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ARTICLE

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Enhancing the cosmetics industry sustainability through a renewed sustainable supplier selection model

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ABSTRACT

The cosmetics industry requires a long-term sustainable strategy to balance its continuously growing trend worldwide and its resources consumption. In this view, the suppliers' selection process is gaining more attention affecting products' overall sustainability. The objective of this contribution is hence to develop and validate the Cosmetics Sustainable Supplier Selection (C-SSS) model allowing the selection of sustainable suppliers for the cosmetic industry, evaluating them in an objective and balanced manner. The model was built relying on both scientific and grey literature, by incorporating the characteristics of existing SSS models usually used separately. The C-SSS enabled to integrate the EMM approach (to reduce the subjectivity), the ANP approach (to evaluate criteria interconnections), and the TOPSIS and ELECTRE models (to create a hybrid compensation model) to support managers in objectively selecting the most sustainable suppliers. The C-SSS model was applied and validated through an industrial use case in a cosmetics Italian company.

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Sustainability; cosmetics industry; sustainable supplier selection; vendor rating; sustainable supply chain

1. Introduction

Nowadays, the sustainability paradigm, which is based on the environmental, social, and economic pillars (i.e. the Triple Bottom Line (TBL)) (Elkington, 2013), is spreading all over the society, becoming a strategic element in governments and companies' plans due to the unprecedent uncontrolled resources usage (United Nations, 2015). In particular, the manufacturing sector is moving towards circular-oriented strategies influencing product design, production, distribution, and consumption (Acerbi, Taisch, 2020; Bjørnbet et al., 2021). Among all, due to its ever-growing size and massive consumption of natural resources, the cosmetics industry is required to update its current operations to face new sustainable requirements and norms (Pereira de Carvalho & Barbieri, 2012; Rocca et al., 2022). For instance, fair-trade labels and sustainability indexes, such as those referred to Corporate Social Responsibility, are introduced to strengthen the relationships with several stakeholders, among which final users, with the goal to clarify the sustainable-oriented characteristics of a certain product (Bom et al., 2019) and facilitate the stakeholders' engagement in the embracement of sustainability pillars (Gong et al.,

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2019). Indeed, the cooperation with industrial entities, external to the company, and also with final consumers are fundamental to undertake a sustainable and circular-oriented path (Santa-Maria et al., 2021) independently from the industry in which the company operates. The growing attention to sustainability pillars (i.e. TBL) in the cosmetics industry (Ambak et al., 2019; Amberg & Fogarassy, 2019) is hence becoming fundamental. Cosmetic products are increasingly spreading in our daily life activities, and consumers are becoming keener on purchasing green products, as environmental and ethical considerations are increasingly relevant factors in their purchase behaviour (Appolloni et al., 2022). According to Bom et al. (2019), 'cosmetics sustainability' can be defined *'as a complex and multi-faceted issue that cannot be evaluated considering single aspects, but using an integrated assessment about the environmental, social and economic dimensions and about the final product quality and performance'*. The increasing importance of the cosmetics industry is visible from an economic perspective too; its value has been estimated at €76.7 billion at retail sales price in 2020 in Europe ('Cosmetics Europe – The Personal Care Association: Cosmetics Industry,' 2021). Also, for the job market, the cosmetics industry represents for Europe a great player, accounting, in 2019, over 2 million jobs, out of which 167,730 were employed for the manufacturing of products ('Socio-Economic Contribution of the European Cosmetics Industry', 2019). The growing trend of this industry in the global market is evident having a steady increment in the last five years with a pick of the 5,5% in 2018 (*Cosmetic industry growth | Statista*, 2020). Therefore, considering, on one hand, the increasing growth of the cosmetics industry and, on the other hand, the necessity to start undertaking a path towards more sustainable systems, it is required by cosmetics manufacturing companies to engage in value chains with sustainable-oriented stakeholders (Bom et al., 2020; Fonseca-Santos et al., 2015) and within this context to keep under control and assess the performances of the stakeholders across the entire value chain (Brown & Bajada, 2018). Therefore, starting from the design phase of products, which is responsible for most of the impacts of the subsequent product life cycle stages (Sassanelli et al., 2020), it is fundamental to choose accurately all the product characteristics among which the materials and thus the related suppliers (Acerbi, Taisch, 2020; Acerbi, Taisch, et al., 2020). Actually, in the extant literature emerged that the two key challenges for sustainability initiatives in value chain flexibility are the lack of suppliers' commitment to sustainable products and the lack of sustainable knowledge along the value chain (Dwivedi et al., 2021). Considering that suppliers might influence the sustainability performances of products and of the entire supply chain (Song et al., 2017) their involvement in the sustainability pathway of producers becomes essential. The scientific literature reports some models to properly select sustainable suppliers such as the one by (van Thanh & Lan, 2022) that is focused on the food industry or the one by (Wang et al., 2022) focused on the resiliency of the supply chain to ensure the supply of critical resources. However, there are still some open points not yet covered by them. For instance, it is still lacking a clear definition of criteria to evaluate suppliers specifically for the context of cosmetics companies under the sustainability umbrella; (Atthirawong, 2020) proposed a preliminary study on cosmetics and then, the research by (Tong et al., 2019) can be considered closed to cosmetics being it focused on chemical industry but there is not a comprehensive sustainable-oriented model focused on cosmetics. Moreover, existing Sustainable Supplier Selection (SSS) models usually cover the TBL pillars in an unbalanced manner (e.g. (Hashemi et al., 2015b), which is focused mainly on economic and environmental aspects). In addition, they may not take into account potential subjective judgements (e.g. (Liu et al., 2019)) or interdependences among criteria (e.g. (Amindoust, 2018)) or the possibility to have more than one decision-maker (e.g. (Hendiani et al., 2020)). There is the need to develop a unique comprehensive model to cover the emerged literature gap and concretely support cosmetics companies in selecting the best sustainable suppliers in accordance with their strategic needs. For this reason, the research objective (RO) of this contribution is to overcome this open gap and develop a novel model allowing the selection of suppliers for cosmetic companies, evaluating them in a balanced and objective manner according to a set of criteria suggesting their sustainability-oriented performances. In doing that, the integration of already existing supplier selection models, which often employ a silos approach, covering the key above mentioned relevant characteristics and weaknesses have been conducted to finally have a complete model tailored on the cosmetics industry. An initial proposal, but neither comprehensive nor focused on cosmetics, was made by (Yu et al., 2019) that included in a single model the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and the Elimination and Choice Translating Reality (ELECTRE) methods, although it assumed that the criteria are independent among each other. Further details will be given in the literature review and model development sections.

The remainder of this contribution is structured as follows. Section 2 reports the research methodology employed to address the RO. Section 3 elucidates the key criteria to be included for the SSS process tailored on cosmetics companies and it also analyses the already existing SSS models. Section 4 describes the novel model (i.e. Cosmetic Sustainable Supplier Selection model (C-SSS model)) developed after a comparison and selection of the already existing ones identified in the extant literature. Section 5 validates the model based on its application in an industrial case. Section 6 discusses the results highlighting the key practical and theoretical implications. Last, Section 7 concludes the contribution by also highlighting the key limitations opening towards future research opportunities.

2. Research Methodology

To address the RO, thus developing a comprehensive model for the SSS for cosmetics companies, it has been firstly conducted a review of the extant literature. This review was performed to ensure that we keep into account all the key sustainable-oriented criteria, thus covering the entire TBL, relevant for cosmetics companies and to analyze the already developed SSS models also in terms of structure. Then, the developed model has been applied and validated in a real industrial case. More in detail, the research process followed in this contribution is depicted in Figure 1 and explained below.

(1) A literature review was conducted to analyze especially the SSS models already available in the extant literature to identify the needed criteria and the characteristics of the existing SSS models. This review has been performed mainly on Scopus database, based on the following string: TITLE-ABS-KEY ((‘sustainabl*’ OR ‘circular’ OR ‘green’) AND ((‘supplier*’ OR ‘vendor*’) AND (‘selection model*’ OR ‘choice model*’))) AND (LIMIT-TO (LANGUAGE, ‘English’)).

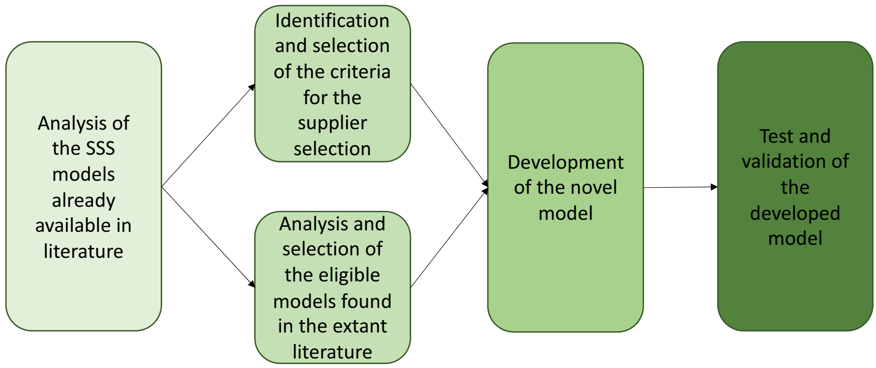


Figure 1. Research process.

This string generated an outcome of 75 contributions, out of which 42 have been considered eligible to be reviewed being them focused on the manufacturing sector, on sustainability-related issues, on supplier selection models and not only on supply chain management. Actually, few contributions were focused specifically on cosmetics and only some of them concerned the chemical, pharmaceutical and food industries (e.g. (van Thanh & Lan, 2022)) which might have some characteristics adherent to the cosmetics one. Therefore, to ensure to grasp all the needed criteria, other documents also coming from grey literature have been reviewed (e.g. the International Organization for Standardization (ISO) standards). Moreover, through a snowball process and suggestions from experts, 40 contributions were added to the systematic literature review results. Out of these 40 contributions, 25 contributions were included in the review to extend the analysis about the cosmetic-related criteria to be assessed during the SSS process. The other 15 contributions were added to enlarge the analysis over the already existing SSS models to ensure the evaluation of all the possible models' characteristics. This initial stage enabled to achieve the following tasks.

(1) Identification and selection of the criteria to be included in the C-SSS model. This step of the methodology relied on the analysis of contributions and documents available in different databases, thus not only Scopus. To ensure to consider all the criteria required in the SSS process for cosmetics companies (i.e. including norms, regulations, and standards), the analysis of the criteria already used in previous SSS models has been merged with the ISO standards developed for the industry, which were analysed through the Sustainable Development Goals (SDGs) lenses.
(2) Analysis of the eligible models available in the extant literature and selection of those coherent with the RO. A deep analysis of the already existing SSS models available in the extant literature has been performed. This enabled to evaluate their key strengths, to be included in the novel model, and their key weaknesses, to be overcome through the novel model, leading to the integration of different SSS models into a comprehensive one.

(2) Development of the novel C-SSS model. Based on the literature review findings, especially on those contributions tailored on the cosmetics industry (e.g.

(Atthirawong, 2020)), a C-SSS model has been developed. As previously anticipated, the model has been conceptualized grounding on the literature findings, both scientific and grey literature, and it has been concretely built to be applied to an industrial use case. The concrete realization of the model was possible thanks to the integration of an excel file and an open-source software, '*SuperDecisions*' (SuperDecisions, 2022). These two technical tools are simple to be used and affordable for any type of company while ensuring to cover all the steps required in selecting the proper supplier by a cosmetics manufacturer (all the steps are detailed in the model application section).

(3) Application and validation of the model. As previously anticipated, the model has been applied and validated in a Small and Medium Enterprise operating in the cosmetics industry localized in the north of Italy.

More specifically, the flow chart for the model conceptualization, development, and application is summarized in Figure 2 which shows the steps employed starting from the literature findings. Additional details for the selection of the approaches are reported in sections 3 and 4, summarized in Figure 6 and reported in sub-section 4.1.

3. Literature review

The increased need for sustainable-related accountability by cosmetics companies to address the requests coming from clients, public opinion, and governments with new

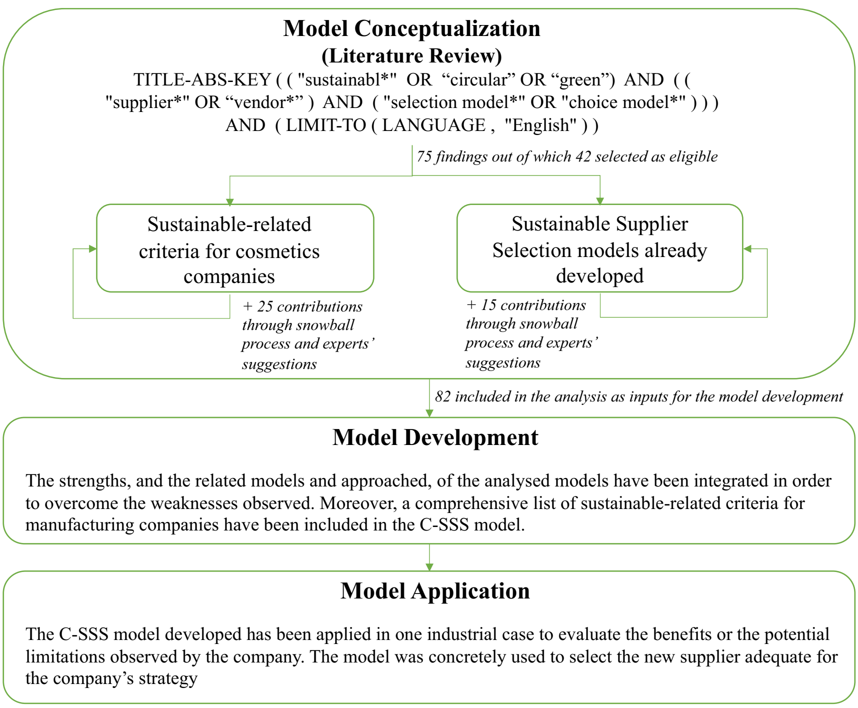


Figure 2. Research design for the realization of the C-SSS model.

norms and regulations, led to the need to create resilient and sustainable supply chains (Pereira de Carvalho & Barbieri, 2012). This need requires a careful and thoughtful selection of partners and suppliers (Giannakis et al., 2020). Thus, the SSS process emerged to be a core aspect for the creation of a sustainable cosmetics supply chain (Chai et al., 2013; Fortunati et al., 2020). This process can be defined as *'the process by which firms identify, evaluate, and contract with suppliers [. . .] to reduce purchase risk, maximize overall value to the purchaser, and develop closeness and long-term relationships between buyers and suppliers'* (Taherdoost & Brard, 2019).

In general, the criteria for the selection of suppliers have changed over time moving from only quantitative indicators (e.g. price), to a mix of both qualitative and quantitative considerations (Tong et al., 2019). Currently, within these criteria, also the sustainability-oriented ones need to be considered, giving a new name to the process: 'Sustainable Supplier Selection' (SSS) process defined as *'a comprehensive consideration of economic, environmental and social aspects in supplier selection process'* (Yu et al., 2019).

In this regard, the analysis of the required criteria for an SSS process undertaken by a cosmetic company, together with an analysis of the existing SSS models present in the extant literature are elucidated below.

3.1. SSS Criteria in Cosmetics

This chapter aims to clarify the key sustainable-oriented criteria to be included in an SSS model for the cosmetics industry looking at both scientific literature (sub-section 3.1.1.) and ISO standards (sub-section 3.1.2).

3.1.1. Criteria from scientific literature

The extant literature, in addition to the standard criteria of price, quality, flexibility and delivery suggested, in most of the contributions (e.g. (Bai & Sarkis, 2010; Hashemi et al., 2015b)) highlighted a set of criteria which can be clustered into four key classes to be considered in the SSS process, especially while dealing with the cosmetic industry: (i) safety, (ii) environmental pollution, (iii) aquatic toxicity and (iv) sourcing and resource consumptions. A brief explanation of the four classes is described below, and Table 1 summarizes the most relevant criteria and sub-criteria identified for the already existing SSS models.

Safety concerns are among the most relevant criteria to be considered when looking at the ingredients and the chemicals used in cosmetics products. To evaluate product safety, manufacturers need to perform a risk assessment starting from product development until the marketing cycle (Engasser et al., 2007). Moreover, there are several standards worldwide to be addressed among which the 1938 Federal Food, Drug and Cosmetic Act and its amendments in the Unites States, and 1976 EU Cosmetics Directive and its revisions in the European Union (Engasser et al., 2007). Another important issue for the cosmetics industry is the animal testing (Sahota, 2014). Although these practices are required to prevent humans from negative consequences on safety issues of cosmetic products, concerns for animals' treatment and wellbeing arose and actions against these practices have been taken (Sreedhar et al., 2020). For instance, in Europe, the first action on the implementation of a ban on sales and import of cosmetics tested on animals was taken in 2013, followed by India in 2014 and New Zealand in 2015 (Sreedhar et al., 2020).

Table 1. Sustainable-related criteria in SSS models.

Criteria	Sub Criteria	Reference
Safety	• Health and safety • Health and safety incidents • Health and safety practices • Staff training • Employer Rights • Cost of work safety and labor health • Social Commitment • Local community influence	(Amindoust, 2018; Bai & Sarkis, 2010; Hashemi et al., 2015b; Hendiani et al., 2020; Kaur et al., 2020, 2020; Park et al., 2018; Rahmadani & Suparno, 2021; Sahota, 2014; Sreedhar et al., 2020; Tavassoli et al., 2020; Thanh & Lan, 2022; Tong et al., 2019; van Thanh & Lan, 2022; Wang et al., 2022)
Environmental Pollution	• Pollution control • Production of toxic products • Production of waste • Environmental Pollutant effects cost • Current environmental efficiency • Average volume of air pollutants, solid waste, and harmful materials released	(Bai & Sarkis, 2010; Dhanirama et al., 2012; Fallahpour et al., 2021; Freeman & Chen, 2015; Guerranti et al., 2019; Hashemi et al., 2015b; Hendiani et al., 2020; Kaur et al., 2020, 2020; Khalilzadeh & Derikvand, 2018; Kuo et al., 2010; Li et al., 2021; Mohammadi et al., 2017; Rahmadani & Suparno, 2021; Sahota, 2014; Thanh & Lan, 2022; Tong et al., 2019; van Thanh & Lan, 2022; Wang et al., 2022)
Aquatic Toxicity	• Production of polluting agents • Average volume of wastewater	(Bai & Sarkis, 2010; Bom et al., 2019; Hashemi et al., 2015b; Secchi et al., 2016; Vita et al., 2018; Wang et al., 2022)
Sourcing and resource consumption	• Consumption of energy • Consumption of raw material • Consumption of water • Environmental programs • Energy Efficiency • Eco-design • Green R&D and innovation • Use of environment friendly material • Recycled Material • Energy Conservation	(Amindoust, 2018; Bai & Sarkis, 2010; Bom et al., 2020; Fallahpour et al., 2021; Freeman & Chen, 2015; Hashemi et al., 2015b; Hendiani et al., 2020; Jaccarini & Refalo, 2017; Jayant & Paul, 2014; Kaur et al., 2020, 2020; Khalilzadeh & Derikvand, 2018; Kuo et al., 2010; Li et al., 2021; Mohammadi et al., 2017; Pulverail & Givaudan, 2013; Rahmadani & Suparno, 2021; Schneiders & Anklin, 2013; Secchi et al., 2016; Tavassoli et al., 2020; Thanh & Lan, 2022; van Thanh & Lan, 2022; Wang et al., 2022, 2022)

This attention let the rising of vegan-friendly and cruelty-free cosmetics brands (InVitro International, 2019). In other countries, this attention is still limited, and no regulations are present although alternatives to animal testing are available (e.g. the Virtual Human Platform (VHP) (Cosmetic Europe, 2020)).

Environmental pollution is another criterion to be included in the analysis, considering that cosmetics products contain a wide range of chemicals and some of them are labeled as 'chemicals of emerging concern' (Dhanirama et al., 2012). In this sense, an important aspect to be considered is the use of microbeads in cosmetics formulations. Microbeads are solid microplastic spheres with small diameter (less than 5 mm) used in cosmetics products to perform for instance the skin exfoliation (Guerranti et al., 2019). Being them composed by plastic material that might be dispersed in the aquatic plants, the substitution with natural ingredients has been considered since they pose a threat to the well-being of the ecosystem and to the biodiversity loss (Guerranti et al., 2019). Actually, the use of plastic materials has impact on both the formulation and the packaging. Plastic represents hence one of the most diffused materials for the packaging because of its flexibility and lightness (Sahota, 2014). There are actions to start thinking at different packaging as the proposal by (Cosmetics Europe, 2019; Jaccarini & Refalo, 2017) of bio-based packaging and the introduction of design for environment practices.

Aquatic toxicity is another important issue to be considered in this industry since after the use phase, several products enter the aquatic environment, and traditional methods of treatment can be used only to remove a limited amount of this waste (Vita et al., 2018). Among the most diffused ingredients representing a threat for the aquatic environment there are the parabens, UV filters in solar protection, antimicrobial and preservatives agents (Vita et al., 2018). Moreover, the petrochemical derivatives are other ingredients to be kept under control since they generate emissions having a non-renewable nature, and the silicones too should be considered being them bioaccumulate and thus posing threat to aquatic life (Bom et al., 2019). Another key aspect to be kept into account in the cosmetics industry is the quantity of water used in the production process that was reported to be one of the most relevant issues after a Life Cycle Assessment study conducted on a bio-based cosmetic product (Secchi et al., 2016).

Additionally, considering the relevant role of the raw materials and ingredients of cosmetics products and of their packaging, also their *sourcing and their resource consumptions* represent important elements in cosmetics (Bom et al., 2020; Jaccarini & Refalo, 2017; Secchi et al., 2016). The ingredients used come from regions worldwide with different conditions and different resource consumptions. Therefore, it cannot be taken for granted that natural ingredients are more sustainable with respect to artificial or synthetic ones. Indeed, there are several issues concerning environmental and social aspects to be considered especially in the procurement phase when ingredients are selected (Bom et al., 2019). Some certifications have been introduced such as the fair-trade partnerships ensuring to operate in a social and environmental responsible manner (Schneiders & Anklin, 2013). In fact, traceability and transparency along the supply chain are becoming more and more relevant in this sense (Pulverail & Givaudan, 2013), also because the cosmetic value chains and more specifically the networks of suppliers are mainly global. This might bring some concerns such as great levels of uncertainty, hidden costs, and different national regulations (Manuj & Mentzer, 2008). For these reasons, sustainable suppliers' development practices have been put in place to support suppliers in improving their performances and capabilities according to the customer needs creating long-term relationships (Belotti Pedroso et al., 2021; Sancha et al., 2015).

3.1.2. Criteria from ISO linked to SDGs

As reported in the methodology section, the ISO standards specifically designed for the cosmetics industry have been investigated to evaluate the performances of a supplier in terms also of adherence to sustainable-oriented standards already in use in the industrial world. The ISOs were analysed in combination with the SDGs to highlight their sustainability-oriented value as reported in Table 2.

3.2. SSS models analysis

Considering the list of criteria to be kept into account in cosmetics, it is important to find a solution allowing to include all these criteria in a comprehensive assessment model by giving them the proper weight. In this regard, the extant literature presents some possibilities in terms of SSS models, even though the majority is not focused on the cosmetics industry. In Table 3 the extensive analysis is described by reporting the type of model adopted, the limitations or strengths highlighted by the authors, the industry in which the model was applied (if available), and the sustainable pillars considered in the criteria used in the model.

Table 2. ISO and related SDGs for the cosmetics industry.

Sub-field	Name	Year	SDG
Analytical approach for screening and quantification methods for heavy metals in cosmetics	ISO/TR 17,276	2014	-
Analytical method	ISO/TR 18,818	2017	-
	ISO 10,130	2009	3
	ISO 12,787	2011	3
	ISO/TR 14,735	2013	-
	ISO 15,819	2014	3
	ISO/TS 22,176	2020	3
Calculation of organic indexes of hydrolates	ISO/TR 23,199	2019	-
Determination of sunscreen UVA photoprotection in vitro	ISO 24,443	2012	3
Good Manufacturing Practices	ISO/TR 24,475	2010	-
	ISO 22,716	2007	3, 8
Guidelines on technical definitions and criteria for natural and organic cosmetic ingredients	ISO 16,128-2	2017	3, 12
	ISO 16,128-1	2016	3, 12
Guidelines on the stability testing of cosmetic products	ISO/TR 18,811	2018	-
Methods of extract evaporation and calculation of organic indexes	ISO/TR 22,582	2019	-
Microbiology	ISO 11,930	2019	3
	ISO 16,212	2017	9
	ISO 17,516	2014	3
	ISO 18,415	2017	3
	ISO 18,416	2015	3
	ISO/TR 19,838	2016	-
	ISO 21,148	2017	3
	ISO 21,149	2017	3
	ISO 21,150	2015	3
	ISO 21,322	2020	-
	ISO 22,717	2015	3
	ISO 22,718	2015	3
	ISO 29,621	2017	3
Packaging and labelling	ISO 22,715	2006	3
Sun protection test methods	ISO 16,217	2020	3
	ISO 18,861	2020	3
	ISO 24,442	2011	3
	ISO 24,444	2019	3
	ISO/TR 26,369	2009	-

These models are all characterised by some strengths and weaknesses. For instance, those focused on cosmetics are not structured neither to capture in a balanced manner the whole panel of sustainability-oriented criteria nor to include more than one decision maker. For this reason, the existing models focused on other industries have been analysed to evaluate how to overcome their limits by combining their useful characteristics, thus integrating them into a unique and comprehensive model. Among all, the main criticalities emerged in the existing models are: (i) subjectivity, (ii) single decision-maker perspective, (iii) no criteria interconnections and (iv) no cosmetics and sustainable-related criteria included.

The Multi Criteria Decision Models (MCDM) have emerged from the extant literature (Giannakis et al., 2020) as good tools ensuring a balanced evaluation of the potential

Table 3. SSS models analysis.

References	Model and Theory adopted	Limitations or Strenghts	Industry	Criteria
(Chan & Chan, 2004)	AHP	It does not consider interdependencies among criteria	advanced technology industry	n.a.
(Lee et al., 2009)	Analytic Hierarchy Process (AHP) and Fuzzy Set Theory (FST)	FST reduces the subjectivity level	n.a.	n.a.
(Zhou et al., 2009)	ANP-ENTROPY-TOPSIS	It considers the TOPSIS approach once the weights have been weighted and aggregated	n.a.	n.a.
(Bai & Sarkis, 2010)	Rough set theory (RST)	Huge amount of data and information should be available to use this model	n.a.	TBL criteria
(Kuo et al., 2010)	Artificial Neural Network (ANN) and two multi-attribute decision analysis (MADA) methods: data envelopment analysis (DEA) and analytic network process (ANP)	ANN is based on historical data.	n.a.	Environmental criteria
(Jolai et al., 2011)	AHP and TOPSIS	It enables to consider several alternatives	n.a.	n.a.
(Zeydan et al., 2011)	Fuzzy AHP, TOPSIS, DEA	Fuzzy numbers limit the subjectivity	n.a.	n.a.
(Dai & Blackhurst, 2012)	AHP and Quality Function Deployment (QFD)	It does not consider interdependencies among criteria	n.a.	Business-related criteria
(Lan, 2013)	Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)	Not focused specifically on sustainability	n.a.	n.a.
(Jayant & Paul, 2014)	ANP (Analytic network process)	The ANP enables to capture the interdependencies among various criteria.	Agricultural-Machinery Industry	Environmental Criteria
(Liu, 2014)	Group Eigenvalue Method (GEM)	Not focused on sustainability	Food	n.a.
(Azadi et al., 2015)	Fuzzy DEA	Qualitative variables can be transformed into quantitative variables	n.a.	n.a.
(Freeman & Chen, 2015)	AHP – Entropy - TOPSIS	AHP and Entropy were used to create the weights and the TOPSIS to perform the ranking	electronic machinery manufacturer	Environmental and economic criteria
(Hashemi et al., 2015a)	Analytic network process (ANP), Grey relational analysis (GRA) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	ANP includes the interdependencies among criteria	automotive industry	Environmental and Economic Criteria

(*Continued*)

Table 3. (Continued).

References	Model and Theory adopted	Limitations or Strenghts	Industry	Criteria
(Mei et al., 2016)	Entropy Measured Method (EMM) to generate Entropy-weighted ANP	It aims to reduce the level of subjectivity asking to the decision makers to evaluate the suppliers' capability and not the weights	One-of-a-kind production	n.a.
(Um, 2016)	AHP and fuzzy set ranking methodologies	Fuzzy set ranking methodologies are used to integrate multiple attribute decision problem reducing the uncertainties	n.a.	Environmental criteria
(Mohammadi et al., 2017)	type 2 fuzzy sets (IT2FSs)	type 2 fuzzy sets (IT2FSs) enable to deal with uncertainties	n.a.	Environmental and Economic criteria
(Tang, 2017)	MCDM	No specific limitations	n.a.	n.a.
(Amindoust, 2018)	FST, Fuzzy Inference System (FIS) and DEA	Focused only on affinity index of each supplier respect to resiliency and sustainability Moreover, it does not consider the dependencies among indicators	producer of special alloy for petrol container for vehicles	TBL including resilience
(Awasthi et al., 2018)	Fuzzy AHP - VIKOR	Fuzzy numbers limit the subjectivity	electronic goods manufacturing company	n.a.
(Khalilzadeh & Derikvand, 2018)	stochastic programming and LP-metric method	stochastic programming is used to manage the uncertainty and the LP-metric method enables to solve the multi-objective model as a single-objective model	n.a.	Environmental and Economic criteria
(Sahu, Narang, et al., 2018)	Integration of VIKOR, SAW and GRA methodology	These methods support the ranking and selection of the weaknesses and strengths of companies	n.a.	n.a.
(Sahu, Sahu, et al., 2018)	Interval-valued fuzzy numbers (IVFNs)	Fuzzy numbers cover issues related to uncertainties. Nevertheless, there are very few criteria considered in the model concerning environmental, green and social issues	n.a.	n.a.
(Park et al., 2018)	Multi-attribute utility theory (MAUT); Multi-objective integer linear programming (MOILP)	More than one objective can be taken into account	bicycle producer	Regional – related criteria
(Zhang, 2018)	Entropy weight method (EWM) and TOPSIS		Construction	n.a.

(*Continued*)

Table 3. (Continued).

References	Model and Theory adopted	Limitations or Strenghts	Industry	Criteria
(Chen, Wang, et al., 2019)	Six Sigma	The main indicator should be related to the quality of suppliers	n.a.	n.a.
(Chen, Huang, et al., 2019)	Six Sigma	Based on QUALITY	n.a.	n.a.
(Liu et al., 2019)	Best-worst method (BWM) and alternative queuing method (AQM)	The ranking results of sustainable suppliers through this model are highly dependent upon decision makers' subjective evaluations	n.a.	n.a.
(Memari et al., 2019)	Fuzzy TOPSIS	Fuzzy numbers limit the subjectivity	n.a.	n.a.
(Rashidi & Cullinane, 2019)	Fuzzy DEA and fuzzy TOPSIS		n.a.	n.a.
(Tong et al., 2019)	FST and TOPSIS	It is considered an opportunity to include more quantitative criteria and use different MCDM tools	Chemical Industry (assessment for evaluating equipment maintenance suppliers in the chemical industry,)	n.a.
(Wang et al., 2019)	FST	Focused mainly on the assessment of resilience performances of suppliers	n.a.	n.a.
(Yadavalli et al., 2019)	Fuzzy TOPSIS	Fuzzy numbers limit the subjectivity	General (manufacturing)	n.a.
(Yazdani et al., 2019)	decision-making trial and evaluation laboratory (DEMATEL) + (evaluation based on distance from average solution) EDAS + VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje)	EDAS to prioritise the alternatives. Uncertainties are not considered, thus it is suggested to use fuzzy numbers in the future	Manufacturing in general	Environmental criteria
(Yu et al., 2019)	TOPSIS method and the Elimination and Choice Translating Reality (ELECTRE) method	This research assumed that sustainable criteria are independent among each other.	home appliances	n.a.
(Atthirawong, 2020)	TOPSIS	Focused on cosmetic	cosmetic	n.a.
(Chen et al., 2020)	Six Sigma	Focused only on QUALITY	n.a.	n.a.
(Deniz, 2020)	MCDM, pairwise comparison among criteria, TOPSIS	It overcomes the cognitive biases	n.a.	n.a.
(el Mariouli & Abouabdellah, 2020)	Fuzzy DEMATEL		n.a.	n.a.
(Giannakis et al., 2020)	ANP	It enables to clarify the links present among the criteria	n.a.	n.a.

(*Continued*)

Table 3. (Continued).

References	Model and Theory adopted	Limitations or Strenghts	Industry	Criteria
(Hendiani et al., 2020)	Multi-criteria decision making (MCDM)	This model was built for a context in which only one decision maker is involved.	n.a.	TBL criteria
(Kaur et al., 2020)	MCDM based on Mixed integer linear program (MILP); Mixed Integer Non-Linear Program (MINLP)	There are not specific limitations, but the authors stated that in the future other approaches like fuzzy-MCDM such as fuzzy-ISM, fuzzy-DEMATEL, fuzzy-TISM, fuzzy-ELECTREE, fuzzy-PROMETHEE etc might be adopted	n.a.	Environmental and Social Criteria
(Liu et al., 2020)	MCDM method integrating regret theory and QUALIFLEX method		automotive industry	n.a.
(Tavassoli et al., 2020)	DEA	Limited set of criteria considered	n.a.	TBL (high -level perspective)
(Fallahpour et al., 2021)	Fuzzy preference programming (FPP) and multi-objective optimization on the basis of ratio analysis (MOORA)	It cannot be considered a predictive model to be used in the future for intelligent-based models	Food	Environmental Criteria
(Li et al., 2021)	MCDM integrating BWM and TODIM	The TODIM method can be used only with crisp numbers.	Machinery Industry ->Cloud Manufacturing	Environmental Criteria
(Song et al., 2021)	Intuitionistic fuzzy analytic hierarchy process (IFAHP)		Pre-fabricated building	n.a.
(Rahmadani & Suparno, 2021)	DEMATEL-ANP and FMEA	This model is much more focused on the risk assessment	pharmaceutical industry	n.a.
(Wang et al., 2021)	Taguchi capability index	The main indicator should be related to the quality of suppliers	Bicycle Manufacturer	n.a.
(Chen & Lin, 2022)	Product Lifetime Performance Index	Focused only on lifetime performance of products	electronics industry	n.a.
(Dang et al., 2022)	MCDM based on spherical fuzzy Analytical Hierarchical Process (SF-AHP) and grey Complex Proportional Assessment (G-COPRAS)	It is focused on the capability to react to a disruptive event like covid in a sustainable manner Other MCDM methods (VIKOR, MABAC, WASPAS, MULTIMOORA, etc.) could be applied to the SSS problem in future research	automotive industry	n.a.

(*Continued*)

Table 3. (Continued).

References	Model and Theory adopted	Limitations or Strenghts	Industry	Criteria
(Sahu et al., 2022)	MCDM approach integrating AHP, DEMATEL, ANP, Extended MOORA and SAW techniques.	DEMATEL facilitates the disclosure of the causal relationships among LARG metrics. MOORA is used to rank suppliers The criteria examined cover Lean-Agile-Resilient-Green (LARG) practices. Only 19 cover the green area and none covers the social area	Automotive	n.a.
(Tavana et al., 2021)	fuzzy best-worst method (HFBWM)	Limited to the reverse logistics suppliers only.	Tire re-utilization	n.a.
(van Thanh & Lan, 2022)	Fuzzy Analytical Hierarchy Process (FAHP)	AHP produces rank reversal	Food	TBL (criteria)
(Wang et al., 2022)	MCDM integrating Fuzzy Analytical Hierarchy Process (FAHP) model and TOPSIS	The are potentialities in exploring other models to be integrated	Garment Industry	Environmental criteria
(Zakeri et al., 2022)	MCDM based on the alternative ranking process by alternatives' stability scores (ARPASS)	Not focused on sustainability	n.a.	n.a.
(Thanh & Lan, 2022)	Fuzzy Analytical Hierarchy Process (FAHP) method, and the Combined Compromise Solution (CoCoSo) algorithm	Fuzzy Analytical Hierarchy Process (FAHP) method, and the Combined Compromise Solution (CoCoSo) algorithm for the selection of suppliers by ranking them	Food-processing industry	Environmental, Social and Economic Criteria

trade-offs among criteria. The evaluation is conducted based on experts' judgments and comparisons between criteria or alternatives (Deniz, 2020). Among all, the extant literature presents MCDM such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP) fuzzy-based approaches, Technique for Order of Preference by Similarity (TOPSIS) (Giannakis et al., 2020; Rashidi & Cullinane, 2019; Zeydan et al., 2011). In addition, to deal with the imprecise data conversion of uncertain and subjective information from the decision-makers into interval of fuzzy numbers, the Fuzzy Set Theory (FST) can be integrated into these models (Awasthi et al., 2018; Azadi et al., 2015; Memari et al., 2019; Rashidi & Cullinane, 2019; Yadavalli et al., 2019). Fuzzy techniques enable to reduce the subjectivity of the evaluation of the decision-makers, highly affecting the MCDM, by translating qualitative linguistic variables into quantitative numeric values (Zadeh, 1965).

Regarding the SSS models, another aspect to be considered is their compensatory nature. It would be possible in fact to compensate a bad performance of a certain criterion with a good performance in another one belonging to a different category as suggested by (Yu et al., 2019). In the sustainability context, a non-compensatory model would better work to ensure not lagging a certain category of criteria (Yu et al., 2019). At the same time, the compensatory model would enable to balance the different criteria and it is well known and diffused into companies. Therefore, hybrid models have been proposed to integrate both the natures, i.e. compensatory and non-compensatory, of the SSS models (Junior et al., 2013; Yu et al., 2019). For instance, it is possible to integrate the TOPSIS model, which has a compensatory nature model currently quite diffused, with the ELECTRE, a non-compensatory nature model, which is coherent with a sustainable oriented evaluation of the suppliers (Yu et al., 2019). Summarizing the main characteristics that necessitate to be considered in the development of a novel SSS model are the following:

- The integration of multiple perspectives of decision-makers
- The reduction of subjectivity of the decision-makers
- The evaluation of the presence of interdependencies and interconnections among criteria
- The model compensation nature.

4. Cosmetics sustainable supplier selection (C-SSS) model development

4.1. Model conceptualization based on scientific findings

The novel C-SSS model relies on the findings from the extant literature about SSS models. More in detail, three key models were taken as references to build the novel one tailored on cosmetics industry. These three were chosen as main reference since they already validated part of the integration of some of the approaches which emerged in the literature as fundamental to address the weaknesses. Atthirawong (2020) developed a model focused on the green supplier selection process in the cosmetics industry. This model relies on the TOPSIS method which has a compensatory nature and is not properly useful for this context due to the high subjectivity given to the evaluation. Thus, a hybrid model proposed by Yu et al., (2019) has been considered to be inserted in the novel model since it includes both the TOPSIS and ELECTRE approaches backed by the Entropy Measured Method (EMM). This integrated solution allows to reduce the level of subjectivity by asking the decision makers to evaluate the suppliers' capability and not the weights. Moreover, still in accordance with the model proposed by (Yu et al., 2019), a quantitative and objective evaluation is required, and this can be performed thanks to the Fuzzy Time Series (FTS) that hence has been considered too in the developed model. The integrated models and approaches proposed by (Yu et al., 2019) are reported in Figure 3.

However, the model proposed by (Yu et al., 2019) has an important limit since the criteria considered by the model are considered as independent, while their interrelations are needed to be taken into account during the selection process of suppliers. For this reason, it was considered valuable the inclusion in the novel model of an ANP model. The ANP enables to keep into account the independencies present among criteria using this information as input for the TOPSIS model. Anyway, the results should be objective and balanced among them thus, both the EMM and the entropy-weighted ANP

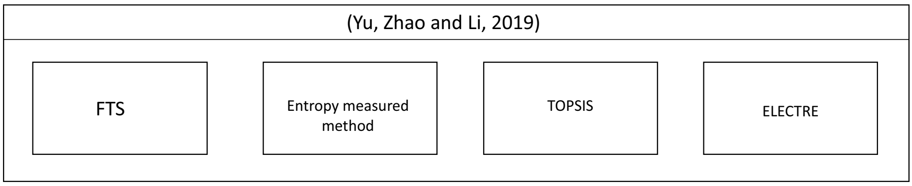


Figure 3. Synthetic structure of the model proposed by (Yu et al., 2019).

evaluation methods were used since they address both objective and subjective judgments as presented also by (Mei et al., 2016). Although this research does not concern the SSS process, it has been taken only as reference as a structured and validated way to link entropy and ANP results. In addition, to strengthen the potential links present between the EMM, the ANP and the TOPSIS model, another model was analysed, the one proposed by (Zhou et al., 2009) even though focused on other industry and topics. Therefore, to address this integration based on already validated models, the research proposed by (Zhou et al., 2009) was included as another grounding model since it considers the TOPSIS approach once the weights have been aggregated. Figure 4 shows the summary of the integrated analysis of (Mei et al., 2016) and (Zhou et al., 2009).

Last, to also include multiple actors in the evaluation phase and to lower the random error possibility made by individuals, it employed the approach used by Shyur & Shih (2006). This model applied the geometric mean to derive group preferences provided by multiple decision makers. Indeed, this model was selected since it already tested the integration between the ANP and the TOPSIS approaches with the geometric mean for the evaluation of a local Taiwanese company's suppliers.

As a result, the model proposed by the authors is an aggregation of the approaches and models applied and already validated by (Mei et al., 2016; Yu et al., 2019) and (Zhou et al., 2009) as depicted in Figure 5.

The final novel C-SSS model structure is reported below in Figure 6 where the specific steps and the related methodologies employed are reported. Immediately below the Figure 6, the steps are described in their details.

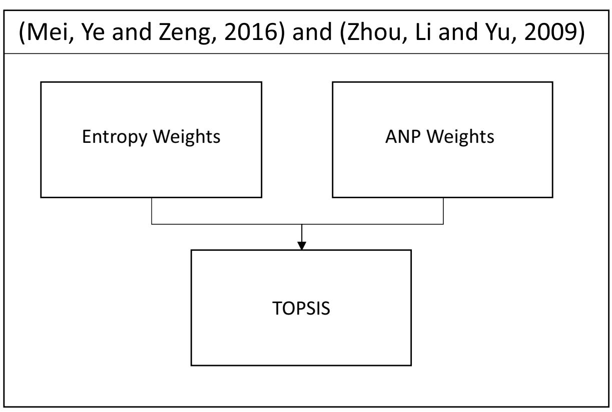


Figure 4. Synthetic structure of the model proposed by (Mei et al., 2016) and (Zhou et al., 2009).

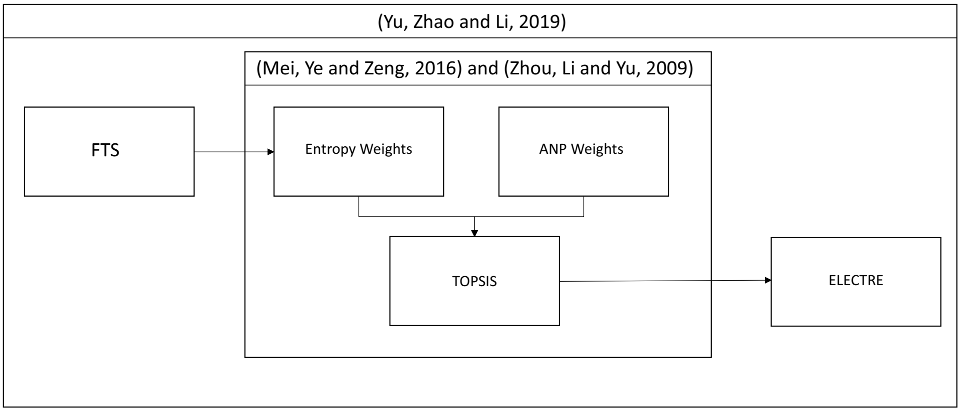


Figure 5. Synthetic structure of the model resulted as aggregation of models proposed by (Mei et al., 2016; Yu et al., 2019) and (Zhou et al., 2009).

Therefore, the extant literature enabled to clarify the key characteristics and criteria to be included in a novel C-SSS model. Based on that, the key steps for the model development are summarized in Table 4.

4.2. Model application

To use the C-SSS model, both the suppliers and the company's decision-makers are involved, and two technical tools are employed to make the process smoother as reported in Table 5. Indeed, as previously described in the methodology section, these tools are easy to be applied in industrial cases being cheap and user-friendly.

4.2.1. Marco-phase 1

Starting with *macro phase 1* (i.e. criteria selection and evaluation of a network), it is first required to select the decision makers, and make them select the proper criteria to be used for the selection of their companies' suppliers (see analysis in sub-section 3.1.1). The selection of a specific set of criteria (see *Step 1* of Table 4) depends on the context of application and on the company's strategy. These criteria can be chosen among those identified from the scientific and grey literature. These criteria were revised and grouped in three main classes corresponding to the TBL pillars, as reported below in Table 6, to ensure the balanced consideration of all the three pillars.

All the criteria are translated into polar questions to ensure an easy adoption of the model by companies. These questions are sent to the suppliers to obtain all the information that need to be evaluated by the decision-makers through the developed model. Indeed, in *Step 2* (see Table 4), the ANP model is introduced. This model enables to keep into account both inner and outer dependences, allowing to consider the interactions within and between groups of criteria (Jayant, 2016). The general structure of these models is based on two layers: the control and the network layers. These layers perform respectively the pairwise comparison and evaluate the influences present among criteria in the network (Jayant & Paul, 2014). The ANP implementation requires first to ask the

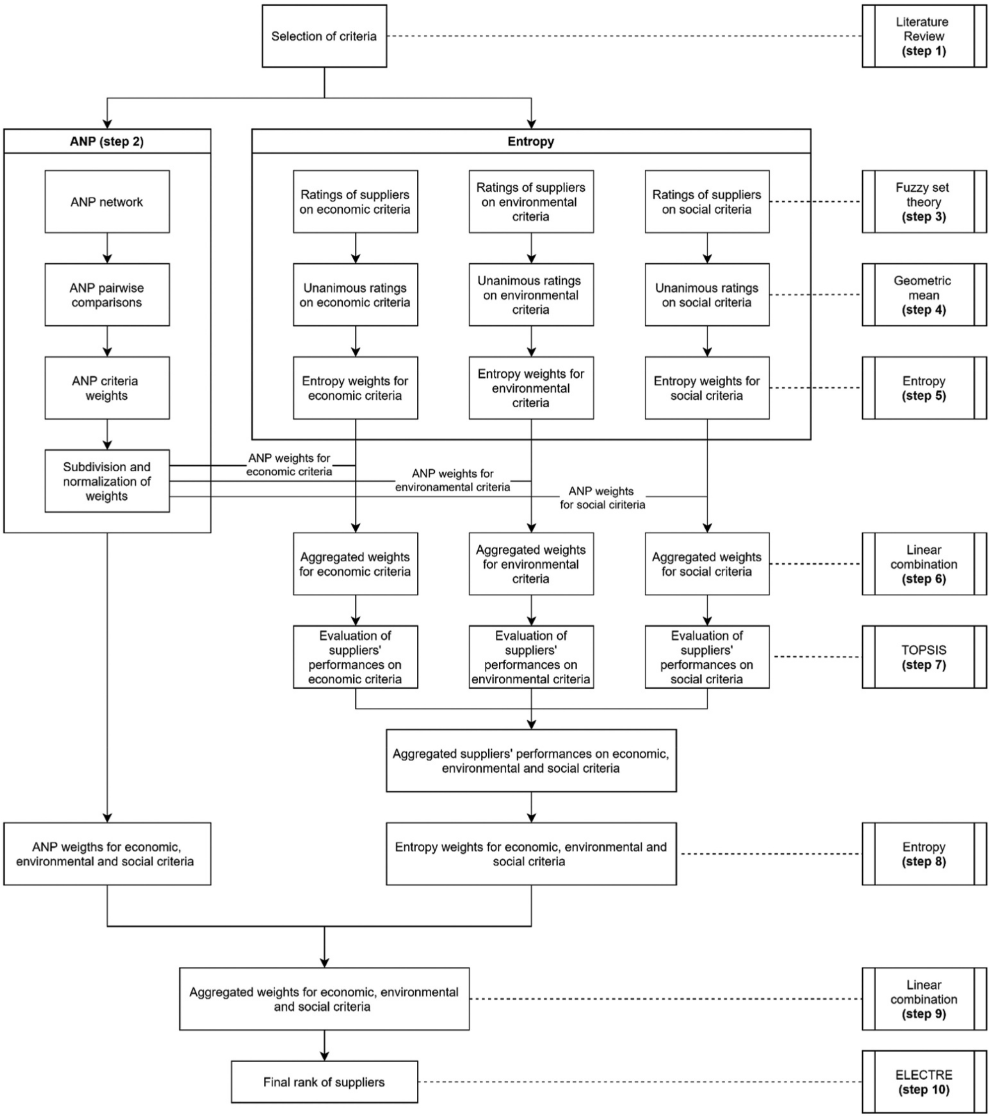


Figure 6. C-SSS model development.

decision-makers to build a network making visible the interdependencies among criteria. Secondly, to define the criteria weights by conducting a pairwise comparisons for each relationship between groups and single criteria. Once the ANP model is built, it is possible to create the 'Supermatrix'. This underlines the relationships among criteria by representing the relative importance of an element on the left of the matrix compared to an element at the top of the matrix, with respect to a particular control criterion by giving specific weights (Saaty, 2006). In this matrix, the subjectivity of the weights is then balanced by more objective weights thanks to the use of the EMM (Mei et al., 2016) which is better described in *Step 5* (see Table 4).

Table 4. Model development steps.

Area	# Step name	Method used
Criteria selection and evaluation of a network (ANP)	1. Sustainable criteria formulation	Literature review
	2. Construction of ANP network of criteria and definition of sub-criteria ANP-based weights	ANP method
Evaluation divided per sustainability pillars	3. Qualitative criteria representation	TFNs
	4. Aggregation of decision makers' evaluations	Geometric mean
	5. Definition of sub-criteria	Entropy measured method
	6. Aggregation of sub-criteria ANP and entropy-based weights	Linear combination
	7 .Suppliers' performances evaluation with respect to economic, environmental, and social aspects, respectively	TOPSIS method
Aggregated evaluation	8. Definition of criteria entropy-based weights	Entropy measured method
	9. Aggregation of criteria ANP and entropy-based weights	Linear combination
	10. Suppliers' final rank	Improved ELECTRE method

Table 5. Stakeholders involved in the selection process and technical interfaces.

Stage	Stakeholder	Technical Interface
Suppliers' questionnaire	Suppliers	Excel
Decision makers' evaluation	Decision makers	Excel
	Decision makers	SuperDecisions
Final computations and ranking	-	Excel

4.2.2. Macro-phase 2

Entering the macro phase 2, and more specifically the *Step 3* (see Table 4), it is required to make sure to use qualitative criteria as the quantitative ones to allow an objective comparison. To address this issue, it has been used the FST (Lee et al., 2009). More specifically, it has been used to convert the qualitative criteria into quantitative values by using the graded mean integration representation method (Jolai et al., 2011), thus by transferring a triangular fuzzy number (TFN) A = (a_1, a_2, a_3) into a crisp real number.

Having set all the criteria as numeric variables, it is possible to enter the *Step 4* (see Table 4) allowing to aggregate the evaluations coming from the several decision-makers. In doing that, geometric mean is used. This is defined as the k^{th} root of the product of k numbers. In the context of suppliers' evaluation, each decision-maker $z = 1, \ldots, k$expresses his opinion $x_{z_{ij}}$ regarding each supplier $i = 1, \ldots, m$ for what concerns criterion $j = 1, \ldots, n$. *Equation 1* defines the geometric mean of evaluations made by all decision makers.

$$x_{ij} = \left(\prod_{z=1}^{k} x_{z_{ij}}\right)^{\frac{1}{k}} = \sqrt[k]{x_1 * x_2 * \ldots * x_k} \quad (1)$$

The aggregated values can be used as inputs for the *Step 5* (see Table 5) requiring the application of the EMM (Mei et al., 2016). According to Shannon (1997), entropy is

Table 6. Criteria for the supplier selection in cosmetics.

ECONOMIC CRITERIA	EC1	ISO 22,716 (Good manufacturing practices) application	Cosmetic
	EC2	ISO 22,715 (Packaging and Labelling) application	
	EC3	ISO 9001 (Quality Management)	General
	EC4	Cost	
	EC5	Quality	
	EC6	Compliance	
	EC7	Market presence	
	EC8	Service	
	EC9	Technology	
	EC10	Time needed to be compliant with quality/economic requirements	Development
	EC11	Willingness to be audited and share information about quality/economic performance improvement	
ENVIRONMENTAL CRITERIA	EN1	Cruelty-free programs and certifications	Cosmetic
	EN2	Water pollution	
	EN3	Toxicity level of production activities (e.g. Freshwater ecotoxicity, Acidification, . . .)	
	EN4	Local territory safeguard and correct harvest practices	
	EN5	Circular practices, recycling initiatives, plastic reduction policies	
	EN6	Supply chain traceability	
	EN7	Energy consumption	
	EN8	Production practices and operations impacts' traceability	
	EN9	ISO 14,001 (Environmental Management System)	General
	EN10	Time needed to be compliant with environmental requirements	Development
	EN11	Willingness to be audited and share information about environmental performance improvement	
SOCIAL CRITERIA	SC1	Fair trade certifications	Cosmetic
	SC2	Local development programs	
	SC3	Sustainable working conditions (e.g. minimum wage, vacation days . . .)	
	SC4	Professional growth opportunity	
	SC5	Equal opportunities for men and women	
	SC6	Rights of Indigenous Peoples	
	SC7	SA 8000 certification (social accountability international)	General
	SC8	Freedom of association	
	SC9	Supplier social assessment	
	SC10	Occupational health and safety	
	SC11	Public policy	
	SC12	Time needed to be compliant with social requirements	Development
	SC13	Willingness to be audited and share information about social performance improvement	

a measure of the uncertainty of information according to which the more data are dispersed, the bigger the uncertainty is, the greater relevance the criterion has. In this way, each decision on the criteria can be expressed by entropy values, and the relative importance can be determined objectively. More specifically, this model presents three main clusters of criteria (e.g. economic, environment, and social as reported in Table 6) within which there are specific criteria to be assessed. So, considering $j = 1, \ldots, n$ as the single criterion and $i = 1, \ldots, m$ the different suppliers, the idea is to compute first the normalized decision matrix $\mathrm{R} = \left(r_{ij}\right)$ based on the nature of the single criterion x_{ij} as follows:

$$\text{Benefit Criterion } r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \qquad 1 \le i \le m, 1 \le j \le n \tag{2}$$

$$\text{Cost Criterion } r_{ij} = \frac{1/x_{ij}}{\sqrt{\sum_{i=1}^{m} 1/x_{ij}^2}}, \qquad 1 \leq i \leq m, 1 \leq j \leq n \tag{3}$$

Figure 7 depicts how it looks like in the excel file

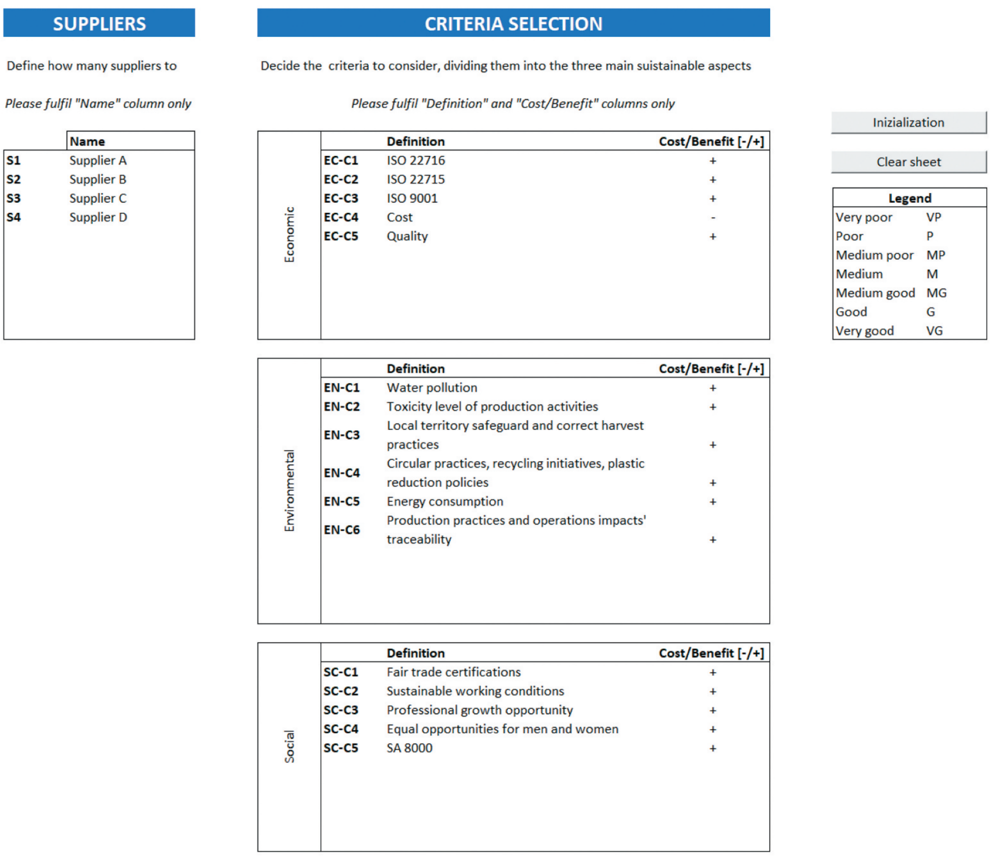
Based on the normalized values p_{ij} of (r_{ij}) to be computed as in *Equation 4*, each entropy measure e_j is computed as reported in Equation 5.

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad and \quad k = \frac{1}{\ln m} \qquad [0 * \ln(0) \equiv 0] \tag{4}$$

$$e_j = -k \sum_{i=1}^{m} p_{ij} * \ln p_{ij} \qquad 1 \leq i \leq m, \; 1 \leq j \leq n \tag{5}$$

The measure e_j allows to calculate the importance of the criterion that is greater when the divergence value d_j computed in *Equation 6* is higher.

$$d_j = 1 - e_j \qquad 1 \leq j \leq n \tag{6}$$



SUPPLIERS

Define how many suppliers to

Please fulfil "Name" column only

	Name
S1	Supplier A
S2	Supplier B
S3	Supplier C
S4	Supplier D

CRITERIA SELECTION

Decide the criteria to consider, dividing them into the three main sustainable aspects

Please fulfil "Definition" and "Cost/Benefit" columns only

		Definition	Cost/Benefit [-/+]
Economic	EC-C1	ISO 22716	+
	EC-C2	ISO 22715	+
	EC-C3	ISO 9001	+
	EC-C4	Cost	-
	EC-C5	Quality	+

		Definition	Cost/Benefit [-/+]
Environmental	EN-C1	Water pollution	+
	EN-C2	Toxicity level of production activities	+
	EN-C3	Local territory safeguard and correct harvest practices	+
	EN-C4	Circular practices, recycling initiatives, plastic reduction policies	+
	EN-C5	Energy consumption	+
	EN-C6	Production practices and operations impacts' traceability	+

		Definition	Cost/Benefit [-/+]
Social	SC-C1	Fair trade certifications	+
	SC-C2	Sustainable working conditions	+
	SC-C3	Professional growth opportunity	+
	SC-C4	Equal opportunities for men and women	+
	SC-C5	SA 8000	+

Inizialization

Clear sheet

Legend	
Very poor	VP
Poor	P
Medium poor	MP
Medium	M
Medium good	MG
Good	G
Very good	VG

Figure 7. Excel for the score computation.

Finally, the divergence value is used to compute the normalized criteria weights $w_j$based on *Equation 7*. The denominator consists in the sum of the criteria grouped by sustainable aspects.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \qquad 1 \le j \le n \tag{7}$$

Step 6 (see Table 4) aims to integrate the results from the ANP and EMM to ensure the objectivity of the evaluations and in doing that, a linear combination of the two is computed as suggested by (Mei et al., 2016). To allow this integration, it is first necessary to associate the ANP weights with the different sustainable pillars and normalize them to align these results with those of the EMM (which have been already computed for the single pillar of the TBL). The vector containing the ANP weights is composed by the weights of the different criteria $j = 1, \ldots, n$ within which n can be considered the sum of all the criteria corresponding to the different sustainable pillars as follows: $n = a + b + c$ where a corresponds to the sum of all the economic-related criteria, b to the sum of all the environmental-related criteria and c to those related to the social aspects. Therefore, the three vectors of normalized ANP weights can be obtained by means of Equation 8, Equation 9, Equation 10.

$$\overline{W_{ij}}(economic) = \frac{\overline{W_{ij}}}{\sum_{j=1}^{a} \frac{\overline{W_{ij}}}{W_{ij}}} \qquad j = 1, \ldots, a \tag{8}$$

$$\overline{W_{ij}}(environmental) = \frac{\overline{W_{ij}}}{\sum_{j=1}^{b} \overline{W_{ij}}} \qquad j = 1, \ldots, b \tag{9}$$

$$\overline{W_{ij}}(social) = \frac{\overline{W_{ij}}}{\sum_{j=1}^{c} \overline{W_{ij}}} \qquad j = 1, \ldots, c \tag{10}$$

The final weight vector $\mathrm{W_j(j = 1, \ldots, n)}$ is obtained as in *Equation 11* where subjective weights provided by ANP are reported as $w_j^{''}$, and those objective weights computed with the EMM are reported in the equation as $w_i^{'}$. This vector multiplied by the evaluation matrix $R = \left(r_{ij}\right)$ allows to obtain the weighted normalized evaluation matrix $V = \left(v_{ij}\right)$ reported in the *Equation 12*.

$$w_j = \frac{w'_j w''_j}{\sum_{j=1}^{n} w'_j w''_j}, j = 1, \ldots, n \tag{11}$$

$$v_{ij} = W_j * r_{ij} \qquad 1 \le i \le m,\ 1 \le j \le n \tag{12}$$

These results are the required inputs to implement the hybrid TOPSIS (*Step 7* of Table 4) adopted to evaluate the performances of suppliers with respect to economic, environmental, and social aspects respectively, which require the EMM adoption for every single pillar. The *TOPSIS* method aims to select the alternative that has (Hwang & Yoon, 1981):

- the shortest distance from the Positive Ideal Solution (PIS), solution that maximizes the benefit criteria and minimizes the cost criteria;
- the farthest distance from the Negative Ideal Solution (NIS), solution that maximizes the cost criteria and minimizes the benefit criteria.

Based on the weighted normalized decision matrices $V = (v_{ij})$ computed above, PIS and NIS are calculated as reported in the *Equations (13)* and *(14)*, respectively by considering 'I' the cluster of the benefit criteria, and 'J' the cluster with the cost criteria.

$$A^{+} = \{v_1^{+}, \ldots, v_n^{+}\} = \{(max_j v_{ij} | i \in I), (min_j v_{ij} | i \in J)\} \tag{13}$$

$$A^{-} = \{v_1^{-}, \ldots, v_n^{-}\} = \{(min_j v_{ij} | i \in I), (max_j v_{ij} | i \in J)\} \tag{14}$$

To finally compute the relative closeness C_i, of each solution i to the best solution with the *Equation 17*, the distance from PIS and NIS is computed for each solution i, as reported in *Equation 15* and Equation 16 respectively:

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{+}\right)^2} \qquad 1 \le i \le m, 1 \le j \le n \tag{15}$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-}\right)^2} \qquad 1 \le i \le m, 1 \le j \le n \tag{16}$$

$$C_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \qquad 1 \le i \le m \tag{17}$$

4.2.3. Macro-phase 3

Entering the third macro-phase means to be able to rank the suppliers and chose the most proper one looking in an aggregated way to the three sustainability pillars. Therefore, the improved ELECTRE method is used to rank all the alternatives (Yu et al., 2019).

First, starting from the weights obtained in *Step2* related to criteria referred to each sustainability pillar, the cumulated weights for each sustainability aspect are computed as the sum of the single weights (*Step 8* of Table 4) with *Equations 18, 19* and *20.*

$$\overline{W_{economic}} = \sum_{j=1}^{a} W_{ij} \tag{18}$$

$$\overline{W_{environmental}} = \sum_{j=1}^{b} W_{ij} \tag{19}$$

$$\overline{W_{social}} = \sum_{j=1}^{c} W_{ij} \tag{20}$$

These weights are combined with those of the decision matrix that is based on the ranks of suppliers with respect to economic, environmental, and social criteria obtained through the TOPSIS method. Therefore, in *Step 9* (see Table 4), the EMM is used and applied to this new decision matrix X to obtain a normalized decision matrix $R = \left(r_{ij}\right)$. Therefore, *Equation 8, Equation 9, Equation 10, Equation 11*, and Equation *12* are applied to obtain three weights w_j one for each sustainable pillar. After *Step 8* and *Step 9*, six weights (i.e. two weights, thus entropy and ANP weights, for each sustainability pillar) are obtained and in *Step 10*, the linear combination is applied aggregating the six weights obtained with the three weights v_j using Equations 11 *and 12)*.

To concretely apply the ELECTRE method, the criteria required to be divided into concordance and discordance subsets C_{kl} and $D_{kl}$for each pair of supplier alternatives A_k and A_l ($k, l = 1, 2, \ldots, m$ and $k = l$), where:

- The concordance set of criteria C_{kl} is the collection of criteria where A_k is better than or equal to A_l (*Equation 21*)
- The discordance set D_{kl} contains all criteria for which A_k is worse than A_l (*Equation 22*)

$$C_{kl} = \left\{j|v_{kj} \geq v_{lj}\right\} \qquad 1 \leq k, l \leq m, k \neq l, 1 \leq j \leq n \tag{21}$$

$$D_{kl} = \{j|v_{kj} < v_{lj}\} = J - C_{kl} 1 \leq k, l = m, k \neq l, 1 \leq j \leq n \tag{22}$$

In this set of criteria, for each pair of suppliers *k* and *l*, it is possible to compute all the concordance and discordance indexes c_{kl} and d_{kl} relying on *Equations 23* and 24. Based on the discordance index, it computed the revised discordance index d'_{kl} (*Equation 25*) to be included in the computation of the revised weighted aggregated matrix $E = (e_{kl})$ as reported in *Equation 26*.

$$c_{kl} = \sum\nolimits_{j \in C_{kl}} w_j \qquad 1 \leq k, l \leq m, k \neq l, 1 \leq j \leq n \tag{23}$$

$$d_{kl}(t_k) = \frac{max_{j \in D_{il}} w_j \left|v_{kj} - v_{lj}\right|}{max_J w_j \left|v_{kj} - v_{lj}\right|} \qquad 1 \leq k, l \leq m, k \neq l, 1 \leq j \leq n \tag{24}$$

$$d'_{kl} = 1 - d_{kl} \tag{25}$$

$$e_{kl} = c_{kl} {}^* d'_{kl} \tag{26}$$

Finally, to evaluate the net advantage value adv_k referred to the supplier K (thus the alternative A_k), it is used *Equation 27*. The higher the adv_k the better the alternative is. This value allows to have a single rank of the alternatives in a decreasing order, with respect to all sustainability aspects and related selected criteria.

$$adv_k = \sum_{i=1, i \neq k}^{m} e_{ki} - \sum_{j=1, j \neq k}^{m} e_{jk} \tag{27}$$

Wrapping up, thanks to this revised C-SSS model, it is possible to overcome some criticalities emerged in previous works as reported in Table 7 and to enable companies

Table 7. Model comparisons.

Criticism of previous models	Solutions in this new model
Agreement on evaluations	Geometric mean on multiple evaluations
Subjectivity in decision makers' evaluations	EMM
Criteria interdependency	ANP network and weights
Model compensation	Hybrid model, composed of TOPSIS and ELECTRE approaches

operating in the cosmetics industry to choose the most appropriate suppliers according to their sustainable-oriented strategies and needs.

5. Cosmetic sustainable supplier selection model application and validation

The proposed C-SSS model was applied in a manufacturing company operating in the cosmetics industry in the north of Italy. The company has a strong commitment towards sustainability, which is also reinforced by the requests coming from their direct clients and final consumers. The application of the model requires the involvement of both the suppliers and the company's decision makers. Therefore, to streamline the information gathering and sharing, two different tools are used: Excel and *SuperDecision* Software as reported in the methodology section (see section 2, Table 5).

First, the decision-makers must select the criteria, grouped in an excel file, to be considered for the supplier selection. Based on this initial choice, the questionnaire is created and sent to the suppliers. The questionnaire is based on both qualitative and quantitative questions reported on an Excel file. While the quantitative questions can be easily filled with numeric variables, the qualitative ones are detailed questions to which it is possible to answer 'yes' or 'no'. An example is reported below in Figure 8.

The answers are filled in by the decision-makers and their judgments are expressed into a unique scale relying on the FST model as previously described. Figure 9 reports an example of the excel sheet used by the single decision-maker.

The decision-makers are also required to create the network among the criteria. By adopting the ANP model it is possible to keep into account the interdependencies present among the different criteria. This network puts the basis to identify the pairwise comparisons and obtain the weights for each single criterion. The ANP approach is concretely adopted relying on *SuperDecisions software*. This software requires first to set and populate the clusters of criteria (in this research the criteria are chosen among those reported in Table 6), second it requires to identify and populate the clusters with the available solutions, which in this case correspond to the different suppliers among which to choose, as presented in Figure 10.

Finally, the software enables to make the decision-makers define the inner and outer dependencies present among the criteria as reported in Figure 11 and to ensure the pairwise comparison among the criteria in a scale from −9 to + 9 as reported in Figure 12.

Based on these analyses, it is possible to obtain the weights of the criteria to make them usable automatically by the software. These weights are normalized based on the clusters considered as reported in the example referred to the case under analysis reported in Table 8.

The normalized values are used in the TOPSIS model while the limiting values, those coming from the automatic computation performed by the *SuperDecision* Software, are used as inputs in the ELECTRE model. These weights, combined with the responses by the

QUESTION	ANSWER	NOTES
Please answer "yes/no" to the following questions. *If a "+" is showed, please insert a numeric value in "notes" column to answer.* *If a "-" is showed, please provide a full answer in "notes" column.* *If a "*" is showed, please consider also "not applicable" as possible answer.*	*yes/no*	*Please provide any relevant information in the "notes" box.*

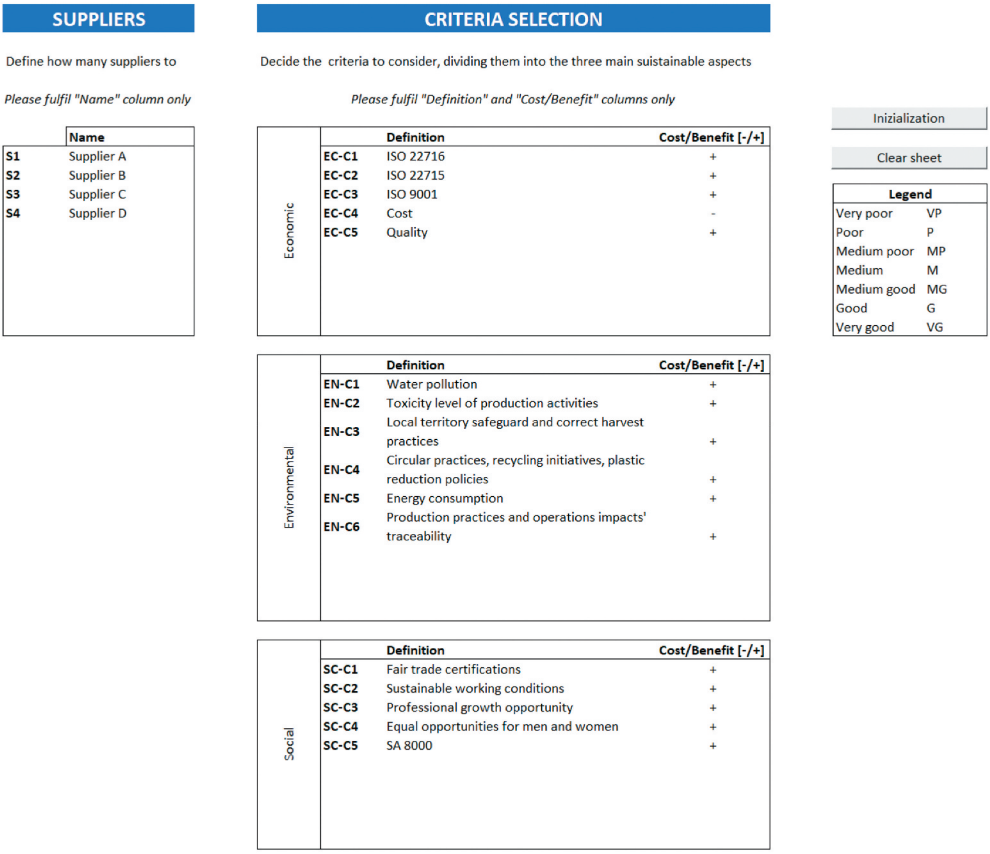
EC1 - ISO 22716 (Good manufacturing practices) application		
ECQ1 - Do you follow the ISO 22716 guidelines on Good manufacturing practices?	No	
ECQ2 - If not, do you have specific regulations you follow?	Yes	We have strict procedures in place
ECQ3 - If not, do you keep extensive documentation throughout the whole process?	Yes	
EC2 - ISO 22715 (Packaging and labelling) application		
ECQ4 - Do you follow the ISO 22715 guidelines on packaging and labelling?	No	
ECQ5 - If not, do you have specific regulations you follow?	Yes	We comply with national regulations
EC3 - ISO 9001 (quality management)		
ECQ6 - Do you have a quality management system?	Yes	
ECQ7 - Do you have a specific quality function in your company?	Yes	
ECQ8 - In what phase(s) of production do you carry out quality testing?	-	Products are tested after all production phases and as final product
ECQ9 - Are you ISO 14001 certified?	No	
ECQ10 - If not, are you planning on getting the certification within the next two years?	Yes	We are in the process of getting the evaluation
EC4 - Cost		
ECQ11 - Can you provide an estimate for the … (a kg of product)	-	**5€/kg**
ECQ12 - Are you willing to share information about your cost breakdown structure?	Yes	
EC5 - Quality		
ECQ13 - Are you open for reviews by our Quality Manager?	Yes	
ECQ14 - Insert specific supply requests	-	97% of good pieces

Figure 8. Questionnaire example.

suppliers, enable to finally rank the suppliers to choose the best option as reported in the example depicted in Figure 13 (the potential suppliers are only four in this specific case). This combination enables the creation of specific scores for the different suppliers looking on the TBL. Based on that, the model enabled to express a preference on the most suitable supplier and additionally, it enabled to look at the results across the different sustainability-related pillars (i.e. TBL pillars). This second result is valuable when there are two or more suppliers reaching the same final score, but it is required to select only one among the two. In this way, it is possible to decide, for instance, to select the one that obtained the highest score in the environmental-related criteria in case it would be more aligned with the strategic goal of the company in that historical moment. In this specific case, Supplier A was chosen as best option for the company as visible in Figure 13.

6. Discussion

As emerged from the results obtained after the model adoption (i.e. the C-SSS model), the company was able to integrate the perspectives of several decision-makers, to balance their judgments and finally to rank the different suppliers considering the sustainability-related criteria enhancing their stakeholders' engagement capabilities. Therefore, the C-SSS model acts as facilitator to improve the circular-manufacturing ecosystem giving the possibility to establish stronger partnerships and collaborations among



SUPPLIERS

Define how many suppliers to

Please fulfil "Name" column only

	Name
S1	Supplier A
S2	Supplier B
S3	Supplier C
S4	Supplier D

CRITERIA SELECTION

Decide the criteria to consider, dividing them into the three main sustainable aspects

Please fulfil "Definition" and "Cost/Benefit" columns only

		Definition	Cost/Benefit [-/+]
Economic	EC-C1	ISO 22716	+
	EC-C2	ISO 22715	+
	EC-C3	ISO 9001	+
	EC-C4	Cost	-
	EC-C5	Quality	+

		Definition	Cost/Benefit [-/+]
Environmental	EN-C1	Water pollution	+
	EN-C2	Toxicity level of production activities	+
	EN-C3	Local territory safeguard and correct harvest practices	+
	EN-C4	Circular practices, recycling initiatives, plastic reduction policies	+
	EN-C5	Energy consumption	+
	EN-C6	Production practices and operations impacts' traceability	+

		Definition	Cost/Benefit [-/+]
Social	SC-C1	Fair trade certifications	+
	SC-C2	Sustainable working conditions	+
	SC-C3	Professional growth opportunity	+
	SC-C4	Equal opportunities for men and women	+
	SC-C5	SA 8000	+

Inizialization

Clear sheet

Legend	
Very poor	VP
Poor	P
Medium poor	MP
Medium	M
Medium good	MG
Good	G
Very good	VG

Figure 9. Example of an excel sheet used by a single decision-maker.

manufacturers and suppliers. Indeed, the selection of specific suppliers stands in the accurate analysis of criteria covering the whole TBL in accordance with the circularity principles, looking for instance at the possibility to recycle resources, reduce resources consumption etc. Moreover, the C-SSS model enabled to overcome the key weaknesses emerged in the already existing models, being it a comprehensive model able to involve different decision-makers while ensuring objectivity in their choices, capable to consider the potential interdependencies present among criteria while ensuring the inclusion of the entire spectrum of sustainability-oriented criteria required for the cosmetics industry. Last, the adoption of the C-SSS model benefitted the company ensuring a deep and thoughtful audit of their suppliers allowing the creation of a stronger and more resilient value chain through their engagement. Indeed, the questionnaire shared with the suppliers increases the suppliers' awareness in terms of the expectations from the company regarding sustainability and circular-oriented certifications or required characteristics. Therefore, the contributions from this research cover both practical and theoretical perspective.

From a practical perspective, the C-SSS model, once used in an industrial case, emphasized its potentialities in addressing a core aspect facilitating the sustainable transition of cosmetics companies, thus the supplier selection process. Through the

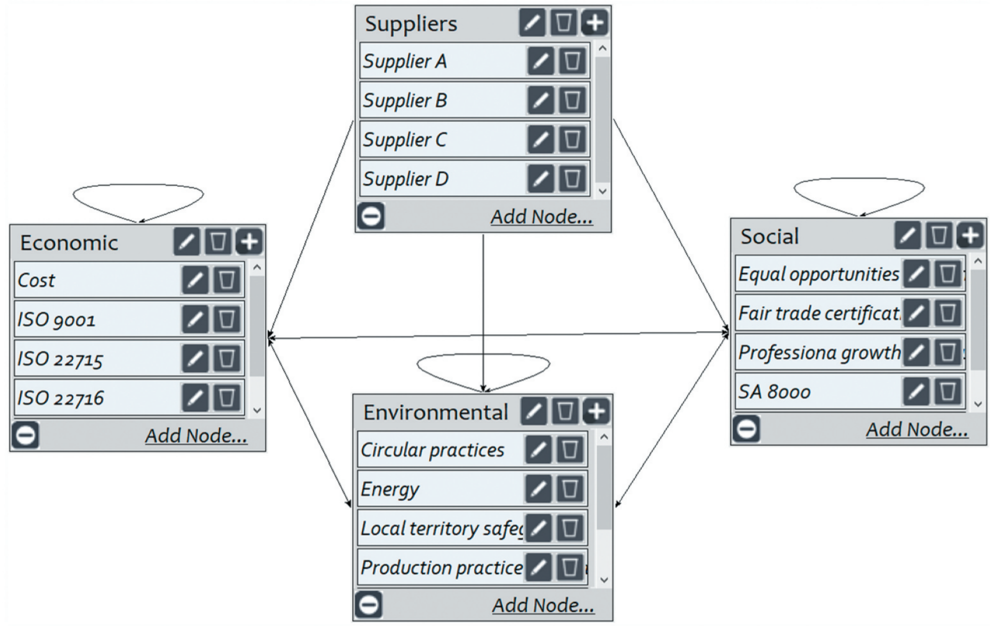


Figure 10. Super decision criteria links.

industrial case, it emerged that the model allows to make collaborate and converge a series of decision-makers, even with contrasting ideas, working for the same company but operating in different departments (e.g. production and quality). Decision-makers from different departments were asked to evaluate and select a set of criteria, under the big umbrella of sustainability for cosmetics companies, required to evaluate the most appropriate supplier for their company. Based on this initial choice, the questionnaire for the suppliers was developed and shared with them to select the best option. Therefore, from the model application, it emerged that the model enables to engage suppliers in the sustainable transition of the producer itself making them aware about the sustainable characteristics required by the company. Actually, thanks to an accurate integration of the needed characteristics of the existing SSS models, it was possible (i) to involve different decision-makers while limiting the subjectivity in their choices, (ii) to consider a wide spectrum of criteria referred to sustainability, together with their potential interdependencies, and finally (iii) to select the most appropriate supplier for the company. This model, hence, based on a mathematical computation, facilitates the company in selecting the best supplier considering among all, the request coming from consumers and governments integrated with the company's strategic objectives. Moreover, it enables to take into account the potential interconnections present among the criteria selected. The set of criteria to be selected by the decision-makers includes those found in the scientific and grey literature in terms of ISO standards mostly linked to the SDGs. In this way, a cosmetics company can conduct an updated vendor rating ensuring the adherence with the current norms and standards for its industry. Moreover, the model modularity and adaptability facilitate its usage also in the future when the set

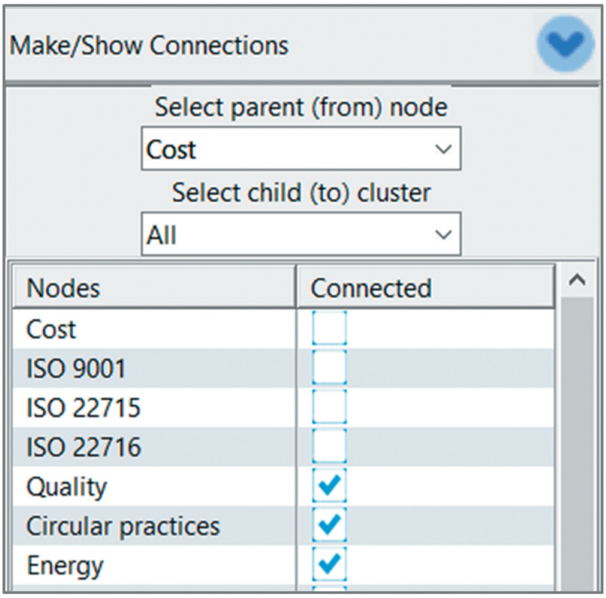


Figure 11. Inner and outer interdependencies among criteria.

of criteria might have been changed due to new norms, regulations, consumers' changed behaviour or updated company's strategic goals.

From a theoretical perspective, the C-SSS model allows to overcome the criticalities emerged in the already existing SSS models by integrating their fundamental characteristics (e.g. judgement objectivity, multiple-decision makers, criteria interdependencies, sustainable criteria, etc.) into a unique and comprehensive model. Therefore, it was possible to create an SSS model, the C-SSS model, tailored on cosmetics companies interested in embracing a sustainable-oriented path, which before was not present in the extant literature. The model innovativeness stands not only in the inclusion of all the sustainable-related criteria needed to be considered by a cosmetics company but also in the accurate usage and selection of existing SSS models' characteristics needed for each specific stage of the supplier selection process. The C-SSS model, with respect to the previous models, includes in the selection process a wider set of criteria for cosmetics companies, including standards, covering the whole TBL. It takes into account criteria interdependences and engages several stakeholders (company's departments and suppliers) while keeping high the level of objectivity of the internal stakeholders' choices. More specifically, referring to the existing models, to ensure an agreement among the different decision-makers on the evaluation, it has been introduced the geometric mean on the different evaluations, and to reduce the subjectivity coming from decision makers' evaluations it has been used the EMM approach. Moreover, to keep into account the interconnections that might be present among the criteria considered, the ANP approach has been included in the model too. Last, to ensure the creation of a hybrid compensation model, the TOPSIS and the ELECTRE models have been concurrently adopted. Indeed, the combination of compensating and non-compensating approached within a unique

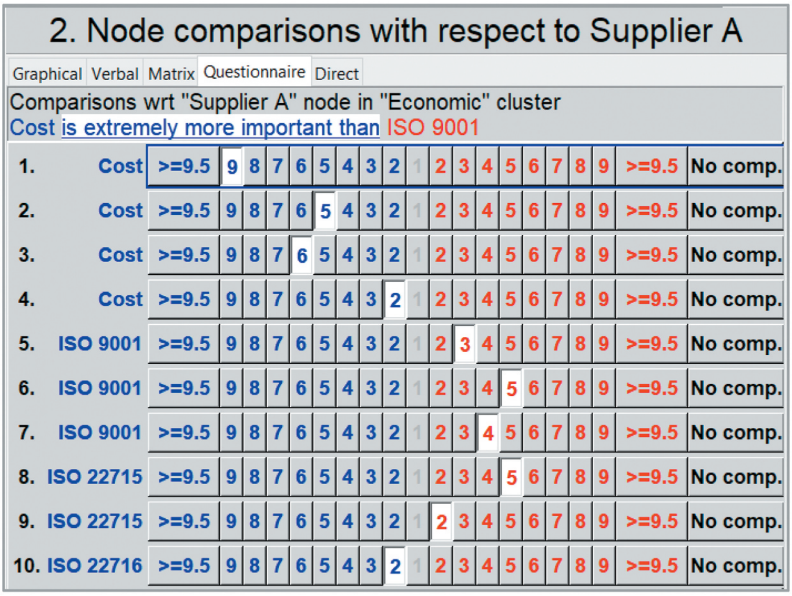


Figure 12. Pairwise comparison.

Table 8. Clustering of criteria evaluation.

Cluster	Name	Normalized By Cluster	Limiting
Economic	Cost	0.3412	0.1367
	ISO 9001	0.0260	0.0104
	ISO 22,715	0.0173	0.0069
	ISO 22,716	0.1716	0.0687
	Quality	0.4439	0.1778
	Partial total	**1**	**0.4006**
Environmental	Circular practices	0.1159	0.0176
	Energy	0.4070	0.0617
	Local territory safeguard	0.4498	0.0682
	Production practices traceability	0.0102	0.0015
	Toxicity level of production activities	0.0036	0.0005
	Water pollution	0.0135	0.0020
	Partial total	**1**	**0.1516**
Social	Equal opportunities for men and women	0.1672	0.0749
	Fair trade certifications	0.1374	0.0615
	Professional growth opportunity	0.0323	0.0145
	SA 8000	0.2661	0.1191
	Sustainable working conditions	0.3971	0.1778
	Partial total	**1**	**0.4478**
Suppliers	Supplier A	0	0
	Supplier B	0	0
	Supplier C	0	0
	Supplier D	0	0
	Partial total	**1**	**0**
Total		**4**	**1**

model facilitates the creation of the ranking of the suppliers keeping into account and respecting the integrity of each single sustainability pillar.

All the above-mentioned elements characterising the C-SSS model developed in this contribution represent the key innovative aspects of the model.

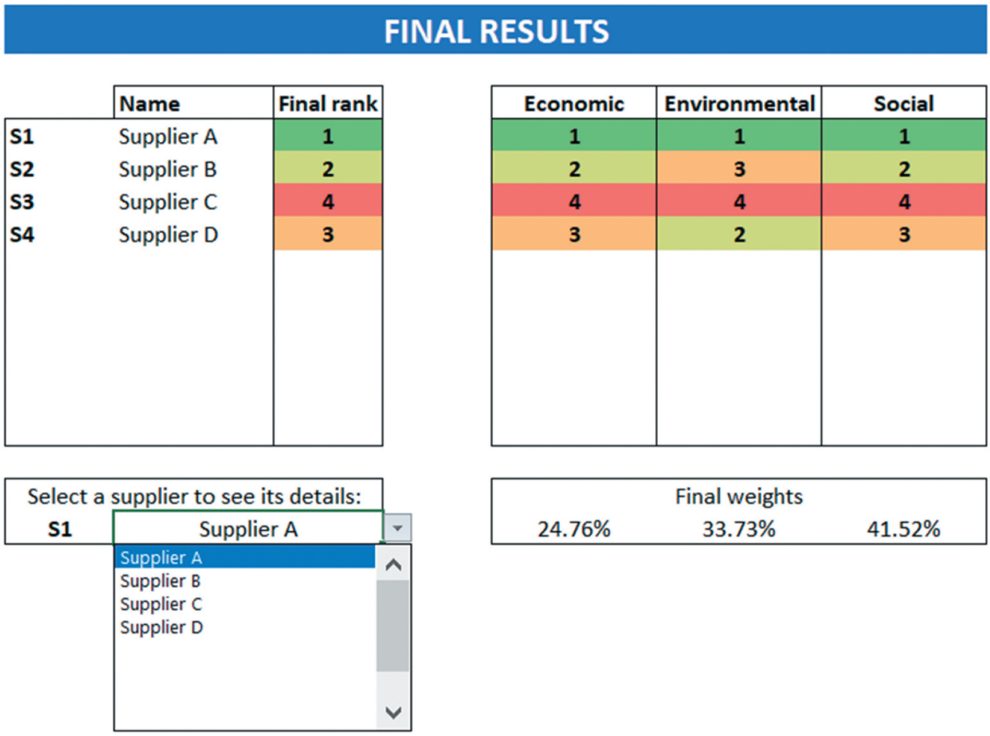


Figure 13. Final ranking.

7. Conclusions

The RO of this contribution aimed at overcoming the inefficiencies and criticalities emerged in the existing SSS models by developing a novel one tailored on the cosmetics industry. This revised model ensures the coverage of the most recent advancements and requirements for cosmetic companies in regards of sustainability and circularity issues leading to the creation of a circular manufacturing ecosystem. In doing that, it has been conducted firstly a review of the extant scientific and grey literature investigating the key sustainable and circular criteria to be included in the model to ensure the coverage of the TBL pillars when dealing with cosmetic companies. In parallel to this, it has been reviewed the literature about existing SSS models to analyse their key characteristics, their key weaknesses and to evaluate what should have been kept into the revised novel tailored on cosmetics. Based on these analyses, the set of sustainable-related criteria for cosmetic companies has been identified and the SSS models to be integrated have been selected and deeply analysed. Grounding of these findings, the C-SSS model has been developed and applied in an Italian manufacturing company operating in the cosmetic industry.

Regarding the limitations of this research, although the technical tools used (i.e. Excel and *SuperDecisions* software) are affordable and easy to be accessed by any type of company, *ad hoc* tools might be considered in the future to be easily integrated with the vendor rating software already used by cosmetics companies. Additionally, a survey could be conducted on a wider set of manufacturing companies operating in the cosmetics industry to verify that the current set of criteria included in the model is exhaustive and complete. In parallel to that, a more extensive literature review focused only on cosmetics sustainable-related criteria might be conducted in future research. Last, the present model should be applied in a wider number of companies in the future to verify its generalizability.

Disclosure statement

No potential conflict of interest was reported by the authors.

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