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Sustainability vs. Circular Economy from a Disposition Decision Perspective: A Proposal of a Methodology and an Applied Example in SMEs

Faustino Alarcón [1], Pascual Cortés-Pellicer [2,*], David Pérez-Perales [1] and Raquel Sanchis [1]

[1] Research Centre on Production Management and Engineering (CIGIP), Universitat Politècnica de València, 46022 València, Spain; faualva@omp.upv.es (F.A.); dapepe@omp.upv.es (D.P.-P.); rsanchis@cigip.upv.es (R.S.)
[2] Department of Business Management, Universitat Politècnica de València, 46022 València, Spain
* Correspondence: pascorpe@omp.upv.es

Received: 8 November 2020; Accepted: 1 December 2020; Published: 3 December 2020

Abstract: Disposition Decision (DD) consists of deciding how to treat a recovered product, and it is one of the most important decisions in reverse logistics. Any of the selected disposition alternatives will have a significant impact on the enterprise sustainability. However, the most sustainable alternative may not be an alternative to make circular economy (CE) possible. In these cases, if the company wishes to adopt a CE strategy, it will have to switch from the most sustainable alternative to a less sustainable one that CE allows. Then, how much should be sacrificed for each sustainability dimension to make CE possible? This paper proposes a methodology for quantitatively comparing the most sustainable disposition alternative and the most sustainable CE alternative. This comparison allows small and medium enterprises (SMEs) to know how exactly all dimensions increase or decrease when selecting the most sustainable CE disposition alternative and to, therefore, assess the interest of adopting a CE policy. The proposed methodology is applied to a used tire recovery company. The results of this example show that the CE alternative offers a better environmental result but presents worst economic and social results. This example can be used as a guide for future applications other SMEs.

Keywords: circular economy; sustainable assessment; disposition decision; disposition alternatives; methodology; reverse logistics; small and medium enterprises; used tires

1. Introduction

As sustainability and circular economy are paid more attention by civil society, governments, and academia, companies strive to modify their business models and incorporate these concepts as a way to gain a new competitive advantage [1].

One of the most widely used definitions of sustainability is “development that meets the needs of the present without compromising the ability of the future generations to meet their own needs” [2]. Currently, it appears to be widely accepted that the sustainability concept includes the so-called triple bottom line [3] to refer to the balanced integration of economic, environmental and social performance. Accordingly, the term sustainability is defined by Geissdoerfer et al. [4] as the balanced and systemic integration of intra- and inter-generational economic, social, and environmental performance in an attempt to show its holistic, adaptive, and flexible nature.

In recent years, the term sustainability has frequently been associated with the term circular economy (CE), and it has been argued that CE strategies help companies to be more sustainable [5]. CE is based on transforming the traditional linear production and logistics structure into more circular and sustainable models. Moreover, most scholars agree that CE forms part of the solution to meet sustainable development objectives [6]. These aspects are included in the CE definition proposed by Prieto-Sandoval et al. [7], who also refers to the importance of eco-innovation:

The CE is an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces and consumes.

There is no doubt about the importance of both concepts for our society to progress, as evidenced by not only them being increasingly incorporated into the agendas of policy makers and the strategies of companies [1,6,8], but also by regulations and laws being developed to promote them in different countries like China, Japan, the UK, France, Canada, The Netherlands, Sweden, Finland, and Spain [9–13].

Being aware of the importance and advantages that these two concepts can offer, companies incorporate them into their strategies and work to implement them at the operational level by focusing their efforts mainly on these areas: Design (long-lasting and flexible functionalities, reusable materials), manufacturing (low raw materials and energy uses, remanufacturing, refurbishing, recycling), maintenance (repair, reuse), and logistics (reverse logistics, disposition decision).

The coordination of actions in these four areas will, therefore, clearly influence both the company's global sustainability level and the functioning of CE, although the importance or impact of each one may vary depending on different factors, such as the type of product or production process, used materials, or even the sector to which the company belongs, among others. However, regardless of the actions carried out in the other areas, the participation of the logistics area will be essential to recover the product, to make a treatment decision (disposition decision), and to initialize the corresponding reverse cycle. In all cases, these logistical actions will clearly impact the company's sustainability level and its CE [14], especially as regards the disposition decision (DD), understood as the decision that determines the treatment that the returned or recovered product should receive [15–17]. Although this is undoubtedly one of the most important decisions in the reverse logistics process [18], it is still one of the least worked decisions in the literature [19]. For all these reasons, our work focuses on the reverse logistics process, and more specifically on the DD.

DDs are organized around two main types of actions performed on the recovered product [20]: With and without value recovery. These types of subdivision give rise to a list of eight possible DDs or treatment alternatives, where the first six are value recovery options and the last two are non-value recovery ones [16,17,21–26]: (1) *Direct reuse* is the most recommended option for products that are completely unused and products that are returned after such light use that upgrade is not required in order to return the product to new status; (2) *repair* allows to recover the value of the product by replacing the damaged components; (3) *refurbishment*, in which its purpose is to bring used products up to a specified quality; (4) *remanufacturing* aims to bring used products up to quality standards that are as rigorous as those for new products; (5) *cannibalization* intends to recover the components or reusable parts from used products for reuse it in repair, refurbishing, or remanufacturing of other products and components; (6) *recycling* chases to recover materials, from used products and components, to reuse it in production of original parts; (7) *incineration*, in which the purpose is to generate a combustion to reduce the waste in volume and weight, turning it into inert materials (ashes) and gases; and (8) *landfilling* consists of burying the residues interspersed with layers of earth in large areas of land.

Considering the consulted definitions of sustainability and CE and being aware of the existing confusion between both terms [4], it is understood that any of the eight possible disposition alternatives could be a sustainable alternative in a specific situation and for a certain weighting of the economic, environmental, and social aspects, while only some alternatives allow value to be retrieved and generate circular flows, and would correspond to the CE.

In other words, despite the fact that CE can be considered a means to achieve business sustainability, not all the systems that incorporate circular flows are intrinsically more sustainable

[1,27]. This may be because CE practices, consisting of reusing of products and their new market position on the market, focus mostly on caring for the environment and are not always the most relevant ones from the perspective of the other two sustainability aspects: Economic and social.

It is, therefore, considered by the authors of the present paper that any of the eight possible treatment alternatives (with or without value recovery) can be selected as the most sustainable option, but only some value recovery options (reuse, repair, refurbishment, remanufacturing, cannibalization, or recycling) can be selected for CE.

This consideration led us to ask the following questions: Is the most sustainable option also a CE option? If so, as we would address both criteria simultaneously, would we have found the ideal option? If not, how much sustainability should be sacrificed to achieve CE?

This paper intends to address these issues by developing a methodology that helps SMEs to make sustainable product disposal and CE decisions. With the proposed methodology, SME decision makers can find out the most sustainable option to treat each recovered product by using a mathematical tool that simultaneously considers the three sustainability aspects (economic, environmental, social), weighted according to the company strategy. Once the most sustainable option has been calculated, a re-adaptation of the mathematical model allows the best CE option to be obtained and to make a comparison to the economic, environmental, and social differences of both options. These differences will allow the company to know the sustainability level that must be sacrificed if it has decided to treat a product by means of CE options.

The development of this methodology aims to help SMEs to overcome some of the barriers they face when achieving sustainable and CE scenarios [28], such as lack of tools [29], inadequate information management systems [7] and difficulties in assessing the benefits of implementing these strategies [28]. In this context, the empirical part of the study to analyze impacts of DD on reverse logistics process sustainability would be most significant for decision makers to make appropriate decisions [15].

The remainder of this paper is organized as follows. Section 2 reviews the literature on works that help to identify the relation between DD and sustainability/CE concepts, and also on methodologies that allow the degree of sustainability and the CE of DD to be quantified and compared. Section 3 puts forward an evaluation methodology to know the treatment alternative and to quantify the differences between a model based on sustainability and another based on CE. Section 4 presents a case study in which the proposed methodology is applied. Finally, Section 5 offers some drawn conclusions.

2. Background

This section aims to analyze the relation between DD and the sustainability and CE concepts by means of a literature review that has been performed through different databases such as Science direct and Scopus, using strings of words that combine the terms Sustainability, Circular Economy, Reverse Logistics, Disposition Decision, Disposition Alternatives, Methodologies, and Methods. The structure of the approach followed, and the results obtained through this literature review, are shown in Figure 1. Firstly, the focus is put on the DD relations with sustainability and CE. To analyze this, the different important decisions related to the reverse logistics are identified, focusing on the DD. In light of this, the different categories are examined, and the disposition alternatives explored. The outputs of this analysis are focused on (i) the development of a classification scheme of the DD alternatives based on three criteria, (ii) the analysis of DD relations with sustainability and CE aspects; and based on the previous two outputs; (iii) the classification of the DD based on its relationship with CE. The second part of the background approach is related to the analysis of methodologies for the sustainability and CE assessment of DD. The exhaustive analysis of the literature review offers relevant information regarding methods for DD that consider generic sustainability aspects while specific methodologies for the implementation, evaluation, or strategic planning of sustainability are also examined highlighting the main findings.

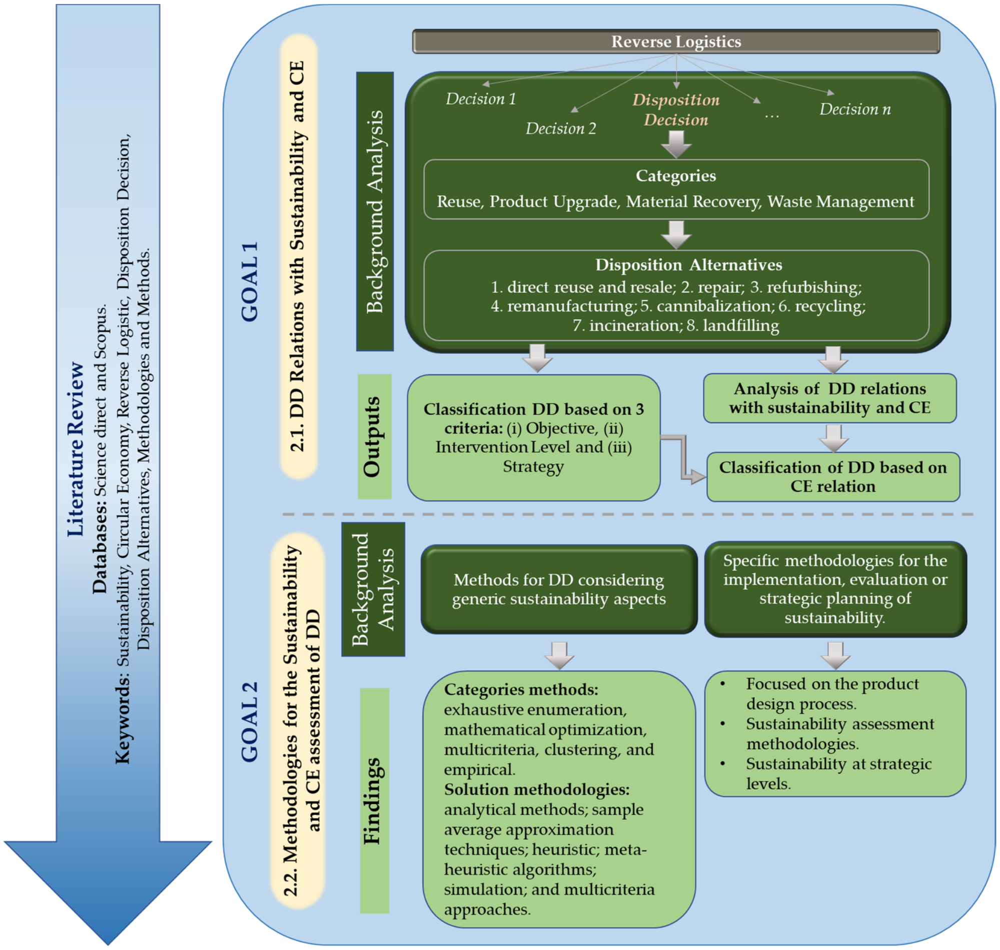

Figure 1. Structure of the approach followed in the background section (Source: Own elaboration).

2.1. DD Relations with Sustainability and CE

According to Rogers and Tibben-Lembke [30], the term reverse logistics (RL) is defined as, *"the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal"*.

RL has become a key competence of modern supply chains [14], mainly due to its importance in recovering the value of products and managing their disposal [30]. Some authors like Narayana et al. [31] and Sarkis et al. [32] also highlight RL management as a key element in fulfilling the Sustainable Development Goals of any organization. This clearly shows the relation between RL and sustainability/CE concepts [32].

Most of the consulted studies highlight the following stages in the RL process [19,20,33,34]: Collection, transport, inspection and sorting, DD, and product treatment.

One of the key activities of the RL process is undoubtedly product disposition decision making for its impact on operational efficiency [15,24], and also for its influence to improve supply chain sustainability by improving its dimensions [35]. This decision, known in the literature as Disposition Decision (DD), consists of choosing the disposal or treatment for recovered or returned products [15,16,22,26,36–38].

DD is possibly one of the most complex decisions in the RL field. This complexity is due mainly to the following four reasons: (1) High degree of uncertainty about the quantity of product to be recovered, quality, place, and time of recovery [16,39–41], (2) each product entails: An independent and specific treatment given its own characteristics [19], (3) a large number of factors related to engineering, business, environmental, and social factors [42], and (4) in many cases, agility and speed to provide a response to customers, mostly about product withdrawal conditions and treatment options.

DD takes place at the beginning of the RL flow, and this fact makes it more relevant because this decision will determine what will be done with the product in the following process stages and will condition company or supply chain efficiency and costs, especially those related to transport, disassembly, and remanufacturing. Actually, it is one of the most influential decisions in the performance of RL from the perspective of sustainability [15] and has the greatest impact on the supply chain and the customer [23,43,44].

Despite its relevancy, DD is one of less studied decisions of the RL process in the literature [19] and is, consequently, an area that needs further study [36,45]. Such lack of information represents an additional barrier when it comes to exploiting the potential benefits of an adequate DD and evolving toward more sustainable business models and CE, particularly for SMEs because they do not often have the necessary resources to implement such knowledge [28].

One of the first works to propose disposition alternatives in an integrated supply chain with a standard return process model was that of Thierry et al. [25]. Three main disposition options for products and components are mentioned in this model: Direct reuse, product recovery management, and waste management. Other later works [46] have modified this proposal and stratified possible disposition alternatives. Although each work defines and emphasizes slightly differing disposition alternatives, four common disposition categories seemingly emerge as to comprise the core taxonomy in recent literature [36]. In hierarchical order, and according to the criteria of residual value that can be recovered, these four alternative categories are [20,24,36]: Reuse, product upgrade, material recovery, and waste management.

Consensus seems to have been reached in the consulted literature about the fragmentation of these four main categories into eight disposition alternatives: (1) Direct reuse and resale; (2) repair; (3) refurbishing; (4) remanufacturing; (5) cannibalization; (6) recycling; (7) incineration; (8) landfilling. The detailed description of all these disposition alternatives can be found in these works [16,17,21–26,30,36,41,47,48].

An analysis of the literature about how the eight disposition alternatives have been established, and the different ways in which they have been grouped [24,36,49–52], allow us to identify three main grouping criteria to be identified: The objective of the disposal (to recover the value of the product or not), the level of intervention on the product (intervene or not), and the strategy followed to fulfill the objective of the disposition (reintroduce the product on the market, use its components, or get rid of them).

Disposition alternatives are frequently grouped according to one or some combinations of these three criteria. They also often appear in a hierarchical manner for the required reprocess level in a form of a pyramid [20,53]. It is the so-called recovery options hierarchy that prioritizes the reuse of the whole product, and then subassembly or component, next material recycling in its original application or, if not possible, in a lower application, and finally energy recovery as either direct fuel or heat to generate electricity [43]. The idea is that resources could be saved by avoiding the premature disposal of components as well as saving large manufacturing costs by shifting material recovery toward component reuse [42,54–56].

The EU strategy to achieve a CE, defined in its VII Action Program of the European Community on Environment for the 2013–2020 period, is precisely based on this hierarchy, by which no waste generation is given the highest priority, followed by its recovery, recycling, valuation, and energy use, which leaves depositing it in a landfill as the last option [57].

Based on the previous review, Figure 2 shows the eight disposition alternatives organized according to the three aforementioned criteria (in columns) and following the pyramidal hierarchy, in which the recovery options at the top of the pyramid are of high value, while the options close to the bottom recover less value from products.

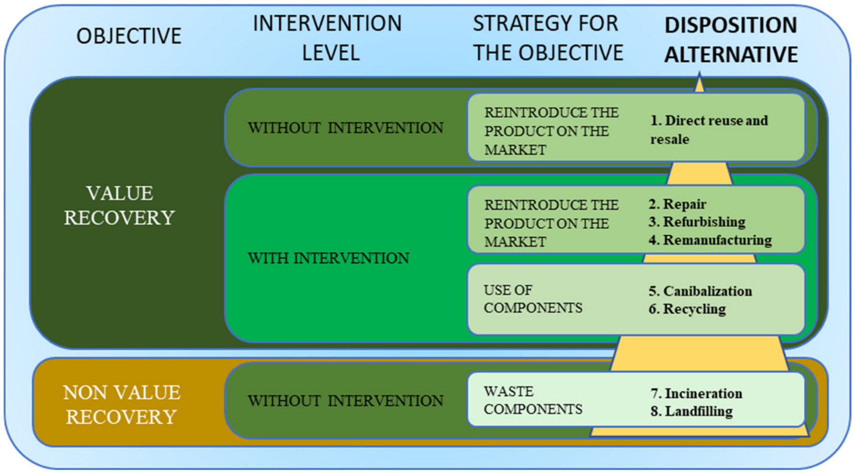

Figure 2. Classification scheme for disposition alternatives (Source: Own elaboration).

The consideration of the recovery options hierarchy is important at a single company management level because, obviously, the aim is to reduce the waste generated from material flows. However, it is also important to hold a macrovision because, when these particular waste flows are viewed in the larger local or regional business network context, arguing that flows should be maximized in order to be exploited by other stakeholders can be justified [9].

Regardless of which the most appropriate DD is for each recovered product, the relation of this decision with the sustainability and CE levels achieved by a company is evident. On this, Agrawal and Signh [15] affirm that the DDs of products after their use are crucial for making reverse logistics sustainable. Obviously, those in charge of DD must know the firm's environmental policy to ensure that their decisions are congruent with existing policies and programs. Consequently, the environmental impact of each disposition alternative can be understood and considered when making DD [58].

This relation is in fact reflected in the definition of one of the sustainable development goals, No. 12 (responsible consumption and production), established in the United Nations 2030 agenda, "*By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse*" [59], in which the main types of disposition alternatives are mentioned. This relation is also evidenced in different sustainability definitions [2,4,60,61] and CE [4,6,62–64], which name the various disposition alternatives.

By considering sustainability and CE definitions and being aware of existing confusion about both terms [4], it could be understood that any of the eight possible disposition alternatives could favor sustainability in a specific situation and for a certain weighting of economic, environmental, and social aspects, while only some would actually correspond to CE practices. This idea could be reinforced by some works that attempt to clarify the differences between the sustainability and CE concepts [4] by indicating that the latter can be considered a means to achieve business sustainability [4,9,28,62,65–67] or sustainable development [6]. That is, a business' degree of sustainability can be understood as a consequence of the different practices and actions carried out in the company, among which CE practices can be found. Hence, not all systems that incorporate circular principles are intrinsically more sustainable, according to Geissdoerfer et al. [27] and Pieroni et al. [1]. This could be justified by the fact that CE practices focus mainly on environment care and are not always the most interesting ones from the perspective of the other two sustainability dimensions, economic and social. Precisely in this line, the research by Geissdoerder et al. [4] indicate that most authors focus on the environmental performance improvements of CE rather than taking a holistic view on all three sustainability dimensions.

So, it seems clear that suitable CE treatment alternatives are those ones whose objective is to recover value because they involve circular flows. This has been confirmed in the consulted studies, which mention that the main CE activities are [9,64]: Repair or refurbishment (reuse at the product level), remanufacturing (reuse at the component level), and recycling (reuse at the material level).

Obviously, to these four disposition alternatives, the other alternatives mentioned in the literature should be added whose objective is also to recover value and, therefore, to favor circular flows: Reuse of products with no intervention or direct reuse [20,25,33] and a variant of recycling, cannibalization [25,41]. In light of the results obtained through the literature review, we have included the disposition alternatives that would favor CE in the classification framework, as it is shown in Figure 3.

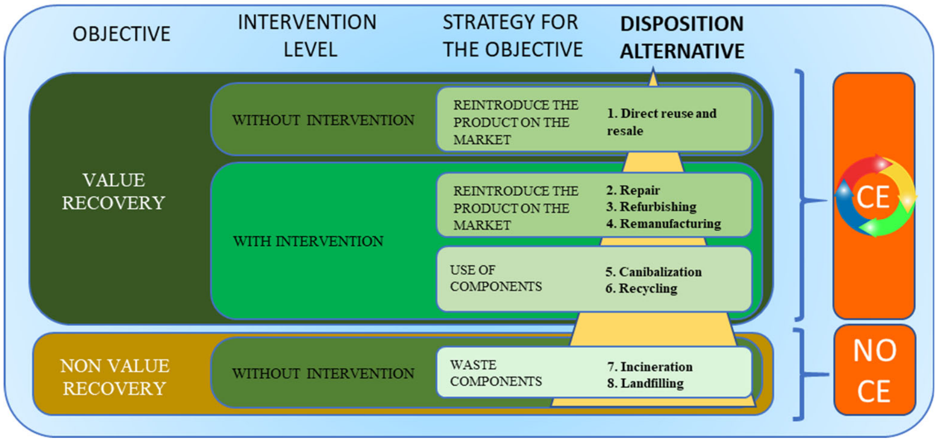

Figure 3. Classification framework for the disposition alternatives with the circular economy (CE) alternatives ranking (Source: Own elaboration).

2.2. *Methodologies for the Sustainability and CE assessment of DD*

No detailed results have been found in the literature about methodologies for DD that approach sustainability and CE as different concepts in their decisions. This might suggest that some functionality, characteristic, or aspect to consider in our proposal has not offered concrete results. It might also confirm that tools to overcome barriers in implementing sustainability and CE into companies are lacking [29], and the interest of empirical studies in analyzing impacts of DD on the RL process' sustainability and guiding decision makers to make appropriate decisions [15]. However, two types of work that may be relevant for our research have been identified: Studies proposing methods for DD by considering generic sustainability aspects; and specific methodologies addressing the implementation, evaluation, or strategic planning of sustainability.

An analysis of the works belonging to the first type shows, in most cases, and despite the fact that a calculation method, a solution method, or a solution methodology is announced in the title, the true core of the work is a mathematical model. Although such a mathematical model is not trivial, the methodology only consists of a few simple steps to operate with the mathematical model. In our proposal, the followed approach differs from that insofar as it interacts with a mathematical model with a black box format and focuses on not the mathematical model or its development, but also on the steps that users must follow to assess the disposition alternatives and to accordingly take decisions. Therefore, the search, filtering, and review of this first type of works on DD methods, by considering generic sustainability aspects, were done by taking this approach into account.

In this first type of work, it is worth mentioning two studies that offer an overview of the solution methods used in the DD field. The first is that of Ziout et al. [42], which shows a wide spectrum of DD methods grouped into five categories: Exhaustive enumeration methods, mathematical optimization methods, multicriteria methods, clustering methods, and empirical methods. Similarly to Ziout et al. [42], the work of Govindan et al. [68] divides the solution methodologies used by researchers into six main categories (indicating the frequencies of exploiting of each): (1) Analytical or exact methods (26.2%); (2) sample average approximation techniques for solving stochastic optimization problems (15.2%); (3) heuristic methods (2.6%); (4) meta-heuristic algorithms such as genetic algorithm, simulated annealing, tabu search, or ant colony, for large-size problems (8.6%); (5) simulation techniques and software to manage uncertainties in real situations (8.6%); (6) multicriteria (or multi-objective) solution approaches, such as goal programming, analytical hierarchy process, analytic network process and technique for the order of prioritization by similarity to ideal solution (4.5%).

Some concrete examples of this type of work are those that use multi-criteria methods to make disposal decisions, either considering the three aspects of sustainability [69]; other aspects such as residual value, environmental load, weight, quantity, and ease of disassembly of each component [70] (multi-criteria matrix); either trying to minimize the environmental impact and the deficit [71] (multi-objective methodology based on a mathematical model); or using the weighted average of several decision criteria in a context of information uncertainty [72] (Gray's relational analysis). In addition, those who use graph theory and the matrix approach to choose the design alternative through a design index used to prioritize the alternatives [22]; the Fuzzy-Vikor method to analyze recovery options from an environmental point of view [73]; or the analytical hierarchy process to choose the best of the elimination alternatives considered [52].

Regarding the second type of work, that is, those proposing specific methodologies related to sustainability, the consulted literature suggests the existence of three main thematic lines.

First, studies that seek to promote or implement sustainability by focusing on the product design process, although they refer to different industrial sectors: Chemical products a [74], electric-electronic products [75–77], automotive industry [78], or buildings [79]. The work of Culaba and Purvis [80] would also appear in this group, who describe a general methodology for the life cycle analysis of a manufacturing process.

A second group focuses on sustainability assessment methodologies in, for example, the field of farms [81] or for smartcities [82].

In the third group, methodologies are proposed that address sustainability at strategic levels [83,84] by tackling the planning of recycling processes [85] or working from the innovation perspective [86].

Unfortunately, this second type of works emphasizes methodological aspects and sustainability, but does not address DD.

3. Methodology for Sustainable and CE Disposition Decision-Making

The proposed methodology for sustainable and CE disposition decision (M-SCE-DD) aims to facilitate product disposal decision making in an RL context through two main functionalities: (a) To be used as an aid to make sustainable decisions about the disposal of recovered products by considering the three sustainability dimensions (economic, environmental, social); (b) facilitate the comparison of the most sustainable disposal alternative to the most sustainable CE one from the perspective of the three considered sustainability dimensions.

This comparison allows the company to know how economic profitability, as well as environmental and social impacts increase or decrease by choosing the most sustainable CE disposal alternative in relation to the initial most sustainable decision and, therefore, to assess the interest of adopting a CE policy for managing each situation.

The calculation core of this M-SCE-DD is a mathematical model (MM) based on mixed integer linear programming whose decision variables represent a closed set of possible disposition alternatives. These variables are of a binary type and take the value of 1 when a certain disposition alternative is carried out, and 0 otherwise. It should be noted that the first four alternatives (reuse, repair, refurbishing, remanufacturing) are applicable to the product as a whole, while the remaining four (cannibalization, recycling, incineration, landfilling) can be independently carried out in each product component. Thus, one of the restrictions that the model is subjected to will force the selected disposition alternative as a solution (hereinafter alternative solution) to be a single alternative applicable to the product as a unit, or a set of alternatives, independently of one another, which are applicable to all the recovered product components. The MM uses two indices, "i" and "j", to respectively refer to products and components.

The MM considers the triple sustainability dimension, for which a set of economic, environmental, and social parameters related to different decision variables is included. Some of these parameters use fixed values, which are taken from the company's information (e.g., disassembly operations costs) or about the product type (e.g., market price of the recycling component), while others use variable values according to each recovered product (e.g., environmental impact on transporting the product from the customer to the company). The objective function (OF) consists of three objectives that can be weighted by a multiplicative factor, which takes values between 0 and 1 depending on the importance that the decision maker attaches to each one: Maximize economic profitability, minimize the environmental impact, and maximize the social impact as we have represented in Figure 4.

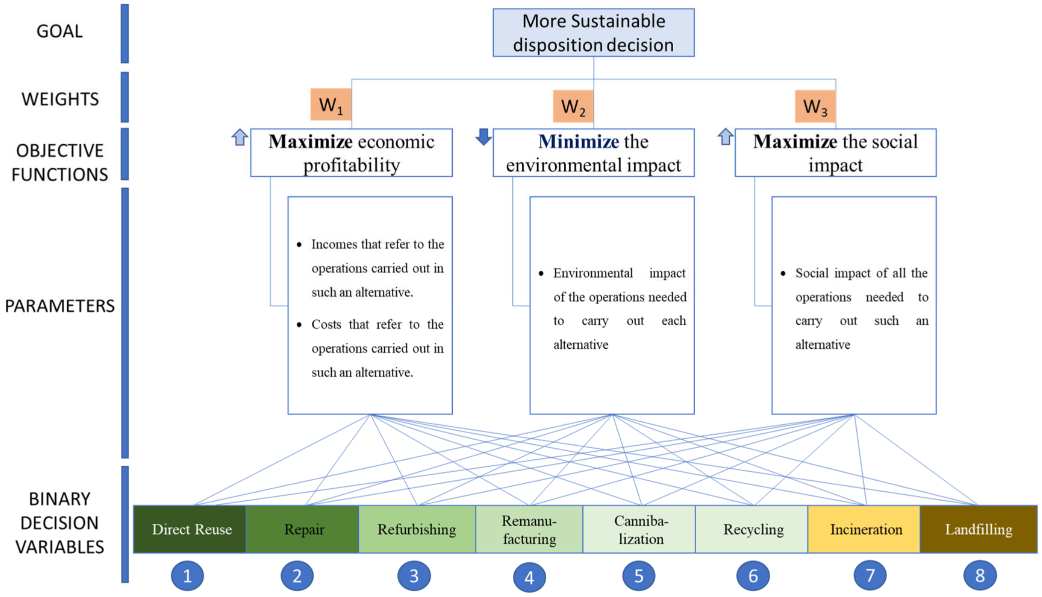

Figure 4. Mathematical model scheme (Source: Own elaboration).

The MM that feeds the M-SCE-DD is a generic model. In the first phases, it must be adapted to each company and each product type, mainly as regards to removing those disposition alternatives and sustainability parameters that are not feasible for a certain company or product type.

Although the MM to be used later in the M-SCE-DD application was developed by the authors of the present paper, the approach involves the methodology interacting with this MM in a black box format, by means of which the link methodology-MM is based on a mere interaction to exchange data: The methodology sends data about the feasible alternatives and the values of the applicable parameters to the MM, while it receives from it the alternative solution for each sustainability dimension and the value of each dimension for all the disposition alternatives.

The black box format aims to turn the MM into a transactional module that can be replaced, perhaps some minor adjustments, with any other module (or MM) that has similar characteristics, of which two can be highlighted: Able to address DDs from the three sustainability dimensions; having economic profitability parameters, and environmental and social impacts, for all the possible disposition alternatives. With this approach, we find that it is not appropriate to explain the MM in depth, so efforts were made to explain the methodology.

The contents or steps of the proposed M-SCE-DD were arranged into three layers with different levels of detail to facilitate their understanding. The hierarchy is as follows: Layer 1 corresponds to the lowest level of detail and is made up of "areas"; layer 2 corresponds to an intermediate level and comprises "blocks"; layer 3 represents the highest level of detail and consists of "phases". Next, the M-SCE-DD is explained following this hierarchical approach.

3.1. Layer 1

Layer 1 of the methodology is made up of three content areas (see Figure 5): Area A, which focuses on calculating the most sustainable solution; area B, which enables the most sustainable CE solution to be calculated; and area C, which deals with the comparison of the solutions obtained in the other two areas, and provides users with the information required for the DD.

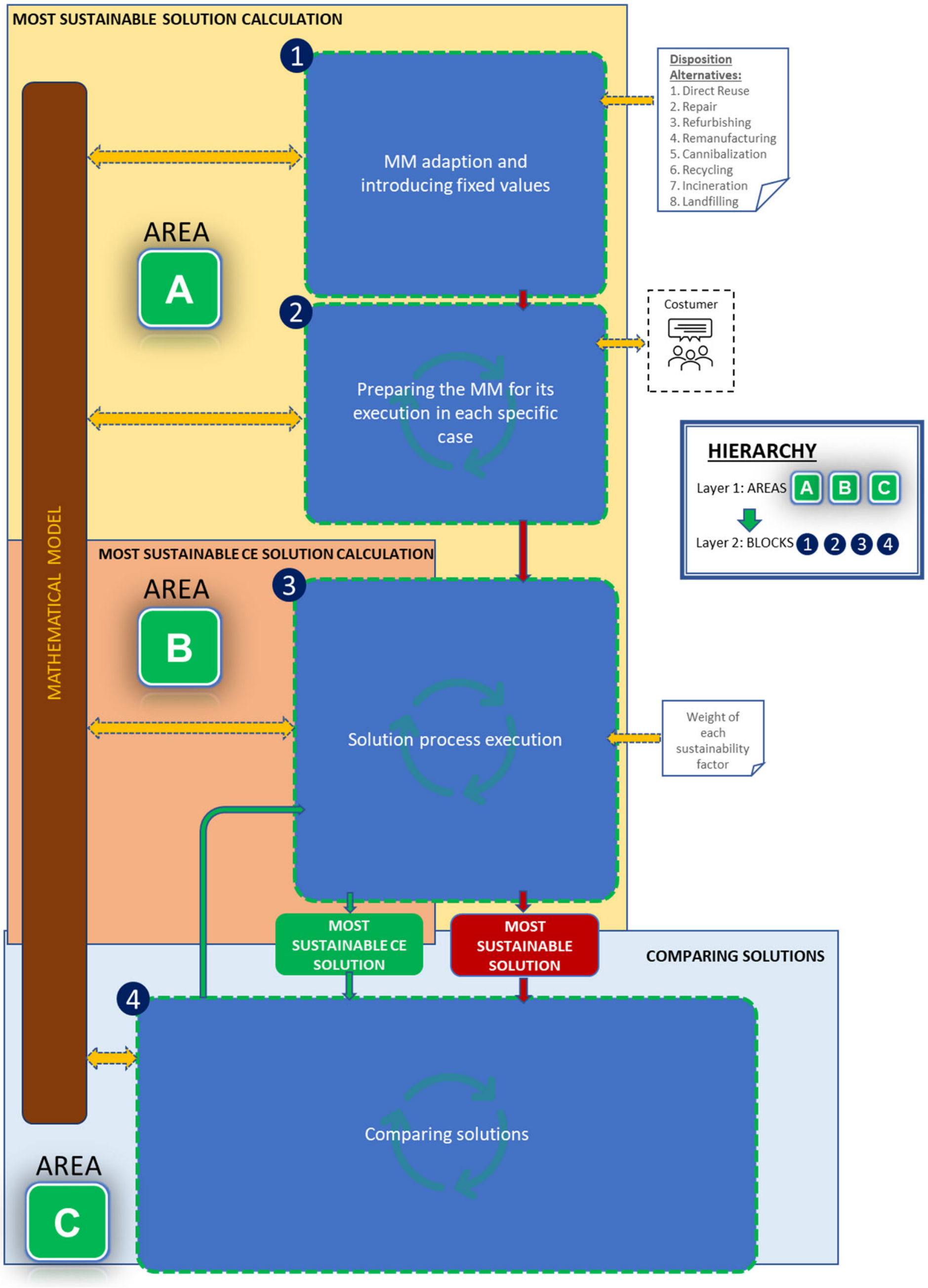

Figure 5. Proposed methodology—Layers 1 and 2.

3.2. Layer 2

In layer 2 (intermediate layer), four blocks were deployed, which are explained below. These blocks are also seen in Figure 5 numbered from 1 to 4, and colored in blue:

- Block 1. MM adaptation and introducing fixed values

In this first block, the generic MM is adapted to the specific company or product type by selecting the feasible disposition alternatives, their corresponding sustainability parameters, and the fixed values from both the company and context. It is precisely this information that should be sent from the methodology to the MM to adapt it. This interaction takes place only once for each company or recovered product type.

- Block 2. Preparing the MM for its execution in each specific case

In this second block, the variable sustainability parameters applicable to each disposition alternative are quantified based on the information transmitted by the customer. Once this quantification takes place, the feasible disposition alternatives in each specific case, and the value of the sustainability parameters that depend on each product are sent to the MM from Block 2 to, thus, prepare the MM for its execution in each specific case.

Executing this block is repeated for each recovered product with each interaction with the customer, which is reflected in Figure 5 with a cycle symbol.

- Block 3. Solution process execution

In Block 3, the solution process is executed to obtain the most suitable alternative solution. The execution of this block is also repeated for each recovered product. For this purpose, the most sustainable disposition alternative is selected as a solution, based on the weighting of the sustainability factors chosen by the decision maker.

This solution process is executed in a first iteration and, if the treatment alternative obtained as the most sustainable solution is not a consistent treatment alternative with CE, the necessary changes are made for a second iteration.

- Block 4. Comparing solutions

In this last block, the two solutions obtained in Block 3 are compared so that if both solutions coincide, it is taken for granted that the most sustainable solution is also a CE one. If, however, both solutions do not match, the solution process is run again to obtain the most sustainable CE solution.

The comparison made of the solutions allows the differences in the sustainability dimensions between the most sustainable solution and the most sustainable CE solution to be quantified. This block is also repeated for each recovered product.

The following figure (Figure 5) represents Layers 1 and 2 of the M-SCE-DD, composed of the three areas (A–C) and four blocks (1–4), respectively.

3.3. Layer 3

The detailed phases of the M-SCE-DD that have been defined for layer 3 are described below. According to the hierarchical approach that has been followed to develop the methodology, all these phases are linked with one of the blocks defined in layer 2. This link is indicated and reinforced with the numbering used to name each phase so that the first digit of the numbering of a phase (from 1 to 4) indicates the block to which that phase belongs, while the second digit represents the order of the phase in the block.

- Phase 1.1 Choose viable disposition alternatives

The eight disposition alternatives herein considered, and in line with the literature consulted in the background section, are: Reuse, repair, refurbishing, remanufacturing, cannibalization, recycling, incineration, and disposal. Some of these eight alternatives may not apply to certain products, or to certain types of businesses. For example, incineration is not contemplated in the recovery of glass or metal products. Likewise, landfilling will not be a feasible alternative for a battery recovery company.

The objective of this first phase is to precisely choose those viable alternatives for the company, and the products to which the methodology is to be applied. The selection of feasible alternatives will allow the MM binary variables that should not be considered to be modified or removed to, therefore, adapt the generic MM to the specific characteristics of the company and its products.

- Phase 1.2 Determine the sustainability parameters applicable to each alternative

In this second phase, the sustainability parameters that are applicable to each feasible disposition alternative selected in the previous phase are determined. These parameters refer to economic profitability, and to environmental and social impacts.

The economic profitability of each alternative is given by the difference between the incomes and costs that refer to the operations carried out in such an alternative, calculated in euros. For example, the economic profitability of the repair alternative is calculated by the difference between the incomes made from selling the repaired product and the costs generated by its repair operations.

The environmental impact of each alternative is obtained after adding the environmental impact of the operations needed to carry out each alternative. For example, the environmental impact of recycling is given by the sum of the environmental impact of the operations needed to recycle the product, which comes in the form of quantifying the carbon footprint, CO_2 emissions, environmental impact points, or any other selected environmental indicator.

Likewise, the social impact of each alternative is also obtained by adding the social impact of all the operations needed to carry out such an alternative. For example, the social impact of repair is given by the sum of the social impact of the operations needed to repair the product, which comes in the form of quantifying the amount of working hours, customer evaluations or any other agreed indicator of social impact.

After determining the parameters, they are fed the MM in order to address the specific features of the company and its products.

- Phase 1.3 Calculate the fixed values from the company and the context

As previously aforementioned, the economic, environmental, and social parameters can take fixed or variable values.

Fixed values are those that always take the same value, for the same type of product, regardless of the characteristics of each recovered product or the information provided by customers.

In this phase, fixed values are calculated with measurements, valuations, and estimates, based on the information available for the company and the context in which operations are carried out.

Some examples of the parameters that take fixed values are available transport options or market prices, which will remain fixed regardless of the status of the product to be recovered or the information provided by customers.

Although the values of this parameter type are considered fixed because they hardly vary, the company must control and update them whenever necessary. After calculating these fixed values, they are entered into the MM before continuing with the next M-SCE-DD phases to obtain the best disposition alternative.

- Phase 2.1 Capture the information transmitted by customers

The previous methodology phases correspond to the block to adapt the MM to the company, and its products and are linearly handled. However, the next phases are cyclically repeated for each product to be recovered and to determine their disposition, as depicted in Figure 6.

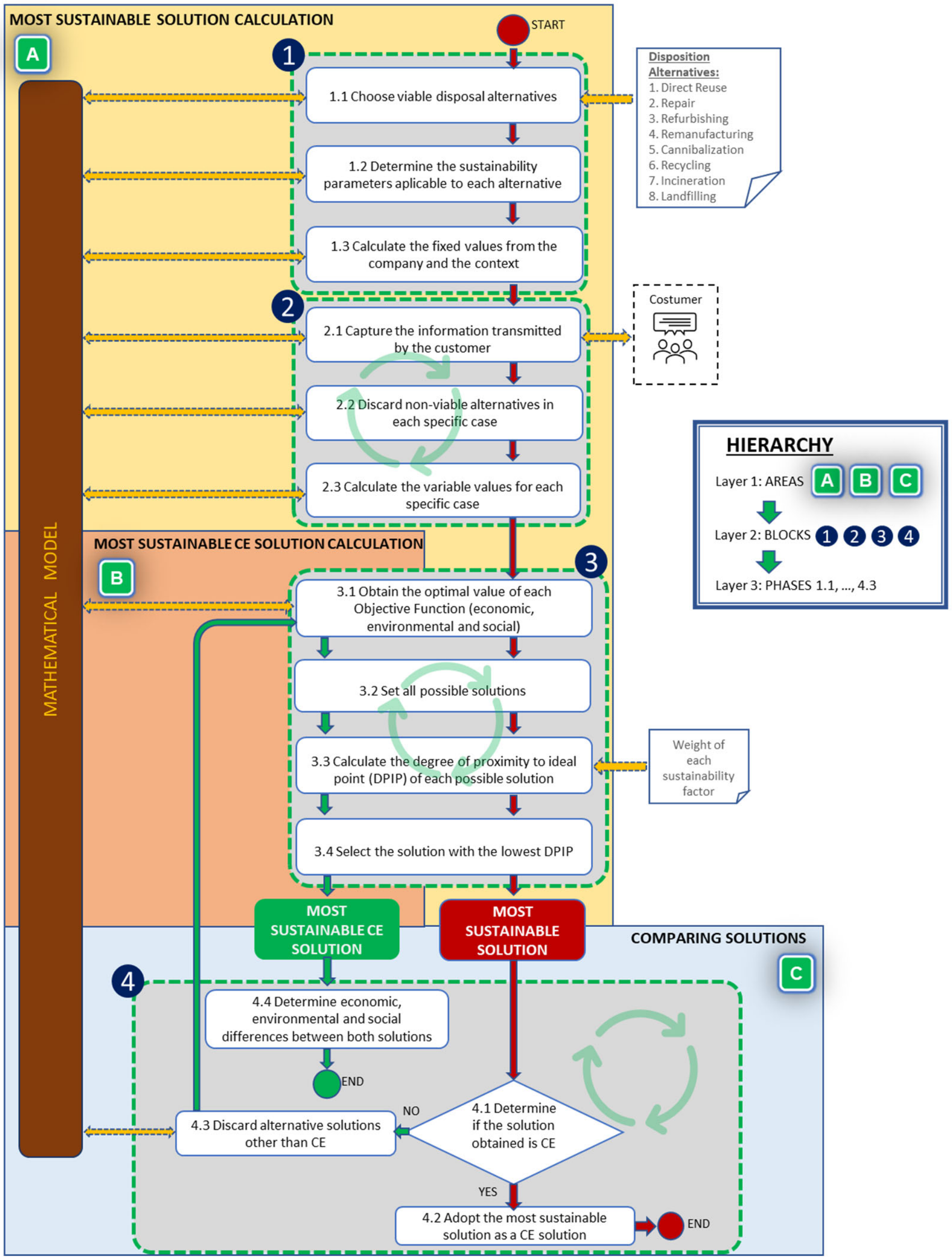

Figure 6. Proposed methodology—Layers 1–3.

In this phase, the information provided by customers about each recovered product is collected, and is generally related to product status, purchase date, and price and current product location.

- Phase 2.2 Discard non-viable alternatives in each specific case

Based on the information provided by customers about the status of the product to be recovered, those disposition alternatives that are not considered feasible are discarded. For example, if the product is not in good condition, the direct reuse alternative can be ruled out. If, on the contrary, the product is in perfect condition, the options for intervention on the product for it to be reintroduced on the market, such as repair, refurbishing, and remanufacturing, can also be discarded.

Consequently, ruling out certain disposition alternatives allows some decision variables of the "adapted" MM to be removed, which thus reduces the possible alternative solutions for the specific product.

- Phase 2.3 Calculate the variable values for each specific case

Once the information provided by the customer for each recovered product case and the viable alternatives are known, the variable values for the parameters of the MM are calculated in this phase. These calculations are obtained through measurements, valuations, and estimates based on the information provided by customers.

These variable values depend on each returned or recovered product. For this reason, these parameters are updated every time a customer is contacted about a return or recovery, and the alternative treatment to be applied must be decided. This interaction with the customer enables the corresponding parameter to be quantified.

For example, when the customer indicates the location of a recovered product, the economic profitability, and the environmental and social impacts related to the product collection and subsequent transfer to the company, can be quantified. After calculating these variable values, they are also entered in the MM to continue with the next methodology phases to obtain the best disposition alternative.

- Phase 3.1 Obtain the optimal value of each of (economic, environmental, social)

The intention of this methodology phase is to obtain the best alternative solution for each OF dimension. Three solutions can be obtained: One solution corresponding to the alternative that provides the most economic profitability; another solution to the alternative with the least environmental impact; and a third one for the alternative with the strongest social impact.

If these three solutions coincide in selecting some specific disposition alternative, that alternative would be the most appropriate from the point of view of all the sustainability dimensions. However, these solutions do not usually coincide with the same alternative. For example, in most cases, increasing the social impact leads to less economic profitability. Therefore, the alternative with the strongest social impact is not that with the most economic profitability.

So, a general solution leads to different optimal values for the economic profitability and environmental and social impacts. These three optimal values determine a three-dimensional point called the ideal point. Hence, the most suitable disposition alternative is that for which the values of the three OFs determine the point closest to the ideal point.

- Phase 3.2 Set all the possible solutions

Some treatment alternatives are applicable to the product as a whole ((1) reuse, (2) repair, (3) refurbishing, (4) remanufacturing) and others are mainly applicable to the product’s components ((5) cannibalization, (6) recycling, (7) incineration, (8) landfilling). In this way, the alternative solution can be an alternative applicable to the product as a whole or a combination of alternatives that are applicable to components, which is constrained by the corresponding MM restriction.

For example, for the recovery of a used tire, one alternative solution applicable to the product as a whole can be refurbishing (retreading) the tire, while a combination of alternatives applicable to the tire components of the tire can be fiber incineration and recycling rubber and steel.

In this methodology phase, all the possible solution alternatives are set and, for each one, the economic profitability value and the environmental and social impacts values are calculated.

- Phase 3.3 Calculate the degree of proximity to the ideal point (DPIP) of each possible solution

As mentioned above, the most suitable alternative solution is that whose economic profitability and environmental and social impacts values determine the three-dimensional point closest to the ideal point. The distance between the three-dimensional point of each possible alternative solution in relation to the ideal point is called the degree of proximity to the ideal point (DPIP).

In this methodology phase, the DPIP of each possible solution alternative is calculated, which is given by the distance between the value of the solution alternative and the ideal point of each objective. Likewise, the three sustainability dimensions that characterize DD may imply different degrees of relevance for decision makers. Therefore, modifying the weight of each sustainability factor of the OF and prioritizing them are allowed to calculate the DPIP according to each situation or decision maker.

Consequently, the DPIP value for each alternative solution is calculated as follows:

$$DPIP = \sum_{j=1}^{3} W_j \left[\frac{|f_j(x) - f_j^*|}{|f_j^*|} \right] \quad (1)$$

where $f_j(x)$ represents the value of the alternative solution in a specific sustainability objective j, f_j^* is the ideal value of such an objective *j*, and *Wj* represents the relative weight of each objective *j*.

- Phase 3.4 Select the solution with the lowest DPIP

In order to select the alternative that provides the best solution, in this methodology phase, all the solution alternatives are ordered according to their DPIP value in such a way that the alternative with the lowest value is selected as the closest viable solution to the ideal point, as previously defined. The optimization problem would be as follows:

$$Min \sum_{j=1}^{3} W_j \left[\frac{|f_j(x) - f_j^*|}{|f_j^*|} \right] \quad (2)$$

- Phase 4.1 Determine if the obtained solution is CE

This methodology phase questions whether the sustainable solution obtained throughout Block 3 corresponds to an alternative CE solution.

If so, the M-SCE-DD continues through Phase 4.2, otherwise it goes directly to Phase 4.3.

- Phase 4.2 Adopt the most sustainable solution as a CE solution

If the most sustainable solution corresponds to a CE solution, the company then selects a sustainable disposition alternative by reducing uses, emissions, and waste and, therefore, fulfilling the basic CE objectives.

- Phase 4.3 Discard alternative solutions other than CE

If the most sustainable alternative solution is not a disposition alternative that is consistent with CE, this methodology phase discards all the possible alternative solutions not considered CE and forces the MM to select the best disposition alternative from among the CE alternatives. For this purpose, these alternatives are removed as possible decision variables from the MM.

As mentioned in previous sections, the alternatives that do not include a CE disposal are those of product removal without recovery, such as incineration or landfilling.

By discarding these alternatives, the steps related to the solution process are re-executed (Block 3—Phases 3.1–3.4) so that the solution alternative to be obtained in this second iteration is the most sustainable CE solution.

- Phase 4.4 Determine the economic, environmental, and social differences between both solutions

In this last methodology phase, the differences between the two obtained solutions are quantified: The most sustainable solution and the most sustainable CE solution. For this purpose, the differences in economic profitability and the environmental and social impacts are calculated by subtracting the values obtained between both alternatives according to the employed economic, environmental, and social indicators.

In this way, the company can finally quantify the differences between both solutions (economically, environmentally, and socially), and is better able to assess the strategy to be followed per product and to, therefore, make better decisions.

For gain a better understanding, a scheme of the proposed M-SCE-DD is depicted in Figure 6.

4. Example of Applying the Methodology to a SME that Recovers and Treats Used Tires.

Used tires can have serious environmental implication mainly for their disposal in landfills and their uncontrolled management. However, the fact that restrictive measures have been taken in the USA, China, Japan, and the EU, has promoted sustainable management to recover this product type by taking a new approach with used tires [87].

In 2019, around 200,000 tons of end-of-life tires were collected in Spain [88]. Once transferred to collection and classification plants, a visual and individual inspection is carried out to classify them into tires that can be reused (TUR) and tires at the end of their useful life (TEUL).

TURs are tires that can be reused, generally after intervention, while TEULs are tires that no longer offer any potential use and are unsuitable for driving and refurbishing. When tires are designated as TEUL, they are valued (shredded) to separate their components (mainly steel, fiber, and rubber) and to attempt to take advantage of the value that may still have. Steel is usually reusable as wire and can be easily sold to steel companies. Fiber is often used as fuel by the cement industry or for recycling as equestrian flooring or acoustic absorbent. Rubber is also normally employed as fuel to generate energy or is crushed to make artificial grass fields, playgrounds, insulation materials, etc.

Next, the proposed M-SCE-DD is applied to a recovery and treatment company of used tires. It is a company that belongs to the tires industry, is located in the province of Valencia (Spain), and operates both nationally and internationally. This business kindly provided all the data employed in this application example.

By applying the methodology, this company was able to identify: First, the most sustainable disposal for a batch of recovered tires of similar condition; second, the best and most sustainable and CE disposal; finally, if the previous two do not coincide, quantify their economic, environmental, and social differences.

Specifically, the proposed methodology can be applied to recover a batch of 30 deteriorated tires.

- Phase 1.1 Choose the feasible disposition alternatives according to product type

Feasible disposition alternatives in the used tires sector are identified by tire type (TUR or TEUL). Three disposition alternatives are considered for TUR. On the one hand, there are two reuse types with no intervention: Reuse on the domestic market and reuse in less restrictive markets, e.g., some foreign markets that have more permissive legislation about tire sheet wear. On the other hand, a reuse type with intervention; that is, refurbishing, which consists of intervening on tires to place them back on the market as retreaded tires.

For tires designated as TEUL, disposition alternatives focus on treating their components. For steel, only recycling is contemplated, while both recycling and incineration are taken into account for fiber and rubber (see Table 1).

Table 1. Viable disposition alternatives for each type of tire.

Tire Type	Disposition Alternatives
TUR	Reuse in the national market Reuse in foreign markets Refurbishment
TEUL	Recycling (steel, fiber, and rubber) Incineration (fiber and rubber)

- Phase 1.2 Determine the sustainability parameters applicable to each alternative.

In this application example, the sustainability parameters applicable to the disposition alternatives are as follows (see Table 2).

Table 2. Sustainability parameters applicable to disposition alternatives.

Economic Profitability Parameters:
Income generated to the company from the sale of the product or component after a specific disposal alternative.
Costs associated with the operations necessary for the execution of a specific disposal alternative.
Environmental Impact Parameters:
Environmental impact of the operations necessary for the execution of a specific disposal alternative.
Social Impact Parameters:
Social impact of the operations necessary for the execution of a specific disposal alternative.

The economic profitability parameters are quantified in euros/unit, while the environmental and social impact parameters are quantified in points/unit by considering the employed environmental and social impact measurement indicators.

- Phase 1.3 Calculate the fixed values from both the company and context

The sustainability parameters with fixed values are shown in Table 3.

Table 3. Sustainability parameters with fixed values.

Economic Parameters with Fixed Values:
Income from recycling of components (steel, fiber, and rubber). Income from incineration of components (fiber and rubber). Cost of inspection and classification of the recovered product. Cost of packaging the product for reuse or resale. Cost of transporting the product from the collection and classification plant to the recovery plant. Cost of valuation of the product in components. Cost of recycling components. Cost of incineration of the components.
Environmental Parameters with Fixed Values:
Environmental impact of transporting the product from the collection and classification plant to the recovery plant. Environmental impact of the operations of valorization of the product in components. Environmental impact of the transport of the components to be recycled. Environmental impact of the transportation of the components to be incinerated. Environmental impact of recycling components. Environmental impact of the incineration of components.
Social Parameters with Fixed Values:
Social impact of transporting the product from the collection and classification plant to the recovery plant. Social impact of the operations of valorization of the product in components. Social impact of the transport of the components to be recycled. Social impact of the transportation of the components to be incinerated. Social impact of recycling components. Social impact of the incineration of components.

The fixed values are calculated by measurements, valuations, and estimates based on the information made available by the company. Once the calculations have been made, the values are entered in the MM.

- Phase 2.1 Collect the information transmitted by customers

In this phase, an interaction with customers comes into place to collect as much information as possible about the recovered products. In this example, we work with a batch of seriously damaged tires, so their reuse on the market would not be advisable. These tires are located in a town in the province of Valencia at an approximate distance of 50 km from the company.

- Phase 2.2 Discard non-viable alternatives in each specific case

As the current status of the batch of tires is deteriorated, tires are classified as TEUL, which means they cannot be reused as tires on the domestic or foreign market. Likewise, they cannot be reconditioned to be sold as retreaded tires. In this case, only the alternatives involving the treatment of components are viable: Recycling and incineration.

Such information is updated in the MM by removing the disposition alternatives that are not applicable to this batch of tires.

- Phase 2.3 Calculate the variable values from each specific case

The variable values that depend on each specific case, and that the company must calculate based on the specific information about each product, are related to the following parameters (see Table 4):

Table 4. Sustainability parameters with variable values.

Economic Parameters with Variable Values:
Cost of transporting the product from the customer to the collection and classification plant.
Environmental Parameters with Variable Values:
Environmental impact of transporting the product from the customer to the collection and classification plant.
Social Parameters with Variable Values:
Social impact of the product collection, categorization, and storage operations from the customer to the collection and classification plant.

By taking into account the fixed and variable values corresponding to the sustainability parameters, the value of economic profitability and the environmental and social impacts of each disposition alternative are calculated. As previously mentioned, the company provides data to calculate the values of each component.

The results are presented in Table 5. The first column indicates the sustainability aspects. The next three columns refer to the recycling of the three product components (one column per component). The last three columns refer to the incineration alternative for each component.

Table 5. Values for each component according to each alternative.

	Recycling			**Incineration**		
	Steel	**Fiber**	**Rubber**	**Steel**	**Fiber**	**Rubber**
Economic profitability (€/unit)	0.1400	0.7020	0.6090	-	1.1600	1.0150
Environmental impact (points/unit)	0.0003	0.0006	0.0012	-	0.0007	0.0013
Social impact (points/unit)	0.1073	0.1463	0.1524	-	0.1694	0.1371

- Phase 3.1 Obtain the optimal value of each OF: economic, environmental and social

Having entered all the above information in the MM, an alternative solution is obtained for each OF that provides the optimal value that is economic, environmental, or social. In this example, as the solution alternatives are related to component treatment, each solution is made up of the alternative that corresponds to each component.

Table 6 shows the solution alternatives for all three OFs with their optimal value in the last column. The cells with a value of “1” indicate the treatment that each component received in each

OF. Obviously, each component can only undergo one treatment, which means a maximum of three "1s" per row (OF).

Table 6. Alternative solutions for each OF.

Objective Function	Recycling			Incineration			Optimal Value
	Steel	Fiber	Rubber	Steel	Fiber	Rubber	
Economic	1	0	0	0	1	1	2.3150
Environmental	1	1	1	0	0	0	0.0021
Social	1	0	1	0	1	0	0.4292

We can see that the optimal alternative for the economical OF is that composed of recycling steel and incinerating fiber and rubber. However, the solution for the environmental OF indicates recycling the three components. Finally, the social OF suggests the optimal alternative to be recycling steel and rubber and incinerating fiber.

The ideal point is defined by the optimal values for each OF: 2.3150 for the economic, 0.0021 for the environmental, and 0.4292 for the social ones.

- Phase 3.2 Set all the possible solutions

This phase shows all the possible alternative solutions with their corresponding economic, environmental, and social values. It is assumed in this application example that only the alternatives for the disposition of components are considered (recycling and incineration), and that recycling is contemplated only for steel. The cells showing the best value for each dimension are marked in green (see Table 7).

Table 7. Possible solution alternatives and economic, environmental, and social values.

	Recycling			Incineration					
	Steel	Fiber	Rubber	Steel	Fiber	Rubber	Econom.	Environ.	Social
Solution 1	1	1	1	0	0	0	1.4510	0.0021	0.4061
Solution 2	1	1	0	0	0	1	1.8571	0.0022	0.3907
Solution 3	1	0	1	0	1	0	1.9092	0.0022	0.4292
Solution 4	1	0	0	0	1	1	2.3151	0.0023	0.4138

- Phase 3.3 Calculate the degree of proximity to the ideal point (DPIP) of each possible solution

The same level of importance is considered for all three sustainability objectives, which means their weights are 33.3%. Table 8 shows the DPIP values for each solution according to a thermal scale that identifies the best result in green and the worst result in red, which blurs the other results in accordance with their proximity to the best or worst result.

Table 8. Degree of proximity to the ideal point (DPIP) values for all possible solution alternatives.

	Recycling			Incineration			W_1 Econom.	W_2 Environ.	W_3 Social	DPIP
	Steel	Fiber	Rubber	Steel	Fiber	Rubber	33.3%	33.3%	33.3%	
Solution 1	1	1	1	0	0	0	0.12	-	0.02	0.14
Solution 2	1	1	0	0	0	1	0.07	0.02	0.03	0.12
Solution 3	1	0	1	0	1	0	0.06	0.01	-	0.07
Solution 4	1	0	0	0	1	1	-	0.04	0.01	0.05

Viewing the thermal scale with the DPIP results for each possible solution, we see how the best solution is reached by solution alternative 4, which suggests recycling component 1 and incinerating components 2 and 3. Therefore, it can be stated that, for the present application example, it is the most sustainable solution.

- Phase 4.1 Determine if the obtained solution is CE

At this time, we must check whether the solution obtained in the previous section is a CE solution. Obviously, the obtained sustainable solution is not considered a CE solution as incinerating components produces large amounts of toxic emissions, and also due to components being removed instead of used [89].

With all the above information, the following phases focus on obtaining the most sustainable CE disposition alternative. It should be noted that, as the disposition alternative is not a CE alternative, Phase 4.2 is omitted and goes directly to Phase 4.3.

- Phase 4.3 Discard alternative solutions other than CE

By assuming that incineration lies beyond the scope of CE solutions, the only available solution for this application example focuses on recycling the three components (Solution 1 in Table 8) as it is also shown in Table 9.

Table 9. Available and unavailable solution alternatives.

	RECYCLING			**INCINERATION**		
	Steel	**Fiber**	**Rubber**	**Steel**	**Fiber**	**Rubber**
Solution 1	1	1	1	0	0	0
~~Solution 2~~	1	1	0	0	0	①
~~Solution 3~~	1	0	1	0	①	0
~~Solution 4~~	1	0	0	0	①	①

Obviously with only one available solution left, the economic, environmental, and social OF values of that solution define the new ideal point (see Table 10).

Table 10. DPIP values for all possible solution alternatives.

Objective Function	**Recycling**			**Incineration**			**Optimal Value**
	Steel	**Fiber**	**Rubber**	**Steel**	**Fiber**	**Rubber**	
Economic	1	1	1	0	0	0	1.4510
Environmental	1	1	1	0	0	0	0.0021
Social	1	1	1	0	0	0	0.4061

Consequently, the table with the DPIP values for all the possible CE solution alternatives (only one in this case) is as follows (see Table 11).

Table 11. DPIP values for all possible CE solution alternatives.

	Recycling			**Incineration**			**Wj Econom.**	**Wj Environ.**	**Wj Social**	**DPIP**
	Steel	**Fiber**	**Rubber**	**Steel**	**Fiber**	**Rubber**	**33.3%**	**33.3%**	**33.3%**	
Solution 1	1	1	1	0	0	0	-	-	-	0

- Phase 4.4 Determine the economic, environmental and social differences between both solutions

Once the most sustainable alternative solutions and the most sustainable CE one were obtained, their economic, environmental, and social values are compared (see Table 12).

Table 12. Comparing values between the solutions obtained.

		REC			BUR					
		Steel	**Fiber**	**Rubber**	**Steel**	**Fiber**	**Rubber**	**Econom.**	**Environ.**	**Social**
Sustainable Solution	Solution 4	1	0	0	0	1	1	2.3150	0.0023	0.4138
CE Solution	Solution 1	1	1	1	0	0	0	1.4510	0.0021	0.4061
							Difference	−0.8640	−0.0002	−0.0077

After comparing the economic, environmental, and social results between both solutions, the CE solution obtains lower values in all the dimensions vs. the most sustainable solution. This means a worse result in economic profitability and social impact terms, but a better result in environmental impact terms because the lower the value, the less impact the solution has and the more beneficial it is for the environment.

Specifically, the CE solution is less profitable (€ 0.864/unit) but has a better environmental result (0.0002 points/unit) and a lesser social impact (0.0077 points/unit) than the initially obtained sustainable solution. It would seem somewhat logical. Although only minor sustainability differences between both solution alternatives are found, it must be taken into account that recovered tires are treated in large quantities and, therefore, a minor difference per unit can spell relevant economic and social profitability, as well as a huge environmental impact, depending on the selected disposition alternative.

5. Conclusions

Despite DD being one of the most relevant decisions in the RL process, very few works are found in the literature. Based on the consulted studies, this work considers that DD comprises eight possible treatment options or alternatives that can be classified according to the criteria of: Objective, level of product intervention, and followed strategy.

Based on the definitions of the sustainability and CE concepts, a relation between both terms in the DD context was established. This relation allowed us to assume that all treatment alternatives can have an impact on company sustainability, but only those that focus on recovering the product value are truly consistent with CE philosophy. This assumption is consistent with some recent works, which affirm that CE can be considered a means to achieve business sustainability, but not all systems that incorporate circular flows are inherently more sustainable. This may be because CE practices are oriented mainly toward environmental care and are not always the most interesting from the perspective of the other two sustainability dimensions, economic and social.

Some questions arise about SMEs making DD to find the most sustainable treatment alternatives (preferably consistent with CE) for a recovered product: Is the most sustainable option also a CE option? Otherwise, how much sustainability should be sacrificed when selecting an EC-consistent treatment alternative?

The literature review revealed the existence of scientific works that treat DD with different solution methods and sustainability objectives, as well as the existence of methodologies to implement, assess, or treat sustainability at a strategic level. However, no work that combines methodologies, DD, sustainability, and CE was found.

For this reason, and in order to answer the posed questions, a methodology was developed so that SME DD decision makers can first know the most sustainable treatment alternative for each recovered product by simultaneously considering three sustainability aspects, economic, environmental, and social, weighted according to the company's strategy. Second, if the most sustainable alternative has no CE alternative, we must determine the most sustainable CE option. Finally, to make a comparison that allows firms to know the economic, environmental, and social differences of both options. These differences allow firms to know the sustainability level that must be sacrificed if it decides to treat the product according to CE options.

The proposed M-SCE-DD was developed with three levels of detail or layers to facilitate its understanding: Layer 1 corresponds to the lowest level of detail and is made up of three "areas"; Layer 2 denotes an intermediate level and is made up of four "blocks"; Layer 3 represents the highest level of detail and is comprised of 14 "phases."

One of the key elements of the M-SCE-DD is the MM that makes the calculations and provides the best disposition alternative in each case. This MM is used with a modular or black box format and can be substituted by any other MM with similar characteristics, among which we highlight two: One related to the ability to address DD from the three sustainability dimensions via a triple OF with economic profitability and environmental and social impact parameters that refer to all possible disposition alternatives; another with the corresponding binary decision variables for disposition alternatives.

This M-SCE-DD was applied to a SME located in the province of Valencia (Spain) that recovers and treats used tires. The discussed case is about recovering a batch of 30 used tires. The results of this application to a real case show the methodology's usefulness.

Ultimately, this work helps SMEs to better manage their implementation of sustainable and CE policies by quantifying the consequences of adopting each possible alternative for product treatment.

Although the M-SCE-DD initially acts at the operational management level of product recoveries, its continued use and the analysis of the historic data generated in successive comparisons can even help to make strategic decisions on adopting CE.

Our experience applying the M-SCE-DD in a used tire company has allowed us to better understand the barriers SMEs face when applying the concepts of sustainability and CE in their operations. In this case, one of the most important limitations that we have had to overcome is related to obtaining accurate data about the company and the costumer to apply our methodology and feed the MM. An insufficient level of maturity of the company's information systems slows down decision-making, has a negative impact on efficiency, costs, and customer service, and also makes it difficult to implement tools such as the one proposed in this work. In light of this, the lack of availability of accurate data from companies is a limitation for the applicability of the methodology. It is not a limitation related to the methodology proposed in this research, but it is associated with the implementation and application of such a methodology. So, in further research, we will focus on the methodology implementation issues, especially on the interaction of the M-SCE-DD with the information enterprise system and its legacy systems. In this sense, a necessary line to exploiting is the automation of data collection and its introduction into the MM. This would expedite the updating of the information used by the MM and would allow more precise and accurate decision making.

Another limitation of the present research is related to the usefulness of the proposed methodology as it has not been confirmed yet in all industrial sectors related to the RL. For this reason, another line of additional research will be the application of the M-SCE-DD to more companies, in order to demonstrate its validity in different sectors and types of companies, which will also allow the identification of possible opportunities for its expansion and improvement. In this research, the application of the methodology proposed involves a SME that operates in an open-loop reverse supply chain. However, other applications consider the implementation of the methodology in closed-loop reverse supply chain, where the used products are returned to the original producers.

Regarding the practical implications, it is important to highlight that the methodology proposed supports and promotes decisions that favor the CE, improving innovation and creating more economic value from natural resources.

Finally, further research will be also addressed to the development of a tool (software) that facilitates getting access to the required data so that provides agility in the decision-making process. Different alternatives such as Internet of Things (IoT) approaches will be considered to support the data capture in a more autonomous and automatic way taking advantage of the opportunities offered by the Industry 4.0 paradigm.

Author Contributions: Design and conceptualization F.A.V. and P.C.P.; writing original draft: Introduction F.A.V. and P.C.P., background F.A.V., D.P.P. and R.S., methodology proposal F.A.V., P.C.P., and R.S., application P.C.P. and F.A.V., and conclusions F.A.V. and D.P.P.; writing review and finishing P.C.P., D.P.P., and R.S.; model development and execution F.A.V. and P.C.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to acknowledge the predisposition of the recovery and treatment company of used tires by facilitating all necessary data to be used in the example application. The support of the Project GV/2017/065 "Development of a decision support tool for the management and improvement of sustainability in supply chains" funded by the Regional Government of Valencia is gratefully acknowledged. The authors also thank the anonymous reviewers and assistant editor who reviewed earlier versions of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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