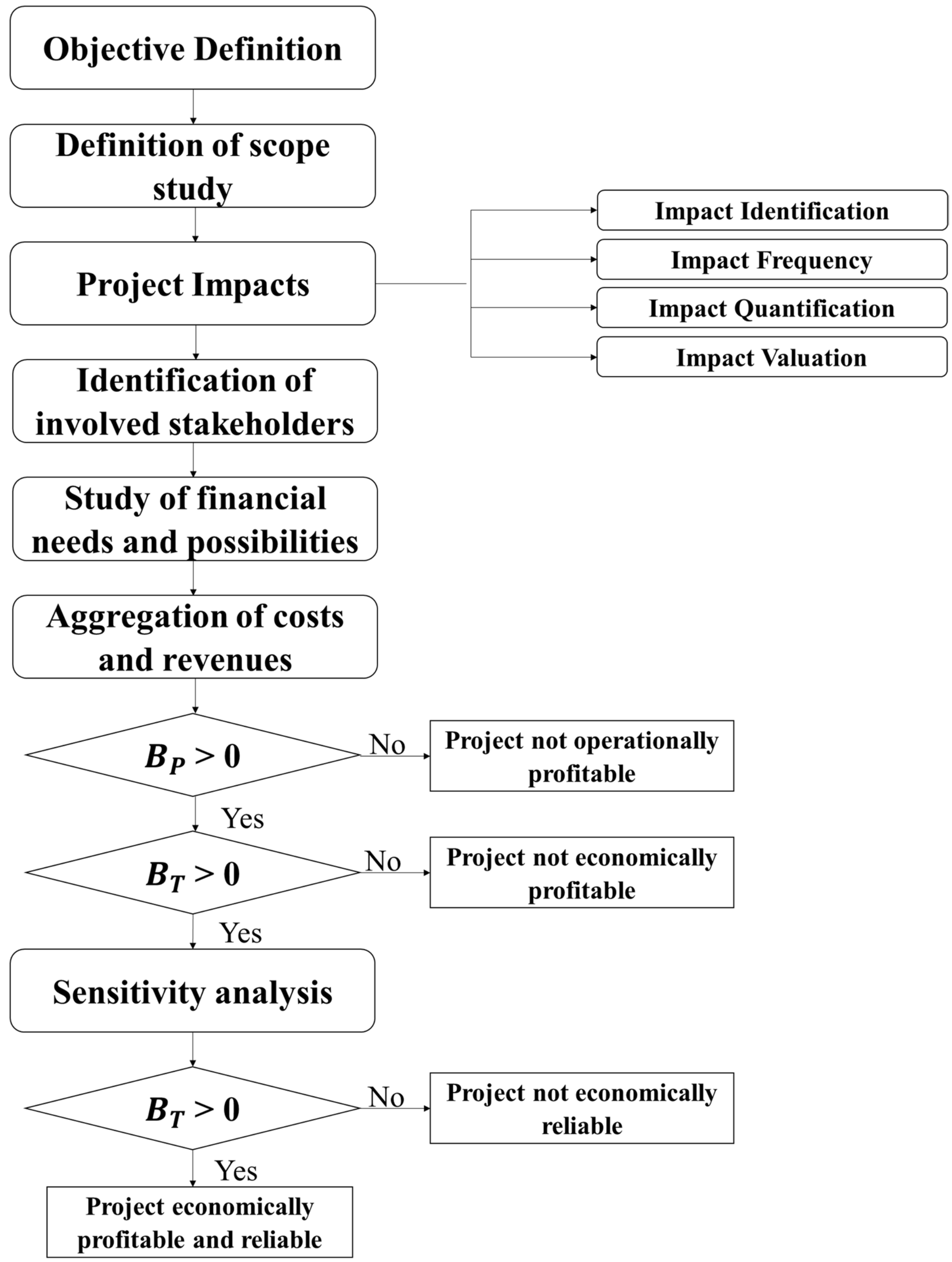

Fig. 2 Steps for technical–economic analysis to evaluate the STF. Source: [20, 23]

occurring after the arrival of the waste at the treatment plant, until their sale to other intermediaries along the value chain (companies of reuse and recycling) are considered. The costs and revenues studied are from 2017 [24], that is $N = 1$.

Impacts of the project

In this section the key points are the identification, frequency, quantification and monetary valuation of the impacts (private and external). The present case study has identified the majority of possible impacts; however, only some have been valued monetarily.

The impacts considered are related to the 3 pillars of sustainability: economic, social and environmental, and the sustainable development indicators established by international organisations such as the United Nations, the European Union, the U.S. Environmental Protection Agency (EPA). The key principle of sustainable development is integrating environmental, social, and economic concerns into decision making [19]. In Fig. 3, the essential aspects that must be promoted in the context of sustainability are included, which are related to impacts that have been considered and economically analysed in this case study.

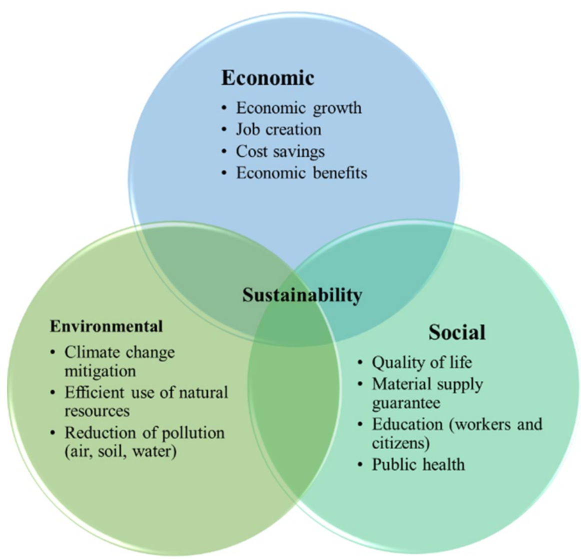

Fig. 3 Impacts related to sustainability pillars. Source: [25]

Table 1 shows a list of the positive and negative impacts to be considered in this case study. The principal characteristics of each impact group analysed are detailed in the following sections.

Infrastructure

Treatment of waste This impact group includes the private expenditures (investment, operation and maintenance costs) relating to the infrastructure of MSW management [26, 27]. These can be classified as CAPEX (Capital expenditures) and OPEX (Operational & Maintenance expenditures).

In this case study only OPEX is considered, as we are focussing on a specific operating year and the capital expenditures are included in the depreciation values. Table 2 shows the costs related to the infrastructure, classified as: (a) labour costs: this includes costs such as wages and salaries, social security payments and training costs, among others; (b) maintenance and repairs of equipment; (c) supply costs, which include the cost of raw materials and supplies as well as payments for services rendered by other companies; (d) depreciation of fixed assets and equipment, the installations used by the plant in performing its tasks are owned by the parent group. The plant and the group signed a contract (1 January 2012) that formalises the transfer of the group's installations, with the fixed price being equivalent to the economic amortisation costs of the ceded plants [24]; and (e) other expenses: this includes a quantity corresponding to other operative costs such as insurance, machinery rental and leasing, among others.

Table 1 Summary of the STF Impacts. Source: authors' elaboration based on [20]

Impact group	Description of impacts	Type of impact
Infrastructure	Treatment of waste	Negative/Private
Reuse, recycling and recovery of waste	Sale of materials	Positive/Private
	Gate fees	Positive/Private
Use of materials	Avoided material sent to landfill	Positive/External
	Guarantee of supply of material	Positive/External
	Quality of material	Positive/External
Environment	Avoided emissions to air	Positive/External
	Avoided emissions to water	Positive/External
Public Health	Physical Risks	Negative/External
	Chemical Risks	Negative/External
Education	Culture of reduction, reuse and recycling of waste	Positive/External
	Technique of workers (reduce of laboral accidents)	Positive/External
Quality of life	Disamenities: odour, dust, windblown litter, visual intrusion, noise	Negative/External

Table 2 Summary of Infrastructure costs generated by the STF. Source: authors' elaboration based on [24]

Concept	Annual costs (€/year)	Cost per ton (€/ton)	Percentage (%)
(a) Labour cost			
Salaries & wages	1,290,339	15.00	15.60
Social security	354,864	4.12	4.28
Other labour costs	50,287	0.58	0.60
(b) Equipment repair and maintenance costs	1,165,892	13.54	14.08
(c) Supply costs			
Raw materials and inputs	281,376	3.27	3.40
Provision of services (subcontracting)	1,412,751	16.41	17.06
(d) Depreciation of fixed assets	1,637,455	19.02	19.78
(e) Other expenses	2,086,242	24.24	25.20
Total	8,279,207	96.18	100

In 2017, a total of 22,806 tons of light packaging waste and 63,275 tons of bulky waste were treated in the plant [12]. The annual private costs are obtained directly from the 2017 annual accounts [24]. These annual values are divided by the total amount of waste treated (86,081 tons) to obtain the cost per ton (€/ton). As can be seen in Table 2, the most representative costs are those relating to other costs and the depreciation of the fixed assets.

Reuse, recycling and recovery of waste

This impact group includes the private revenues obtained by the plant (Table 3), which can be classified as: (a) revenues from the sale of materials obtained from waste; (b) gate fees, which represent the payment to the provider of treatment services for each ton of waste treated; and (c) other revenues, such as payment for services rendered to other companies and rental of equipment, among others [28]. Referring to the 2017 revenues, this includes the sale of treated light packaging waste, which recovered 15,868 tons of materials that were sent to recycling plants and 6938 tons were sent to the energy recovery facility. Regarding the treated bulky waste, 7027 tons of different materials such as cardboard, plastic and scrap metal, among others, were sold to authorised firms and 48,045 tons of woodchip were sold for the manufacture of chipboard panels. Finally, 8203 tons were considered as residual waste and were sent to the energy recovery facility.

The annual revenues are obtained directly from the 2017 annual accounts [24]. The annual revenues result from multiplying the sale price by the quantity sold of the materials recovered in the treatment plant (*AVW * SP*). There is a market price for the different materials treated in the facility, such as scrap, paper, glass, plastic, and wood. In addition, the gate fees established (for light packaging and bulky waste) are multiplied by the amount of waste treated. These annual values are divided by the total amount of waste treated (86,081 tons) to obtain the revenue per ton (€/ton). As can be seen in Table 3, the most representative revenues are

Table 3 Summary of private revenues generated by the STF. Source: authors' elaboration based on [24]

Concept	Description	Quantity (ton)	Sale price (€/ton)	Annual revenues (€/year)	Revenue per ton (€/ton)	Percentage (%)
Sales	Scrap	3374	81.08	273,548	3.18	3.08
	Paper/Cardboard	98	26.98	2644	0.03	0.03
	Glass	93	11.86	1103	0.01	0.01
	Plastic	12,243	1.06	13,008	0.15	0.15
	Other materials	7,087	0.05	378	0.00	0.00
	Wood chips	48,045	11.40	547,788	6.37	6.17
Gate fees	Light-Packaging waste	22,806	194.44	4,434,506	51.52	49.89
	Bulky Waste	63,275	54.55	3,451,628	40.10	38.83
Other revenues		–	–	163,932	1.90	1.84
	Total revenues ($\sum$ revenues)			8,888,535	103.26	100

that relating to the provision of a waste management service, for both light packaging (49.89%) and bulky (38.83%) waste.

Use of materials

This impact group is related to the needs that the waste satisfies, as well as the benefits obtained from the waste used in different applications; for example, the use of recycled plastic can reduce the dependency on fossil fuels and reach the target fixed by the European Commission, increasing the percentage of preparation for municipal waste reuse and recycling to 65% for 2030.

Avoided material sent to landfill One positive impact of the plant is that it allows the waste generated in Barcelona to be treated and sorted for recycling and reuse. Without this plant the waste would end up in landfills. To evaluate the benefits obtained by not sending the waste to landfill, consider the savings of the fixed rate, applied by the Generalitat de Cataluña, of 47.10 € per ton of waste sent to a controlled landfill [29]. The main objective of this fee is to discourage the use of landfills and reach the targets for waste management set by the European Commission. A total of 70,940 tons of materials have been recovered, instead of being sent to landfills, thereby producing a saving of 47.10 €/ton of recovered waste.

Guarantee of supply of materials This impact group is related to the value that users give to a guaranteed supply of raw materials, in the context of a shortage of resources. Plastics made from fossil resources are a cheap but limited resource. To evaluate the benefits obtained from the use of materials generated from waste it is necessary to apply the contingent valuation method or a choice experiment to determine the consumers' opinions and their willingness to pay (WTP) for the guarantee of an uninterrupted supply of materials at a reasonable price.

Quality of materials Another impact to be evaluated is the value that consumers give the products (packaging, furniture, etc.) generated from waste in terms of their ecological and recycled status. In this case, it is necessary to design a choice experiment or a contingent valuation method to estimate the consumers' preferences and their willingness to pay (WTP) for these products or materials. The ecological or recycled status of products can be considered as a differentiating factor that will allow companies to produce an added value and by communicating this extra value to customers obtain higher profits in the market [30].

In general, few studies have determined consumers' WTP for ecological products, such as the study performed by [31], which evaluated the consumers' WTP for different plastics used for water packaging. This study was realised in France, and 148 people were interviewed in February 2014. The results show that people are willing to pay an average premium of 0.79 €/pack of six 1.5 L bottles of recycled PET instead of PET bottles; this is a 21.94% extra, because the normal price for a pack of six PET bottles is 3.6 €.

Related to ecological furniture [32], realised a structured questionnaire to examined consumer stated willingness to pay a price premium for eco-friendly children's furniture. This study was realised in Shanghai and Shenzhen (China), and 320 consumers were interviewed in 2013. Results indicate that 98% of respondents would be willing to pay a premium for such products. Of these respondents, 53% stated a WTP of no greater than 10%, while 45% stated a WTP of more than 10%. Moreover, [33] explored the influence of demographic factors on willingness to pay more for eco-friendly furniture. This study was realised in Czech Republic (Prague), and 195 consumers were interviewed between March and May 2017. The results show that the majority were willing to pay 557.69 USD higher than furniture's normal price for environmentally friendly ones.

A survey conducted in Europe and the United States with 1000 consumers was considered [34] to calculate the economic benefit related to the impact of ecological

Table 4 Summary of private revenues generated by the STF. Source: authors' elaboration based on [24]

Concept	Description	Quantity (ton)	Sale price (€/ton)	Annual revenues (€/year)	Adittional WTP (%)	Adittional revenues (€/year)
Sales	Paper/Cardboard	98	26.98	2,644	16%	423.04
	Glass	93	11.86	1,103		176.48
	Plastic	12,243	1.06	13,008		2081.28
	Revenues from the sale of packaging materials	–	–	16,755		2680.80
	Wood chips	48,045	11.40	547,788	13%	71,212.44
	Revenues from the sale of material for ecological furniture	–	–	547,788		71,212.44
	Total revenues ($\sum$ revenues)					73,893.24

quality of materials recovered in the STF. This study indicates that 50% of consumers are willing to pay an additional 13% for ecological furniture and a 16% extra for green packaging. Therefore, an increase in sales revenues is considered (16% for packaging materials and 13% for wood). Currently, as in Table 4 is indicated, annual revenues of 16,755 € are received from the sale of packaging materials (paper, plastic and glass) and 547,788 € from the sale of wood, giving an additional profit of 2,681 €/year and 72,212 €/year, respectively.

Environment

The treatment of waste by the STF is principally related to the positive impact that the plant has, as it avoids several negative externalities such as the degradation of natural systems from leaks, greenhouse gas emissions and the impact on health and the environment of the substances contained in these materials (especially plastics).

Avoided emissions to air The CO_2 emissions are very important due to their effect on global warming. In general, the production of plastics uses fossil raw materials, which has a significant impact due to the CO_2 emissions generated during their extraction [8]. On the other hand, the use of recycled wood chips allows for a saving in the consumption of tons of virgin timber, as the wood treated in the plant is used for the production of chipboard panels, which reduces the CO_2 emissions.

Table 5 shows the amount of different types of materials recovered in the STF. Several studies have estimated the net CO_2 emissions obtained from the difference between the emissions from the primary production of the materials (with virgin raw materials) and those of the secondary production (using recycled materials), such as [35–37]. To calculate the total net CO_2 eq. emissions from the recycling of the different materials, the information about net emissions by material presented in [38, 39] was used, where the mean and the standard deviation in terms of CO_2 eq. per ton of recycled material was determined. Finally, the mean in terms of net emissions of CO_2 eq. per ton of material was multiplied by the amount of each type of material recovered. In this case, the emission of 69,655 tons of CO_2 eq. were avoided.

The CO_2 emissions from industrial activities are taxed at an average estimated value of approximately 10 €/ton of CO_2 eq [41]. In general, governments determine the abatement/avoidance cost of a specific contaminant to implement a CO_2 tax [42]. In 2025, this tax will reach a level of 30 €/ton of CO_2 eq. Therefore, when calculating the economic impact of avoided CO_2 emissions, the figure of 10 €/ton of CO_2 eq is used, and it is multiplicated by the total avoided CO_2 emissions.

Avoided emissions to water One of the principal impacts of plastic waste is the degradation of natural systems, especially in bodies of water such as oceans and rivers, as a result of breaks in the production and consumption chains. Worldwide, it is calculated that there are more than 150 million tons of plastic in the oceans [8]. Recycling plastics reduces the negative externalities generated, because although more waste is managed and treated correctly there is less probability of these wastes finding their way into natural ecosystems. In Europe the potential cost of cleaning coastlines and beaches may be as much as 630 million €/year. As well as the direct costs, there are possible adverse effects on human health and livelihoods, the food chain and other essential economic and social systems (tourist industry, fishing, maritime transport) [8].

It has been calculated that Barcelona is responsible for 1787 ton/year of the plastic waste found in the Mediterranean Sea [43]. To calculate the benefits obtained through the correct management of this waste, the clean-up cost method [44, 45] should be used, where the savings in the

Table 5 Net emissions of CO_2 eq. generated by the STF in 2017. Source: authors' elaboration based on [38–40]

Material	Amount of materials recovered (ton)	Net emissions by type of material (ton of CO_2 eq./ton of recycled material)	Total net emissions by recovered material (ton of CO_2 eq)
Plastic HDPE	1451	− 1.530	− 2220
Plastic PET	5495	− 3.400	− 18,683
Plastic LDPE	2700	− 2.900	− 7830
Plastic Mix	2597	− 0.788	− 2047
Glass	93	− 0.280	− 26
Steel	2822	− 0.940	− 2653
Aluminium	552	− 11.640	− 6425
Cardboard	98	− 0.320	− 31
Wood	48,045	− 0.619	− 29,740
Avoided CO_2 emissions			− 69,655

cost of cleaning the beaches of Barcelona and its metropolitan area are considered. It was determined that the approximate cost of cleaning 1 km of coastline is 53,416.40 €/year [46], with plastic waste responsible for 60% of this cost. Finally, it is considered that only 25% of this cost corresponds to the collection of waste from the beaches. The approximate quantity of plastic waste per km of coastline is 26.1 kg/day, or 9.53 ton/year [43].

According to this information the cost per ton of plastic waste is calculated as 841.11€. This value is close to that estimated by [47], who showed that the cost of collecting different types of waste from the beach varied from 980 to 2610 €/ton, with an average value of 1340 €/ton. Finally, it is assumed that the correct management and treatment of plastic waste in the sorting plant has prevented 1% of these materials (122.43 tons) from ending up on Barcelona's beaches, avoiding higher cleaning costs and producing a saving of 102,977 €.

Table 6 Information about Accident rates and costs generated by the STF. Source: authors' elaboration based on [12, 24, 50]

Concept	Year 2016	Year 2017
Frequency Index[1]	132.85	59.1
Incidence rate[2]	23.91	10.64
Absenteeism rate[3]	5.64%	7.58%
Workers	54	56
Working Hours per worker (hour/year)	1800	1800
Risk prevention expense (€)	56.91	2,278.43
Accidents	13	6
Sick Leave per worker (days)	20.59	27.67
Average daily wage per worker (€/day)	62.86	63.13
Medical expenses (€/accident)	1,721.78	1,721.78

[1] Accidents with sick leave/hours worked * 1,000,000

[2] Accidents with sick leave/workers *100

[3] % of days lost due to professional contingency compared to the total number of calendar days

Public health

This impact group includes damage to public health, which can be evaluated from the perspective of the workers and/or the inhabitants of the areas surrounding the MSW treatment plants.

Physical risks Damage to health in the STF is mainly connected with physical risks, such as injuries and cuts from metal or glass. These injuries were caused by minor accidents and consist mainly of dislocations, sprains and strains, as well as superficial injuries and fractures.

According to the methodology for the economic evaluation of work accidents in Spain, presented by [48], the following variables should be considered: (1) cost of time lost (the injured worker and others who have stopped work due to the accident); (2) material costs of machinery, plant or material; (3) costs due to losses, which could be the profits unobtained by the company as a result of the accident and the consequent temporary, partial or complete stoppage of the production system, or an increase in the costs of measures to keep production at the same level (overtime, employing a replacement, subcontracting the task, etc.); (4) general expenses, the costs of the accident (transporting the injured, fines, professional and medical costs, etc.). They also include the Social Security costs, such as compensation for the worker on sick leave (usually 25% of the salary is paid by the company and the 75% by Social Security) and the company's payments to the system for the injured worker during this period; and (5) the time spent on the accident by the other workers, for example, in investigating the causes.

Table 6 shows the index of accident frequency, the index of incidents and the absenteeism index. In addition, it provides information about the costs needed to calculate the economic impact of accidents occurring in the STF, in both 2016 and 2017, to observe the changes in the different indices. In 2017, there were 56 employees and 6 accidents requiring sick leave. It can be seen that the number of accidents in 2017 was considerably lower than in 2016, while spending on accident prevention increased. To prevent double accounting of the costs, only those incurred by public bodies are considered, because salaries, social security quotas and other concepts have already been included in the company's annual accounts as part of the operating and maintenance cost (*OMC*). As shown in Table 6, only the medical expenses due to fractures, sprains and dislocations are considered, at an average cost of 1,721.78 €/accident [49]. In 2017, it is considered that the daily salary per worker is 63.13 €, and there were approximately 27.67 days of sick leave by accident, the total payment of the salary to injured workers was 1746.81 €/accident; therefore, the social security payment (75% of the salary) was 1310.10 €/accident. In 2017, there were 6 accidents with sick leave, with a total cost by accident of 3031.88 €. Finally, the total cost for physical injuries was 18,191.28 €.

Chemical risks Another risk present in the waste treatment plants is that of fires which, due to the presence of wood, increases above all in the bulky waste treatment plants. Waste fires have a high risk of spreading towards urban areas (in other words they carry the risk of structural fires), as well as forested areas (with the risk of forest fires) [51]. These fires may produce costs for the waste management company (related to the loss of materials and damage to buildings, among others), environmental costs due to air, land and water pollution, costs to society (such as health care and insurance compensation, among others) [52] and socioeconomic costs (such as emotional stress caused by public fears) [53]. In the case of the STF, there were no fires in 2017, so the cost associated with fire damage was considered 0 €.

Education

This impact group considers the benefits due to the change in behaviour of the workers and/or citizens due to awareness and training programmes.

Culture of reduction, reuse and recycling of waste The STF runs awareness programmes with the aim of educating and raising awareness regarding the environment, by means of activities relating to climate change, energy, the cycle of materials and waste. This involves communications activities and environmental training, such as guided tours of the plants for schools, university students of related fields and technicians from public and private companies [54]. These programmes lead to better separation of waste by the citizens, thereby preventing improper waste which does not belong to the light packaging fraction from ending up in the yellow container. To achieve a change in the public's behaviour it is necessary to invest in staff trained in communications and social media, publications and the programme's implementation [55]. Figure 4 shows the improper waste from the light packaging fraction in Catalonia obtained from statistics databases [56] and the percentage of rejected light packaging waste in the STF [12]. It can be observed that the improper waste rate in Catalonia is minor than the improper waste rate in the STF. In addition, it can be seen that the percentage of rejected waste of the STF decreased from 35.2 to 30.4% in 2017.

Taking the changes between 2016 and 2017 as a reference, in this case, we can evaluate the benefits of awareness programs for citizens by considering the reduction of improper waste in the STF (Table 7). To determine the economic benefits, it is necessary to calculate the reduction of costs due to the payment of gate fees for

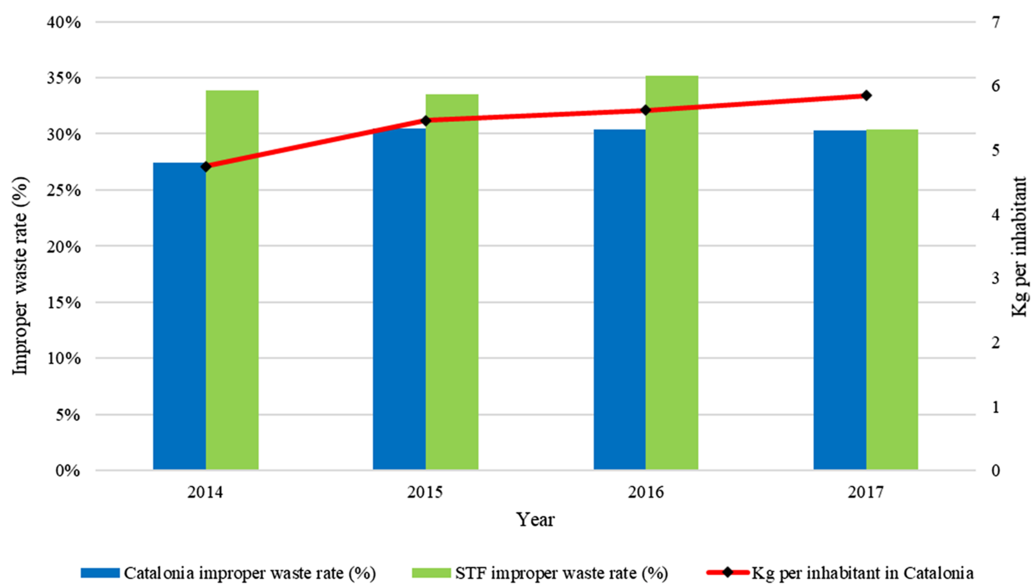

Fig. 4 Improper waste from light packaging waste fraction in Catalonia and the STF. Source: authors' elaboration based on [12, 56]

Table 7 Comparison of scenarios related to the reduction of improper waste in the STF. Source: authors' elaboration based on [12, 56]

Impact	Concept	Scenario 1 (year 2016)	Scenario 2 (year 2017)
Reduction of improper waste in the STF	Total light packaging waste treated (Ton)	22,157	22,806
	% Rejected waste	35.24%	30.42%
	Amount of improper waste (tons)	7810	6938
	Gate fee (€/ton)	51.52	51.52
	Total payment of gate fees for improper waste (€)	402,371.20	357,445.76
	Benefit (€)	–	44,925.44

improper waste. Therefore, two different scenarios are evaluated. First, scenario 1 assesses the costs due to the payment of gate fees for improper waste treated at the plant in 2016 (i.e., 35.24%). Second, scenario 2 evaluates the cost considering the percentage of improper waste in 2017 (i.e., 30.42%). In total, it was avoided that 872 tons of improper waste were treated, thereby avoiding the payment of 51.52 €/ton for the gate fees.

An increase in processing costs, errors in production and damage to equipment in the treatment plants are the additional costs engendered by the incorrect sorting of waste, as well as accidents and even fires during the storage phase [57].

For their part, the awareness programmes may affect the quantity of waste that is left on the beaches, reducing the amount of waste that has to be collected and consequently the cost of cleaning the beaches. According to the Ajuntament de Barcelona, the cleaning costs could be reduced by 25% if the public did not leave its rubbish on the beach. This amount is not included in the economic analysis, because a more in-depth study is needed of the quantity of waste left on the beaches and its year-by-year reduction.

Technique of workers Every year, the STF invests in training courses for its workers, which means a responsible and professional workforce. Personnel training leads to the acquisition of new skills and improvements in existing ones, providing economic benefits from significant improvements in productivity and quality, a decrease in rejected waste, reductions in production times, more flexibility in meeting demands and even a lower accident rate in the workplace [58].

Taking the changes between 2016 and 2017 as a reference, in this case we can evaluate the benefits of training by considering only the reduction in work accidents, which can be attributed to the workers' training. In 2017, the company invested 19,917.12 € in training schemes. A fall in the accident rate can be observed (from 13 to 6) but there was an increase in the number of days lost to sick leave per employee (from 20.59 to 27.67) (Table 8).

To determine the economic benefits, it is necessary to calculate the reduction of costs due to the decrease in accidents. The main assumptions are that each day of sick leave due to fractures, strains and dislocations costs 63.13 € and the average medical cost is 1721.78 € [49].

Table 8 Comparison of scenarios related to workers training benefit of the STF. Source: authors' elaboration based on [12, 24]

Impact	Concept	Scenario 1 (year 2016)	Scenario 2 (year 2017)
Reduction of workplace accidents	Accidents	13	6
	Salary by worker (€/day)	63.13	63.13
	Sick leave by worker (days)	20.59	27.67
	Medical Cost by accident (€)	1,721.78	1,721.78
	Total Medical Cost (€)	22,383.14	10,330.68
	Total Salary (€)	16,898.00	10,480.84
	Total Accidents Cost (€)	39,281.14	20,811.52
	Benefit (€)	–	18,469.62

Quality of life

Some MSW treatment plants may disturb the nearby households, as their very existence may cause bad odours, dust, windborne rubbish, visual intrusion, noise and traffic [42].

Disamenities In STF's case, the plant is located in an industrial and farming zone, so there is no housing in the vicinity; consequently, this impact does not affect the STF and generates no costs. On the contrary, if there were houses nearby, it would be necessary to perform a choice experiment to estimate the owners' preferences and their willingness to pay (WTP) to avoid having an incinerator near them, or to use the Hedonic Pricing Method to quantify the impact on house prices due to the problems caused and the change in environmental quality [59, 60].

Other types of facilities generate costs due to the negative effects on environmental quality. In the case of incinerators, a value of 8 € per ton of waste treated is estimated; this is a value slightly lower than the impacts caused by the landfill disamenities, that is, 10 €/ton [61].

Identification of the stakeholders

Stakeholders are individuals, groups or institutions who have an interest in or a relationship with the company, such as workers, investors, consumers, among others, and that can be affected by the impacts that the organisation's activities and operations have in the social, work, environmental, and economic arenas [62].

Once the impacts of the MSW system have been determined, the stakeholders can be identified. It is also important to decide from which stakeholder's perspective the economic analysis should be performed, as this will determine the impacts to be considered. It was determined from the impact analysis that the stakeholders in this case study are: (a) the STF; (b) the parent group (TERSA); (c) Ajuntament de Barcelona; (d) managers of recoverable materials; and (e) citizens of the Barcelona metropolitan area. The economic analysis was carried out from the STF's perspective, which is a public company part of the TERSA group (Government body).

Study of the needs and financial possibilities

Determining the sources and conditions of financing is an important aspect to be considered before conducting cost–benefit analysis [63]. The STF will count on its own funds; thus, the study considers all financing sources from social capital shareholders in line with substancial number of firms in this industry who opt for equity financing [64] seeking no short term overhead expenses with debt financing and assuming the low opportunity cost determinants [65] that arises from bootstrap financing that arises in this case with self-financing [66].

Aggregation of costs and revenues

Once the impacts have been quantified and valuated monetarily, using Eqs. (1) and (2), it is possible to add the different costs and revenues to obtain the Total Benefit generated by the STF. Consequently, the situations can be determined and viewed separately. First of all, whether the STF is economically and financially profitable in its functions, which is defined by determining the Private Benefit ($B_P > 0$); second, whether the STF is economically, financially, socially and environmentally profitable, which is defined by determining the Total Benefit ($B_T > 0$).

The Financial Costs (*FC*) are considered as zero, as the company has its own funds and no debts. Taxes (*T*) are calculated considering that company taxes are 25% of the exploitation results. A discount of 99% is applied to this value for providing a local public service, obtaining a value of 1299 €, or 0.015 €/ton [67].

Regarding the Opportunity Cost (*OC*), this is the value of the rejected alternative actions; within the concept of sustainable development and its three pillars, the best alternative provides not only the best economic impulse but also the best social and environmental development [20, 68]. The concept of opportunity cost applied to MSW systems can be explained from two main conditions. First, when there are several alternatives for the use of waste, opportunity cost will be given by the use that provides the best economic performance, as long as these yields are higher than those of financial instrument. Second, when there are no alternative uses, opportunity cost comes from the performance that provides some financial instrument when investment costs are invested in this one [20].

In terms of the Opportunity Cost, it is considered that there is no better use for the waste treated, because another alternative for the treatment of waste (light packaging waste and bulky waste) would be sending it to incinerators or landfills, consequently, not respecting the waste management hierarchy established by the European Parliament, where recycling is prioritised over energy valorisation and the deposit in landfills.

Therefore, the Opportunity Cost is considered to have come from the revenue provided by some financial instrument when the social capital and the reserves are invested in it. This facility has a total capital and reserves equal to 2,366,212.52 € and the interest on financial instruments was estimated as 3% in 2017 [69]; therefore, the Opportunity Cost is 70,986.37 €, the equivalent of 0.82 €/ton.

Results and discussion

After applying the presented methodology, Table 9 shows the impacts considered in this case study; it should be pointed out that only some of them have been monetarily valued. In addition, several elements have been presented, such as the identification, frequency, quantification and monetary valuation of the impacts (private and external) of the STF, a key point in the methodology used. Table 9 shows the main types of impacts (private or external) generated by the STF. These may have a positive or negative effect, either as costs or revenues. Regarding the Impact Frequency, in the current project all of the identified impacts have effects during the project's useful life. In the case of the Impact Quantification, the units that allow these impacts to be translated into monetary values have been defined. Finally, the Impact Valuation is shown, where the monetary value of some impacts was calculated. First of all, the costs and revenues referring to 2017 (€/year) are presented, then the costs and revenues per unit of waste treated (€/ton), with 86,081 tons of waste receiving the full treatment.

It should be mentioned that some impacts have not been valuated economically, such as the positive impact related to the value that consumers give to a guaranteed supply of raw materials; other impacts have been calculated from secondary studies or have considered only some of the aspects relating to the analysed impacts. For example, in the case of the workers' training schemes, only the reduction of accidents has been considered; however, this impact is linked to improved productivity, quicker production time and greater flexibility in responding to demands, among others. These impacts have been included and described to have a more complete view of the impacts generated by the facility, allowing policy makers to consider these impacts in future economic analyses of other projects or waste management systems. These impacts or aspects have not been monetarily valued, as each one has its own methodology, which should be presented and developed individually and exhaustively. To keep this article as concise as possible, it was decided to briefly present these impacts, which should then be studied and monetarily valued in future works.

Table 9 Summary of the economic results of Impacts considered for the STF per €/year and €/ton (year 2017). Source: authors' elaboration

Type of impact	Impact group	Impact identification		Impact frequency	Impact quantification	Impact valuation (€/year)		Impact Valuation (€/ton)		Percentage (%)	
		Costs	Revenues			Costs	Revenues	Costs	Revenues	Costs	Revenues
Private	Infrastructure	Labour Costs		During the life of project	86,081 tons of waste	1,695,490		19.70		20.44%	
		Equipment repair and Maintenance costs			86,081 tons of waste	1,165,892		13.54		14.05%	
		Provision costs			86,081 tons of waste	1,694,127		19.68		20.42%	
		Depreciation of fixed assets			86,081 tons of waste	1,637,455		19.02		19.73%	
		Other Costs			86,081 tons of waste	2,086,242		24.24		25.15%	
Private	Reuse, recycling and recovery of waste		Scrap	During the life of project	3,374 tons of waste		273,548		3.18		2.08%
			Plastic, Paper/cardboard, glass and others		19,521 tons of waste		17,133		0.19		0.12%
			Wood chips		48,045 tons of waste		547,788		6.37		4.16%
			Fees for Light Packaging sorting Service		22,806 tons of waste		4,434,506		51.52		33.68%
			Fees for Bulky treatment service		63,275 tons of waste		3,451,628		40.10		26.22%
			Other revenues		86,081 tons of waste		163,932		1.90		1.24%
External	Use of materials		Avoided Material send to landfill	During the life of project	70,940 tons of waste		3,341,274		38.82		25.38%
			Quality of materials		60,479 tons of waste		73,893		0.86		0.56%
External	Environment		Avoided Emissions to air (CO_2)	During the life of project	69,655 tons CO_2 eq.		696,550		8.09		5.29%
			Avoided Emission to water		122.43 tons of plastic waste		102,977		1.20		0.78%
External	Public Health	Accidents (injuries)		During the life of project	6 People affected	18,191		0.21		0.22%	
		Fires			0 People affected	0		0		0%	
External	Education		Culture of 3R for citizens	During the life of project	Amount of People		44,925		0.52		0.34%
			Technique of workers		% productivity		18,470		0.21		0.14%
External	Quality Life	Disamenities		During the life of project	Price of households or WTP to avoid	0		0		0%	
Total Private Costs and Revenues ($\sum$ Private Impacts)						8,279,206	8,888,535	96.18	103.26	99.78%	67.51%
Total External Costs and Revenues ($\sum$ External Impacts)						18,191	4,277,089	0.21	49.69	0.22%	32.49%
Total Impacts (Private Impacts + External Impacts)						8,297,397	13,165,624	96.39	152.95	100.00%	100.00%

In Table 9, private costs and revenues related to the operation and maintenance of the STF are presented. The most significant costs correspond to the impacts concerning infrastructure, where they reach a total value of 96.18 €/ton; of these, the costs related to the insurance, maintenance and leasing of machinery are the most significant (37.78 €/ton). On the other hand, the most important revenues are related to the recycling and recovery of waste, reaching a total value of 103.26 €/ton; here, the revenue derived from the light packaging sorting service is the most significant (51.52 €/ton), followed by revenues from the bulky waste treatment service (40.10 €/ton). In this case, the provision of the service generates more profit than the sale of materials. In addition, in Table 9, external revenues and costs related to environmental and social aspects are presented. In the case of external costs and revenues, the most representative revenues correspond to economic savings, since the sending of waste to landfills has been avoided, and therefore, the payment of gate fees to these facilities, giving revenues of 38.82 €/ton. This facility only generates external costs due to physical damages that correspond to 0.21 €/ton.

Table 9 allows to visualise the relative weight of each type and group of impacts generated by the STF. Being able to observe that, in the case of costs, 99.78% corresponds to private impacts. On the other hand, in terms of revenues, 67.51% corresponds to private impacts and 32.49% to external impacts. The relationship between private revenues and costs (R/C) indicates a ratio of 1.07, which shows that revenues are greater than costs. On the other hand, the relationship between total revenues and costs (R/C) presents a ratio of 1.58, which indicates that the STF becomes a more profitable project due to externalities.

Using Eqs. (1) and (2), the Private Benefit (*BP*) and Total Benefit (*BT*) for this facility are calculated. *AVW*SP* corresponds to the sum of the private revenues and it is equal to 103.26 €/ton. Operational and Maintenance Costs (*OMC)* correspond to the sum of private costs, and it is equal to 96.18 €/ton. In this case study, only *OMC is* considered, as we are focussing on a specific operating year, and the Investment Costs (*IC*) are included in the depreciation values; consequently, *IC* is 0. As described in the section "Aggregation of costs and revenues", *FC* is equal to 0, because the company does not have any debt; *T* corresponds to the company's taxes minus the discounts applied, and it is equal to 0.015 €/ton. *PE* corresponds to the sum of the revenues due to the positive external impacts (Table 9), and it is equal to 49.69 €/ton. *NE* corresponds to the sum of the costs due to the negative external impacts (Table 9); it is equal to 0.21 €/ton. Finally, *OC* corresponds to the revenue from the investment of capital and reserves in a financial instrument, and it is equal to 0.82 €/ton.

Equations (3) and (4) show the results obtained from the Private Benefit and the Total Benefit, respectively. The values are expressed in € per ton of waste treated.

$$B_P = \sum_{n=1}^{1} [(103.26) - (0 + 96.18 + 0 + 0.015)] = 7.06 \quad (3)$$

$$B_T = \sum_{n=1}^{1} [(103.26) - (0 + 96.18 + 0 + 0.015) + (49.69 - 0.21) - 0.82] = 55.72 \quad (4)$$

Once the total revenues and costs (private and external) have been determined, it is possible to evaluate whether the treatment plant is operationally ($B_P > 0$) and economically ($B_T > 0$) profitable. In the analysis that takes only the private revenues and costs of the STF into account, the results show a positive economic return ($B_P > 0$); consequently, the project is operationally profitable, with the Private Benefit being 7.06 €/ton. The analysis that takes the private and external revenues and costs of the STF into account is $B_T > 0$, which gives a Total Benefit of 55.72 € /ton of waste, which means the project is economically profitable.

Although the private costs and revenues have the greatest weight in this case study, the Total Benefit increases considerably, because the monetary valuation of the externalities. One important aspect of the applied methodology is that it allows the effects of the externalities on the Total Benefit to be seen. In this case, the plant could easily become operationally unprofitable, as the Private Benefit (B_p) only reaches a value of 7.06 €/ton; however, the externalities raise the Total Benefit (B_T) of the treatment plant, making it more profitable and reliable.

The STF fulfils an important function for the city of Barcelona and its environs, as its waste management service of light packaging and bulky waste prevents waste from being sent to landfills, thereby reducing the possible environmental and societal damage caused by these installations. Another important aspect is that it prevents damage to natural systems due to breaks in the production and consumption chain. The impact of plastic is so serious that it has been calculated that in 2050 the oceans will contain more plastic than fish [8]. All these positive impacts (environmental and social) are reflected in the company's Total Benefit. This plant is highly advantageous from an environmental and social perspective, with few negative externalities. All the impacts that have not been valued monetarily are positive ones; therefore, the total benefit will be higher.

If the results are compared with the landfills, these have lower private costs, as shown in [70], where it can be seen that private costs vary from 37 to 44 €/ton. However, due to their possible impact on society and the environment, they have greater external costs, which are between 16.27 and 21.01 €/ton [27]. These values show that the private costs of the STF are higher than those of the landfills; however, the STF is highly profitable due to both its private and external revenues. On the other hand, if the results are compared with another facility that provides waste treatment in the AMB, we can see that the Energy Recovery Facility (ERF) has a Private Benefit (B_P) of 9.86 €/ton and a Total Benefit (B_T) of 23.97 €/ton [28]. This shows that the STF is more advantageous from an environmental and social point of view, consistent with the current hierarchy of priorities established by the European Parliament [71].

Sensitivity analysis

The sensitivity analysis is used to test the robustness of the results of the technical–economic analysis. The sensitivity analysis changes one variable at a time and then determines the effect of this change [72]. The variables that can be analysed are the opportunity cost, the used capacity of the treatment plant and the treatment service fees, among others.

The first variable to consider is the revenue received from the light packaging sorting service and the treatment of bulky waste, which corresponds to the highest revenue of the treatment plant, with a total value of 91.62 €/ton treated. In this case, the project could become unprofitable if the revenue obtained from the waste management services fell below 35.89 €/ton treated, where B_T becomes negative and does not fulfil the condition $B_T > 0$. This is unlikely, however, as there is a fixed fee for the waste treatment and sorting services, and the plant treats a constant amount of waste every year.

The second variable to consider is the opportunity cost. In this case study, it is considered as the interest earned from the use of a financial instrument, as there is no better alternative use for waste. However, should better alternatives arise in the future the project might become economically unprofitable if the opportunity cost exceeds 56.54 €/ton treated, where B_T becomes negative and does not fulfil the condition $B_T > 0$.

Therefore, the sensitivity analysis shows that under current conditions, the plant is economically profitable and reliable.

Conclusions

The main aims of this case study are to determine the Total Benefit of a light packaging and bulky waste sorting and treatment facility, and looking at the two situations separately. First of all, the treatment plant is economically and financially profitable in its operations, as defined by determining the Private Benefit (a situation generally of interest to technicians and politicians); second, the treatment system is economically, financially, socially and environmentally profitable (of interest to economists and society). Although the details in this document are specific to a Spanish context, the methodology used is of universal application, as it can determine and analyse different potential impacts (private and external) arising from the MSW treatment. It can also be extrapolated to the analysis of other treatment plants, allowing the researchers to consider the same types of impacts described in this work but adapted to specific contexts to reduce decision-makers' uncertainty.

The STF fulfils a primordial function for the city of Barcelona and its environs, as it treats waste for later reuse and recycling, preventing waste from being sent to landfills and reducing the CO_2 emissions from the extraction of virgin raw materials, thereby helping to reach the objectives set by the European Commission, among others. All these impacts can be reflected as costs or revenues that determine whether the STF is profitable or not. From the findings of the present case study, it can be concluded that the STF is both operationally ($B_P = 7.06$ €/ton) and economically ($B_T = 55.72$ €/ton) profitable. However, it should be noted that some external (positive) impacts have not been quantified, such as the value that consumers give to a guaranteed supply of materials. In addition, others have been valued, considering only some aspects related to the analysed impacts. A monetary valuation of these externalities would increase the Total Benefit of the plant, making it more profitable and reliable.

An essential aspect of the research conducted allows the effect of the externalities on the Total Benefit to be highlighted. The valuation study of the externalities related to the waste management systems is essential, and help decide on the economic viability of the treatment plant [73]. If only the private impacts are evaluated, the management system may look unprofitable and, therefore, be rejected [73]. However, if the externalities are evaluated and added, the system may become profitable.

It is recommended that future research should analyse the externalities that have not been valued monetarily, broadening the analysis of some aspects related to these externalities. In addition, an analysis of the other processes of the management system (waste collection and transport) for light packaging waste and bulky waste is needed [74], taking into consideration the different companies involved to determine the impacts generated depending on various factors such as types of transport (electric, hybrid or diesel), collection systems (door-to-door, green point, drop-off system) and percentage of waste separation from citizens.

It is also important to extend the current study into the impacts of emissions to water (oceans and rivers), considering all the possible effects that could be avoided by correct waste management [75]. Furthermore, there is a need to focus on obtaining specific data about the willingness of the citizens of Barcelona to pay for ecological products [76] and, thus, the outcomes of this paper raises awareness of its importance and opens the line for a future research.

Abbreviations

AMB: Metropolitan Area of Barcelona; AVW: Annual volume of waste treated; BP: Private Benefit; BT: Total Benefit; FC: Financial Costs; IC: Investment Costs; N: Total project duration; n: Project year index ($n = 0, \ldots, N$); NE: Negative externalities; OC: Opportunity cost; OMC: Operational and Maintenance Costs; PE: Positive externalities; SP: Sale Price per Volume Unit; STF: Sorting and treatment facility; T: Taxes.

Supplementary Information

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Additional file 1: Table S1. Definitions about the elements of equations used.

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Authors' contributions

RMM: conceptualisation, methodology, investigation, writing–original draft, writing–review and editing. SAEZ: investigation, writing–review and editing. HGGR: investigation, writing–review and editing. LSA: conceptualisation, methodology, investigation, writing–review and editing. All authors read and approved the final manuscript.

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Competing interests

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