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Abstract

End of Life (EoL) management represents a great challenge to develop new opportunities towards sustainability. Indeed, international institutions, organizations, academics, researchers and practitioners highlighted the importance of EoL management, since it is associated with relevant environmental, social and economic impacts. Yet, the appraisal of EoL alternatives represents a particularly complex task to address due to the difficulties arising from the assessment of social and economic key-criteria. In this regard, several gaps related to bio-based products have been stressed by the literature, especially with reference to socio-economic indicators. This report focuses on the existing EoL options with the aim of identifying key community priorities for sustainable EoL management of bio-based products. This is achieved by developing a win-win asset-based model that has been tested on a selected case study, i.e. Poly Lactic Acid (PLA)-based packaging film. The results show that recycling (both mechanical and chemical) is the best EoL option for the considered product.

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Table of Contents

List of Acronym

AHP	Analytic Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
CV	Column vector
EoL	End of Life
EU	European Union
MCDA	Multi-criteria decision analysis
PLA	Poly Lactic Acid
RI	Random Inconsistency
RV	Row vector
SEI-EoL	socio-economic indicator for EoL strategy
SLCA	Social Life Cycle Assessment

Executive summary

The production of bio-based products is rapidly growing but still represent a niche market. The acceleration of the market uptake of these products depends largely on providing clear information about their sustainability, though there are still numerous measurement gaps and an internationally agreed set of criteria has yet to be established. Specifically, as emerged from the literature, a number of gaps concern the EoL stage, with particular reference to its socio-economic dimension.

Against this background, the objective of this deliverable is to identify key community priorities for sustainable EoL management of bio-based products. This has been achieved by firstly deepening the work done in Task 6.2 and 6.3 (undertaken within WP6 "Social assessment") where criteria and indicators were identified, some of them pertaining to EoL stage. Subsequently, by developing a win-win asset-based model focused on end-of-life treatment of bio-based products. Specifically, a four step process (getting started, coming together, action planning and implementation) was implemented – Figure 1. To maximize its effectiveness and generalizability, the model was tested by different categories of stakeholders (i.e. Academicians, Trade Associations, Policy Makers and Waste Management Companies) from geographically and culturally distant European regions (e.g. Germany, Greece, Italy, Spain and Sweden).

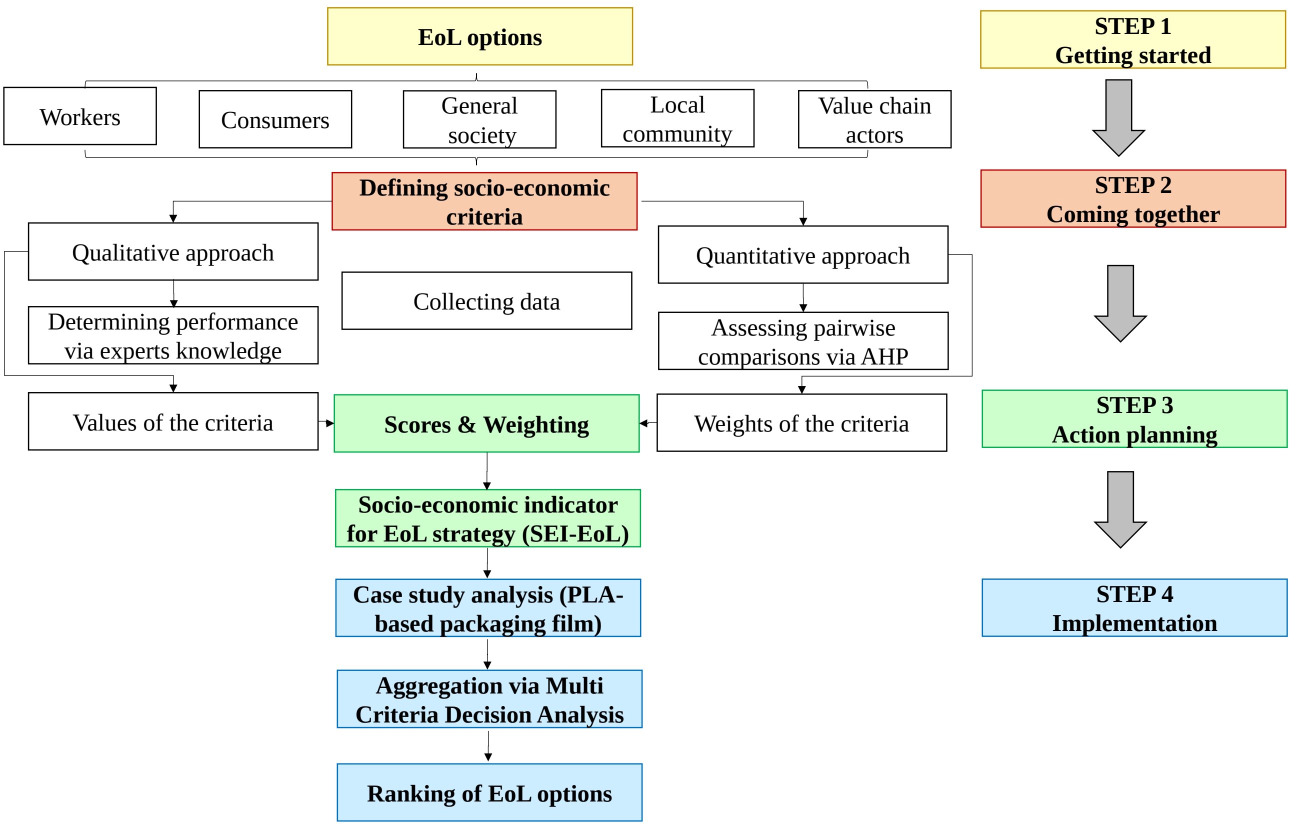

Figure 1. The systemic approach for socio-economic sustainability assessment of EoL options

The final result of this model is represented by the development of a new indicator, called socio-economic indicator for EoL strategy (SEI-EoL), which includes several perspectives of analysis. Indeed, the assessment is based on social and economic criteria, but the know-how of experts also concerns environmental and technical aspects. Consequently, the assessment value refers to a multi-disciplinary context. The model was tested on a selected case study, i.e. PLA-based packaging film, which was chosen from among STAR-ProBio’s case studies due to the product’s potential applicability to all EoL options. PLA-based packaging film is obtained by lactic acid from corn utilizing a production process based on fermentation. It is aimed at replacing the oil-based plastics, glass or metal packaging. The main result shows that mechanical and chemical recycling obtain the highest values of SEI-EoL, while landfill use is the least preferred option.

1 Introduction

The replacement of fossil-based products with sustainable bio-based products sourced from a broad variety of biomass feedstocks (e.g. forestry and biowaste) can play a pivotal role in achieving the global goals for sustainable development since they are expected to provide great environmental, societal and economic benefits (DeBoer, Panwar, Kozak, & Cashore, 2019; FAO, 2016; Staffas, Gustavsson, & McCormick, 2013). The market share of bio-based products has increased in recent years, though still represent a niche market (Spekreijse, Lammens, Parisi, Ronzon, & Vis, 2019). As stressed by (STAR-ProBio, 2018) – Deliverable D9.1, there are a number sustainability-related risks associated with the development of bio-based products. Therefore, much greater impact in the market is likely to be achieved if clear information about their sustainability is provided to policy makers and consumers (Falcone & Imbert, 2018; Russo, Confente, Scarpi, & Hazen, 2019). Specifically, this means ensuring that a bio-based product is sustainable across its whole life cycle by taking into account simultaneously its environmental, social and economic impacts (Lokesh, Ladu, & Summerton, 2018).

Although all life cycle stages deserve consideration, particular attention must be paid to the EoL stage, considering the global size of solid wastes and marine litter (Kaza, Yao, Bhada-Tata, & Van Woerden, 2018; OECD, 2018a). It is worth noting that 5.0 tonnes of waste were generated per European Union (EU) inhabitant in 2016 of which 45.5 % were landfilled.

Accordingly, a sustainable bio-based product should entail a design in which its value can be recaptured/created after use (European Commission, 2018a; OECD, 2018b). This implies an efficient use of by-products and waste and, thereby, a fruitful integration between the priciples of the circular economy and bioeconomy (Bezama, 2016; D'Amato, Veijonaho, & Toppinen, 2018). In this regard, strong synergies have been identified between the 2015 Circular Economy Action Plan, the 2018 Circular Economy Policy Package and the 2012/2018 Bioeconomy Strategy (EEA, 2018).

According to the European waste hierarchy, which summarises the European Union's approach to waste management, waste either needs to be avoided or treated to reduce its impact (European Commission, 2010). Indeed, after prevention activities, reuse and recycling activities are the preferred EoL options since they are perceived as valorisation practices and have the highest potential to reduce greenhouse gas emissions (European Commission, 2018b).

However, the determination of a product's most sustainable EoL option is highly complex as it is based on a wide range of criteria and is product specific. Moreover, the literature outlined that knowledge on EoL of bio-based products is particularly lacking, especially with reference to socio-economic criteria (Majer et al., 2018). Against this background, this report aims to further the work previously completed for the project's sixth work package, "Social assessment", by focusing on selected EoL criteria and integrating them into a win-win asset-based model. This model has been developed in order to identify key community priorities for sustainable EoL management of bio-based products. The win-win asset-based model is grounded on the multi-criteria decision analysis (MCDA) - (Zhao & Ying, 2019) that enabled us to capture a broad variety of judgements in order to define a ranking of the EoL options by means of a new indicator called socio-economic indicator for EoL strategy (SEI-EoL). The model has been tested on a specific product selected from STAR-ProBio's list of case studies identified in Deliverable D1.3.

The report is organised as follows. Section 2 introduces basic topics and critical issues related to bio-based products EOL stage. Section 3 describes the methodology and Section 4 presents the results. Section 5 then discusses the implications of our analysis. Finally, Section 6 concludes the report.

2 Background

One of the major challenges of the bioeconomy is related to the EoL valorization of bio-based products, which can deliver positive environmental impacts by reducing waste which goes to landfills and litter along with socio-economic benefits through a more efficient use of resources, the creation of jobs and social equity through gender balance (Lokesh et al., 2018). Moreover, it is worth mentioning that the results from a Delphi analysis carried out within STAR-ProBio's WP5 "market assessment", which focused on identifying sustainability criteria which are of relevance to consumers (including public procures), showed that a sustainable EoL strongly affects consumer acceptance of bio-based products (STAR-ProBio, 2019) – Deliverable D5.1.

Yet, according to the STAR4BBI (2018) – Deliverable D2.1, the EoL of bio-based products has been identified by numerous stakeholders as one of the most critical area currently affecting the market entry of bio-based products, primarily because there is no common view on the most preferable EoL option for different bio-based products. Indeed, (Majer et al., 2018) identified a number of gaps related to EoL bio-based products sustainability certification activities, standards and labels.

Generally, the determination by producers of the most suitable EoL option is affected by a broad range of factors, primarily economic (Ziout, Azab, & Atwan, 2014), and is subject to product components (Lee, Lye, & Khoo, 2001). Indeed, significant differences can be found across bio-based product categories. Hence, it is a complex decision-making process during which all prospective EoL options should be considered by producers during the design stage (Erdos, Kis, & Xirouchakis, 2001; European Commission, 2019). Alternatives for bio-based products include reuse, mechanical recycling, chemical recycling, aerobic composting, anaerobic digestion, energy recovery and landfilling (Table 1).

Table 1. EoL options for bio-based products (Briassoulis, Pikasi, & Hiskakis, 2019)

EoL option	**Definition**
Reuse	Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived (European Parliament and Council, 2008).
Mechanical recycling	A method by which waste materials are recycled into "new" (secondary) raw materials without changing the basic structure of the material" (European Bioplastics, 2015).

Chemical recycling	The process in which polymers are chemically converted to monomers or partially depolymerized to oligomers through a chemical reaction (a change occurs to the chemical structure of the polymer) - (Grigore, 2017).
Aerobic composting	The decomposition of organic substrates in the presence of oxygen (Haug, 2018). It produces a compost residue that can be used in agriculture or horticulture.
Anaerobic digestion	A set of biological processes in which organic matter is converted into biogas (mainly a mixture of methane and carbon dioxide) and digestate by micro-organisms in the absence of oxygen (Evangelisti, Lettieri, Borello, & Clift, 2014). This option produces a product that can be used in agriculture or horticulture (Smith, Brown, Ogilvie, Rushton, & Bates, 2001) as well as biogas.
Energy recovery	Incineration of waste with energy recovery (Cucchiella, D'Adamo, & Gastaldi, 2017).
Landfilling	A landfill is a waste disposal site for the deposit of the waste onto or into land. According to the European waste hierarchy, it is the least preferable EoL option.

It should be noted that aerobic composting and anaerobic digestion, which result in the production of biogas and digestate, are considered by the EU as a recycling operation, while waste incineration with limited energy recovery is regarded as disposal (European Commission, 2017). In this regard, priority is given to materially reuse and recycling biomass from discarded bio-based products before energy recovery (Fritsche & Iriarte, 2014).

However, the above mentioned lack of information and knowledge has resulted in a lack of clear labelling on how to dispose of bio-based products and generated confusion among policy makers and consumers. In addition, symmetric shortcomings were observed in academic studies, since in several life cycle analysis related to bio-based products, the use phase and disposal phase have not been included in the analysis (Rafiaani et al., 2018). More specifically, it has been noted that socio-economic criteria associated to bio-based product EoL are particularly lacking, in spite of EoL responsibility emerging as a key indicator in Social Life Cycle Assessment (SLCA) related studies (Falcone & Imbert, 2018; Sala, Vasta, Mancini, Dewulf, & Rosenbaum, 2015). These findings call for the assessment of the quantities of reuse products and the amounts of recycled wastes in order to study green economic growth. In this direction, it is necessary to develop useful indicators that capture the value of different EoL options (Giampietro, 2019).

3 Methodology

MCDA supports decision-making choices characterized by multiple and often conflicting goals (Vogdrup-Schmidt et al., 2019). This method integrates information about the performance of each alternative (scoring criteria) and the subjective assessment of the experts about the relevance of a certain criteria (weighting factor) (Stoycheva et al., 2018). The final goal is to provide a methodology that may be used to define key community priorities for sustainable EoL management of bio-based products in order to identify the best EoL strategy. An asset-based model of community engagement was developed considering different stakeholders during the survey phase (academicians, trade associations, policy makers, waste management companies). It is constructed on four-step process (Matthiesen, Froggatt, Owen, & Ashton, 2014):

- Getting started, in which both public and private actors provide interest towards the several bioeconomy sectors, underlying some critical issues and new opportunities. This was supported also by literature review.
- Coming together, in which several experts are involved during the several phases related to the definition of this new methodology, evaluating multiple criteria and their role within the EoL strategies.
- Action planning, in which starting from the previous deliverables and considering additional works published in scientific journals, a new methodology based on MCDA is defined. This methodology supports the decision-makers providing a new indicator, called socio-economic indicator for EoL strategy (SEI-EoL), that is able to incorporate both weights and values of the socio-economic criteria associated to each EoL option.
- Implementation, in which this methodology and SEI-EoL is applied to a specific bio-based product, i.e. PLA-based packaging film, to provide information on the preferable EoL strategy for the product. This product is chosen because, among STAR-ProBio selected case studies, it includes potentially all EoL options. The analysis included regarded experts coming from several countries (Germany, Greece, Italy, Spain and Sweden).

3.1 The definition of a new indicator

MCDA is a decision-making tool developed for complex problems. By using MCDA, the interviewees do not have to agree on the relative importance of the criteria or the rankings of the alternatives. Each expert provides his or her own judgements, and makes a distinct, identifiable contribution to a jointly reached conclusion. All weights and values of criteria are aggregated in a new indicator, called SEI-EoL. It is obtained as the product between the weights of socio-economic indicators and their value considering a specific EoL option.

The final aim of MCDA is to aggregate several criteria providing a final decision. Equation (1) describes the value of the indicator obtained by a single interviewee ($SEI\text{-}EoL_{E,I}$) and Equation (2) shows the sum of all experts considering that each of them has the same relevance ($SEI\text{-}EoL_{E}$).

$$SEI - EoL_{E,I} = RV_{E,C,I} * CV_{C,I} \quad (1)$$

$$SEI - EoL_{E} = \sum_{I=1}^{N_I} SEI - EoL_{E,I} \quad (2)$$

in which RV = row vector, CV = column vector, E = EoL strategy, C = criteria, I = interviewee, N_I = number of interviewees. The row vector depends by all three variables analysed, while the column vector only by criteria and interviewees. A unique SEI-EoL_E is provided for each EoL strategy and it is undimensionless. EoL options represent the alternative to evaluate through this new indicator.

3.2 Selecting End of Life strategies

The international scientific community underlines that an optimised management of waste is able to reach the sustainable goal (Cucchiella, D'Adamo, Lenny Koh, & Rosa, 2015). Firms have modified business models in order to capture the new concept of waste in which it is proposed as a resource and not as a burden (Perey, Benn, Agarwal, & Edwards, 2018), thus favouring the circularity of resources (Cobo, Dominguez-Ramos, & Irabien, 2018). The adoption of circular economy models permits better use of resources and materials through reuse, recycling and recovery, and minimizing the use of landfills (Zeller, Towa, Degrez, & Achten, 2019). According to the literature section, the full list of EoL strategies for bio-based products are 7 (see Table 1): i) Reuse; ii) Mechanical recycling; iii) Chemical recycling; iv) Aerobic composting; v) Anaerobic digestion; vi) Energy recovery and vii) Landfilling.

3.3 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) methodology, developed by Saaty (1980), is able to produce a list of priorities through pairwise comparisons based upon the judgements of experts. Their knowledge and perspectives in the specific area of investigation represents the key-success of this analysis.

3.3.1 Selecting experts

The first step is the identification of the experts, who were selected from members that have participated previously in Horizon and Life projects and/or profiles that have published scientific journals published in Scopus database. The key-word selected to define the topic of competence is: "End of Life". Additionally, another requisite required that all participants must have had at least ten years of direct experience on the management of products during EoL phase. Once identified, a mass e-mail was sent out to the experts in March 2019 in order to reach an adequate number of interviewees (Cucchiella, D'Adamo, Gastaldi, Koh, & Rosa, 2017). It was specified that only the first twenty-positive responses to this e-mail would be selected considering the constraint represented by the temporal deadline of the project.

During the month of March 2019, we have collected the positive response of 20 experts from 5 countries (Germany, Greece, Italy, Spain and Sweden), allowing for the capture of several perspectives considering the wide range of categories selected (e.g. academicians, trade associations, policy makers and waste management companies). Table 2 provides detailed data on these experts.

Table 2. Survey participants (experts)

N°	Category	Role	Country	No. years of expertise
1	Academician	Full Professor	Germany	25
2	Academician	Associate Professor	Italy	16
3	Academician	Full Professor	Sweden	21
4	Academician	Research Fellow	Greece	11
5	Academician	Lecturer	Greece	10
6	Academician	Associate Professor	Spain	18
7	Academician	Full Professor	Spain	21
8	Trade Association	Member (Consumer)	Italy	12
9	Trade Association	Member (Consumer)	Germany	14
10	Trade Association	Member (Industry)	Italy	10
11	Trade Association	Member (Industry)	Spain	15
12	Trade Association	Chairman (Consumer)	Spain	20
13	Policy Maker	Urban Planner	Italy	14
14	Policy Maker	Urban Planner	Germany	21
15	Policy Maker	Municipal Councillor	Italy	19
16	Policy Maker	Municipal Councillor	Greece	12
17	Waste Management Company	Manager	Italy	16
18	Waste Management Company	Manager	Sweden	18
19	Waste Management Company	Worker	Italy	10
20	Waste Management Company	Worker	Spain	10

3.3.2 Defining the evaluation of the matrix

AHP is based on the Eigenvalue method and each factor has a certain relative priority level (Billig & Thraen, 2017). We can make a matrix considering a group composed by N_C components and thus we have N_C x N_C matrix. The diagonal elements of the matrix are always 1 and we need to fill up the upper triangular matrix – Table 3.

The sum of priority levels must be equal to one and consequently, all matrices must be normalized – Table 4. Each factor is evaluated according to their relative importance on a nine-level scale (Saaty, 2008) – Table 5. For example, if the factor D is considered "strongly preferred" than factor A, the value of V_{DA} is equal to 5 and consequently, its reciprocal value (V_{AD} or 1/ V_{DA}) is equal to 0.20. Equations (3)-(5) provide an example referred to the mathematical procedure to follow in order to calculate the priority level of factor D (AR_D).

$$SC_A = 1 + V_{BA} + V_{CA} + V_{DA} + V_{EA} \tag{3}$$

$$SR_D = V_{DA}/SC_A + V_{DB}/SC_B + V_{DC}/SC_C + 1/SC_D + 1/(V_{ED}/SC_D) \tag{4}$$

$$AR_D = SR_D/N_C \tag{5}$$

in which A, B, C, D, E = factors; N_C = number of factors; SC_A = sum of values regarding the column of factor A (repeated for all factors); V_{DA} = value of factor D than one A (repeated for all factors); SR_D = sum of values regarding the row of factor D (repeated for all factors); AR_D = average of values regarding the row of factor D (repeated for all factors)

Table 3. Pairwise comparisons per group

	A	**B**	**C**	**D**	**E**
A	1	$1/V_{BA}$	$1/V_{CA}$	$1/V_{DA}$	$1/V_{EA}$
B	V_{BA}	1	$1/V_{CB}$	$1/V_{DB}$	$1/V_{EB}$
C	V_{CA}	V_{CB}	1	$1/V_{DC}$	$1/V_{EC}$
D	V_{DA}	V_{DB}	V_{DC}	1	$1/V_{ED}$
E	V_{EA}	V_{EB}	V_{EC}	V_{ED}	1
Sum	SC_A	SC_B	SC_C	SC_D	SC_E

Table 4. Normalized pairwise comparisons per group

	A	**B**	**C**	**D**	**E**	**Sum**	**Avg**
A	$1/SC_A$	$1/(V_{BA}/SC_A)$	$1/(V_{CA}/SC_A)$	$1/(V_{DA}/SC_A)$	$1/(V_{EA}/SC_A)$	SR_A	AR_A
B	V_{BA}/SC_A	$1/SC_B$	$1/(V_{CB}/SC_B)$	$1/(V_{DB}/SC_B)$	$1/(V_{EB}/SC_B)$	SR_B	AR_B
C	V_{CA}/SC_A	V_{CB}/SC_B	$1/SC_C$	$1/(V_{DC}/SC_C)$	$1/(V_{EC}/SC_C)$	SR_C	AR_C
D	V_{DA}/SC_A	V_{DB}/SC_B	V_{DC}/SC_C	$1/SC_D$	$1/(V_{ED}/SC_D)$	SR_D	AR_D
E	V_{EA}/SC_A	V_{EB}/SC_B	V_{EC}/SC_C	V_{ED}/SC_D	$1/SC_E$	SR_E	AR_E
Sum	1	1	1	1	1	5	1

Table 5. Pair-wise comparison scale for AHP preferences (Saaty, 2008)

Numerical rating	Verbal judgements of preferences
1	Equally preferred
2	Equally to moderately preferred
3	Moderately preferred
4	Moderately to strongly preferred
5	Strongly preferred
6	Strongly to very strongly preferred
7	Very strongly preferred
8	Very strongly to extremely preferred
9	Extremely preferred

The following step concerns the calculation of a Consistency Ratio (CR), able to measure the consistency of a pairwise comparison matrix. The judgements are trustworthy if the CR is lower than 0.10. It is calculated as the ratio between the Consistency Index (CI) and the Random Inconsistency (RI). Equations (6) – (8) show the relative mathematical steps in which the Largest Eigenvalue ($\lambda_{\max}$) is calculated (Saaty, 2008).

$$\lambda_{\max} = SC_A * AR_A + SC_B * AR_B + SC_C * AR_C + SC_D * AR_D + SC_E * AR_E \tag{6}$$

$$CI = (\lambda_{\max} - n)/(n-1) \tag{7}$$

$$CR = CI/RI \tag{8}$$

3.4 Selecting categories

The UNEP-SETAC guidelines (2009) describe social impacts as consequences of positive or negative pressures on social endpoints (i.e. stakeholder well-being). It is widely recognized in the SLCA literature that the identification of social impacts arises from an analysis of the stakeholder categories that represent all social groups of actors affected by production, consumption and end of life processes. Originally, Grießhammer et al., (2006) identified four main groups of stakeholders: workforce, local community, society and consumers. Adding to this, the UNEP-SETAC guidelines proposed an additional group of stakeholders – value chain actors. Consequently, this work considers 5 categories of stakeholders: i) workers; ii) consumers; iii) general society; iv) local community and v) value chain actors.

3.5 Choosing socio-economic criteria

The dimension of the AHP comparison matrix is typically 7 ± 2 (Emrouznejad & Marra, 2017). The assessment of SEI-EoL is strictly linked to the choice of criteria.

This indicator considers only two of three pillars of sustainability (environmental side is not covered). In addition, the first step of this analysis is to evaluate the results obtained during the previous deliverables. Some criteria are selected because they are considered suitable to measure the impact of EoL option. The following step is represented by the literature analysis, in which we have found similar criteria than ones already selected in D3.1 and D6.2 and we have added new criteria according to the specific context of EoL management. Table 6 proposes the full list of criteria considered in this work and we have assumed two hypotheses: the first concerns that some criteria can be repeated for multiple categories and the second concerns that the number of criteria for each category must be the same. We have found 5 criteria for each category and consequently, the overall number of criteria is equal to 25.

Table 6. List of criteria

Criteria		Description	Reference
Workers			
W1	Human toxicity	accounts for the effects of toxic substances on the human environment, usually not focused on the working environment	(Van Schoubroeck, Van Dael, Van Passel, & Malina, 2018)
W2	Human health	accounts for human health effects due to exposure to ambient particulates and for toxicological impacts related to cancer and non-cancer effects	(Van Schoubroeck et al., 2018)
W3	Working conditions	freedom of association and collective bargaining	(Ren, Manzardo, Mazzi, Zuliani, & Scipioni, 2015)
W4	Skills	number of workers that have received training (for skills development, education, etc.) each year, or number of working days spent in training provided by the operation each year, type of training.	(Rutz & Janssen, 2014)
W5	Equal opportunities	presence of formal policies on equal opportunity	(Falcone et al., 2019)
Consumers			
C1	End-of-life Responsibility	the commitment by stakeholders to be responsible of the actions the end-of-life of products avoiding negative consequences for humans and ecosystems.	(Martin, Røyne, Ekvall, & Moberg, 2018)
C2	Human toxicity	accounts for the effects of toxic substances on the human environment, usually not focused on the working environment	(Van Schoubroeck et al., 2018)
C3	Human health	accounts for human health effects due to exposure to ambient particulates and for toxicological impacts related to cancer and non-cancer effects	(Van Schoubroeck et al., 2018)
C4	Transparency	the need for an organization to provide information and report on non-financial aspects	(Falcone et al., 2019)
C5	Feedback mechanism	presence of a mechanism for customers to provide feedback	(Falcone & Imbert, 2018)
General society			
G1	Public governance	political support measures (enabling governance) and regulatory tools (constraining governance) that can use to develop a sector.	(Dietz, Börner, Förster, & von Braun, 2018)
G2	Green Public Procurement	presence of policies that favour purchases or utilizations of products, services and works that respect the ecosystems	(Kottner, Štofová, Szaryszová, & Lešková, 2016)
G3	End-of-life Responsibility	the commitment by stakeholders to be responsible of the actions the end-of-life of products avoiding negative consequences for humans and ecosystems.	(Martin et al., 2018)
G4	Resource efficiency	environmentally through reduction of waste for treatment and disposal; economically by enabling resource efficiency and through transformation of waste	(Lokesh et al., 2018)
G5	Social investment	accounts for the contribution through employment and philanthropic and community development projects	(Van Schoubroeck, Springael, Van Dael, Malina, & Van Passel, 2019)
Local community			

L1	Local employment	the development of new products and activities from which workers are generated	(Ronzon & M'Barek, 2018)
L2	Economic development	the development of new products and activities from which turnover and value added are developed	(Ronzon & M'Barek, 2018)
L3	Human toxicity	accounts for the effects of toxic substances on the human environment, usually not focused on the working environment	(Van Schoubroeck et al., 2018)
L4	Human health	accounts for human health effects due to exposure to ambient particulates and for toxicological impacts related to cancer and non-cancer effects	(Van Schoubroeck et al., 2018)
L5	Access to material resources	waste can be a resource that are employed for the development of new products	(Briassoulis et al., 2019)
Value chain actors			
V1	New value chain	identifying value chains that generate products that can potentially favour the circularity of the flow of materials	(Lokesh et al., 2018)
V2	End-of-life Responsibility	the commitment by stakeholders to be responsible of the actions the end-of-life of products avoiding negative consequences for humans and ecosystems.	(Martin et al., 2018)
V3	Resource efficiency	environmentally through reduction of waste for treatment and disposal; economically by enabling resource efficiency and through transformation of waste	(Lokesh et al., 2018)
V4	Waste disposal cost	calculates the costs related to waste disposal	(Van Schoubroeck et al., 2019)
V5	Illnesses and accidents cost	calculates the cost related to illnesses and accidents	(Van Schoubroeck et al., 2018)

3.6 Assigning weights to the criteria

A consistent number of criteria permits to increase the assessment of the socio-economic performance. At the same time, a matrix of 25 components is complex to manage. The theory of AHP has fixed a value significantly lower than 25 and in particular (Brudermann, Mitterhuber, & Posch, 2015) have proposed two types of priority weights: i) local priority weight and ii) global priority weight. The first is derived from each set of pairwise comparisons in all levels. The second are obtained multiplying the local priorities of the criteria and the global priority of their relative categories. In this way, the relevance of each local criteria is balanced by the importance of the category to which it belongs.

The survey is been conducted through an Excel file and a Skype video-call is proposed if the expert required it – see Annex 1. In particular, this choice is defined by the consideration that the experts can freely check if their judgements are trustworthy. In fact, the value of CR is proposed automatically. During March-April 2019 all experts have completed their pairwise comparisons.

The analysis requires two steps. Initially, the experts provide pairwise comparisons among 5 categories and subsequently, the same operation is repeated for 5 factors linked to each category. The two following research questions are investigated:

- EoL strategy influences the management of a product. What is the impact of the category in this phase of product's life and in particular, what category has a greater relevance?
- Socio-economic criteria influence the sustainability of a product. What is the impact of the factors in the assessment of sustainability and in particular, what criteria has a greater relevance within the same category?

Figure 2 shows the conceptual map of the AHP. Starting by the model presented in section 3.3.2, the priority of each category is calculated: p_W = priority of the workers group, p_C = priority of the consumers group, p_G = priority of the general society group, p_L = priority of the local community group and p_V = priority of the value chain actors group. The sum of these five priority groups must be equal to 1 following the values AR_A, AR_B, AR_C, AR_D and AR_E (see Table 4). The same calculation is repeated for all factors analyzing separately the categories. For example, W1, W2, W3, W4 and W5 identify five criteria (SEI_1, SEI_2, SEI_3, SEI_4 and SEI_5, respectively) and for each of them is calculated a local priority. The weight WL_{SE1} is linked to the criteria SEI_1. The sum of WL_{SE1}, WL_{SE2}, WL_{SE3}, WL_{SE4} and WL_{SE5} is equal to 1. Each interviewee provides 60 responses, because a matrix 5x5 requires 10 responses and 6 comparisons are analyzed. After the collection of single questionnaire, we calculate the global priority of each factor as follows:

$$\text{Global priority} = \text{Local priority} * \text{Group priority} \qquad (9)$$

For example, the global priority of factor W1 (WG_{SE1}) is obtained multiplying WL_{SE1} and p_W. In this way, the sum of all global priorities referred to the workers are equal to its priority group as follows: $WG_{SE1} + WG_{SE2} + WG_{SE3} + WG_{SE4} + WG_{SE5} = p_W$. Finally, if the values referred to the local priority linked to the different categories are not comparable, the calculation of global priority resolves this issue and all criteria can be comparable. In this way, a global ranking is obtained by pairwise comparisons among 25 criteria.

		Local Priority	Rkg			Local Priority	Rkg			Local Priority	Rkg			Local Priority	Rkg			Local Priority	Rkg
Workers (W) [Priority: p_W]				Consumers (C) [Priority: p_C]				General society (G) [Priority: p_G]				Local community (L) [Priority: p_L]				Value chain actors (V) [Priority: p_V]			
W1	SEI_1	WL_{SE1}	1.	C1	SEI_6	WL_{SE6}	4.	G1	SEI_{11}	WL_{SE11}	1.	L1	SEI_{16}	WL_{SE16}	2.	V1	SEI_{21}	WL_{SE21}	2.
W2	SEI_2	WL_{SE2}	3.	C2	SEI_7	WL_{SE7}	3.	G2	SEI_{12}	WL_{SE12}	2.	L2	SEI_{17}	WL_{SE17}	4.	V2	SEI_{22}	WL_{SE22}	4,
W3	SEI_3	WL_{SE3}	2.	C3	SEI_8	WL_{SE8}	2.	G3	SEI_{13}	WL_{SE13}	3.	L3	SEI_{18}	WL_{SE18}	3.	V3	SEI_{23}	WL_{SE23}	3.
W4	SEI_4	WL_{SE4}	4.	C4	SEI_9	WL_{SE9}	1.	G4	SEI_{14}	WL_{SE14}	4.	L4	SEI_{19}	WL_{SE19}	1.	V4	SEI_{24}	WL_{SE24}	1.
W5	SEI_5	WL_{SE5}	5.	C5	SEI_{10}	WL_{SE10}	5.	G5	SEI_{15}	WL_{SE15}	5.	L5	SEI_{20}	WL_{SE20}	5.	V5	SEI_{25}	WL_{SE25}	5.
∑W		1.0		∑C		1.0		∑G		1.0		∑L		1.0		∑V		1.0	
		Global Priority	Rkg			Global Priority	Rkg			Global Priority	Rkg			Global Priority	Rkg			Global Priority	Rkg
W1	SEI_1	WG_{SE1}	4.	C1	SEI_6	WG_{SE6}	20.	G1	SEI_{11}	WG_{SE11}	1.	L1	SEI_{16}	WG_{SE16}	8.	V1	SEI_{21}	WG_{SE21}	10.
W2	SEI_2	WG_{SE2}	16.	C2	SEI_7	WG_{SE7}	17.	G2	SEI_{12}	WG_{SE12}	6.	L2	SEI_{17}	WG_{SE17}	15.	V2	SEI_{22}	WG_{SE22}	18.
W3	SEI_3	WG_{SE3}	11.	C3	SEI_8	WG_{SE8}	12.	G3	SEI_{13}	WG_{SE13}	7.	L3	SEI_{18}	WG_{SE18}	9.	V3	SEI_{23}	WG_{SE23}	13.
W4	SEI_4	WG_{SE4}	19.	C4	SEI_9	WG_{SE9}	5.	G4	SEI_{14}	WG_{SE14}	14	L4	SEI_{19}	WG_{SE19}	2.	V4	SEI_{24}	WG_{SE24}	3.
W5	SEI_5	WG_{SE5}	24.	C5	SEI_{10}	WG_{SE10}	25.	G5	SEI_{15}	WG_{SE15}	21.	L5	SEI_{20}	WG_{SE20}	22.	V5	SEI_{25}	WG_{SE25}	23.
∑W		p_W		∑C		p_C		∑G		p_G		∑L		p_L		∑V		p_V	

LEGEND: SEI = name of socio economic criteria WL = weight local; WG = weight global

Figure 2. The logic map of weights

3.7 Assigning values to the criteria

Several criteria measure the socio-economic performance regarding the management of EoL option of a product. After the aggregation of all responses and the calculations necessary to define the ranking of criteria, a new questionnaire is proposed to the same experts.

During April-May 2019 all interviewees have completed their assessments. Also in this step, the survey has been conducted through an Excel file and a Skype video-call is proposed if the expert required it – see Annex 2. The following research questions are investigated:

- Starting by your judgements useful to develop a ranking of socio-economic criteria, what is the value that this criteria assumes for a specific EoL option?
- Several EoL strategies are possible from a technological point of view, what is the comparison among all suitable EoL options?

The value scale that experts can be used to evaluate the single criteria specifically for an EoL strategy varies from 1 (that is the worst evaluation) to 10 (that is, instead, the best evaluation). The assessment is based on social and economic criteria, but the know-how of experts concerns also environmental and technical aspects. Consequently, this value is referred to a multi-disciplinary context. Figure 3 shows that experts are aware of the global priority before defining the value of the considered criteria. In addition, each value is associated to a specific EoL alternative and the number of alternatives considered is equal to 7 (see Table 1). A general model is developed and the assignments of values has a practical sense when a specific product is considered. We analysed a PLA-based packaging film, which is obtained from renewable resources.

Criteria	Global priority	EoL no. 1	EoL no. 2	EoL no. 3	EoL no. 4	EoL no. 5	EoL no. 6	EoL no. 7
G1	WG_{SE11}	V_{G1-E1}	V_{G1-E2}	V_{G1-E3}	V_{G1-E4}	V_{G1-E5}	V_{G1-E6}	V_{G1-E7}
L4	WG_{SE19}	V_{L4-E1}	V_{L4-E2}	V_{L4-E3}	V_{L4-E4}	V_{L4-E5}	V_{L4-E6}	V_{L4-E7}
V4	WG_{SE24}	V_{V4-E1}	V_{V4-E2}	V_{V4-E3}	V_{V4-E4}	V_{V4-E5}	V_{V4-E6}	V_{V4-E7}
W1	WG_{SE1}	V_{W1-E1}	V_{W1-E2}	V_{W1-E3}	V_{W1-E4}	V_{W1-E5}	V_{W1-E6}	V_{W1-E7}
C4	WG_{SE9}	V_{C4-E1}	V_{C4-E2}	V_{C4-E3}	V_{C4-E4}	V_{C4-E5}	V_{C4-E6}	V_{C4-E7}
G2	WG_{SE12}	V_{G2-E1}	V_{G2-E2}	V_{G2-E3}	V_{G2-E4}	V_{G2-E5}	V_{G2-E6}	V_{G2-E7}
G3	WG_{SE13}	V_{G3-E1}	V_{G3-E2}	V_{G3-E3}	V_{G3-E4}	V_{G3-E5}	V_{G3-E6}	V_{G3-E7}
L1	WG_{SE16}	V_{L1-E1}	V_{L1-E2}	V_{L1-E3}	V_{L1-E4}	V_{L1-E5}	V_{L1-E6}	V_{L1-E7}
L3	WG_{SE18}	V_{L3-E1}	V_{L3-E2}	V_{L3-E3}	V_{L3-E4}	V_{L3-E5}	V_{L3-E6}	V_{L3-E7}
V1	WG_{SE21}	V_{V1-E1}	V_{V1-E2}	V_{V1-E3}	V_{V1-E4}	V_{V1-E5}	V_{V1-E6}	V_{V1-E7}
W3	WG_{SE3}	V_{W3E1}	V_{W3E2}	V_{W3-E3}	V_{W3-E4}	V_{W3-E5}	V_{W3E6}	V_{W3E7}
C3	WG_{SE8}	V_{C3-E1}	V_{C3-E2}	V_{C3-E3}	V_{C3-E4}	V_{C3-E5}	V_{C3-E6}	V_{C3-E7}
V3	WG_{SE23}	V_{V3-E1}	V_{V3-E2}	V_{V3-E3}	V_{V3-E4}	V_{V3-E5}	V_{V3-E6}	V_{V3-E7}
G4	WG_{SE14}	V_{G4-E1}	V_{G4-E2}	V_{G4-E3}	V_{G4-E4}	V_{G4-E5}	V_{G4-E6}	V_{G4-E7}
L2	WG_{SE17}	V_{L2-E1}	V_{L2-E2}	V_{L2-E3}	V_{L2-E4}	V_{L2-E5}	V_{L2-E6}	V_{L2-E7}
W2	WG_{SE2}	V_{W2-E1}	V_{W2-E2}	V_{W2-E3}	V_{W2-E4}	V_{W2-E5}	V_{W2-E6}	V_{W2-E7}
C2	WG_{SE7}	V_{C2-E1}	V_{C2-E2}	V_{C2-E3}	V_{C2-E4}	V_{C2-E5}	V_{C2-E6}	V_{C2-E7}
V2	WG_{SE22}	V_{V2-E1}	V_{V2-E2}	V_{V2-E3}	V_{V2-E4}	V_{V2-E5}	V_{V2-E6}	V_{V2-E7}
W4	WG_{SE4}	V_{W4-E1}	V_{W4-E2}	V_{W4-E3}	V_{W4-E4}	V_{W4-E5}	V_{W4-E6}	V_{W4-E7}
C1	WG_{SE6}	V_{C1-E1}	V_{C1-E2}	V_{C1-E3}	V_{C1-E4}	V_{C1-E5}	V_{C1-E6}	V_{C1-E7}
G5	WG_{SE15}	V_{G5-E1}	V_{G5-E2}	V_{G5-E3}	V_{G5-E4}	V_{G5-E5}	V_{G5-E6}	V_{G5-E7}
L5	WG_{SE20}	V_{L5-E1}	V_{L5-E2}	V_{L5-E3}	V_{L5-E4}	V_{L5-E5}	V_{L5-E6}	V_{L5-E7}
V5	WG_{SE25}	V_{V5-E1}	V_{V5-E2}	V_{V5-E3}	V_{V5-E4}	V_{V5-E5}	V_{V5-E6}	V_{V5-E7}
W5	WG_{SE5}	V_{W5-E1}	V_{W5-E2}	V_{W5-E3}	V_{W5-E4}	V_{W5-E5}	V_{W5-E6}	V_{W5-E7}
C5	WG_{SE10}	V_{C5-E1}	V_{C5-E2}	V_{C5-E3}	V_{C5-E4}	V_{C5-E5}	V_{C5-E6}	V_{C5-E7}
Total								

LEGEND: $V_{CRITERIA-EoL\ STRATEGY}$ = value of socio economic considering no. EoL option

Figure 3. The logic map of values

Finally, the last step is represented by the sum of all contributions (product between weight and relative value) for all alternatives considered. SEI-EoL ranges from 1 to 10 and two final results can be obtained:

- The ranking of EoL options.
- The maximum value of EoL option can be a reference level.

Figure 4 shows an example of the ranking regarding the several alternatives. The option EoL no. 3 shows the best performance for the PLA-based packaging film and its value is near to the maximum one.

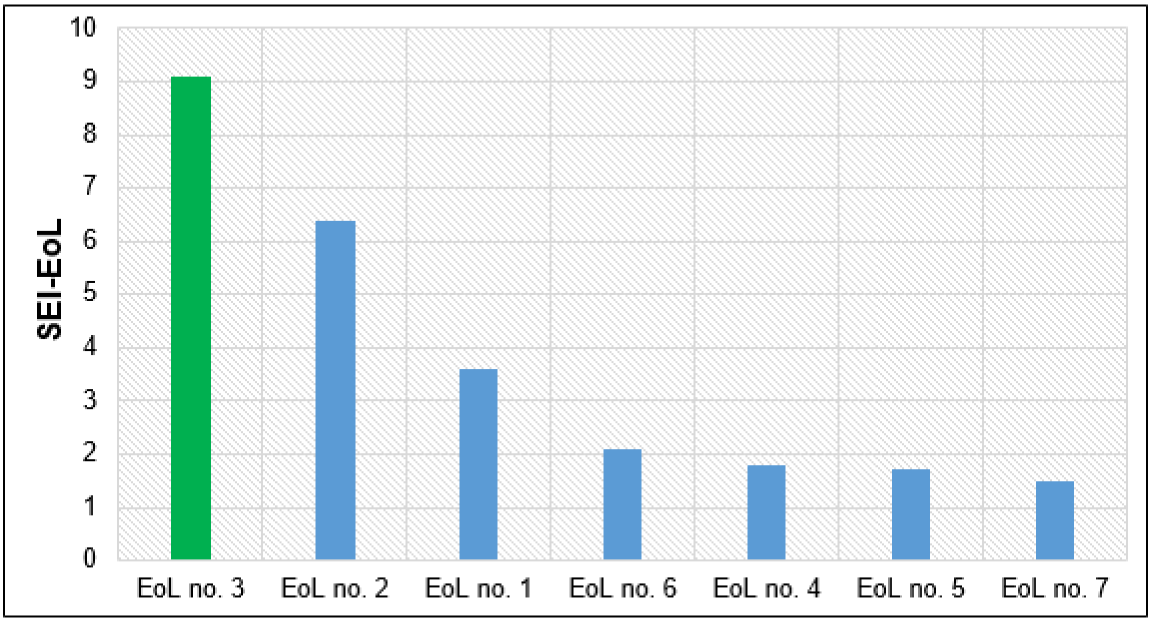

Figure 4. The ranking of alternatives – An example

4 Results

A new indicator, called SEI-EoL is calculated as the product of the row vector (RV - which represents the values of criteria that measure the performance of EoL strategy) and the column vector (CV - which represents the weights of each criteria). The final scope is to develop initially a model that can be replied for several bio-based products and subsequently, we applied this model to a specific case study. In this way, the best option of EoL strategy is identified by the maximum value of SEI-EoL according to socio and economic criteria.

4.1 Calculating weights of socio-economic indicators – local priority

Starting by the column vector referred to the local priority (CVL), an explicative evaluation scale (proposed by one of the interviewees) is reported in Table 7, aiming to evaluate the relevance of one criteria than others. It is referred to five criteria selected for the category workers. Then, a normalized approach is used – Table 8. Starting from the sum of the W1 column values equal to 9 and taking the 3 value of the second row and first column (W2 vs W1), the normalization to 1 of this value is performed as follows:

$$(3*1)/9 = 0.33 \quad (9)$$

Later, we proceed to add up all the value of the indicator line matrix and to divide this result for the number of indicators. For example, the weight of W2 is obtained as follows:

$$(0.33+0.16+0.21+0.18+0.13)/5 = 1.01/5 = 0.20 \quad (10)$$

By repeating this operation for all criteria, we got the following normalized column vector, obtained from the information given by the resulting survey:

$$CVL_W = [0.14\ 0.20\ 0.11\ 0.08\ 0.47]^T \quad (11)$$

The following step is represented by the evaluation of CR. Firstly, λ_{max} is the inner product of the last row of Table 7 and the last vector of Table 8, as shown below:

$$\lambda max = [9\ 6.33\ 9.5\ 11\ 2] * [0.14\ 0.20\ 0.11\ 0.08\ 0.47]T = 5.37 \quad (12)$$

The CI is calculated as follows:

$$CI = (5.37 – 5)/(5-1) = 0.09 \quad (13)$$

Secondly, RI value is equal to 1.12 for n=5 and CR is calculated as follows:

$$CR = 0.09/1.12 = 0.08 \quad (14)$$

This value is smaller than 0.10 and it is possible to say that there is a required consistency in the judgement.

Table 7. Judgement scale (workers) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**
W1	1	0.33	2	2	0.25
W2	3	1	2	2	0.25
W3	0.5	0.5	1	2	0.25
W4	0.5	0.5	0.5	1	0.25
W5	4	4	4	4	1
Total	9	6.33	9.5	11	2

Table 8. Normalized judgement scale (workers) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**	**Total**	**Average**
W1	0.11	0.05	0.21	0.18	0.13	0.68	0.14
W2	0.33	0.16	0.21	0.18	0.13	1.01	0.20
W3	0.06	0.08	0.11	0.18	0.13	0.55	0.11
W4	0.06	0.08	0.05	0.09	0.13	0.40	0.08
W5	0.44	0.63	0.42	0.36	0.50	2.36	0.47
Total	1.00	1.00	1.00	1.00	1.00	5.00	1.00

The same operation is repeated by the same expert also for socio-economic indicators linked to other categories: consumers (Tables 9-10), general society (Tables 11-12), local community (Tables 13-14) and value chain actors (Tables 15-16).

Table 9. Judgement scale (consumers) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**
W1	1	2	2	2	2
W2	0.5	1	0.5	2	2
W3	0.5	2	1	2	2
W4	0.5	0.5	0.5	1	2
W5	0.5	0.5	0.5	0.5	1
Total	3	6	4.5	7.5	9

Table 10. Normalized judgement scale (consumers) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**	**Total**	**Average**
W1	0.33	0.33	0.44	0.27	0.22	1.60	0.32
W2	0.17	0.17	0.11	0.27	0.22	0.93	0.19
W3	0.17	0.33	0.22	0.27	0.22	1.21	0.24
W4	0.17	0.08	0.11	0.13	0.22	0.72	0.14
W5	0.17	0.08	0.11	0.07	0.11	0.54	0.11
Total	1.00	1.00	1.00	1.00	1.00	5.00	1.00

Table 11. Judgement scale (general society) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**
W1	1	0.33	2	2	2
W2	3	1	2	2	4
W3	0.5	0.5	1	2	2
W4	0.5	0.5	0.5	1	2
W5	0.5	0.25	0.5	0.5	1
Total	5.5	2.58	6	7.5	11

Table 12. Normalized judgement scale (general society) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**	**Total**	**Average**
W1	0.18	0.13	0.33	0.27	0.18	1.09	0.22
W2	0.55	0.39	0.33	0.27	0.36	1.90	0.38
W3	0.09	0.19	0.17	0.27	0.18	0.90	0.18
W4	0.09	0.19	0.08	0.13	0.18	0.68	0.14
W5	0.09	0.10	0.08	0.07	0.09	0.43	0.09
Total	1.00	1.00	1.00	1.00	1.00	5.00	1.00

Table 13. Judgement scale (local community) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**
W1	1	0.33	2	0.25	0.25
W2	3	1	5	2	2
W3	0.5	0.2	1	0.33	0.25
W4	4	0.5	3	1	0.33
W5	4	0.5	4	3	1
Total	12.5	2.53	15	6.58	3.83

Table 14. Normalized judgement scale (local community) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**	**Total**	**Average**
W1	0.08	0.13	0.13	0.04	0.07	0.45	0.09
W2	0.24	0.39	0.33	0.30	0.52	1.79	0.36
W3	0.04	0.08	0.07	0.05	0.07	0.30	0.06
W4	0.32	0.20	0.20	0.15	0.09	0.96	0.19
W5	0.32	0.20	0.27	0.46	0.26	1.50	0.30
Total	1.00	1.00	1.00	1.00	1.00	5.00	1.00

Table 15. Judgement scale (value chain actors) – example: data of expert no. 1

	W1	**W2**	**W3**	**W4**	**W5**
W1	1	0.5	0.33	0.25	4
W2	2	1	0.33	0.5	4
W3	3	3	1	0.5	4
W4	4	2	2	1	4
W5	0.25	0.25	0.25	0.25	1
Total	10.25	6.75	3.92	2.5	17

Table 16. Normalized judgement scale (value chain actors) – example: data of expert no. 1

	W1	W2	W3	W4	W5	Total	Average
W1	0.10	0.07	0.09	0.10	0.24	0.59	0.12
W2	0.20	0.15	0.09	0.20	0.24	0.86	0.17
W3	0.29	0.44	0.26	0.20	0.24	1.43	0.29
W4	0.39	0.30	0.51	0.40	0.24	1.83	0.37
W5	0.02	0.04	0.06	0.10	0.06	0.28	0.06
Total	1.00	1.00	1.00	1.00	1.00	5.00	1.00

It is possible to define the column vector for each category:

$$CVL_C = [0.32\ 0.19\ 0.24\ 0.14\ 0.11]^T \quad (15)$$

$$CVL_G = [0.22\ 0.38\ 0.18\ 0.14\ 0.09]^T \quad (16)$$

$$CVL_L = [0.09\ 0.36\ 0.06\ 0.19\ 0.30]^T \quad (17)$$

$$CVL_V = [0.12\ 0.17\ 0.29\ 0.37\ 0.06]^T \quad (18)$$

The CR obtained varies from 0.05 to 0.08 and it is confirmed the consistency of the values provided by the expert. The same phases are repeated for all the twenty interviewees, by defining the percentage weights of five criteria for each category: workers (Figure 5), consumers (Figure 6), general society (Figure 7), local community (Figure 8) and value chain actors (Figure 9). For example, the weights reported in equations (11)-(15)-(16)-(17)-(18) are transferred in each Figure and regarding expert no.1 the analysis is able to underline which specific criteria assume the weight more greater: W5 (0.47), C1 (0.32), G2(0.38), L2 (0.36) and V4 (0.37).

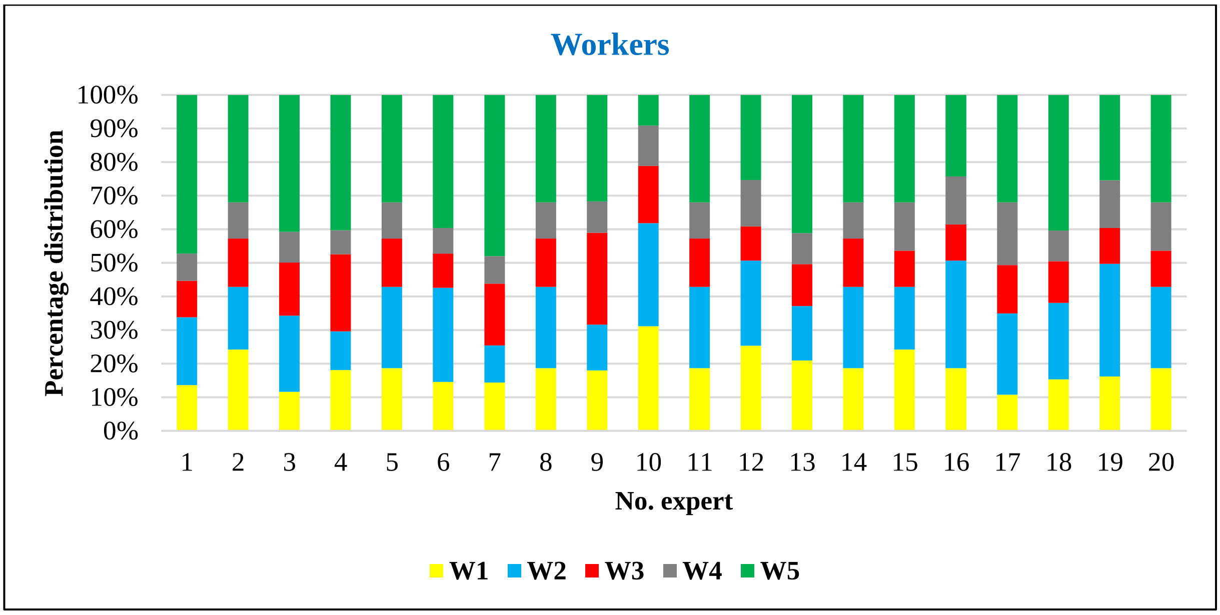

Figure 5. Percentage weights of five criteria by twenty interviewees – workers

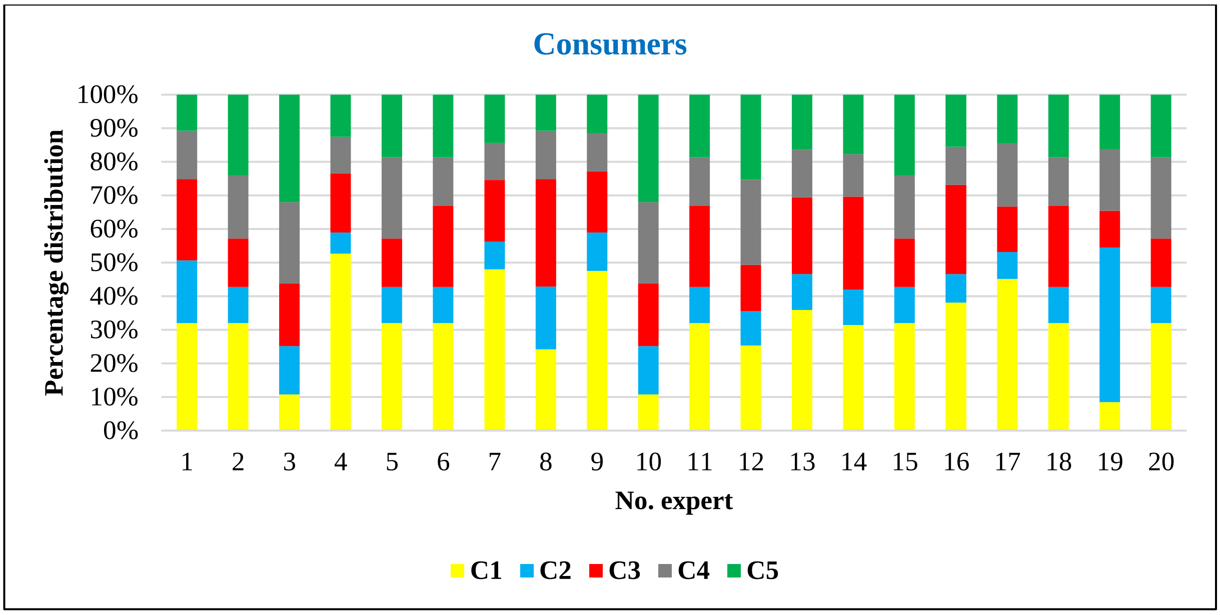

Figure 6. Percentage weights of five criteria by twenty interviewees – consumers

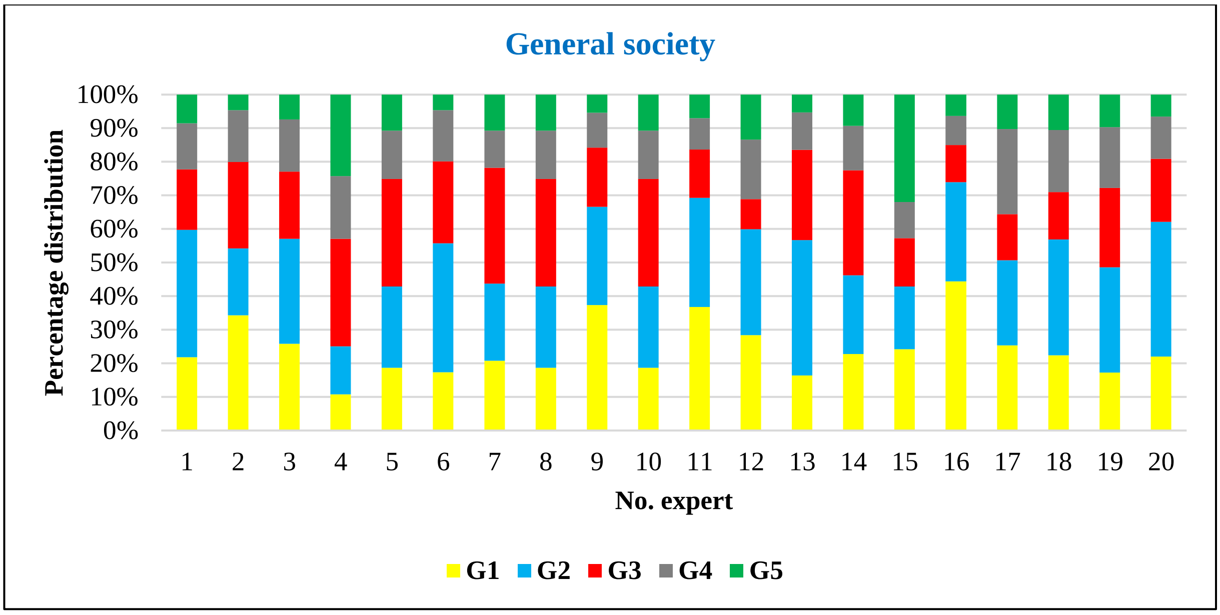

Figure 7. Percentage weights of five criteria by twenty interviewees – general society

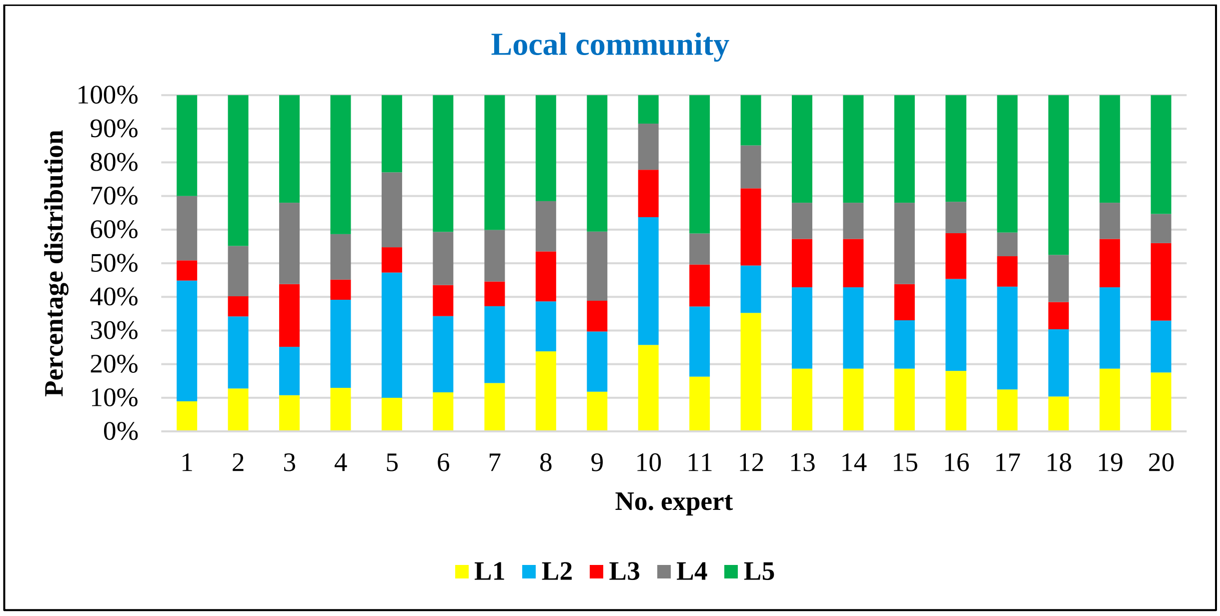

Figure 8. Percentage weights of five criteria by twenty interviewees – local community

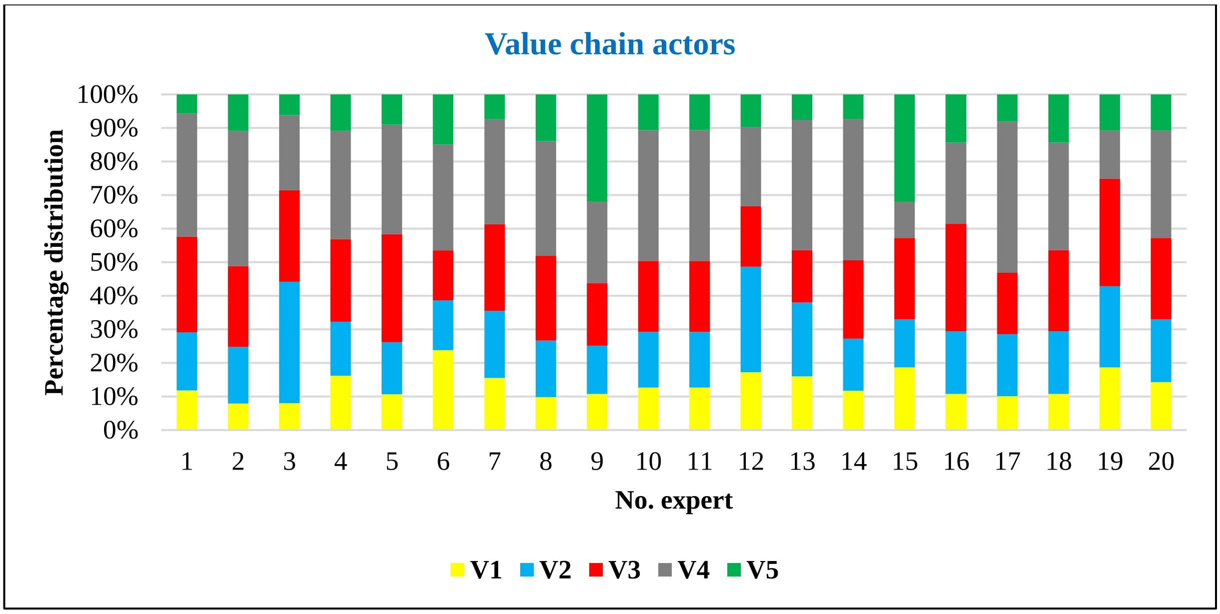

Figure 9. Percentage weights of five criteria by twenty interviewees – value chain actors

Analyzing all 100 combinations (giving by the product between 5 categories and 20 interviewees), results show as some criteria have a dominant position in four of five categories:

- Indicator W5 occupies the first position for 17 of 20 experts.
- Indicator C1 has a weight greater than others for 16 of 20 experts.
- Indicator L5 presents the value more significant for 16 of 20 experts.
- Indicator V4 is defined as the criteria more relevant for 14 of 20 experts.

Regarding, instead, the category of general society G2 and G3 occupy the first position for 8 and 6 of 20 experts, respectively. The analysis of all interviewees shows the variability of results obtained and the advantage of AHP is able to capture different perspectives providing an average value, called ACVL (average column vector referred to the local priority). All experts have the same relevance.

$$ACVL_X = (\sum_{Y=1}^{N} CVL_{X,Y})/N \tag{19}$$

in which X = categories, Y = experts, N = number of experts and $CVL_{X,Y}$ is the column vector referred to the local priority for a specific X category according to the evaluation of the expert Y.

The first step of the AHP analysis has regarded the definition of the weight of each criteria within the same category and consequently, in this phase of evaluation the categories are separated and experts give the weight for five distinct situations. For this motive, the term local priority is used in this phase of the work and results obtained applying equation (19) are the following:

$$ACVL_W = [0.19\ 0.23\ 0.14\ 0.11\ 0.33]^T \tag{20}$$

$$ACVL_C = [0.32\ 0.13\ 0.20\ 0.17\ 0.19]^T \tag{21}$$

$$ACVL_G = [0.24\ 0.29\ 0.22\ 0.14\ 0.10]^T \tag{22}$$

$$ACVL_L = [0.16\ 0.23\ 0.12\ 0.15\ 0.34]^T \tag{23}$$

$$ACVL_V = [0.13\ 0.19\ 0.24\ 0.31\ 0.12]^T \tag{24}$$

A picture of these values is reported for each category: workers (Figure 10), consumers (Figure 11), general society (Figure 12), local community (Figure 13) and value chain actors (Figure 14).

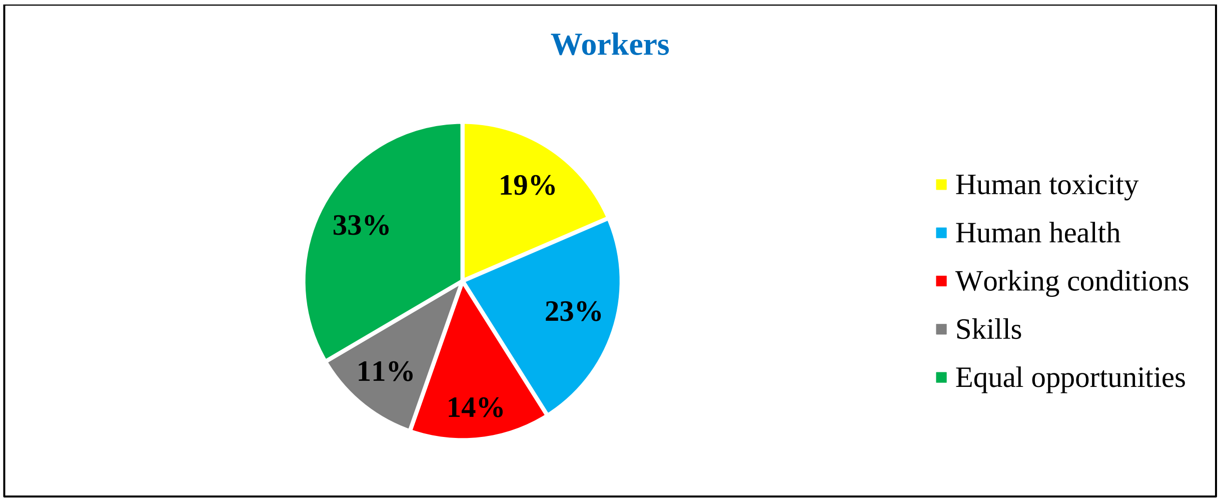

Figure 10. Average column vector (local priority) for the category workers

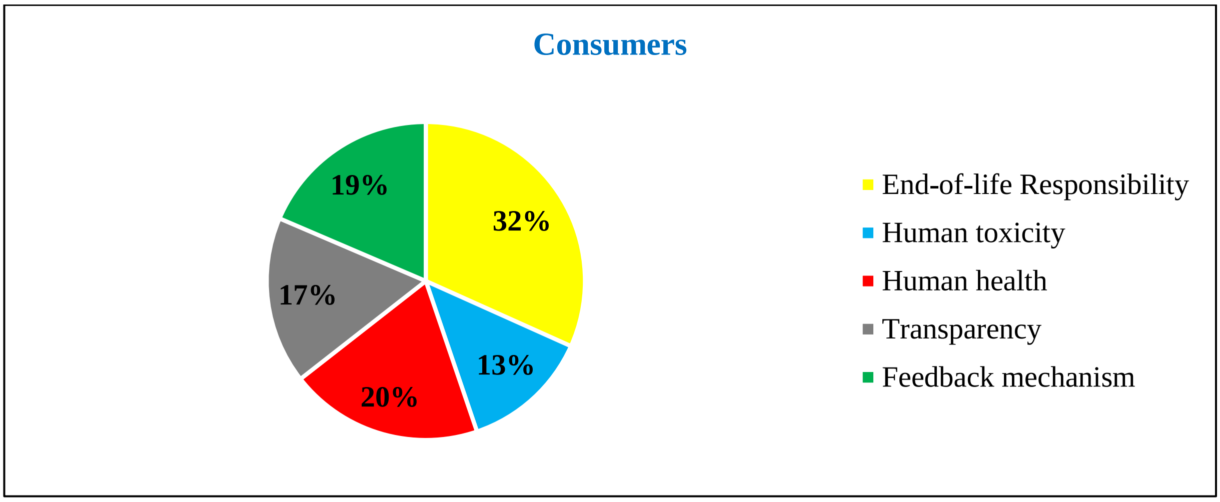

Figure 11. Average column vector (local priority) for the category consumers

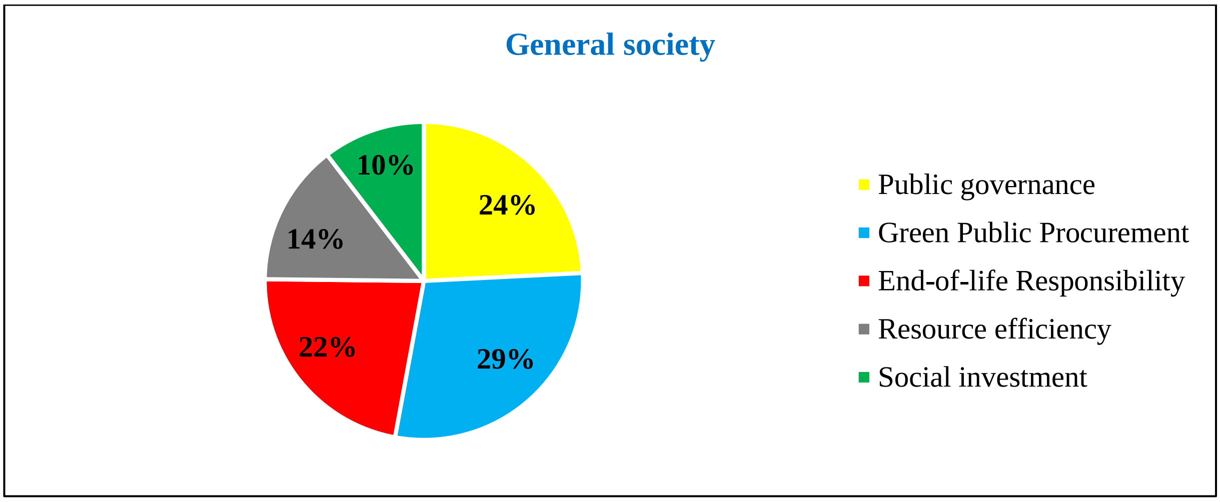

Figure 12. Average column vector (local priority) for the category general society

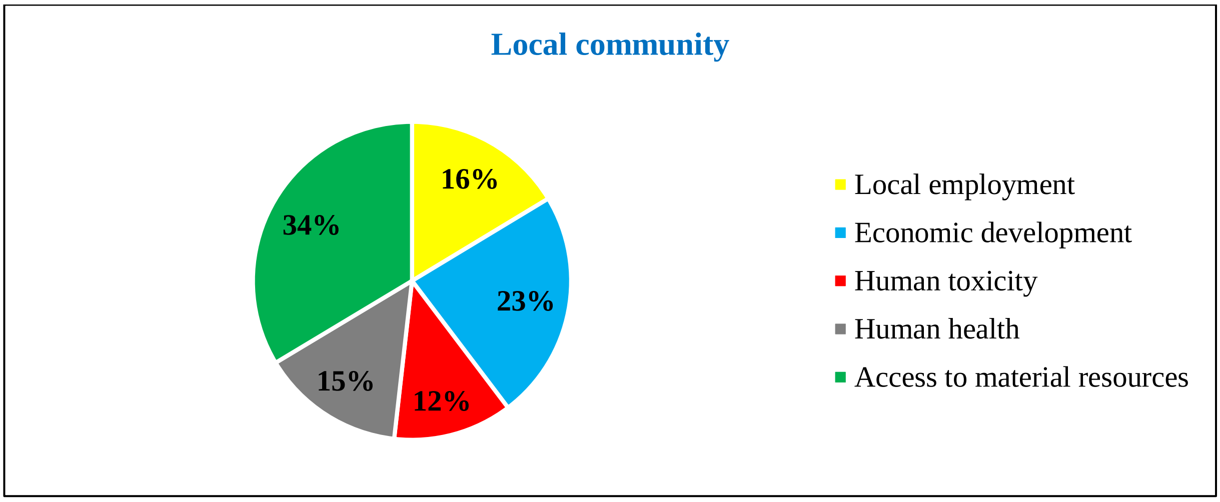

Figure 13. Average column vector (local priority) for the category local community

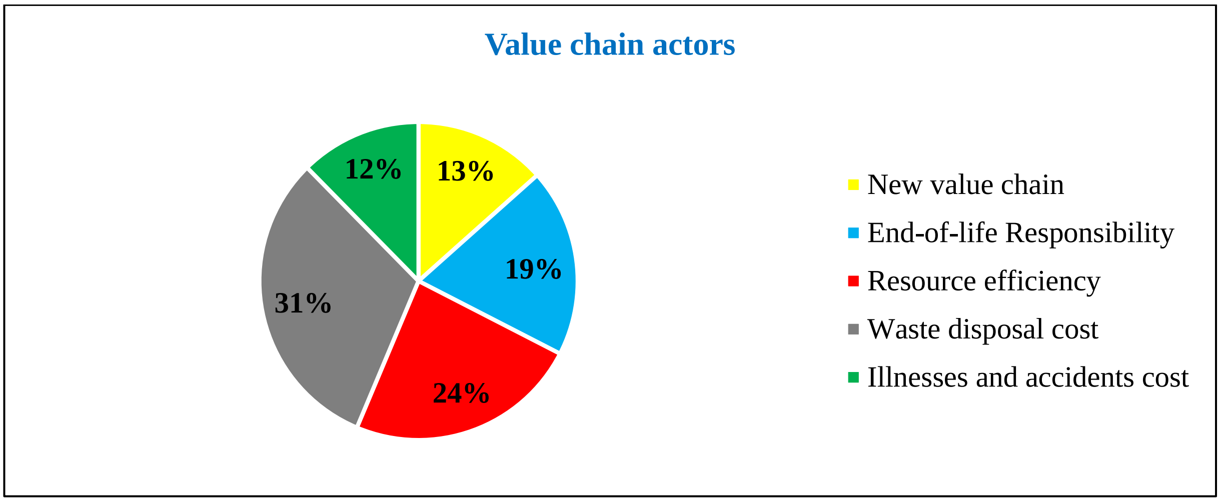

Figure 14. Average column vector (local priority) for the category value chain actors

A simple comparison of criteria is able to define a ranking, while a pair-wise comparison provides a ranking assigning also values to each criteria. The dominant position of some criteria for each category of analysis determines the results registered in Figures 10-14.

The presence of formal policies on equal opportunity (criteria W5) has a weight equal to 33% within workers' category. It is followed by human health (W2) and human toxicity (W1) that are far of almost ten percentage points. The commitment by stakeholders to be responsible of the actions the end-of-life of products avoiding negative consequences for humans and ecosystems (criteria C1) shows the main weight among consumers criteria (equal to 32%). Also in this case the distance from the following criteria are significant: C3 (20%), C5 (19%) and C4 (17%). Only regarding the category of general society, the difference of weight among the first indicators is the lowest (about 5-7%). The first position is assumed by the presence of policies that favour purchases or utilizations of products, services and works that respect the environment (criteria G2) with a value of 29% followed by G1 (24%) and G3 (22%). Waste can be a resource that are employed for the development of new products (criteria L5) plays a key-role among local community criteria with a percentage weight of 34%. In this case, the second position is assumed by L2 (23%). Finally, the costs related to waste disposal (criteria V4) presents the weight more significant among value chain actors (equal to 31%) followed by V3 (equal to 24%).

4.2 Calculating weights of categories

The direct comparison of 25 criteria is not simple to analyse through an AHP analysis. For this motive, we have subdivided these criteria into five categories. As above-cited, the first step of this analysis has defined the ranking of criteria within specific categories. The second step regards the AHP analysis applied to the same categories in order to obtain a new ranking. In this way, we calculate global priority of all criteria as the product between local priority assigned to criteria for each category and the group priority linked to categories. Experts have defined which category has an impact more significant and the methodology explained in the previous sub-section is repeated during this step – Figure 15.

For example, the expert no. 1 has assigned the greatest weight to the value chain actors (0.320) and the lowest one to the workers (0.108). Intermediate values are assigned to other three categories: general society (0.242), local community (0.187) and consumers (0.143). In this way, we obtain the components of the column vector referred to categories (CVC).

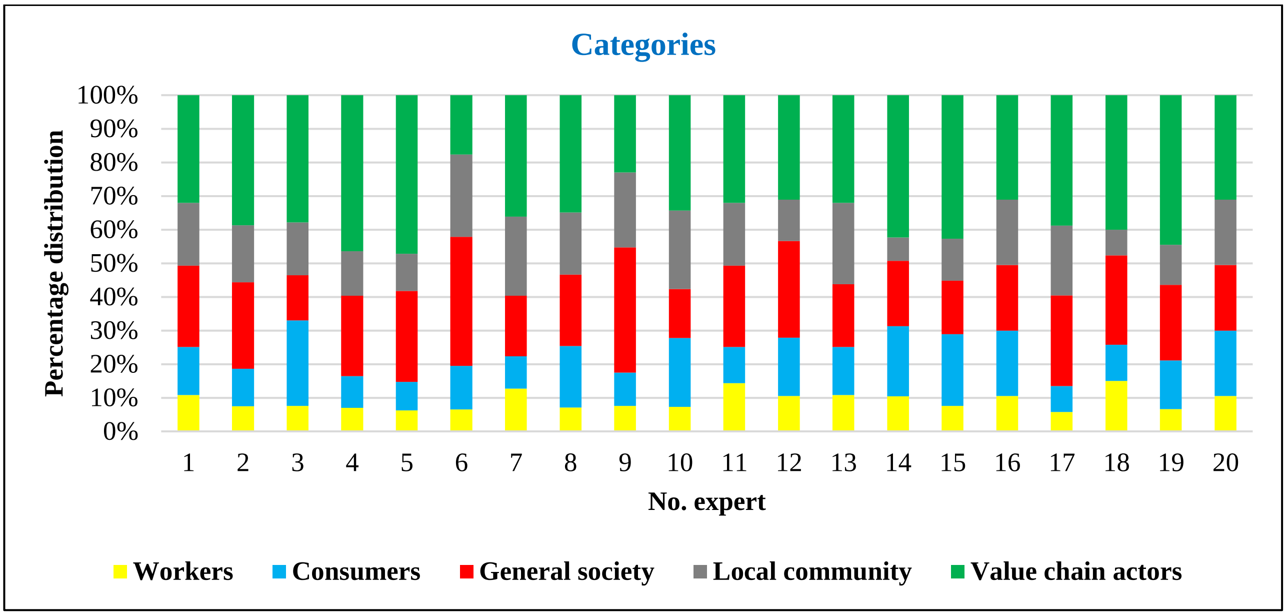

Figure 15. Percentage weights of five categories by twenty interviewees

The analysis of weights provided by experts shows as the category value chain actors is the most relevant for 18 of 20 interviewees (only no. 6 and no. 9 have assigned a weight greater to the general society). Also in this phase of work, the weight assigned by several experts is different and thanks to the AHP is possible to obtain a unique value of reference. All experts have the same relevance in order to calculate the average value, called ACVC (average column vector referred to the categories).

$$ACVC_X = (\sum_{Y=1}^{N} CVC_{X,Y})/N \quad (25)$$

in which X = categories, Y = experts, N = number of experts and $CVC_{X,Y}$ is the column vector referred to the categories for a specific X category according to the evaluation of the expert Y. Considering that $ACVL_X$ has a dimension [5, 1] for each category, also $ACVC_X$ must be composed by five rows and one column. For this motive, the same average value is repeated for five times. It is defined as follows – Figure 16:

$$ACVC_W = [0.09\ 0.09\ 0.09\ 0.09\ 0.09]^T \quad (26)$$

$$ACVC_C = [0.15\ 0.15\ 0.15\ 0.15\ 0.15]^T \quad (27)$$

$$ACVC_G = [0.23\ 0.23\ 0.23\ 0.23\ 0.23]^T \quad (28)$$

$$ACVC_L = [0.17\ 0.17\ 0.17\ 0.17\ 0.17]^T \quad (29)$$

$$ACVC_V = [0.36\ 0.36\ 0.36\ 0.36\ 0.36]^T \quad (30)$$

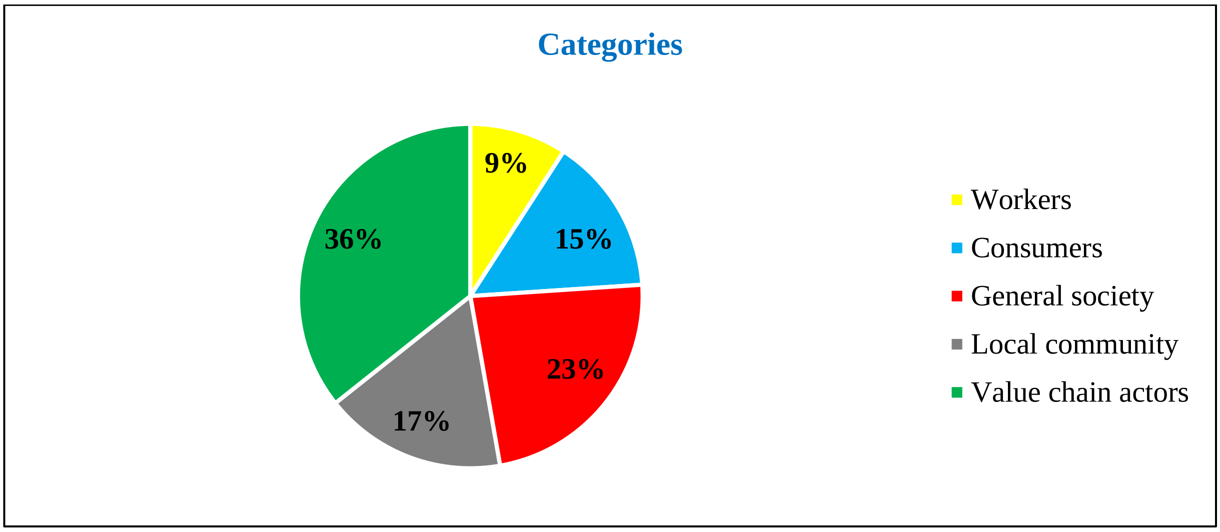

Figure 16. Average column vector (categories)

The analysis of results shows as value chain actors is the category that mainly influences the EoL strategy. The average value assigned by experts is equal to 36% that is significantly greater than other categories. In particular, general society occupies the second position with 23%. These two categories have a weight equal to two thirds of the total. The weight of local community (17%) is slightly greater than one of consumers (15) and the last position of the ranking is occupied by workers with 9%.

4.3 Calculating weights of socio-economic indicators – global priority

The final value of global priority is influenced by local priority. This third step of the analysis does not require more the support of experts. In fact, it is based on the values obtained in the two previous steps. The average column vector referred to the global priority (ACVG) is obtained as follows:

$$\mathrm{ACVG_W = ACVL_W * ACVC_W} \quad (31)$$

$$\mathrm{ACVG_C = ACVL_C * ACVC_C} \quad (32)$$

$$\mathrm{ACVG_G = ACVL_G * ACVC_G} \quad (33)$$

$$\mathrm{ACVG_L = ACVL_L * ACVC_L} \quad (34)$$

$$\mathrm{ACVG_V = ACVL_V * ACVC_V} \quad (35)$$

Both $ACVL_X$ and $ACVC_X$ have a dimension of the matrix equal to [5, 1], so the product between these two matrixes determines that also $ACVG_X$ has the same dimension. The shift from a local priority to a global one is able to transform the weights obtained in order to have homogeneous data. Several $ACVL_X$ cannot be grouped because each has a vision that regards only a defined category, while the same is not true for $ACVG_X$ in which all perspectives are integrated in the evaluations provided by experts. Starting by both groups of equations (20)-(24) and (26)-(30) and applying equations (31)-(35), we obtain the following weights linked to the socio-economic indicators:

$ACVG_W = [0.19\ 0.23\ 0.14\ 0.11\ 0.33]^T * [0.09\ 0.09\ 0.09\ 0.09\ 0.09]^T = [0.017\ 0.021\ 0.013\ 0.010\ 0.031]^T$ (36)

$ACVG_C = [0.32\ 0.13\ 0.20\ 0.17\ 0.19]^T * [0.15\ 0.15\ 0.15\ 0.15\ 0.15]^T = [0.047\ 0.019\ 0.029\ 0.025\ 0.028]^T$ (37)

$ACVG_G = [0.24\ 0.29\ 0.22\ 0.14\ 0.10]^T * [0.23\ 0.23\ 0.23\ 0.23\ 0.23]^T = [0.056\ 0.067\ 0.052\ 0.034\ 0.024]^T$ (38)

$ACVG_L = [0.16\ 0.23\ 0.12\ 0.15\ 0.34]^T * [0.17\ 0.17\ 0.17\ 0.17\ 0.17]^T = [0.028\ 0.040\ 0.021\ 0.025\ 0.057]^T$ (39)

$ACVG_V = [0.13\ 0.19\ 0.24\ 0.31\ 0.12]^T * [0.36\ 0.36\ 0.36\ 0.36\ 0.36]^T = [0.048\ 0.068\ 0.085\ 0.112\ 0.044]^T$ (40)

Finally, the column vector (CV) is composed by five $ACVG_X$. It has a dimension of matrix equal to [25, 1], that is composed by 25 criteria (called I).

$CV_{I,*} = [ACVG_W\ ACVG_C\ ACVG_G\ ACVG_L\ ACVG_V]$ (41)

All data required for the equation (41) are provided by the equations (36)-(40) and the percentage distribution of the weights in term of global priority can be described in the following equation:

$CV_{I;*} = [0.017\ 0.021\ 0.013\ 0.010\ 0.031\ 0.047\ 0.019\ 0.029\ 0.025\ 0.028\ 0.056\ 0.067\ 0.052\ 0.034\ 0.024\ 0.028\ 0.040\ 0.021\ 0.025\ 0.057\ 0.048\ 0.068\ 0.085\ 0.112\ 0.044]^T$ (42)

Table 17 shows both local and global priority of all socio-economic criteria providing a complete summary of the survey conducted among experts of EoL strategies. The list of weights is given to experts following the ranking of relevance and consequently, the weight of V4 is the first component of the column vector and one W4 is the last.

$CV_I = [ACVG_{V4}\ ACVG_{V3}\ ACVG_{V2}\ ACVG_{G2}\ ACVG_{L5}\ ACVG_{G1}\ ACVG_{G3}\ ACVG_{V1}\ ACVG_{C1}\ ACVG_{V5}\ ACVG_{L2}\ ACVG_{G4}\ ACVG_{W5}\ ACVG_{C3}\ ACVG_{L1}\ ACVG_{C5}\ ACVG_{C4}\ ACVG_{L4}\ ACVG_{G5}\ ACVG_{L3}\ ACVG_{W2}\ ACVG_{C2}\ ACVG_{W1}\ ACVG_{W3}\ ACVG_{W4}]^T$ (43)

$CV_I = [0.112\ 0.085\ 0.068\ 0.067\ 0.057\ 0.056\ 0.052\ 0.048\ 0.047\ 0.044\ 0.040\ 0.034\ 0.031\ 0.029\ 0.028\ 0.028\ 0.025\ 0.025\ 0.024\ 0.021\ 0.021\ 0.019\ 0.017\ 0.013\ 0.010]^T$ (44)

Table 17. Ranking of socio-economic criteria

Socio-economic criteria		Local priority		Global priority	
Workers [Priority: 0.091]					
W1	Human toxicity	0.185	**(3.)**	0.017	**(23.)**
W2	Human health	0.225	**(2.)**	0.021	**(21.)**
W3	Working conditions	0.143	**(4.)**	0.013	**(24.)**
W4	Skills	0.112	**(5.)**	0.010	**(25.)**
W5	Equal opportunities	0.335	**(1.)**	0.031	**(13.)**
Consumer [Priority: 0.148]					
C1	End-of-life Responsibility	0.317	**(1.)**	0.047	**(9.)**
C2	Human toxicity	0.131	**(5.)**	0.019	**(22.)**
C3	Human health	0.196	**(2.)**	0.029	**(14.)**
C4	Transparency	0.170	**(4.)**	0.025	**(17.)**
C5	Feedback mechanism	0.186	**(3.)**	0.028	**(16.)**
General society [Priority: 0.233]					
G1	Public governance	0.242	**(2.)**	0.056	**(6.)**
G2	Green Public Procurement	0.287	**(1.)**	0.067	**(4.)**
G3	End-of-life Responsibility	0.223	**(3.)**	0.052	**(7.)**
G4	Resource efficiency	0.144	**(4.)**	0.034	**(12.)**
G5	Social investment	0.104	**(5.)**	0.024	**(19.)**
Local community [Priority: 0.171]					
L1	Local employment	0.164	**(3.)**	0.028	**(15.)**
L2	Economic development	0.233	**(2.)**	0.040	**(11.)**
L3	Human toxicity	0.121	**(5.)**	0.021	**(20.)**
L4	Human health	0.146	**(4.)**	0.025	**(18.)**
L5	Access to material resources	0.336	**(1.)**	0.057	**(5.)**
Value chain actors [Priority: 0.357]					
V1	New value chain	0.134	**(4.)**	0.048	**(8.)**
V2	End-of-life Responsibility	0.192	**(3.)**	0.068	**(3.)**
V3	Resource efficiency	0.238	**(2.)**	0.085	**(2.)**
V4	Waste disposal cost	0.313	**(1.)**	0.112	**(1.)**
V5	Illnesses and accidents cost	0.124	**(5.)**	0.044	**(10.)**

The analysis of results shows clearly as the impact of the priority group has a key-role in the evaluation of the global factor priority. In fact, three criteria referred to the value chain actors occupy the first three positions of the global ranking (Figure 17). Waste disposal cost (criteria V4) has a value of 0.112 followed by resource efficiency (criteria V3) with 0.085 and end-of-life responsibility (criteria V2) with 0.068. These three criteria have a weight equal to three quarters of the local priority and one quarter of the global one. The fourth position is occupied by green public procurement (criteria G2), that is the main criteria of the general society, followed by access to material resources (criteria L5), that is, instead, the first criteria of the local community. Analysing the first ten positions of the global ranking, we found eight criteria linked to the two specific categories (value chain actors and general society) that have a weight equal to two thirds of the total mix. End-of-life responsibility, human toxicity and human health are present in three categories, but their value cannot be combined because they are evaluated specifically for a defined category. The same is valid also for resource efficiency that is present in two categories. Regarding consumers, end-of-life responsibility occupies the first position in terms of local priority and the ninth position as global priority. Finally, four of five criteria referred to workers are positioned in the last five positions of the global priority. The exception is represented by equal opportunities.

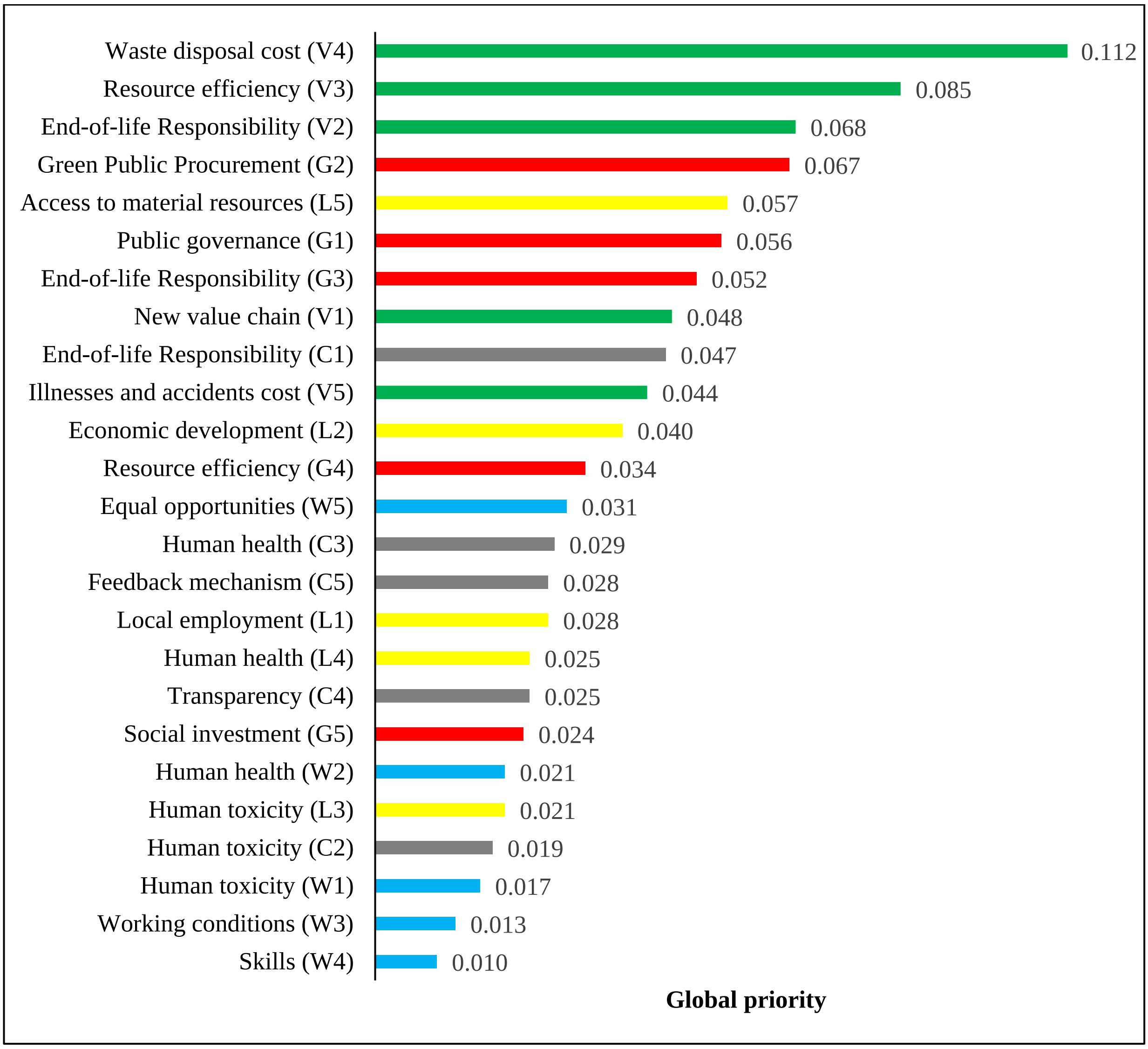

Figure 17. Global priority of criteria. Legend: Colours represent different stakeholders (green = value chain actors; red = general society; yellow = local community; grey = consumers and blue = workers).

4.4 Calculating values of socio-economic indicators

AHP conducted on two levels (local priority and global priority) has permitted to propose a ranking of a consistent number of indicators. Table 17 has identified the weight of all criteria and this model can be applied to several products. Literature section has demonstrated as the role of EoL strategies is crucial within the development of sustainable practices. The definition of the best EoL option is based not only on the weights assigned to the criteria, but it is necessary to define their value. In some cases, these data can be historical data or future estimations. In other cases, the analysis of literature is able to provide values of reference. The condition necessary to elaborate this phase is that all data are homogeneous. For this motive, we have asked a new support to experts already employed during the definition of the weights. A specific product is proposed and we have considered the PLA-based packaging film, which is suitable to be treated through alternative EoL options. The expert can assign ten potential values varying from 1 to 10, in which 1 is the worst evaluation and 10 is the best evaluation. This judgement is based on the value of the specific criteria analysing a defined EoL strategy applied to the PLA-based packaging film. Seven strategies are considered: reuse, mechanical recycling, chemical recycling, aerobic composting, anaerobic digestion, energy recovery and landfilling. The weights of each criteria are provided in order of relevance to experts (see Table 17).

$$RV_{E,I,Y} = [RV_{E,V4,Y}\ RV_{E,V3,Y}\ RV_{E,V2,Y}\ RV_{E,G2,Y}\ RV_{E,L5,Y}\ RV_{E,G1,Y}\ RV_{E,G3,Y}\ RV_{E,V1,Y}\ RV_{E,C1,Y}\ RV_{E,V5,Y}\ RV_{E,L2,Y}\ RV_{E,G4,Y}\ RV_{E,W5,Y}\ RV_{E,C3,Y}\ RV_{E,L1,Y}\ RV_{E,C5,Y}\ RV_{E,C4,Y}\ RV_{E,L4,Y}\ RV_{E,G5,Y}\ RV_{E,L3,Y}\ RV_{E,W2,Y}\ RV_{E,C2,Y}\ RV_{E,W1,Y}\ RV_{E,W3,Y}\ RV_{E,W4,Y}] \quad (45)$$

in which $RV_{E,I,Y}$ is the row vector referred to the criteria I evaluated by the expert Y considering EoL strategy E. The order of criteria follows one defined by the global priority and consequently, the components of both row and column vectors are comparable. Table 18 shows the values proposed by the expert no.1 and for example a value of 10 is linked to the indicator V4 evaluating the mechanical recycling as EoL strategy (in this case, $RV_{Mechanical\ recycling,V4,1}$ is equal to 10).

Table 18. Values of socio-economic criteria in function of the EoL strategy - example: data of expert no. 1

Ranking of criteria	Reuse	Mechanical recycling	Chemical recycling	Aerobic composting	Anaerobic digestion	Energy recovery	Landfilling
V4	2	10	10	3	3	3	1
V3	3	10	10	2	3	3	1
V2	2	10	10	3	3	3	1
G2	2	10	10	3	3	3	1
L5	3	10	10	3	3	3	1
G1	2	10	10	3	3	3	1
G3	2	10	10	3	2	2	1
V1	2	9	9	2	2	2	1
C1	2	10	10	3	2	2	2
V5	3	9	9	2	2	4	2
L2	2	10	10	2	2	2	2
G4	2	10	10	2	1	4	2
W5	2	10	10	3	1	3	2
C3	2	10	9	3	1	2	1
L1	2	10	10	3	1	3	1
C5	3	10	10	3	1	3	1
C4	2	9	9	3	1	2	1
L4	4	10	9	3	1	2	1
G5	2	10	10	3	1	2	1
L3	4	10	9	3	1	2	1
W2	2	10	9	3	1	2	1
C2	2	10	9	3	1	2	1
W1	2	10	9	3	3	2	1
W3	2	10	10	3	2	2	1
W4	2	10	10	3	2	2	1

The row vector has a dimension [1, 25] and it is composed by 25 values attributed to the criteria. For example, equation (46) describes the row vector proposed by the expert no.1 considering the reuse, while the equation (47) one linked to the mechanical recycling.

$RV_{reuse,I,1}$ = [2 3 2 2 3 2 2 2 2 3 2 2 2 2 2 3 2 4 2 4 2 2 2 2 2] (46)

$RV_{mechanical\ recycling,I,1}$ = [10 10 10 10 10 10 10 9 10 9 10 10 10 10 10 10 9 10 10 10 10 10 10 10 10] (47)

This judgement is provided for each criteria considering all EoL strategies. The number of data collection for each strategy is equal to 500, deriving by the product between 25 criteria and 20 experts. The percentage distribution of the values assigned by experts is proposed as follow: reuse (Figure 18), mechanical recycling (Figure 19), chemical recycling (Figure 20), aerobic composting (Figure 21), anaerobic digestion (Figure 22), energy recovery (Figure 23) and landfilling (Figure 24). For example, considering reuse as EoL option the interviewees have applied the value 2 for 213 times to several indicators and so, its percentage distribution is equal to 42.6% (dividing 213 for 500).

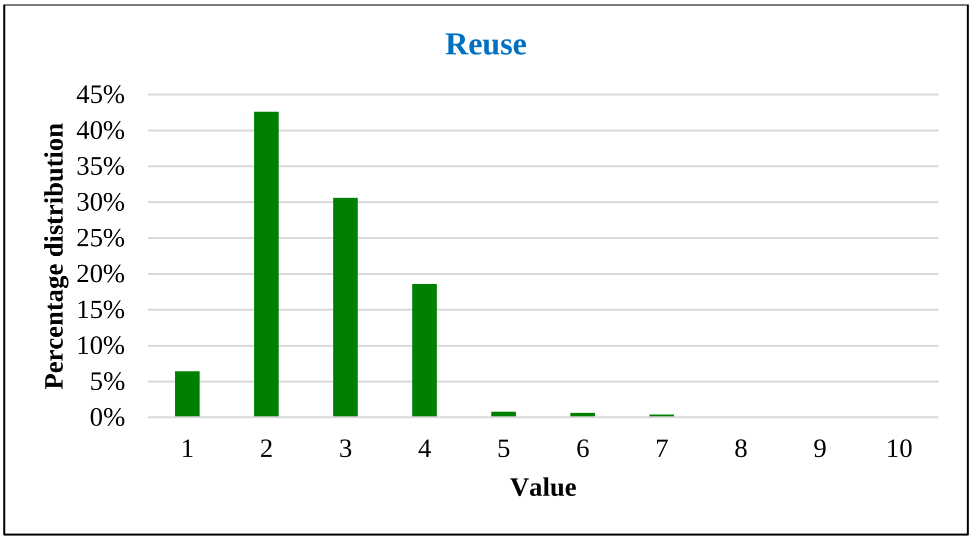

Figure 18. Percentage distribution of values assigned by twenty interviewees – reuse

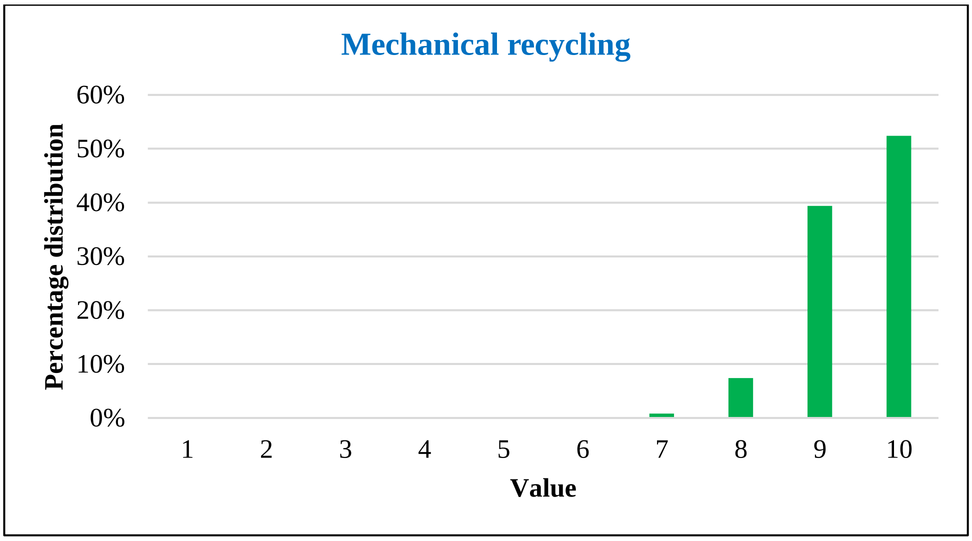

Figure 19. Percentage distribution of values assigned by twenty interviewees – mechanical recycling

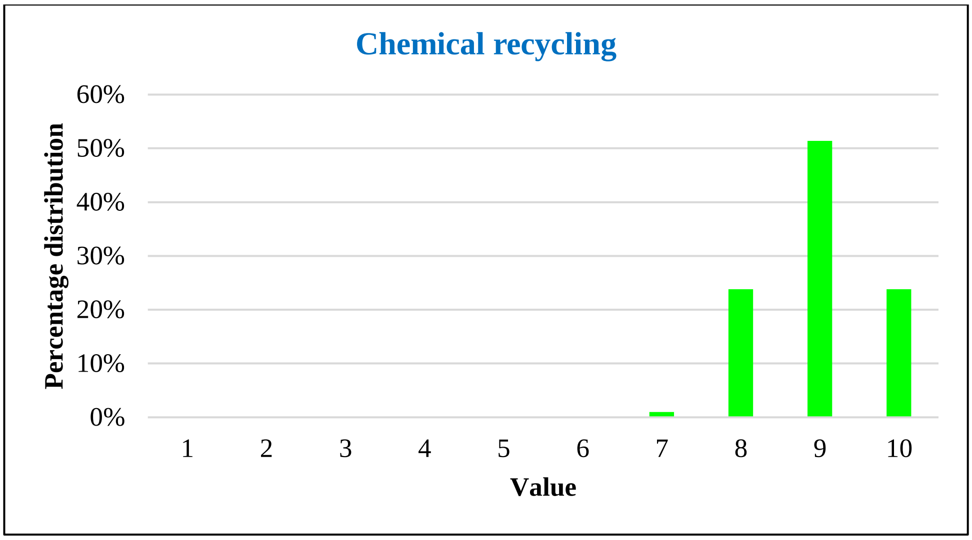

Figure 20. Percentage distribution of values assigned by twenty interviewees – chemical recycling

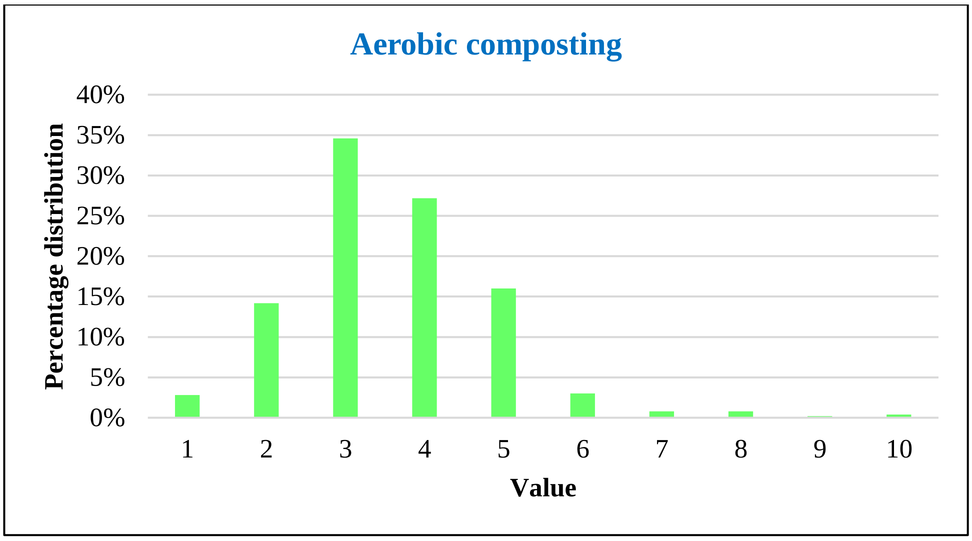

Figure 21. Percentage distribution of values assigned by twenty interviewees – aerobic composting

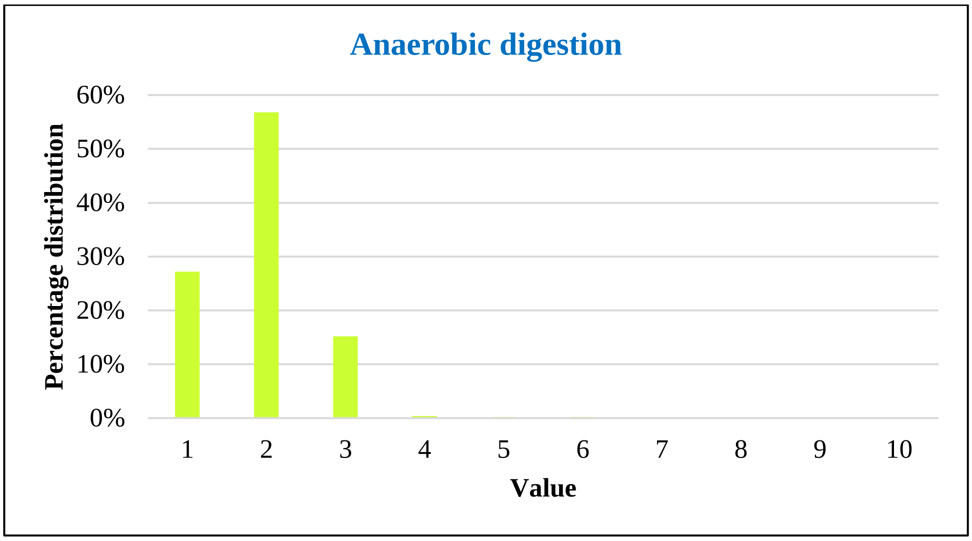

Figure 22. Percentage distribution of values assigned by twenty interviewees – anaerobic digestion

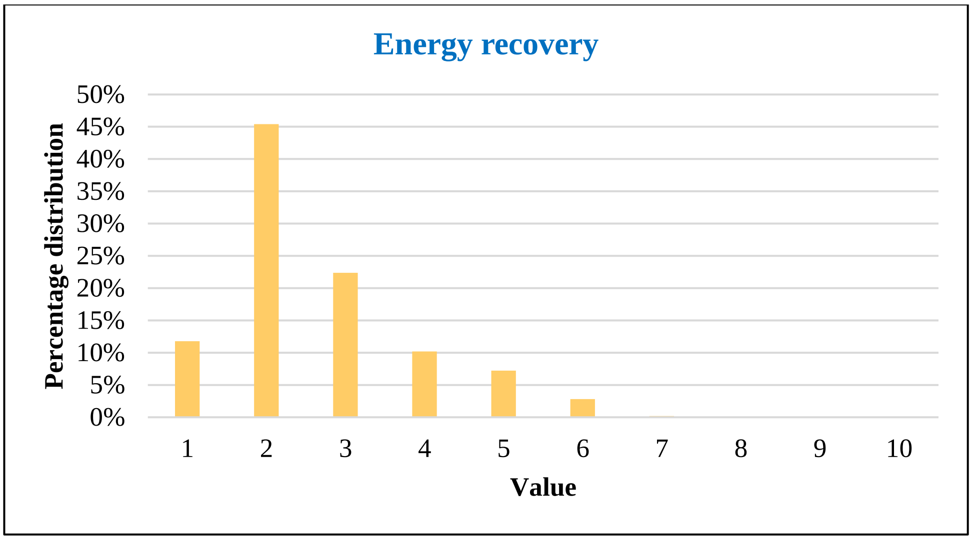

Figure 23. Percentage distribution of values assigned by twenty interviewees – energy recovery

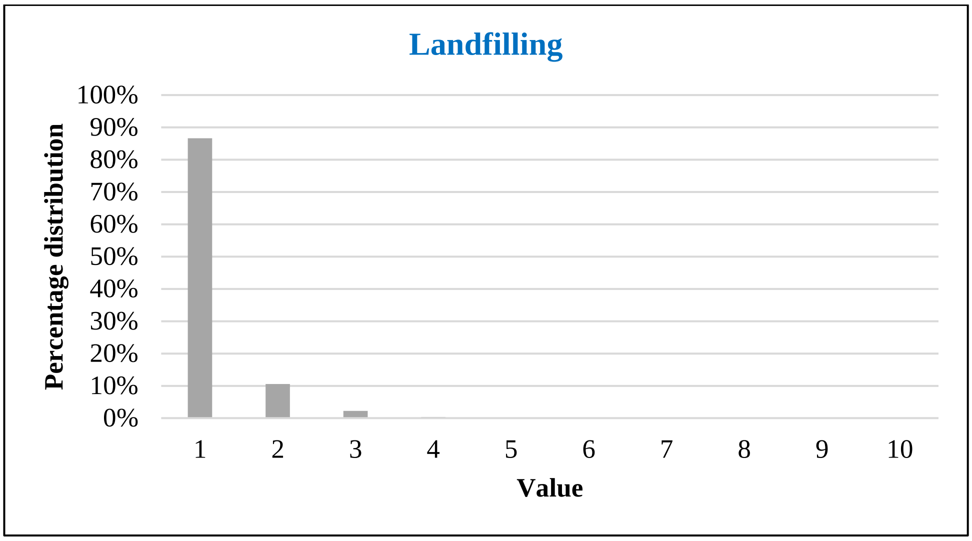

Figure 24. Percentage distribution of values assigned by twenty interviewees – landfilling

Experts have opted to propose concentrated values, in fact the analysis of results underlines as they have mainly assigned a certain value to each EoL strategy:

- 43% of the values referred to the reuse are assigned equal to 2, followed by the value 3 (31%).
- about the half of the values (52%) is attributed to the maximum value (equal to 10) when the mechanical recycling is considered and 39% of this EoL shows values equal to 9.
- regarding chemical recycling, about the half of the values (51%) is linked to the value 9, followed by the values 8 and 10, that have both a percentage of 24%.
- aerobic composting is the EoL strategy in which is lower the difference between first two values indicated by experts with 35% for the value 3 and 27% for the one 4.
- about three-fifths of the total (57%) is assigned to the value 2 when the anaerobic digestion is hypothesized, followed by the value 1 with 27%.
- also for the energy recovery the value 2 is the most chosen one by experts (45%), but it is followed by the value 3 (22%).
- considering landfilling, a consistent percentage equal to 87% of the values has assumed the minimum one, that is 1.

Comparing different EoL strategies, only both mechanical and chemical recycling present high values of judgement. However, the same value assigned to two or more several criteria determines a different final result in function of the weight attributed to criteria.

4.5 Calculating the socio-economic indicator for End-of-Life strategy

The final value of SEI-EoL for a specific EoL strategy is obtained following two steps. In the first, this new indicator is calculated according to both weights (section 4.3) and values (section 4.4) of the socio-economic criteria provided by an expert – equations (48)-(49). In the second, all data are aggregated, considering that experts have the same relevance equation (50).

$$\mathrm{SEI-EoL_{E,I,Y}} = \mathrm{RV_{E,I,Y}} * \mathrm{CV_{I,Y}} \tag{48}$$

$$\mathrm{SEI-EoL_{E,Y}} = \textstyle\sum_{I=1}^{M} \mathrm{SEI-EoL_{E,I,Y}} \tag{49}$$

$$\mathrm{SEI-EoL_{E}} = (\textstyle\sum_{Y=1}^{N} \mathrm{SEI-EoL_{E,Y}})/\mathrm{N} \tag{50}$$

in which E = EoL strategy, I = criteria, Y = experts, M = number of criteria, N = number of experts, $\text{SEI-EoL}_{E,I,Y}$ is the final indicator for a specific EoL strategy E according to the evaluation of the expert Y referred to the criteria I, $\text{SEI-EoL}_{E,Y}$ is the final indicator for a specific EoL strategy E according to the evaluation of the expert Y and SEI-EoL_{E} is the final indicator for a specific EoL strategy E according to the assessments of all experts.

For example, the judgement of expert no.1 is provided in Table 19 applying the equation (48). $\text{SEI-EoL}_{E,I,Y}$ is an unitary vector (dimension [1, 1]) obtained as the product between the row vector (dimension [1, 25]) and the colum vector (dimension [25, 1]). $\text{SEI-EoL}_{reuse,1,V4}$ is equal to 0.224 obtained multiplying 2 (see Table 20) with 0.112 (see Table 9). Having available all $\text{SEI-EoL}_{reuse,I,1}$, the following step is represented by the sum of these components in order to obtain $\text{SEI-EoL}_{reuse,1}$ and in the example proposed, it is equal to 2.308 (see equation (49)). The same steps are repeated also for other EoL strategies and in this way, the aggregation of judgements provided by the expert has defined a ranking of alternatives. The expert no.1 clearly indicates as only two options are suitable to reach a correct management of the product after its lifetime. In fact, both mechanical and chemical recycling have a value near to the maximum one and the difference than other EoL strategies is almost of 7. Considering that the value of the final indicator can range from 1 to 10, this difference is extremely significant.

Table 19. Values of SEI-EoL in function of the EoL strategy - example: data of expert 1

Ranking of criteria	Reuse	Mechanical recycling	Chemical recycling	Aerobic composting	Anaerobic digestion	Energy recovery	Landfilling
V4	0.224	1.12	1.12	0.336	0.336	0.336	0.112
V3	0.255	0.85	0.85	0.17	0.255	0.255	0.085
V2	0.136	0.68	0.68	0.204	0.204	0.204	0.068
G2	0.134	0.67	0.67	0.201	0.201	0.201	0.067
L5	0.171	0.57	0.57	0.171	0.171	0.171	0.057
G1	0.112	0.56	0.56	0.168	0.168	0.168	0.056
G3	0.104	0.52	0.52	0.156	0.104	0.104	0.052
V1	0.096	0.432	0.432	0.096	0.096	0.096	0.048
C1	0.094	0.47	0.47	0.141	0.094	0.094	0.094
V5	0.132	0.396	0.396	0.088	0.088	0.176	0.088
L2	0.08	0.4	0.4	0.08	0.08	0.08	0.08
G4	0.068	0.34	0.34	0.068	0.034	0.136	0.068
W5	0.062	0.31	0.31	0.093	0.031	0.093	0.062
C3	0.058	0.29	0.261	0.087	0.029	0.058	0.029
L1	0.056	0.28	0.28	0.084	0.028	0.084	0.028
C5	0.084	0.28	0.28	0.084	0.028	0.084	0.028
C4	0.05	0.225	0.225	0.075	0.025	0.05	0.025
L4	0.1	0.25	0.225	0.075	0.025	0.05	0.025
G5	0.048	0.24	0.24	0.072	0.024	0.048	0.024
L3	0.084	0.21	0.189	0.063	0.021	0.042	0.021
W2	0.042	0.21	0.189	0.063	0.021	0.042	0.021
C2	0.038	0.19	0.171	0.057	0.019	0.038	0.019
W1	0.034	0.17	0.153	0.051	0.051	0.034	0.017
W3	0.026	0.13	0.13	0.039	0.026	0.026	0.013
W4	0.02	0.1	0.1	0.03	0.02	0.02	0.01
Sum	2.308	9.893	9.761	2.752	2.179	2.69	1.197

The following step is represented by the aggregation of twenty responses – Table 20. For example, 18 of 20 interviewees have assigned a value of the SEI-EoL for the mechanical recycling greater than 9 and only two experts no. 6 and no.12 have proposed a value of 8.552 and 8.768, respectively. Concerning, chemical recycling about the half of experts has attributed a value between 8 and 9, while the other half of interviewees has chosen a value between 9 and 10.

Table 20. Values of SEI-EoL in function of the EoL strategy – aggregate results

No. expert	Reuse	Mechanical recycling	Chemical recycling	Aerobic composting	Anaerobic digestion	Energy recovery	Landfilling
1	2.308	9.893	9.761	2.752	2.179	2.69	1.197
2	2.41	9.41	9.009	2.896	2.669	2.604	1.001
3	2.254	9.211	8.858	2.878	2.579	1.825	1.256
4	3.567	9.444	8.743	4.079	2.789	2.625	1.544
5	1.67	9.42	8.718	4.733	1.391	4.785	1.001
6	3.949	8.552	8.273	5.411	2.08	2	1.154
7	4.004	9.307	8.849	4.003	2.002	3.694	1.001
8	2.411	9.565	8.455	3.469	1.286	2.429	1.001
9	2.889	9.621	9.34	3.896	2.102	3.203	1.001
10	2.813	9.623	8.711	4.516	1.698	4.006	1.001
11	3.039	9.246	8.486	4.511	1.589	3.237	1.08
12	2.413	8.768	8.453	2.861	2.076	1.494	1.14
13	2.002	9.814	9.378	3.328	1.546	2.195	1.001
14	2.346	9.878	8.824	3.336	1.483	2.408	1.132
15	3.748	9.6	8.531	3.249	1.962	2.284	1.113
16	2.505	9.858	9.602	4.252	1.372	2.614	2.311
17	1.193	9.979	9.861	1.526	1.11	1.561	1.066
18	2.28	9.932	9.479	3.115	2.48	2.597	1.396
19	2.716	9.756	9.542	4.17	1.89	2.37	1.448
20	2.359	9.657	9.458	2.125	1.442	1.413	1.001

The analysis of results underline as all experts have agree with the consideration that mechanical recycling occupies the first position followed always by chemical recycling. In addition, landfilling is defined as the worst solution by nineteen of twenty experts. The last step is represented by the average value calculated by twenty experts – see equation (50). Figure 25 shows 7 potential EoL strategies applied to the product PLA-based packaging film.

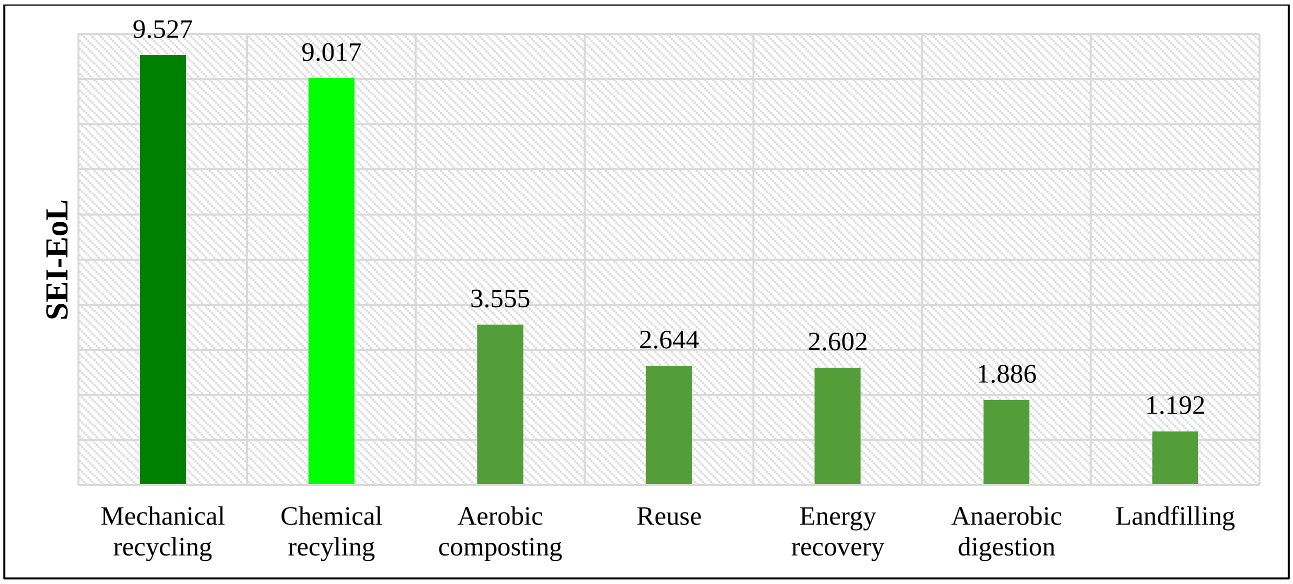

Figure 25. Ranking of EoL strategy for PLA-based packaging film

Some observations can be obtained by the analysis of these results. The first concerns the definition of the best EoL option. It is represented by mechanical recycling with a value of 9.527, which is extremely near to the maximum one (equal to 10). The experts do not only have chosen this EoL strategy as the first of the ranking but they have attributed a high value. Consequently, it is able to reach the sustainable goal. Results show a low difference among two typologies of recycling and a value of 9.017 is attributed to the chemical recycling. Instead, there is a great difference with the other five options, in which the value varies from 3.555 for aerobic composting to 1.192 for landfilling.

The second regards that this value is calculated for PLA-based packaging film and can be useful to compare it with other products evaluating what is the bio-based product more sustainable considering socio-economic criteria during EoL phase.

The third concerns the main issue of this indicator, in which environmental aspects are not directly analysed. However, the analysis has demonstrated as experts are guided also by these considerations. In fact, mechanical and chemical recycling are two solutions defined suitable for the protection of the ecosystems and at the same time, landfill use occupies the last position. The ranking proposed by experts has demonstrated that also technological considerations are been evaluated. Reuse is certainly a better option than recycling considering the environmental perspective, but PLA-based packaging film is not adaptable to this practice in the real context.

The fourth concerns that this methodology has both quantitative and qualitative nature and AHP is able to capture this double perspective. Currently, the EoL of bio-based products is poor of data, as demonstrated by literature analysis, but when the number of data will be consistent this methodology could be improved through values assigning not more by experts but directly from real observations. For example, waste disposal cost has been identified as the first criteria to analyse and this variable has certainly values different for the several EoL options. Several criteria have different unit of measure, but through the normalization process all data will be homogeneous.

The fifth concerns the variability of results in function of experts' background. At the same time, this work has demonstrated as the assessment tend to be uniform and AHP is able to resolve this initial dilemma.

5 Discussions

5.1 General aspects

The waste hierarchy promotes prevention as the best EoL option, while landfilling occupies the lowest place on the hierarchy. Despite the increasing number of policy strategies at country level (Andersson & Stage, 2018; Han & Go, 2019), the wide-ranging scope and intricacy of the waste management issues leave much room for alternative EoL routes to be investigated at different geographical scales and sectorial contexts. As a matter of fact, there is a general need for a deeper consideration of downstream actions to close material loops in order to supplement the rooted upstream measures for waste management (such as eco-design, business models, consumer behaviours and related initiatives) (Petrescu-Mag, Petrescu, & Robinson, 2019). When it comes to bio-based products, it should be noted that we are faced with several innovative materials and products at different stages of technical maturity and commercial development. This poses several challenges related to the EoL options of these products.

Bio-based products offer several EoL alternatives compared to their conventional counterparts, but can also enter traditional disposal routes, such as landfilling. Depending on the product's use, not all EoL options make sense from an environmental perspective (InnProBio, 2018). The methodology proposed in this Deliverable allows comparing the EoL strategies presented in Section 2 with regard the bio-based products.

The aim is the implementation, by means of a participatory involvement of stakeholders and experts, of the basic principles of sustainability, namely, minimization of waste, efficient and sustainable use of resources in the identification of the most suitable EoL strategies. Specifically, the first information provided is a ranking of the EoL alternatives which allows for the selection of strategies that optimize the considered socio-economic criteria. In order to test the model, we considered a specific bio-based product (i.e. PLA-based packaging film) that is suitable to be treated through the alternative EoL options.

A relevant aspect emerging from the analysis concerns the relative low relevance assumed by the reuse option of the considered product. Although reusing (bio-based) materials/products is the most effective way to reduce the environmental impacts, as we expected, this option is quite difficult to be undertaken for the PLA-based packaging film. When no longer useable, it can follow the EoL routes of the waste management hierarchy described in the previous section. Specifically, the case study examined demonstrates that there is a clear preference of the experts towards recycling (both mechanical and chemical) as a solution that is respectful of the environmental perspective.

As recognized by the experts, the intrinsic properties of bio-based materials should allow for a more environmentally friendly design of the bio-based packaging with emphasis placed on recyclability. This should be improved without compromising the functionality of the product, or even refining its functionality (Mistriotis, Briassoulis, Giannoulis, & D'Aquino, 2016). Moreover, packaging information like labels should be restyled for bio-based products to be compatible with the recyclability requirements but also compostability requirements of the final product (Briassoulis et al., 2019).

Besides recycling options another, although less relevant, EoL strategy for PLA-based packaging film is aerobic composting. The main condition for the bio-based materials and products to be acceptable for industrial composting is that they can provide proof of their compostability by successfully meeting biodegradability and/or compostability standards, such as the harmonised European standard, EN 13432 (Packaging: requirements for packaging recoverable through composting and biodegradation) or EN 14995 (Plastics - Evaluation of compostability - Test scheme and specifications). These standards define the technical specifications for the compostability of bioplastics products. Finally, landfilling represents the worst EoL option for the considered bio-based product since it will undergo anaerobic digestion, producing methane, a greenhouse gas with a detrimental effect on the environment.

5.2 Relevant aspects to consider for the development of tailored EoL options

Based on the results presented in the previous sections and discussed above, several recommendations can be made for assessing and further developing efforts on towards EoL alternatives pertaining to bio-based products.

i) *Methodological features*

Starting from the idea that the most appropriate EoL option for a bio-based product is often specific to this single product, our methodology allows for the development of a ranking of alternatives. This ranking, starting from expert's knowledge and perspectives, could help identify the most appropriate options so as to reflect the basic principles of the circular economy: waste management, waste prevention and resource efficiency.

ii) Data collecting

Creating a database reporting the quantitative impacts of different EoL options with reference to relevant bio-based products (e.g. bioplastics, detergents, etc.) in order to have reference information useful for the assessment of the values of socio-economic criteria. In this way, the SEI-EoL is obtained considering both real data as well as expert knowledge.

iii) *Selection of EoL options*

Considering the socio-economic criteria encompassing all categories of potentially affected stakeholders (i.e. workers, consumers, society, value chain actors, local community), experts strongly consider the mechanical and chemical recycling options to be the most desirable for the studied bio-based product (i.e. PLA-based packaging film). The identification of the most adequate EoL requires efforts from both value chain actors (i.e., producers, processers, recyclers, etc.) and general society (e.g. policy makers), which represent the categories with the strongest influence on the selection of the optimal EoL option for the considered product.

iv) Bio-based products comparison

Supplementing the analysis by means of a cross comparison among different bio-based products could add details about the most sustainable EoL route among the available alternatives. This could help providing a list of best practices for the considered products. As a matter of fact, each SEI-EoL is associated to a specific product, and among the SEI-EoLs, we can easily identify those with higher values.

v) Three side of EoL responsibility

Having clear information provided to stakeholders on how bio-based product waste can be treated might help to attain a greater bio-based product sustainability. In this perspective, it is important to communicate the recommended EoL option to the end-consumer and waste processor so as to mandate them to internalize EoL costs. Specifically, consumers are required to increase their attitude towards consumption and recycling of resources (see consumer responsibility). Similarly, producers should consider: i) the product EoL alternatives and provide original design to moderate their impacts and ii) the product recovery and treatment at the end of the life cycle, (see extended producer responsibility). Finally, policy makers should carefully account for long-term actions developed to allow a sustainable future for future generations (see policy responsibility).

vi) Consumers commitment

Besides boosting the separate waste collection and increasing the attitude to buy bio-based products that include also a sustainable EoL management.

vii) Industry commitment

Besides increasing the attitude to implement a circular approach by using/buying/selling a larger amount of reused/recycled/recovered resources (resource efficiency), the economic feasibility of the industrial processes should be achieved.

viii) Policy strategies

Besides awareness campaigns on the impacts of unsustainable EoL and waste management related policies, policy makers should give priority to waste disposal cost. Indeed, based upon the polluter pay principle, increasing the price of CO_2eq within all sectors should be implemented. At the same time the development of profitable markets for recycled bio-based raw materials should be encouraged.

ix) Stakeholders cooperation

The management of products is extremely complex given that the matching between demand and supply is based on market dynamics (e.g. innovation, preferences, duties, etc.). Supporting scientific and technological collaborations among different stakeholders (e.g. university, firms, policy makers, etc) such as those directed at favouring R&D activities among different value-chain actors would improve the bio-based product sustainability including EoL management.

6 Conclusions

Transitioning towards more sustainable systems of production and consumption requires consideration of the prevention of pollution, the conservation of resources and the development of sustainable products. The production of innovative bio-based products, i.e. products wholly or partly derived from materials of biological origin deriving from innovative production processes and/or innovative biomass such as food waste or forest residuals, is part of this process. However, while the European Commission since the launch of the Bioeconomy Strategy is strongly supporting the production of renewable biological resources and their conversion into value added products and bio-energy, there are also issues regarding the sustainability of bio-based products along the whole life cycle, from feedstock provision to end-of-life (InnProBio, 2018). Knowing the possible end-of-life strategies applicable to bio-based products is paramount since, in several European countries, separate waste collection is mandatory or advocated. In this context, designing products in a smarter way, extending their useful lives, and providing complete and clear information for consumers regarding the most sustainable EoL options represent necessary changes for going well beyond the traditional waste disposal.

Against this background, this work has elaborated a new methodology useful to define a ranking of socio-economic criteria used during EoL management through a new indicator, called SEI-EoL. The analysis highlights that, according to a wide range of experts covering different areas of expertise related to products EoL, the most important criteria to be assessed are waste disposal cost, resource efficiency and EoL responsibility. Within the specific case studies of Star-ProBio, our analysis focused on PLA-based packaging film. Results show that mechanical and chemical recycling represent the best EoL options.

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Zeller, V., Towa, E., Degrez, M., & Achten, W. M. J. (2019). Urban waste flows and their potential for a circular economy model at city-region level. *Waste Management*.

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Ziout, A., Azab, A., & Atwan, M. (2014). A holistic approach for decision on selection of end-of-life products recovery options. *Journal of Cleaner Production*.

Annex 1. Data collecting for the weights assignment

1. The final aim of this analysis is to define a priority level among five categories (workers, consumers, general society, local community, value chain actors) ad five indicators selected for each category through a pairwise comparison. The core of the analysis is their impact on the end of life strategy.

2. Both categories and indicators are selected according to the literature. The full list is reported in the file word attached.

3. Categories and Indicators are evaluated according to their relative importance on a nine-level scale as reported in file Numerical Rating (NR).

4. The analysis requires two steps: in the first, categories are compared (see file categories), while in the second, five indicators that characterize each category are compared (see file workers (named W), consumers (C), general society (G), local community (L), value chain actors (V).

5 For example, see file W. If skills (W4) are "strongly preferred" than working conditions (W3), you indicate the value 5 in the "yellow" cell E8. If instead, working conditions are "strongly preferred" than skills, you report the value 0,20 (or = 1/5) in the same cell E8. The same is repeated only for other nine cells underlined in "yellow".

6 The judgements are trustworthy if the consistency ratio (CR) is lower than 0.10. CR is reported in "green cell" E21. Check this value.

7 Repeat points 5. and 6. for all six files CATEGORIES, W, C, G, L, V

Instructions | NR | CATEGORIES | W | C | G | L | V

Figure A1. Instructions – first questionnaire

Numerical rating	Verbal judgements of preferences
1	Equally preferred
2	Equally to moderately
3	Moderately preferred
4	Moderately to strongly
5	Strongly preferred
6	Strongly to very strongly
7	Very strongly preferred
8	Very strongly to extremely
9	Extremely preferred

Instructions | NR | CATEGORIES | W | C | G | L | V

Figure A2. File numerical rating

	A	B	C	D	E	F	G	H	I
1									
2		**Categories**							
3									
4			**WORKERS**	**CONSUMERS**	**GENERAL SOCIETY**	**LOCAL COMMUNITY**	**VALUE CHAIN ACTORS**		
5		**WORKERS**	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
6		**CONSUMERS**		1	#DIV/0!	#DIV/0!	#DIV/0!		
7		**GENERAL SOCIETY**			1	#DIV/0!	#DIV/0!		
8		**LOCAL COMMUNITY**				1	#DIV/0!		
9		**VALUE CHAIN ACTORS**					1		
10		Total	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
11									
12			**WORKERS**	**CONSUMERS**	**GENERAL SOCIETY**	**LOCAL COMMUNITY**	**VALUE CHAIN ACTORS**	Total	Average
13		**WORKERS**	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
14		**CONSUMERS**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
15		**GENERAL SOCIETY**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
16		**LOCAL COMMUNITY**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
17		**VALUE CHAIN ACTORS**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
18		Total	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19									
20			λmax	CI	CR				
21			#DIV/0!	#DIV/0!	#DIV/0!				
22									
23									

Instructions | NR | **CATEGORIES** | W | C | G | L | V

Figure A3. File categories

	A	B	C	D	E	F	G	H	I
1									
2		**Workers**							
3									
4			**W1**	**W2**	**W3**	**W4**	**W5**		
5		**W1**	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
6		**W2**		1	#DIV/0!	#DIV/0!	#DIV/0!		
7		**W3**			1	#DIV/0!	#DIV/0!		
8		**W4**				1	#DIV/0!		
9		**W5**					1		
10		Total	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
11									
12			**W1**	**W2**	**W3**	**W4**	**W5**	Total	Average
13		**W1**	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
14		**W2**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
15		**W3**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
16		**W4**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
17		**W5**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
18		Total	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19									
20			λmax	CI	CR				
21			#DIV/0!	#DIV/0!	#DIV/0!				
22									
23									

Instructions | NR | CATEGORIES | **W** | C | G | L | V

Figure A4. File workers

	A	B	C	D	E	F	G	H	I
1									
2		**Consumers**							
3									
4			**C1**	**C2**	**C3**	**C4**	**C5**		
5		**C1**	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
6		**C2**		1	#DIV/0!	#DIV/0!	#DIV/0!		
7		**C3**			1	#DIV/0!	#DIV/0!		
8		**C4**				1	#DIV/0!		
9		**C5**					1		
10		Total	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
11									
12			**C1**	**C2**	**C3**	**C4**	**C5**	Total	Average
13		**C1**	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
14		**C2**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
15		**C3**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
16		**C4**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
17		**C5**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
18		Total	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19									
20			λmax	CI	CR				
21			#DIV/0!	#DIV/0!	#DIV/0!				
22									
23									

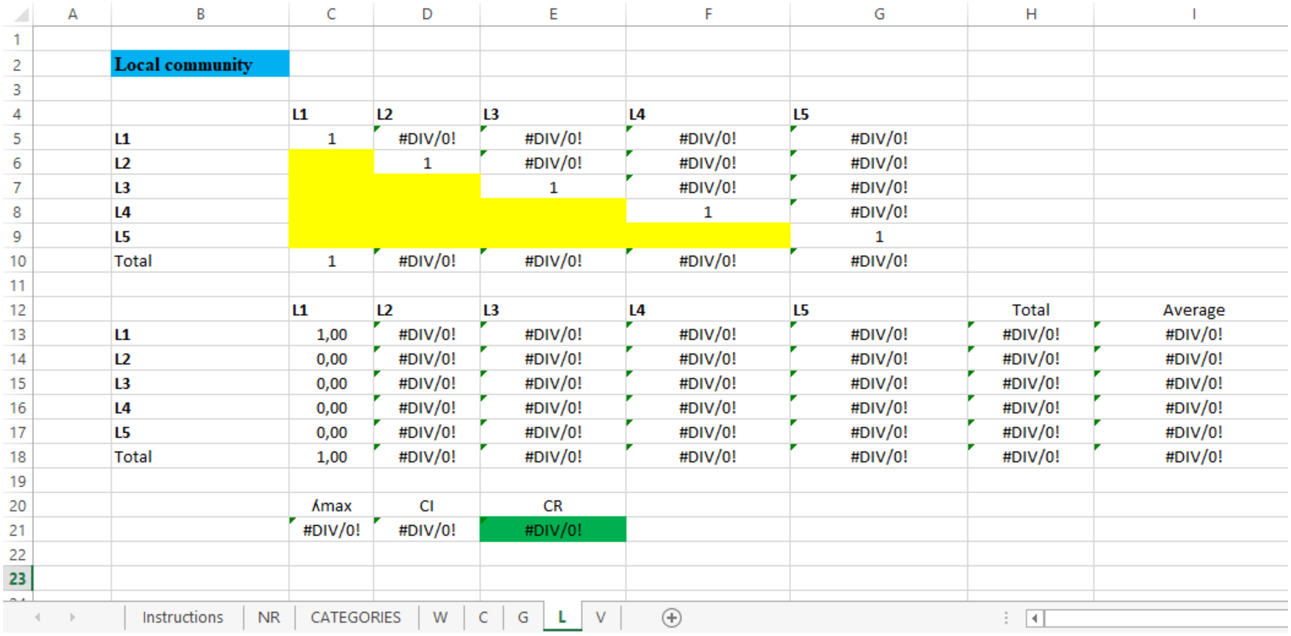
Instructions | NR | CATEGORIES | W | C | G | L | V

Figure A5. File consumers

	A	B	C	D	E	F	G	H	I
1									
2		**General Society**							
3									
4			**G1**	**G2**	**G3**	**G4**	**G5**		
5		**G1**	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
6		**G2**		1	#DIV/0!	#DIV/0!	#DIV/0!		
7		**G3**			1	#DIV/0!	#DIV/0!		
8		**G4**				1	#DIV/0!		
9		**G5**					1		
10		Total	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
11									
12			**G1**	**G2**	**G3**	**G4**	**G5**	Total	Average
13		**G1**	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
14		**G2**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
15		**G3**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
16		**G4**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
17		**G5**	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
18		Total	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19									
20			λmax	CI	CR				
21			#DIV/0!	#DIV/0!	#DIV/0!				
22									
23									

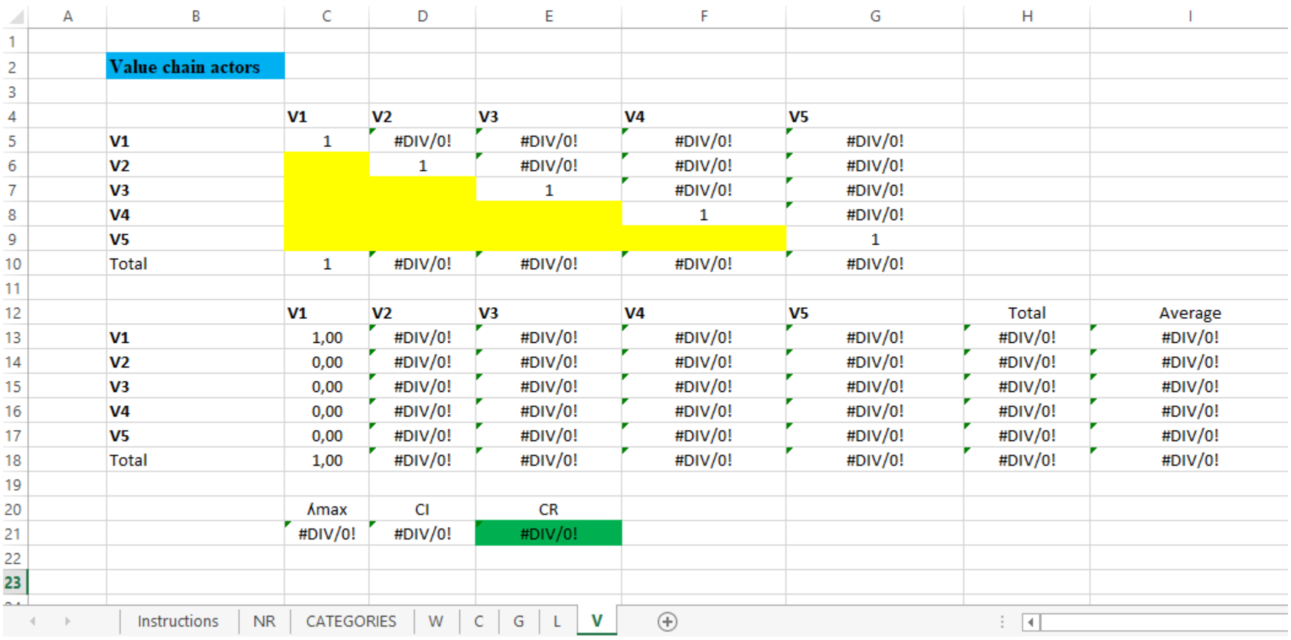
Instructions | NR | CATEGORIES | W | C | G | L | V

Figure A6. File general society



	A	B	C	D	E	F	G	H	I
1									
2		**Local community**							
3									
4			L1	L2	L3	L4	L5		
5		L1	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
6		L2		1	#DIV/0!	#DIV/0!	#DIV/0!		
7		L3			1	#DIV/0!	#DIV/0!		
8		L4				1	#DIV/0!		
9		L5					1		
10		Total	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
11									
12			L1	L2	L3	L4	L5	Total	Average
13		L1	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
14		L2	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
15		L3	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
16		L4	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
17		L5	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
18		Total	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19									
20			λmax	CI	CR				
21			#DIV/0!	#DIV/0!	#DIV/0!				
22									
23									

Figure A7. File local community



	A	B	C	D	E	F	G	H	I
1									
2		**Value chain actors**							
3									
4			V1	V2	V3	V4	V5		
5		V1	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
6		V2		1	#DIV/0!	#DIV/0!	#DIV/0!		
7		V3			1	#DIV/0!	#DIV/0!		
8		V4				1	#DIV/0!		
9		V5					1		
10		Total	1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
11									
12			V1	V2	V3	V4	V5	Total	Average
13		V1	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
14		V2	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
15		V3	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
16		V4	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
17		V5	0,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
18		Total	1,00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
19									
20			λmax	CI	CR				
21			#DIV/0!	#DIV/0!	#DIV/0!				
22									
23									

Figure A8. File value chain actors

Annex 2. Data collecting for the values assignment

1.	The final aim of this analysis is to define the best choice among several End of Life strategies.
2.	This analysis is linked to the AHP proposed during the first step of your contribution.
3.	File Priority Level Weights (PLW) shows the results of the AHP (average values obtained by twenty experts, in which all have the same relevance). Initially, it is calculated a local priority based on the relevance of indicators for each category. Additionally, also a priority among several categories was required. In this way a global priority is obtained as product between local priority and category group. In this way, it is calculated a ranking for all twenty five indicators (some are twofold (or threefold) but all are referred to a specific category).
4.	The list of potential End of Life strategies are the following: i) Reuse; ii) Mechanical recycling; iii) Chemical recycling; iv) Aerobic composting; v) Anaerobic digestion; vi) Energy recovery and vii) Landfilling - see file EoL(general).
5	MCDA is obtained as a product between the weight of indicators and their value. For this goal, the expert can assign a value from 1 to 10 to EoL strategies for each indicator. 1 is the worst evaluation. 10 is the best evaluation.
6	A specific product is proposed as a case study - see file Product.
7	The expert proposes a value from 1 to 10 according to point 5 analysing the specific case study. For example the value of "waste disposal cost (V4)" is 6 for the option Anaerobic digestion (the value of 6 is inserted in the cell I3), while is 2 for the option Landfilling (2 is inserted in the cell K3). Please complete all yellow cells considering the product "food packaging film" .

Instructions | PLW | EoL(general) | Product | EoL(product)

Figure A9. Instructions – second questionnaire

	Local Priority	Rkg		Local Priority	Rkg		Local Priority	Rkg		Local Priority	Rkg		Local Priority	Rkg
Workers (W) [Priority: 0.09]			Consumers (C) [Priority: 0.15]			General society (G) [Priority: 0.23]			Local community (L) [Priority: 0.17]			Value chain actors (V) [Priority: 0.36]		
W1	0.19	3.	C1	0.32	1.	G1	0.24	2.	L1	0.16	3.	V1	0.13	4.
W2	0.23	2.	C2	0.13	5.	G2	0.29	1.	L2	0.23	2.	V2	0.19	3.
W3	0.14	4.	C3	0.20	2.	G3	0.22	3.	L3	0.12	5.	V3	0.24	2.
W4	0.11	5.	C4	0.17	4.	G4	0.14	4.	L4	0.15	4.	V4	0.31	1.
W5	0.33	1.	C5	0.19	3.	G5	0.10	5.	L5	0.34	1.	V5	0.12	5.
∑W	1.0		∑C	1.0		∑G	1.0		∑L	1.0		∑V	1.0	
	Global Priority	Rkg		Global Priority	Rkg		Global Priority	Rkg		Global Priority	Rkg		Global Priority	Rkg
W1	0.017	23.	C1	0.047	9.	G1	0.056	6.	L1	0.028	15.	V1	0.048	8.
W2	0.021	21.	C2	0.019	22.	G2	0.067	4.	L2	0.040	11.	V2	0.068	3.
W3	0.013	24.	C3	0.029	14.	G3	0.052	7.	L3	0.021	20.	V3	0.085	2.
W4	0.010	25.	C4	0.025	17.	G4	0.034	12.	L4	0.025	18.	V4	0.112	1.
W5	0.031	13.	C5	0.028	16.	G5	0.024	19.	L5	0.057	5.	V5	0.044	10.
∑W	0.09		∑C	0.15		∑G	0.23		∑L	0.17		∑V	0.36	

Instructions | PLW | EoL(general) | Product | EoL(product)

Figure A10. File priority level weights

			Reuse	Mechanical recycling	Chemical recyling	Aerobic composting	Anaerobic digestion	Energy recovery	Landfilling
Indicator		Global priority	EoL 1	EoL 2	EoL 3	EoL 4	EoL 5	EoL 6	EoL 7
V4	Waste disposal cost	0.112							
V3	Resource efficiency	0.085							
V2	End-of-life Responsibility	0.068							
G2	Green Public Procureme	0.067							
L5	Access to material resou	0.057							
G1	Public governance	0.056							
G3	End-of-life Responsibility	0.052							
V1	New value chain	0.048							
C1	End-of-life Responsibility	0.047							
V5	Illnesses and accidents	0.044							
L2	Economic development	0.040							
G4	Resource efficiency	0.034							
W5	Equal opportunities	0.031							
C3	Human health	0.029							
L1	Local employment	0.028							
C5	Feedback mechanism	0.028							
C4	Transparency	0.025							
L4	Human health	0.025							
G5	Social investment	0.024							
L3	Human toxicity	0.021							
W2	Human health	0.021							
C2	Human toxicity	0.019							
W1	Human toxicity	0.017							
W3	Working conditions	0.013							
W4	Skills	0.010							

Instructions | PLW | **EoL(general)** | Product | EoL(product)

Figure A11. File End of Life (general model)

<u>Product:</u> **Food packaging film**

<u>Target:</u> replacement of oil-based plastics, glass or metal packaging.

<u>Feedstocks:</u> Lactic acid production from corn

<u>Production processes:</u> From lactic acid produced by fermentation.

Instructions | PLW | EoL(general) | **Product** | EoL(product)

Figure A12. File product

			Reuse	recycling	recyling	Aerobic composting	Anaerobic digestion	Energy recovery	Landfilling
Indicator		Global priority	EoL 1	EoL 2	EoL 3	EoL 4	EoL 5	EoL 6	EoL 7
V4	Waste disposal cost	0.112							
V3	Resource efficiency	0.085							
V2	End-of-life Responsibility	0.068							
G2	Green Public Procureme	0.067							
L5	Access to material resou	0.057							
G1	Public governance	0.056							
G3	End-of-life Responsibility	0.052							
V1	New value chain	0.048							
C1	End-of-life Responsibility	0.047							
V5	Illnesses and accidents	0.044							
L2	Economic development	0.040							
G4	Resource efficiency	0.034							
W5	Equal opportunities	0.031							
C3	Human health	0.029							
L1	Local employment	0.028							
C5	Feedback mechanism	0.028							
C4	Transparency	0.025							
L4	Human health	0.025							
G5	Social investment	0.024							
L3	Human toxicity	0.021							
W2	Human health	0.021							
C2	Human toxicity	0.019							
W1	Human toxicity	0.017							
W3	Working conditions	0.013							
W4	Skills	0.010							

Instructions | PLW | EoL(general) | Product | **EoL(product)**

Figure A13. File End of Life (specific product)