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A framework for assessing corporate sustainability risks along global supply chains: An application in the mobile phone industry

Abstract

In today's globalized world, characterized by complex supply chains networks, integrating sustainability supply chains risks into the corporate assessment models seems crucial. To tackle the global challenges this paper presents a Sustainability Risk Assessment Framework that allows measuring environmental and social risks upstream and downstream, along global supply chains, using a combination of quantitative methods (environmental and social footprint computing tools) and qualitative methods (hotspots analysis) from three dimensions (by scenarios, by product components, by life cycle stage). To test this framework this study focuses on the mobile phone industry, due to the importance of its environmental and social impacts. The results show the low impact of recycling strategies in environmental terms and social terms on the mobile phone industry. Fostering reuse strategies by companies will substantially improve their impacts. This framework overcomes some of the weaknesses of the corporate sustainability risks assessment methodologies combining quantitative methods and qualitative methods.

Keywords: Sustainability risk assessment (SRA), supply chain management, environmental and social footprint, hotspots analysis and mobile phone industry.

Paper type: Research paper

1. Introduction

The global sustainability agenda and the effects of the Covid-19 pandemic, which has negatively impacted 13 of the 17 Sustainable Development Goals (SDSN 2020), has forced companies to prepare for long-term future sustainability risks. In this context, the European Union's Sustainable Finance Disclosure Regulation (SFDR 2019), which came into force in March 2021, imposes transparency and disclosure requirements about the integration of sustainability risks into the investment decision-making process. Moreover, the recent communication entitled 'Europe's moment: Repair and Prepare for the Next Generation' (European Commission 2020) confirms the intention of the European Commission of "ensuring environmental and social interests are fully embedded into business strategies". To that end, it is crucial to strengthen business resilience, improve predictability and sustainability risk control, including it in supply chains management.

In this context, the aim of this paper is to define a Sustainability Risk Assessment Framework that allows measuring environmental and social risks upstream and downstream, along global supply chains.

Sustainability risk is defined as "an environmental, social or governance event or condition that, if it occurs, could cause an actual or potential material negative impact on the value of the investment arising from an adverse sustainability impact" (SFDR 2019, Art.2). Consequently, sustainability risk is based on the estimation of the probability of the occurrence of environmental and social events and their impacts (Boiral, Talbot, and Brotherton 2020) that could affect sustainable development. Therefore, sustainability risks could influence not only financial performance but also environmental performance (Semenova and Hassel 2015) and social performance (Miemczyk and Luzzini 2018).

Sustainability risks may depend on various factors, such as number of suppliers, type of industry, production schemes, etc., being crucial the identification of these risks along the supply chains (Teuscher, Grüninger, and Ferdinand 2006). However, the lack of clear criteria to integrate supply chains concerns into corporate sustainability risks assessment emerges as a gap in theory and practice. Supply chains are complex networks with a variety of risks that can affect a firm's operating (Freise and Seuring 2015) and can have negative impacts on economic and reputation terms (Mzougui et al. 2020). If all supply chain risks are managed, it can improve the corporate sustainability performance (Shafiq et al. 2017), therefore an effective assessment of supply chain risks (SCRs) is decisive.

Until now, academics have been focused on evaluating risks along the whole supply chain analyzing in an isolated way economic risks (e.g., Wever et al. 2012), social risks (e.g., Altay and Ramirez 2010), and environmental risks (e.g., Fiksel 2010). Only a few authors have made proposals to assess supply chain sustainability risks in a holistic way (Xu et al. 2019). Some of them have advanced in the definition of conceptual frameworks for managing sustainability risks along the supply chains (e.g., Hofmann et al. 2014). However, there still lacks a whole framework to assess supply sustainability risks quantitatively and qualitatively; integrating the impacts of any sector, upstream and downstream, along the global value chain (Cabernard, Pfister, and Hellweg 2019).

These research gaps encouraged us to present a framework for assessing and managing sustainability risks upstream and downstream, along the supply chains, that that allows us to improve the current corporate risk assessment methodologies. Among the improvements to consider, we can highlight: i) the lack of a holistic assessment of sustainability risks from a Triple Bottom Line perspective (Xu et al. 2019); ii) the lack of integration of stakeholder expectations in the assessment processes (Escrig-Olmedo et al.

2019); iii) the difference between measuring performance and risks (Semenova and Hassel 2015); iv) or the difficulty in quantifying sustainability risk due to the multidimensionality of the concept and the unpredictability of sustainability risks (Boiral, Talbot, and Brotherton 2020). The concept of risk cannot be reduced to current or past performance and requires an estimate of the probability of occurrence of events (Boiral, Talbot, and Brotherton 2020). Consequently, the following research question arises:

(RQ): *How could we cover the assessment requirements that contribute to measuring corporate sustainability risks considering the whole supply chain?*

To answer this research question, our main objective is to present a framework to assess corporate sustainability risks upstream and downstream, along the supply chains. This Sustainability Risk Assessment Framework will allow knowing the main environmental and social risks of any industry, analyzing their main impacts along the supply chain in various scenarios, but also according to the components of the products or services they offer. Concretely, we define an analytic framework to measure environmental and social risks, based on Muñoz-Torres et al. (2018), that combines the computation of the Organizational Environmental Footprint (OEF) from the European Commission (European Commission 2013) and the Social Footprint following the UNEP/SETAC methodology with the identification of sectoral hotspots following UNEP-SETAC (2017) hotspots analysis methodology.

In this paper, the framework to assess corporate sustainability risks is tested in the mobile phone industry through the definition of three simulated scenarios. The mobile phone industry is characterized by its huge unsustainable impacts, and the complexity of its global supply chain (Catalan and Kotzab 2003). Moreover, mobile phones are one of the most extended mass consumer products as 3.8 billion people use smartphones in the world (Statista Platform 2021).

The SimaPro tool to compute footprints and Ecoinvent and SHDB databases, which are world-leading databases, are used as sources of quantitative data in the environmental and social dimensions.

The paper's primary contribution overall body of knowledge is presenting a framework to assess sustainability risks using science-based tools and metrics (footprints, hotspots analysis, and definition of scenarios), integrating social and environmental dimensions of sustainability along the supply chains, which allow the mitigation of the systemic unsustainability of business. The assessment of sustainability risks along supply chains requires rigorous evaluation tools. However, there are no clearly defined tools to measure sustainability risks (Boiral, Talbot, and Brotherton 2020). Therefore, the present study extends the existing literature on sustainability risk assessment.

The originality of the framework lies in the combination of quantitative (footprints) and qualitative (hotspot analysis) methods for risk assessment along the global supply chains. This combination would provide the best way of supporting decision-making (Aven 2012). In fact, from a more practical perspective, the results of this research could help the decision-making process of policymakers, asset managers, companies and different stakeholders along global supply chains. First, this is a relevant issue considering the changing European regulatory framework, which will foster the European financial market to mainstream sustainability into risk management. Second, as the results of Boiral, Talbot, and Brotherton (2020) confirm, clear information about the assessment of corporate sustainability risks is important for institutional investors. Asset managers require comparable and measurable information to consider sustainability issues in their risk assessment processes (Stewart 2015). Third, companies need a framework that could be used as a corporate risk management tool along global supply chains. In this sense, risk management is the process that allows the identification, assessment, and prevention of exposure to negative events that can affect the company or society as a whole (Boiral, Talbot, and Brotherton 2020). The mismanagement of sustainability risks can have negative consequences for companies and investors (Younas and Zafar 2019) and affect directly the financial performance (Semenova and Hassel 2016).

The remainder of this paper is organized as follows. Section 2 briefly reviews the related literature. Section 3 describes data and methods. Section 4 presents our main results. In Section 5 the implications and contributions are discussed, and Section 6 concludes the paper.

2. Literature Review

Following Dyllick and Muff (2016) 'input-process-output' proposed model, the rationale of this research is summarized as follows (Figure 1):

{Insert **Figure 1. Input-Process-Output Research definition**.}

a) 'Inputs' approach is related to the main concerns for the definition and measurement of corporate sustainability risks (what?).

b) 'Process' approach identifies the main limitations related to corporate sustainability risks assessment upstream and downstream, along global supply chains (how?).

c) 'Output' approach presents a Sustainability Risk Assessment Framework through the analysis of the significant impacts on the mobile phone industry (what for?).

2.1. Sustainability Risks

The Royal Society Study Group (1992) defines risk as "a combination of the probability, of occurrence, or frequency, of a defined hazard and the magnitude of the consequences of the occurrence”. Risk is also defined as a set of uncertain events that affect achieving objectives (Abdel-Basset et al. 2019). Similar definition is provided by ISO 31000 standard. According to ISO 31000 standard risk is defined as “the effect of uncertainty on objectives”. This definition implies that uncertainty can have either a positive or a negative effect on the achievement of objectives (ISO 2018). Therefore, management is crucial to manage all the events that can influence the company’s goals. (Schulte and Hallstedt 2018). Furthermore, in this context of high volatility, unstable environment and significant environmental and social changes the management of sustainability risks should be considered for the survival of the companies (Valinejad and Rahmani 2018)

Focusing on the sustainability risk and going beyond the above-mentioned definition provided by SFDR (2019), Boiral, Talbot, and Brotherton (2020) define sustainability risk as the estimation of the probability of occurrence of events related to environmental and social issues and their impacts that affect sustainable development. Meanwhile, Van der Velden and Taylor (2017) define sustainability risk as a “potential impact, that is an activity in a product’s lifecycle that poses a threat of a breach of defined planetary and social boundaries”. The planetary boundaries approach, defined by scientists at the Stockholm Resilience Centre, delimits the biophysical conditions that offer a high probability that the planet will continue in a state that can support the development of the modern world in a way sustainable (Rockström et al. 2009; Steffen, Rockström, and Costanza, 2011; Steffen et al. 2015,), that is, the ability of the biosphere to recover from disturbances and return to a stable state (Rockström et al. 2009). Humanity must make it a priority to prevent such limits from being crossed, to protect them and to restore the crossed limits. Transgressing these limits puts societies in a dangerous zone.

In this vein, Schulte and Hallstedt (2018) propose the following definition: “sustainability risks are threats and opportunities that are due to an organization’s contribution or counteraction to society’s transition towards strategic sustainable development”. This definition evidence the connection between sustainability risks for the planet and sustainability risks for companies. Companies, as entities that have an impact on the environment where they are located, play a key role in the fight against the different global environmental risks that the Planet faces. With their actions they must contribute to reducing these risks and for this it is essential that they adequately manage their impacts on the environment.

According to the Annual Report of the World Economic Forum (2022) on Global Risks, among the sustainability risks with the greatest impact in the next decade are climate action failure followed by extreme weather and other environmental risks, social cohesion erosion, livelihood crises, infectious diseases, debt crises and geoeconomic confrontation.

Considering the diversity and the impact of sustainability risks, they are playing a crucial role, on the one hand, for investors (Boiral, Talbot, and Brotherton 2020), because their integration into the decision-making processes allows them to make better decisions. Under the European Union’s Sustainable Finance Disclosure Regulation (SFDR 2019), financial market institutions will be required to rethink their risk assessment methodologies to integrate sustainability risks into the investment decision-making process. Rating agencies are the market actors that have made the most efforts to develop sustainability risks assessment methodologies (Escrig-Olmedo et al. 2019). However, the heterogeneity of their measurements (Saadaoui and Soobaroyen 2018); the unpredictability of sustainability risks, the lack of reliable information (Boiral, Talbot, and Brotherton 2020); the differences between measuring risks and performance

(Semenova and Hassel 2015); and the sustainability assessments based on the short-term results (Muñoz-Torres et al. 2019) makes this particularly challenging.

On the other hand, sustainability risks play a determining role for companies that should manage them looking for a balance between environmental protection and corporate sustainable development (Zu 2013) considering that has become a part of their competitive strategy (Avetisyan and Hockerts 2017). In practice, the two main risk management frameworks used globally, the COSO Enterprise Risk Management Framework (2002) (Committee of the Sponsoring Organizations of the Treadway Commission) and the International Organization for Standardization (ISO) 31000 Risk Management Standard (WBCSD 2016), do not appear to present problems in incorporating sustainability aspects into the risk management process (Saardchom 2013). In this sense, several proposals have emerged (e.g., Fernández-Izquierdo, Muñoz-Torres, and Ferrero-Ferrero 2014) to integrate environmental, social and corporate governance risks into the ERM Integrated Framework, elaborated by the Committee of Sponsoring Organizations of the Treadway Commission (COSO).

2.2. Sustainability risk Management

Risk management is the process of treating with risks and becoming prepared to face with those risks and their consequences (Valinejad and Rahmani 2018). Considering this definition, risk management is fundamental to manage the threats that could affect the sustainable development purposes (Bakhtiari 2014). Therefore, companies need to establish sound sustainability risk management systems in order to survive potentially major financial and sustainability damages (Anderson 2005). The management of corporate sustainability risks imply a long-term vision that considers future challenges

(Boiral, Talbot, and Brotherton 2020) and contributes to long-term business sustainability (Valinejad and Rahmani 2018).

Hofmann et al. 2014 emphasize that for risk management in companies it is necessary to consider sustainability issues within supply chains in the process. Failure to consider sustainability risks can lead to severe negative impacts for companies. To address this important gap, the authors propose a theoretically sound concept for sustainability-oriented supply chain risk management based on stakeholder theory.

To make this concept effective, it is necessary to define an adequate risk management process. The aim of this process is to determine, implement and monitor an optimal combination of measures to avoid, defer, reduce or transfer all relevant risks (Hofmann et al. 2014). Recent academic literature highlights that managing risks should follow a structured approach to identifying all relevant risks, assessing probability and impact for each identified risk, reducing risk, and risk monitoring (Hofmann et al. 2014).

The second step, risk assessment, is defined as "the estimation process of the likelihood and consequence of risks, which face the enterprise and prioritizing them or treatment" (Abdel-Basset et al. 2019). In today's global world, it is important to assess risks along the supply chains to recognize the most significant leverage points for improvement (Cabernard, Pfister, and Hellweg 2019) being a strategic requirement for companies (Song, Ming, and Liu 2017).

2.3. Sustainability risks along the Supply chain and their Measurement

Goh, Lim, and Meng (2007) defined supply chain sustainability risk (SCSR) as "the appearance of an accident with the disability of the influenced companies to deal with consequences and impacts". Focusing on the stakeholders involved throughout the supply chain, Hofmann et al. (2014) define SCSR as a "potential sustainability-related condition or event that can provoke harmful stakeholder reactions within the supply chain". While Jüttner, Peck, and Christopher (2003) consider SCR as "the potential and influence of mismatch among supply and demand". More recently, Chowdhury and Quaddus (2021) emphasize supply chain sustainability risk as a function of supply chain disruption and its vulnerability instigated by economic, social and environmental issues.

According to Giannakis and Papadopoulos (2016), sustainability supply chains risks could be ordered into two key categories. Endogenous risks, among which stand out pollution, ozone depletion, emission of greenhouse gases, etc. among environmental risks; work-life imbalance, excessive working time, healthy and safe working environment, etc. among social risks; antitrust claims, tax evasion, etc. among financial risks. Exogenous risks, among which it should be noted are natural disasters, water scarcity, etc. among environmental risks; pandemic, social instability, etc. among social risks; boycotts, litigations, etc. among financial risks.

These sustainability supply chains risks are gradually becoming a strategic requirement for companies (Song, Ming, and Liu 2017). In fact, the European Commission has adopted a proposal for a Directive on Corporate Sustainability Due Diligence (European Commission 2022). The main objective of this proposal is to foster sustainable and responsible corporate behaviour throughout global value chains. They will be required to identify and, where necessary, prevent, end or mitigate adverse impacts of their activities on human rights and on the environment. The actions that a company takes to conduct due diligence should be commensurate to the severity and likelihood of the adverse impact. The results of the Due Diligence will be the feedback into the risk assessment. This clearly reflects the connections between environmental and social impacts in the supply chain and risks for the company.

However, supply chain managers show the difficulty of managing the complex supply chains despite adopting different risk mitigation strategies (Gouda and Saranga 2018). In this sense, for managing supply chains risks (effectively mitigate, avoid or consciously accept them), it needs proper risk identification and supply chain risks assessment frameworks (Kern et al. 2012). From a practical perspective, the COSO model stresses the importance of defining suitable risk assessment methodologies for efficient risk management.

In the current context, where supply chain sustainability risks and their impacts have a greater presence than ever before, different frameworks are being defined for their measurement. Taking into account the definition of risk, several of these frameworks are based on different methodologies for measuring potential impacts along the supply chains.

To tackle with the challenge of measuring impacts related to sustainability risks along the supply chains, different metrics have been developed, among which we should highlight Life Cycle Assessment (LCA) (Arcese, Lucchetti, and Massa 2017; Tsalis, Avramidou, and Nikolaou 2017) and footprints (Cûcêk, Klemeš, and Kravanja 2012). As Zimmer et al. (2017) state, the LCA approach can easily support the assessment process of social and environmental risks along the supply chains.

Focusing on the environmental impacts, for the European Commission (2003) the LCA methodology is the most suitable methodology to measure environmental impacts along the supply chains, from the extraction of raw materials until their final disposal. The International Standards Organization has standardized it into the standards ISO 14040 and ISO 14044. These standards involve the quantification of all resources used and emissions associated with a product’s life cycle. The vast majority of research studies have focused on conducting empirical studies based on the life cycle assessment method (e.g., Bevilacqua et al. 2014; Zhang et al. 2018). Some of the most recent studies have used the environmental footprint tool for computing and assessing environmental impacts (Testa et al. 2017). Muazu, Rothman, and Maltby (2021), after conducting a critical review of 36 articles, highlight the benefits of integrating LCA and environmental risk assessment, which allow addressing the limitations presented in individual assessments. Other authors combine the LCA methodology with other methodologies to assess sustainability risks from a company perspective. For example, Palousis, Luong, and Abhary (2008) develop a framework that integrates LCA and Activity-Based Life Cycle Costing with risk assessment to identify, assess and model the impact of sustainability risks to a product life cycle. In a later work, Palousis, Luong, and Abhary (2010) advances in the development of a sustainability risk assessment model that combines methodologies such as LCA and life-cycle cost (LCC) to asses risks along the supplu chain. Therefore, although LCA is a tool originally used to measure environmental impacts, it has been extended to include sustainability concerns (Matos and Hall 2007).

In this sense, regarding the measurement of social impacts on the supply chain, Social Life Cycle Assessment (SLCA) is one of the most applied methods in the literature (Bonilla-Alicea and Fu 2019). Specifically, Huarachi et al. (2020) highlight the significant role developed by the Guidelines for SLCA of products (UNEP-SETAC 2009a), the Methodological Sheets for Subcategories developed under this framework (UNEP-SETAC 2013), and the Social Hotspots Database (SHDB) related to them (Benoit-Norris, Cavan, and Norris 2012), to implement SLCA analyses.

The hotspot analysis methodology can be a useful tool for identifying potential risks for a specific sector or industry, such as violations or reputational risks (Benoit-Norris, Cavan, and Norris 2012). Several research papers have used the hotspot analysis methodology to measure sustainability risks along supply chains (Roos et al. 2016;

Zamani et al. 2018). However, this methodology seems to offer better results for identifying sustainability risks when combined with other quantitative risk measurement methodologies, as is the case proposed by Kolotzek et al. (2018).

Supply chains risk assessment is the current theme in the supply chain literature and several authors have tried to define comprehensive assessment frameworks for sustainability risks along the supply chains. Xu et al. (2019) develop a framework to assess supply chains sustainability risks based on the triple bottom line. Kolotzek et al. (2018) propose an assessment model that integrates supply risks, environmental impact and social implications using relevant (semi-)quantitative indicators from a company perspective. To the environmental dimension, the LCIA method ‘ReCiPe’ is used for impact assessment. This method assesses impact categories (midpoints) based on life cycle inventories (LCIs) and uses normalization and weighting factors to aggregate these values into damage categories (endpoints) (Goedkoop et al. 2013). For the social dimension, where data are mainly qualitative, the SLCA research method is used (UNEP-SETAC 2009a).

Cunha, Ceryno, and Leiras (2019) go beyond these studies making a systematic literature review and categorizing twenty-four social risks and thirteen consequences of those risks for the company. This analysis helps them to design a Social Supply Chain Risk Management (SSCRM) taxonomy and a framework for practitioners managing social supply chain risks. Recently, Medina-Serrano et al. (2021), based on ISO 31000, developed a practicable risk management process for upstream Supply Chain Risk Management that includes the following phases: (i) risk assessment, (ii) risk identification, (iii) risk analysis, (iv) risk evaluation and (v) risk treatment. It was empirically validated through a case study.

Moreover, considering that risk assessment methodologies must work with uncertainty, some authors propose the use of multi-criteria decision-making methodologies to that end. For example, Mangla, Kumar, and Barua (2015) define a framework of decision-making based on combined fuzzy analytic hierarchy process (AHP) and interpretive ranking process (IRP) methodology to assess the risks linked to green supply chain practices under the fuzzy surroundings. Zimmer et al. (2017) define a social risk assessment model to assess social risks along global supply chains, considering all upstream tiers. It combines fuzzy analytical hierarchy process, structural path analysis, Leontief's input-output model, and methods from SLCA. Most recently, Abdel-Basset et al. (2019) suggest combining the AHP methodology with the TOPSIS technique using triangular neutrosophic numbers to quantify the risks of the supply chain.

Therefore, academic literature presents some proposals to assess supply chains sustainability risks. Some of them integrate the different dimensions of sustainability holistically (e.g. Xu et al. 2019) following Freise and Seuring (2015), that state that economic, environmental and social risks should be included in risk assessment. Furthermore, some of these methodological proposals assess sustainability risks using (semi-)quantitative tools for measuring environmental and social impacts and for identifying sectoral hotspots (Kolotzek et al. 2018). However, to our knowledge, no previous research on sustainability risks assessment has been carried combining: on the one hand, a quantitative method, that assesses sustainability risks with a global perspective considering the impacts of the material and components of a product and integrating upstream and downstream the sustainability impacts of any sector along the global supply chains, under different scenarios and including the usage and recycling stages and; on the other hand, a qualitative method, such as hotspot analysis, that integrates stakeholders expectations in the assessment process using the expert knowledge. The originality of this paper lies in filling the gap evidenced by the literature with the proposal of a Sustainability Risk Assessment Framework.

3. Methods

To answer RQ described in Section 1, we present a Sustainability Risk Assessment Framework. Abovementioned, the development of this framework is based on Muñoz-Torres et al. (2018), that combines the computation of the OEF from the European Commission (European Commission 2013) and the Social Footprint following the UNEP/SETAC methodology with the identification of sectoral hotspots following UNEP-SETAC (2017) hotspots analysis methodology. The combination of these methodologies covers the assessment requirements that contribute to measuring corporate sustainability risks considering the whole supply chain.

This Sustainability Risk Assessment Framework is structured into five main steps (See Figure 2 for more information on the development of this framework).

First, the definition of a goal and scope of a company that produces products. The goal is to identify the key environmental impacts and social impacts and the main hotspots along the global supply chain. To operationalize this concern, we focus on the mobile phone lifecycle as a case study. Specifically, it is based on a company that produces mobile phones. Its components are included in Figure 2. Their choice is based on the findings of Muñoz-Torres et al. (2020).

Second, after analyzing different sources of information (academic literature, standards and sectoral guidelines), the generic structure of a product life cycle is determined.

Third, after gathering data and seeking expert advice, three different testing scenarios are proposed. Scenario analysis is a methodology that makes it possible to study situations of risk or uncertainty. Based on the expert knowledge, two extreme scenarios and an intermediate scenario have been defined in order to collect the possible casuistic of the sector. The three simulated scenarios are defined taking into account the same parameters for all phases of the life cycle, except for the 'End-of-Life' phase. Concretely, in this research, advancing in the existing literature, we propose possible alternatives to landfill, disassembly and reuse stages. As shown in Figure 2, the proposed scenarios extend the life cycle of the product, especially scenario 3. Scenario 1 is the most restrictive and the closest to the current context. However, the objective to foster sustainability is to move towards scenarios 2 and 3. In fact, the new EU regulatory frameworks tend to promote the context defined in scenario 3. See for example the case of Waste Framework Directive (WFD), Landfill Directive (LFD), and Packaging and Packaging Waste Directive (PPWD). The information to define each scenario is based on the public information of one European company that produces mobile phones that are available for the European market. Figure 3 shows the main phases of a mobile phone life cycle and the three scenarios that are considered to apply the Sustainability Assessment Framework (Muñoz-Torres et al. 2020).

Fourth, the Organizational Environmental Footprint (European Commission 2013) and Social Footprint based on the Social Life Cycle Assessment method of UNEP-SETAC (2009a, 2013) are computed using the different scenarios. For the analysis of the environmental dimension, the data are obtained from the SimaPro tool using quantitative data from the database Ecoinvent V3.2. Ecoinvent offers life cycle inventory (LCI) and life cycle impact assessment (LCIA) results. The assessment of the environmental life cycle impacts is carried out with the EF 3.0 Method (adapted) V1.00, the impact assessment method of Environmental Footprint proposed by the European Commission. For the analysis of the social dimension, the data are obtained from the SimaPro tool using quantitative data from the database SHDB v2.1. Based on the analysis of possible social impacts, the Social Hotspots Database (SHDB) allows identifying the main hotspots, countries and sectors of interest, in supply chains with the help of country and sector-specific tables. Concretely, grouped into five social categories (Labor Rights, Health & Safety, Human Rights, Governance, and Community), twenty-two Social Themes Tables are defined. The assessment of the social life cycle impacts is carried out with the SHDB_Ecoinvent_Hybrid_2017_v1_version84. This quantification can be considered as the Social Footprint of the organization analyzed, following UNEP-SETAC (2009b).

Fifth, based on the quantification of the environmental and social footprint for the previously defined simulated scenarios and the introduction of supply chain expert knowledge, the main hotspots of the industry are identified and validated. The hotspots analysis of mobile phone contained in this work is based on the review of the literature and the results of the H2020 WP4 SMART (2016-2020) Project team set out in Van der Velden and Taylor (2017). Their proposed sustainability hotspots analysis based on, UNEP Hotspots Analysis Framework, consists of five phases: (i) identification of the impact categories, (ii) specification of the significance of each impact, (iii) ranking of the salience of the phase for the overall sustainability of the lifecycle, (iv) identification of the sustainability hotspot takes place by multiplying the significance of an impact with the salience of the phase with which it is associated and (v) stakeholder evaluation and verification of hotspots in stakeholder consultations. The criteria applied for identifying the sectoral hotspots follow UNEP-SETAC (2017) and the Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint pilot phase (European Commission 2016), where hotspots are elementary flows '*cumulatively contributing at least 50% to any impact category*' before normalization and weighting. Therefore, considering the science-based footprints impact categories and the expert knowledge of the project team, stakeholders or working group, a consensus on the environmental and social footprints impacts considered as critical points is achieved.

The proposed Sustainability Risk Assessment Framework is tested in the mobile phone industry. The choice of this case study for analysis is due to two main reasons. First, the strategic importance of this sector for the European Union who have funded this research. Specifically, the research conducted is framed within the SMART Project funded by the European Union's Horizon 2020 Research and Innovation Programme. Second, mobile phone industry is stimulating one of the most important technological revolutions (Chatterjee and Kar 2018) and its impacts and challenges must be studied in depth (Harris and Cooper 2019). Moreover, the globality of its supply chain characterizes the mobile phone industry and it is in many cases associated with a range of challenges such as conflict minerals (Jameson, Song, and Pecht 2016), air pollution (Zawacki et al. 2018), labor rights issues related to child labor and forced labor (Wilhelm et al. 2015), and unsustainable e-waste practices (Wilhelm et al. 2015), that have a direct impact on the environment and society. The relevance of these issues fosters the European Union to work to overcome the challenges presented by the sector.

{Insert **Figure 2: Flow chart for the RQ**}
{Insert **Figure 3. Mobile phone lifecycle and scenarios.**}

4. Results

This section presents a framework to assess sustainability risks upstream and downstream along the supply chains. The mobile phone industry is used, from a technical point of view, to empirically show the framework methodology and to highlight the most important risks in this controversial sector.

4.1. Mobile phone industry impacts: a framework to assess sustainability risks along the global supply chains

Considering the sustainability risk definition provided by SFDR (2019) and Boiral, Talbot, and Brotherton (2020) we propose to calculate the environmental and social footprint of a product, in this case of a mobile phone, and identify the main sectoral hotspots based on the expert knowledge. In this sense, the indicators provided by Product Environmental Footprint (PEF) and Social Footprint, based on the foundations of the Social Life Cycle Assessment (S-LCA) method (UNEP-SETAC 2009a, 2013), will allow us to measure the impacts along the supply chains. The combination of the results provided by the impact analysis together with the identification of the hotspots along global supply chain allows us to identify the main environmental and social risks. The results of the evaluation process will allow us to know the most relevant environmental and social risks of the mobile phone industry along the supply chains.

4.1.1. Environmental Footprint

The Product Environmental Footprint (PEF), based on a LCA method, identifies environmental hotspots and quantifies the environmental impacts of products in downstream and upstream processes along the supply chain. The implementation is based on EF method 3.0 (adapted) V1.00 of the European Commission for the 16 environmental impact categories (see Table 1).

This section includes four information inputs for developing an adequate and robust analysis of the main environmental impacts along the supply chains, based on the Environmental Footprint:

(i) The weighted results of the 16 EF impact categories from each scenario that allow us to identify the most relevant impact categories for the industry according to different life cycle scenarios.

(ii) The results of the 16 OEF impact categories and subcategories that arise from each scenario with their units of measurement. The information by categories allows a deeper explanation of the results for each impact category and scenario.

(iii) The cumulative impact contribution of each lifecycle phase to the overall impact by impact category.

(iv) The environmental impact analysis by components that shows which component of a mobile phone presents the greatest environmental impact.

4.1.1.1. Weighted Results

Figure 4 shows the weighted results of the impact categories. The analysis is carried out using the three scenarios previously defined. The weighted results allow us to identify the most important ones according to different life cycle scenarios. The results show that the main impacts for the mobile phone industry are linked to the category of "Resource use, minerals and metals", "Climate Change", and "Resource use, fossils". Analyzing the results by scenarios, scenarios 1 and 2 present greater impacts in all categories except for the category "Acidification", "Photochemical ozone formation" and "Eutrophication, terrestrial", where the impacts for scenario 3 are greater.

{Insert **Figure 4. Environmental weighted results by scenarios.**}

4.1.1.2. Impact Categories Results

Table 1 displays the results of the environmental impacts associated with a mobile phone life cycle for each scenario according to the 16 impact categories and subcategories of the Environmental Footprint, in the corresponding measurement units for each category.

In the specific case of the impact category "Climate Change", the main environmental impacts are associated with the use of fossil fuels, which could be due to the use of energy for the operation of mobile phones. However, this statement cannot be confirmed without performing the analysis for each phase of the life cycle.

{Insert **Table 1. Environmental impact analysis results considering a mobile phone lifecycle by scenarios}**

Carrying out a more detailed analysis of the main impact categories for the mobile phone industry ("Resource use, minerals and metals", "Climate Change", and "Resource use, fossils") for each scenario (see Figure 5), scenario 3 is the scenario that most extends the life cycle through reuse. Therefore, the impacts linked to these three environmental impact categories ("Resource use, minerals and metals", "Climate Change", and "Resource use, fossils") are lower than in scenarios 1 and 2.

{Insert **Figure 5. Results of the analysis of the environmental impact in the three main impact categories of the mobile phone industry by scenarios**}

4.1.1.3.Cumulative Impact Contribution

Table 2 and Figure 6 allow us to identify the cumulative impact contribution by impact category throughout the life cycle for the three proposed scenarios. We can observe that for the three proposed scenarios, the impact categories "Resource use, minerals and metals", "Climate Change", and "Resource use, fossils" accumulate the main impacts for the mobile phone industry. Concretely, in the case of scenarios 1 and 2, these impacts represent 76% of all impacts. However, for scenario 3, which extends the life cycle with the reuse of the product, they represent 68% of the total impact. To deepen the explanation of these results, environmental analysis is required.

{Insert **Table 2. Cumulative environmental impact contribution of each life-cycle phase of a mobile phone scenario.}**

{Insert **Figure 6. Cumulative environmental impact contribution of each life-cycle scenario**.}

4.1.1.4. Components Results

Analyzing the environmental impact by components (see Table 3), the greatest impacts are linked to electronics, representing 91% of the impacts by components (see Figure 7).

{Insert **Table 3. Environmental impact analysis by components.}**

{Insert **Figure 7. Environmental Impact contribution by component**.}

Focusing on the accumulated impacts by components and by impact categories, "Climate Change" is the category that accumulates the main impacts (see Table 4). Concretely, as shown in Figure 8, in the impact category "Climate Change" the main impacts are related to electronics. Therefore, the analysis by impact categories shows similar results to the general analysis by components.

{Insert **Table 4. Total environmental impact by components**.}

{Insert **Figure 8. Environmental Impact contribution by component**.}

4.1.2. Social Footprint

The Social Footprint, based on the foundations of the Social Life Cycle Assessment (S-LCA) method (UNEP-SETAC 2009a, 2013), quantifies an organization's social impact.

This technique aims to assess the social and socio-economic impacts (and potential impacts) of products along their life cycle based on the general guidelines of ISO 14 044.

This section includes three information inputs for carrying out the suitability analysis of the Social Footprint:

(i) The weighted results of the social categories from each scenario to identify the most relevant. These results are presented in terms of points following the UNEP-SETAC method.

(ii) The results of the 18 impact categories associated with 5 social categories that arise from each scenario.

(iii) The social impact analysis by component that shows which component of a mobile phone presents the greatest social impact.

4.1.2.1. Weighted Results

Figure 9 shows the weighted results of the social categories for the three scenarios previously defined. The weighted results, presented in terms of points, allow us to identify the most important ones. The results show that the main impacts for the mobile phone industry are linked to the social categories "Labor right and decent work" and "Health and safety" for the three scenarios, although these impacts are lower in the case of scenario 3.

{Insert **Figure 9. Social weighted results by scenarios**.}

4.1.2.2. Impact Categories Results

Table 5 shows the 18 impact categories results associated with the mobile phone lifecycle. The analysis is carried out using the three scenarios previously defined.

{Insert **Table 5. Social impact analysis results considering a mobile phone lifecycle by scenarios.}**

Focusing on the “Labor rights and decent work” social category, the two most important impact categories are: “Collective bargaining” and “Wage assessment”. Regarding the “Health and safety” social category, the main impacts are related to the impact category “Toxics and hazards”. In the case of the social category “Human rights” it is “High conflicts” impact category the most relevant in terms of greater social impacts. For the social category “Governance” it is “Corruption” and finally for the social category “Community infrastructure” it is “Hospital beds” for scenario-3 and “Improved sanitation” for the scenario 1-2.

Furthermore, this analysis makes it possible to evaluate the impacts based on the life cycle scenarios that are defined and analyze the possible differences. In this case, scenario 3 shows better results in all the social categories analyzed.

4.1.2.3.Components results

Table 6 shows the social impact by components and, as in the analysis of environmental impacts, the greatest impacts are linked to electronics.

{Insert **Table 6. Social impact analysis by components.}**

Focusing on the accumulated impacts by components and by social categories, “Labor right and decent work” is the category that accumulates the main impacts (see Table 7). Concretely, as shown in Figure 10, in the social category "Labor right and decent work" more than 75% of the impacts are linked to the electronics. This result is the same for the rest of the categories. Therefore, the analysis by social categories shows similar results to the general analysis by components.

{Insert **Table 7. Total social impact by components**.}

{Insert **Figure 10. Social Impact contribution by component**.}

4.1.3. Hotspots analysis

The Sustainability Risk Assessment Framework along the supply chains proposed in this paper establishes that the technical results derived from footprints tools (the identified environmental and social impacts) should be provided to experts for discussion and subsequent validation. Following the UNEP Hotspots Analysis Framework, and specifically the Sustainability Hot Spots Analysis (SHSA) methodology, experts enable the potential connections between similar impacts, in different phases of the lifecycle, and they weigh the different impacts. This weighting involved ranking the identified impacts, first considering their likelihood in relation to a particular phase, and, second, in relation to their salience of that phase to the sustainability of lifecycle overall. This allows the identification and assessment of the main sustainability risks along the supply chains. But while the task is not entirely easy, each risk, which arose the life cycle, might translate into a salient risk to a planetary or social boundary (See the Van der Velden and Taylor [2017] proposal). We strongly believe that companies should focus on minimizing its sustainability risks and seeking to generate a positive impact in the society and the planet.

Focusing in our case of study, the expert knowledge to the hotspots identification is based on the review of the literature and the results of the H2020 WP4 SMART Project team set out in Van der Velden and Taylor (2017), which carry out a hotspots analysis in the lifecycle of two mobile phones based on a literature review, interviews and discussions with stakeholders. It is important to note that Van der Velden and Taylor (2017) selected the “Sustainability Hot Spots Analysis” (SHSA) methodology for their analysis.

Van der Velden and Taylor (2017) point out the risk of “Biodiversity loss (Hazardous materials/ecotoxicity)” in resource extraction and production lifecycle phases as one of the main environmental risks for the mobile phone industry, which is directly related to the categories of impact “Resource use, fossils” or “Human toxicity – non-cancer effects”. Furthermore, Van der Velden and Taylor (2017) find the social hotspots associated with the mobile phone lifecycle are found in the social categories: “Labor rights and decent work” and “Health and safety”. Concretely, in the social category “Labor rights and decent work” the main impacts are in the impact category “Collective bargaining” which can be connected to the risk Labor Rights (No union work) in the qualitative analysis; and in the impact category “Wage assessment” which can be connected to the risk Labor Rights (low wages) in the qualitative analysis. Note that these impacts belong mainly to the production lifecycle phase. Regarding social category “Health and safety” the main impacts are in the impact category “Toxics and hazards” that can be connected to the risks “Eco-human toxicity” and “Labor Rights (Hazardous materials/Human toxicity)” in the qualitative analysis. These impacts belong mainly to the resource extraction and production lifecycle phases.

On the basis of hotspots analysis, and based on the results of the footprints, a selection of priority sustainability risks along the supply chains can be determined.

5. Discussion

Growing globalization means that many products today cross multiple boundaries before they end up in someone’s home and contain parts from many different places and countries. These extended supply chains are more vulnerable and expose companies to a large number of global risks (Giannakis and Papadopoulos 2016). This complex context is forcing companies to rethink their supply risk assessment methodologies (Harwood and

Humby 2008). In particular, to avoid the possible negative impacts derived from operations with the different actors of the supply chain, it is necessary to define frameworks for measuring sustainability risks upstream and downstream, along the supply chains (Ellis, Henry, and Shockley 2010), as well as, to establish risks management systems (Shafiq et al. 2017). In this context, *how could we cover the assessment requirements that contribute to measuring corporate sustainability risks considering the whole supply chain?*

This research presents an innovative Sustainability Risk Assessment Framework to assess sustainability risks along the global supply chains, considering not only direct impacts but also upstream and downstream ones, using the environmental and social footprint calculation tool, under different scenarios including the usage and recycling stages, and hotspots analysis. The combination of quantitative (footprints tools) and qualitative methods (hotspots analysis) for risk assessment along the global supply chains would provide the best way of supporting decision-making (Aven 2012).

As has been previously discussed in this paper, both management practice and academia have made efforts to define frameworks for measuring sustainability risks along global supply chains (e.g. Kolotzek et al. 2018; Xu et al. 2019). However, there are still certain challenges to overcome in these proposals. Some of those challenges have been addressed in this research, for example:

(i) The lack of a holistic framework that integrates all dimensions of sustainability. Most proposals to assess risks along the supply chain do so in an isolated way, social risks (e.g., Altay and Ramirez 2010), and environmental risks (e.g., Fiksel 2010). Only a few authors have made proposals to assess supply chain sustainability risks in a holistic way (Xu et al. 2019). This research presents an innovative Sustainability

Risk Assessment Framework to assess in an integrated way the sustainability risks along the global supply chains.

(ii) The lack of integration of stakeholders' expectations in the evaluation process (Escrig-Olmedo et al. 2019), or the lack of risk assessment under different scenarios including, for instance, the usage and recycling stages.

(iii) The lack of works that combine quantitative methodologies (e.g., footprints) and qualitative methodologies (e.g., Hotspot Analysis) for the assessment of sustainability risks. In this sense, Kolotzek et al. (2018) highlight that Hotspot Analysis methodology seems to offer better results for identifying sustainability risks when combined with other quantitative risk measurement methodologies. This Sustainability Risk Assessment Framework allows the measurement of sustainability risks by carrying out a quantitative analysis of environmental and social impacts from three dimensions (by scenarios, by product components, by life cycle stage); and qualitative analysis through hotspot analysis

Therefore, the Sustainability Risk Assessment Framework tested in this paper improves the current risk assessment models. In particular, it presents the following advantages from a professional perspective:

(i) It can be useful for assessing and managing corporate sustainability risks associated with the life cycle, which contributes to reducing environmental and social impacts. However, for this purpose, it would be necessary to integrate the Sustainability Risk Assessment Framework proposed in this research into an assessment tool that integrates Sustainability Principles into the Global Supply Chain such as the one proposed by Muñoz-Torres et al. (2018).

(ii) Growing of environmental and social awareness and lifecycle thinking at all levels of the supply chain.

(iii) Increases transparency on material environmental and social hotspots for the sector.

(iv) Combines science-based techniques with expert knowledge and political interests (stakeholders' expectations and needs).

(v) Data sources and methods are fully transparent and allow the comparison of annual results.

(vi) It is applicable to any kind of organization, regardless of its location, size, business area, and structure.

Moreover, this framework should be able to be used as a sustainability risks management tool. To that end, this Sustainability Assessment Framework should be based on three important processes following Muñoz-Torres et al. (2018):

(i) Traceability in the product's sustainable management that facilitates the identification of both direct and indirect impacts.

(ii) Assurance that the information is relevant and reliable for all stakeholders.

(iii) Continuous improvement of sustainability practices, processes, and performance that allows the extension of the scope of the Sustainability Assessment Framework implementation over time.

Finally, considering that good corporate governance is a fundamental pillar of an organization, the Sustainability Assessment Framework should define its bases. In this sense, it is crucial defining six action areas, which address critical issues in corporate governance and sustainability: governance foundations, stakeholder engagement, internal governance structures, tools for board's due diligence, sustainability information and communication, and governance mechanisms for the supply chain. Several authors, such as Chowdhury and Quaddus (2021), remark that sustainability governance could reduce supply chains sustainability risks.

6. Conclusions

To overcome the sustainability risks assessment weaknesses presented by risks assessment methodologies, this paper presents the application of the Sustainability Risk Assessment Framework using the environmental and social footprint calculation tool and hotspots analysis. Footprints are tested in three simulated scenarios in the mobile phone industry.

The findings have important implications for organizations and managers. First, it provides information on impacts and critical points of any sector that facilitates the decision-making process of stakeholders in the supply chain. Second, this framework should be able to be used by organizations as a sustainability risks management tool. Third, asset managers require comparable and measurable information to consider sustainability issues and the significant impacts for a specific sector in their risk assessment processes. The results obtained after implementing the framework tested in this paper could facilitate the creation of different financial products and help asset managers in their choice of sustainability risks measurement and management approaches allowing them to take better and informed investment decisions.

All market actors in the mobile supply chain are concerned and interested in these results, which show the environmental and social consequences of different waste strategy included in the waste management hierarchy using three scenarios. The results show the low impact of recycling strategies, not only in environmental terms, but also in social terms. Fostering reuse strategies by companies (scenario 3) will improve substantially, not only their environmental impact but also their social impact. This could have implications for the different decision-makers, in terms of business models and regulatory decisions promote more circular solutions, where extending the life of products is the main path for optimizing social and environmental impacts.

There are several limitations of this study that should be addressed in future research. First, the lack of standardized social indicators entails the presence of a degree of interpretation in the work of analysts, also applicable in the correspondences defined between social impact categories used by SHDB and social issues cataloged by UNEP-SEPAC. However, the intervention of more than one analyst in each analysis has reduced the potential bias that could arise. Finally, the definition of scenarios and the selection of one product for a simulated company is a simplification of business reality. However, it increases the soundness of the study and enriches the conclusions, allowing to detect potential differences depending on the lifecycle features defined in each scenario.

There are other avenues for future research on this topic. First, economic impacts should be included in the sustainability risks assessment process, defining a holistic framework that integrates social, environmental, and economic risks in the sustainability assessment process along the global supply chain including a multi-tier approach. Research should advance in addressing the extension of lifecycle strategies to also achieve economic sustainability, both for the company and for society. Second, the integration of traceability in the product's sustainable management, the assurance process, and the continuous improvement are processes that should be integrated into the sustainability risk assessment process to better manage sustainability risks.

References

References

Abdel-Basset, M., M. Gunasekaran, M. Mohamed, and N. Chilamkurti, 2019. "A framework for risk assessment, management and evaluation: Economic tool for quantifying risks in supply chain." *Future Generation Computer Systems* 90 (1): 489-502. doi: https://doi.org/10.1016/j.future.2018.08.035

Altay, N., and A. Ramirez. 2010. "Impact of disasters on firms in different sectors: implications for supply chains". *Journal of Supply Chain Management* 46 (4): 59-80. doi: https://doi.org/10.1111/j.1745-493X.2010.03206.x.

Anderson, D. 2005. *Corporate Survival: the Critical Importance of Sustainability Risk Management*. Universe, Incorporated. ISBN: 9780595364602

Arcese, G., M. C. Lucchetti, and I. Massa. 2017. "Modeling Social Life Cycle Assessment framework for the Italian wine sector." *Journal of Cleaner Production* 140:1027–1036. doi: https://doi.org/10.1016/j.jclepro.2016.06.137.

Aven, T. 2012. "The risk concept – historical and recent development trends." *Reliability Engineering & System Safety* 99: 33–44.doi: https://doi.org/10.1016/j.ress.2011.11.006.

Avetisyan, E., and K. Hockerts. 2017. "The consolidation of the ESG rating industry as an enactment of institutional retrogression." *Business Strategy and the Environment* 26(3): 316–330.doi: https://doi.org/10.1002/bse.1919.

Bakhtiari, S. 2014. "Risk management: a powerful instrument for sustainable development." OIDA International Journal of Sustainable Development *7*(05): 95-104.

Benoit-Norris, C., D. A. Cavan, and G. Norris. 2012. "Identifying social impacts in product supply chains: overview and application of the social hotspot database." *Sustainability*. 4 (9): 1946-1965. doi: https://doi.org/10.3390/su4091946.

Bevilacqua, M., F. E. Ciarapica, G. Mazzuto, and C. Paciarotti. 2014. "Environmental analysis of a cotton yarn supply chain." *Journal of Cleaner Production* 82: 154–165. doi: https://doi.org/10.1016/j.jclepro.2014.06.082.

Boiral, O., D. Talbot, and M.C. Brotherton. 2020. "Measuring sustainability risks: A rational myth?" *Business Strategy and the Environment* 29 (6): 2557-2571. doi: https://doi.org/10.1002/bse.2520

Bonilla-Alicea, R. J., and K. Fu. 2019. "Systematic map of the social impact assessment field." *Sustainability* 11 (15): 4106. doi: https://doi.org/10.3390/su11154106.

Cabernard, L., S. Pfister, and S. Hellweg. 2019. "A new method for analyzing sustainability performance of global supply chains and its application to material resources." *Science of The Total Environment* 684 (2019): 164-177. doi: https://doi.org/10.1016/j.scitotenv.2019.04.434.

Catalan, M., and H. Kotzab. 2003. "Assessing the responsiveness in the Danish mobile phone supply chain." *International Journal of Physical Distribution & Logistics Management* 33(8), 668-685. doi: https://doi.org/10.1108/09600030310502867.

Chatterjee, K., and S. Kar. 2018. "Supplier selection in Telecom supply chain management: a Fuzzy-Rasch based COPRAS-G method." *Technological and Economic Development of Economy* 24(2): 765-791. doi: https://doi.org/10.3846/20294913.2017.1295289

Chowdhury, M. M. H., and M. A Quaddus. 2021. "Supply chain sustainability practices and governance for mitigating sustainability risk and improving market performance: A dynamic capability perspective." *Journal of Cleaner Production*. 278: 123521. doi: https://doi.org/10.1016/j.jclepro.2020.123521.

Cûcêk, L., J. J. Klemeš, and Z. Kravanja. 2012. "A review of footprint analysis tools for monitoring impacts on sustainability." *Journal of Cleaner Production* 34: 9–20. doi: https://doi.org/10.1016/j.jclepro.2012.02.036.

Cunha, L., P. Ceryno, and A. Leiras. 2019. "Social supply chain risk management: A taxonomy, a framework and a research agenda." *Journal of Cleaner Production* 220: 101-1110. doi: https://doi.org/10.1016/j.jclepro.2019.02.183.

Dyllick, T., and K. Muff, 2016. "Clarifying the meaning of sustainable business: Introducing a typology from business-as-usual to true business sustainability." *Organization & Environment* 9 (2): 156-174. doi: https://doi.org/10.1177/1086026615575176.

Ellis, S.C., R.M. Henry, and J. Shockley. 2010. "Buyer perceptions of supply disruption risk: a behavioral view and empirical assessment." *Journal of Operations Management* 28 (1): 34-46. doi: https://doi.org/10.1016/j.jom.2009.07.002.

Escrig-Olmedo, E., M. Á. Fernández-Izquierdo, I. Ferrero-Ferrero, J. M. Rivera-Lirio, and M. J. Muñoz-Torres. 2019. "Rating the raters: Evaluating how ESG rating agencies integrate sustainability principles." *Sustainability* 11 (3): 915. doi: https://doi.org/10.3390/su11030915.

European Commission. 2003. *Communication from the commission to the Council and the European Parliament. Integrated Product Policy, Building on Environmental Life-Cycle Thinking. Brussels.* https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2003:0302:FIN:en:PDF (Accessed on 16 November 2020)

European Commission. 2013. *2013/179/EU: Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations*. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013H0179 (Accessed on 16 November 2020)

European Commission. 2016. *Product Environmental Footprint Pilot Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint (EF) pilot phase. Version 5.2 – February 2016*. http://ec.europa.eu/environment/eussd/smgp/pdf/Guidance_products.pdf (Accessed on 16 November 2020)

European Commission. 2020. *Europe's moment: Repair and Prepare for the Next Generation.* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0456&from=ES (Accessed on 3 February 2021)

European Commission. 2022. *Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Corporate Sustainability Due Diligence and amending Directive (EU) 2019/1937.* https://commission.europa.eu/publications/proposal-directive-corporate-sustainability-due-diligence-and-annex_en (Accessed on 22 January 2023).

Fernández-Izquierdo, M.A., M.J. Muñoz-Torres, and I. Ferrero-Ferrero. 2014. "Comprehensive Management and Financial and Extra-financial Risk Control to Overcome the Business Crisis." *European Company Law* 11 (2): 81 – 85. doi: https://doi.org/10.54648/eucl2014015.

Fiksel, J. 2010. "Evaluating supply chain sustainability". *Chemical Engineering Progress* 106 (5): 28-38.

Freise, M., and S. Seuring. 2015. “Social and environmental risk management in supply chains: a survey in the clothing industry.” *Logistics Research* 8 (2015): 1-12. doi: https://doi.org/10.1007/s12159-015-0121-8.

Giannakis, M. and T. Papadopoulos. 2016. “Supply chain sustainability: A risk management approach.” *International Journal of Production Economics* 171 (2016): 455-470. doi: https://doi.org/10.1016/j.ijpe.2015.06.032.

Goedkoop, M., R. Heijungs, A. De Schryver, J. Struijsvan, and R. Zelm. 2013. *ReCiPe 2008. A LCIA method which comprises harmonised category indicators at the midpoint and the endpoint level. Characterisation. Updated RIVM report.* Bilthoven, Netherlands: RIVM.

Goh, M., J. Y. Lim, and F. Meng. 2007. “A stochastic model for risk management in global supply chain networks.” *European Journal of Operational Research* 182 (1): 164-173. doi: https://doi.org/10.1016/j.ejor.2006.08.028.

Gouda, S. K., and H. Saranga. 2018. “Sustainable supply chains for supply chain sustainability: impact of sustainability efforts on supply chain risk.” *International Journal of Production Research* 56(17): 5820-5835. doi: https://doi.org/10.1080/00207543.2018.1456695.

Harris, A., and M. Cooper. 2019. “Mobile phones: Impacts, challenges, and predictions.” *Human Behavior and Emerging Technologies* 1(1), 15-17. doi: https://doi.org/10.1002/hbe2.112.

Harwood, I., and S. Humby. 2008. “Embedding corporate responsibility into supply: a snapshot of progress.” *European Management Journal* 26 (3): 166-174. doi: https://doi.org/10.1016/j.emj.2008.01.005.

Hofmann, H., C. Busse, C. Bode, and M. Henke. 2014. “Sustainability-related supply chain risks: Conceptualization and management.” *Business Strategy and the Environment* 23 (3): 160-172. doi: https://doi.org/10.1002/bse.1778.

Huarachi, D. A. R., C. M. Piekarski, F. N. Puglieri, and A. C. de Francisco. 2020. “Past and future of Social Life Cycle Assessment: Historical evolution and research trends.” *Journal of Cleaner Production* 264: 121506. doi: https://doi.org/10.1016/j.jclepro.2020.121506.

ISO (International Organization for Standardization). 2018. *ISO 31000:2018 risk management – Guidelines*. International Standards Organisation.

Jameson, N. J., X. Song, and M. Pecht. 2016. “Conflict minerals in electronic systems: An overview and critique of legal initiatives.” *Science and engineering ethics* 22 (5): 1375-1389. doi: https://doi.org/10.1007/s11948-015-9704-7.

Jüttner, U., H. Peck, and M. Christopher. 2003. “Supply chain risk management: outlining an agenda for future research.” *International Journal of Logistics: Research and Applications*. 6(4):197-210. doi: https://doi.org/10.1080/13675560310001627016

Kern, D., R. Moser, E. Hartmann, and M. Moder. 2012. “Supply risk management: model development and empirical analysis.” *International Journal of Physical Distribution & Logistics Management* 42(1): 60-82. doi: https://doi.org/10.1108/09600031211202472.

Kolotzek, C., C. Helbig, A. Thorenz, A. Reller, and A. Tuma. 2018. “A company-oriented model for the assessment of raw material supply risks, environmental impact and social implications.” *Journal of Cleaner Production* 176: 566-580. doi: https://doi.org/10.1016/j.jclepro.2017.12.162.

Mangla, S. K., P. Kumar, and M. K. Barua. 2015. “Flexible decision modeling for evaluating the risks in green supply chain using fuzzy AHP and IRP methodologies." *Global Journal of Flexible Systems Management* 16 (1): 19-35. doi: https://doi.org/10.1007/s40171-014-0081-x.

Matos, S., and J. Hall. 2007. "Integrating sustainable development in the supply chain: The case of life cycle assessment in oil and gas and agricultural biotechnology." *Journal of operations management* 25 (6): 1083-1102. doi: https://doi.org/10.1016/j.jom.2007.01.013.

Medina-Serrano, R., R. Gonzalez-Ramirez, J. Gasco-Gasco, and J.Llopis-Taverner. 2021. "How to evaluate supply chain risks, including sustainable aspects?. A case study from the German Industry." J*ournal of Industrial Engineering and Management* 14 (2): 73-89. doi:10.3926/jiem.3175.

Miemczyk, J., and D. Luzzini, 2018. "Achieving triple bottom line sustainability in supply chains." *International Journal of Operations & Production Management* 39(2), 238-259. doi: https://doi.org/10.1108/IJOPM-06-2017-0334.

Muazu, R. I., Rothman, R., and Maltby, L. 2021. "Integrating Life Cycle Assessment and Environmental Risk Assessment: A critical review." *Journal of Cleaner Production* 293: 126120. doi: https://doi.org/10.1016/j.jclepro.2021.126120.

Muñoz-Torres, M.J., M.Á. Fernández-Izquierdo, J.M., Rivera-Lirio, and E. Escrig-Olmedo. 2019. "Can environmental, social, and governance rating agencies favor business models that promote a more sustainable development?" *Corporate Social Responsibility and Environmental Management* 26 (2): 439-452. doi: https://doi.org/10.1002/csr.1695.

Muñoz-Torres, M. J., M. Á. Fernández-Izquierdo, J. M. Rivera-Lirio, I. Ferrero-Ferrero, E. Escrig-Olmedo, J. V. Gisbert-Navarro, and M. C. Marullo. 2018. "An assessment tool to integrate sustainability principles into the global supply chain." *Sustainability* 10 (2): 535. doi: https://doi.org/10.3390/su10020535.

Muñoz-Torres, M. J., M. Á. Fernández-Izquierdo, J. M. Rivera-Lirio, I. Ferrero-Ferrero, E. Escrig-Olmedo, and J.V Gisbert-Navarro. 2020. D5.6. *Testing Sustainability Assessment Tool in the selected case studies from Textile and Mobile Phone Sectors.* Report SMART H2020 Project. https://www.smart.uio.no/publications/reports/d5.6.v3_final.pdf (Accessed on 16 November 2020)

Mzougui, I., S. Carpitella, A. Certa, Z. E. Felsoufi, and J. Izquierdo. 2020. “Assessing Supply Chain Risks in the Automotive Industry through a Modified MCDM-Based FMECA”. *Processes* 8 (5):579. doi: https://doi.org/10.3390/pr8050579.

Palousis, N., L. Luong, and K. Abhary. 2008. *An integrated LCA/LCC framework for assessing product sustainability risk.* WIT Transactions on Information and Communication Technologies 39:121–128. doi:10.2495/RISK080131.

Palousis, N., L. Luong, and K. Abhary. 2010. “Sustainability risk identification in product development.” *International Journal of Sustainable Engineering* 3 (2): 70–80. doi: https://doi.org/10.1080/19397031003686900.

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, E. F. Lambin, et al. 2009. “A safe operating space for humanity.” *Nature* 461(7263): 472-475. doi: https://doi.org/10.1038/461472a.

Roos, S., B. Zamani, G. Sandin, G. M. Peters, and M. Svanström. 2016. “A life cycle assessment (LCA)-based approach to guiding an industry sector towards sustainability: the case of the Swedish apparel sector.” *Journal of Cleaner Production* 133: 691-700. doi: https://doi.org/10.1016/j.jclepro.2016.05.146.

Royal Society Study Group. 1992. *Risk: analysis, perception and management*. The Royal Society.

SDSN (Sustainable Development Solutions Network). 2020. *Sustainable Development* Report. Cambridge University Press. https://www.sdgindex.org/ (Accessed on 16 November 2020)

SFDR (EU Sustainable Finance Disclosure Regulation). 2019. *Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R2088 (Accessed on 16 November 2020)

Saadaoui, K., and T. Soobaroyen, 2018. "An analysis of the methodologies adopted by CSR rating agencies." *Sustainability Accounting, Management and Policy Journal* 9(1): 43-62. doi: https://doi.org/10.1108/SAMPJ-06-2016-0031.

Saardchom, N. 2013. "Enterprise risk management under sustainability platform." *Journal of Business and Economics* 4 (1): 32-41. ISSN 2155-7950.

Semenova, N., and L.G. Hassel. 2015. "On the validity of environmental performance metrics." *Journal of Business Ethics* 132 (2015): 249-258. doi: https://doi.org/10.1007/s10551-014-2323-4.

Semenova, N., and Hassel, L.G. 2016. "The moderating effects of environmental risk of the industry on the relationship between corporate environmental and financial performance." *Journal of Applied Accounting Research* 17 (1): 97– 114. doi: https://doi.org/10.1108/JAAR-09-2013-0071.

Shafiq, A., P.F. Johnson, R. D. Klassen, and A. Awaysheh. 2017. "Exploring the implications of supply risk on sustainability performance." *International Journal of Operations & Production Management* 37(10): 1386-1407. doi: https://doi.org/10.1108/IJOPM-01-2016-0029.

Schulte, J., and S. I. Hallstedt. 2018. "Company risk management in light of the sustainability transition." *Sustainability* 10(11): 4137. doi: https://doi.org/10.3390/su10114137.

Song, W., X. Ming, and H. C. Liu. 2017. "Identifying critical risk factors of sustainable supply chain management: A rough strength-relation analysis method." *Journal of Cleaner Production* 143: 100-115. doi: https://doi.org/10.1016/j.jclepro.2016.12.145.

Statista Platform. 2021. Number of smartphone users worldwide from 2016 to 2021. https://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/ (Accessed on 10 January 2021)

Steffen, W., Richardson, K., Rockstrom, J., et al. 2015. "Planetary boundaries: guiding human development on a changing planet." *Science* 347(6223): 1259855. doi: 10.1126/science.1259855.

Steffen, W., J. Rockström, R. Costanza. 2011. "How defining planetary boundaries can transform our approach to growth." *Solutions*: F*or A Sustainable & Desirable Future* 2(3):59-65. doi: http://archives.pdx.edu/ds/psu/8764.

Stewart, L.S. 2015. "Growing demand for ESG information and standards: Understanding corporate opportunities as well as risks." *Journal of Applied Corporate Finance* 27 (2): 58– 63. doi: https://doi.org/10.1111/jacf.12118.

Testa, F., B. Nucci, F. Iraldo, A. Appolloni, and T. Daddi. 2017. "Removing obstacles to the implementation of LCA among SMEs: A collective strategy for exploiting recycled wool." *Journal of Cleaner Production* 156: 923–931.doi: https://doi.org/10.1016/j.jclepro.2017.04.101.

Teuscher, P., B. Grüninger, and N. Ferdinand. 2006. "Risk management in sustainable supply chain management (SSCM): lessons learnt from the case of GMO-free soybeans." *Corporate Social Responsibility and Environmental Management*. 13 (1): 1-10. doi: https://doi.org/10.1002/csr.81.

Tsalis, T., A. Avramidou, and I. E. Nikolaou. 2017. "A social LCA framework to assess the corporate social profile of companies: Insights from a case study." *Journal of Cleaner Production* 164: 1665–1676. doi: https://doi.org/10.1016/j.jclepro.2017.07.003.

UNEP-SETAC (United Nations Environment Programme/Society of Environmental Toxicology and Chemistry). 2017. *Hotspots analysis. An overarching methodological framework and guidance for product and sector level application*. www.lifecycleinitiative.org (Accessed on 25 February 2019).

UNEP-SETAC (United Nations Environment Programme/Society of Environmental Toxicology and Chemistry). 2009a. *Guidelines for Social Life Cycle Assessment of Products.* http://www.unep.fr/shared/publications/pdf/DTIx1164xPA-guidelines_sLCA.pdf (Accessed on 25 February 2020).

UNEP-SETAC (United Nations Environment Programme/Society of Environmental Toxicology and Chemistry). 2009b. *Life Cycle Management. How business uses it to decrease footprint, create opportunities and make value chains more sustainable.* www.unep.fr (Accessed on 25 February 2020).

UNEP-SETAC (United Nations Environment Programme/Society of Environmental Toxicology and Chemistry). 2013. *The Methodological Sheets for Sub-categories in Social Life Cycle Assessment (S-LCA).* www.lifecycleinitiative.org (Accessed on 25 February 2019).

Valinejad, F., and D. Rahmani. 2018. "Sustainability risk management in the supply chain of telecommunication companies: A case study." *Journal of Cleaner Production* 203: 53-67. doi: https://doi.org/10.1016/j.jclepro.2018.08.174.

Van der Velden, M., and M.B. Taylor. 2017. *Sustainability Hotspots Analysis of the Mobile Phone Lifecycle*. University of Oslo, Oslo.

WBCSD (World Business Council For Sustainable Development).2016. *Sustainability and enterprise risk management: The first step towards integration*. https://www.wbcsd.org/Programs/Redefining-Value/Business-Decision-Making/Assess-and-Manage-Performance/Resources/Sustainability-and-enterprise-risk-management-The-first-step-towards-integration (Accessed on 25 February 2021).

Wever, M., P.M. Wognum, J.H. Trienekens and S.W.F Omta. 2012. "Supply chain-wide consequences of transaction risks and their contractual solutions: towards an extended transaction cost economics framework." *Journal of Supply Chain Management* 48 (1): 73-91.

Wilhelm, M., M. Hutchins, C. Mars, and C. Benoit-Norris. 2015. "An overview of social impacts and their corresponding improvement implications: a mobile phone case study." *Journal of Cleaner Production* 102: 302-315. doi: https://doi.org/10.1016/j.jclepro.2015.04.025.

World Economic Forum. 2022. *The Global Risks Report 2022, 17th Edition*. https://www.weforum.org/reports/global-risks-report-2022/ (Accessed on 22 January 2023).

Xu, M., Y. Cui, M. Hu, X. Xu, Z. Zhang, S. Liang, and S. Qu. 2019. "Supply chain sustainability risk and assessment." *Journal of Cleaner Production* 225: 857-867. doi: https://doi.org/10.1016/j.jclepro.2019.03.307.

Younas, Z. I., and , A. Zafar. 2019. "Corporate risk taking and sustainability: A case of listed firms from USA and Germany." *Journal of Global Responsibility* 10, (1): 2–15. doi: https://doi.org/10.1108/JGR-07-2018-0027.

Zamani, B., G. Sandin, M. Svanström, and G. M. Peters. 2018. “Hotspot identification in the clothing industry using social life cycle assessment—opportunities and challenges of input-output modelling.” *The International Journal of Life Cycle Assessment*. 23 (3): 536-546.doi: https://doi.org/10.1007/s11367-016-1113-x.

Zawacki, M., K. R. Baker, S. Phillips, K. Davidson, and P. Wolfe. 2018. “Mobile source contributions to ambient ozone and particulate matter in 2025.” *Atmospheric Environment* 188: 129-141.doi: https://doi.org/10.1016/j.atmosenv.2018.04.057.

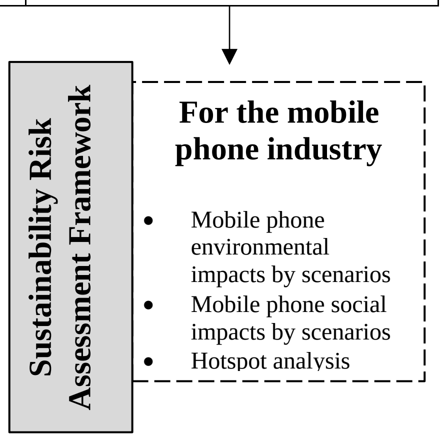
Zhang, Y., H. Kang, H. Hou, S. Shao, X. Sun, C. Qin, and S. Zhang. 2018. “Improved design for textile production process based on life cycle assessment.” *Clean Technologies and Environmental Policy* 20 (6): 1355–1365. doi: https://doi.org/10.1007/s10098-018-1572-9

Zimmer, K., M. Fröhling, P. Breun, and F. Schultmann. 2017. “Assessing social risks of global supply chains: a quantitative analytical approach and its application to supplier selection in the German automotive industry.” *Journal of Cleaner Production* 149: 96-109. doi: https://doi.org/10.1016/j.jclepro.2017.02.041.

Zu, L. 2013. “Sustainability risk management.” In Encyclopedia of Corporate Social Responsibility. Berlin: Springer-Verlag.

Figure 1. Input-Process-Output Research definition.

(1) Inputs What is analyzed?	(2) Process How?	(3) Output What for?
Corporate sustainability risks assessment methodologies	Identifying, through the analysis of the academic literature and professional practice, the main limitations presented by the sustainability risk assessment methodologies along the supply chains	For proposing a framework to manage sustainability risks upstream and downstream, along global supply chains, that overcomes the limitations of current corporate risks assessment methodologies



Source: Own elaboration

Figure 2: Flow chart for the RQ

RQ: How could we cover the assessment requirements that contribute to measure corporate sustainability risks considering the whole supply chain?

Framewor

Case study **of mobile phone industry impacts**

STEP 1: Definition of goal and scope

The aim is to identify the key environmental impacts (following the OEF) and social impacts (following the UNEP/SETAC methodology) and crucial hotspots for mobile phone sector. To that end, this study is based on a company that produces mobile phones. Its components are:

- Electronics: electronic components and board
- Screen: LCD type
- Housing: polycarbonate
- Battery: lithium
- Charger: low voltage transformer, incl. cable and connectors
- Package (carton)
- Packaging (plastic)

STEP 2: Definition of a mobile product life-cycle stages

- **Raw material acquisition** that includes mining and preparation processes of non-ferrous metal ores.
- **Bulk processing** that refers to the activities of smelting, refining and the manufacture of metal alloys. It also includes the manufacture of plastic materials in primary forms.
- **Transportation** that represents the sea freight transport or rail bulk transport for the international movements of materials.
- **Engineered/ specialty material** that comprises the manufacture of finished plastic products, electronic components, batteries, and photographic equipment and optical instruments.
- **Manufacture/ assembly** that involves the process of manufacturing and assembly mobile phone from its components in previous phases.
- **Transportation and distribution** that encompasses two subphases: transport to move the product to distribution center or retail stores and the retail sale of mobile phone in stores.
- **Consumer use** that contains the user's practices.
- **Disposal/reuse** that refers to recycling, recovery of sorted materials and treatment and disposal of waste.
- **Design** that is integrated in all phases of mobile phone life-cycle, therefore, it has not been considered as a separate phase.

STEP 3: Definition of three scenarios

The scenarios considered only affect the 'End-of-Life' phase, changing the percentages of the mobile phone's residue allocated to landfill, disassembly and reuse detailed below:

- **Scenario 1:** Sent to Landfill: 75%; sent to Disassembly: 20%; Reuse: 5%
- **Scenario 2:** Sent to Landfill: 30%; sent to Disassembly: 60%; Reuse: 10%
- **Scenario 3**: Sent to Landfill: 5%; sent to Disassembly: 20%; Reuse: 75%

STEP 4: Footprints Tools

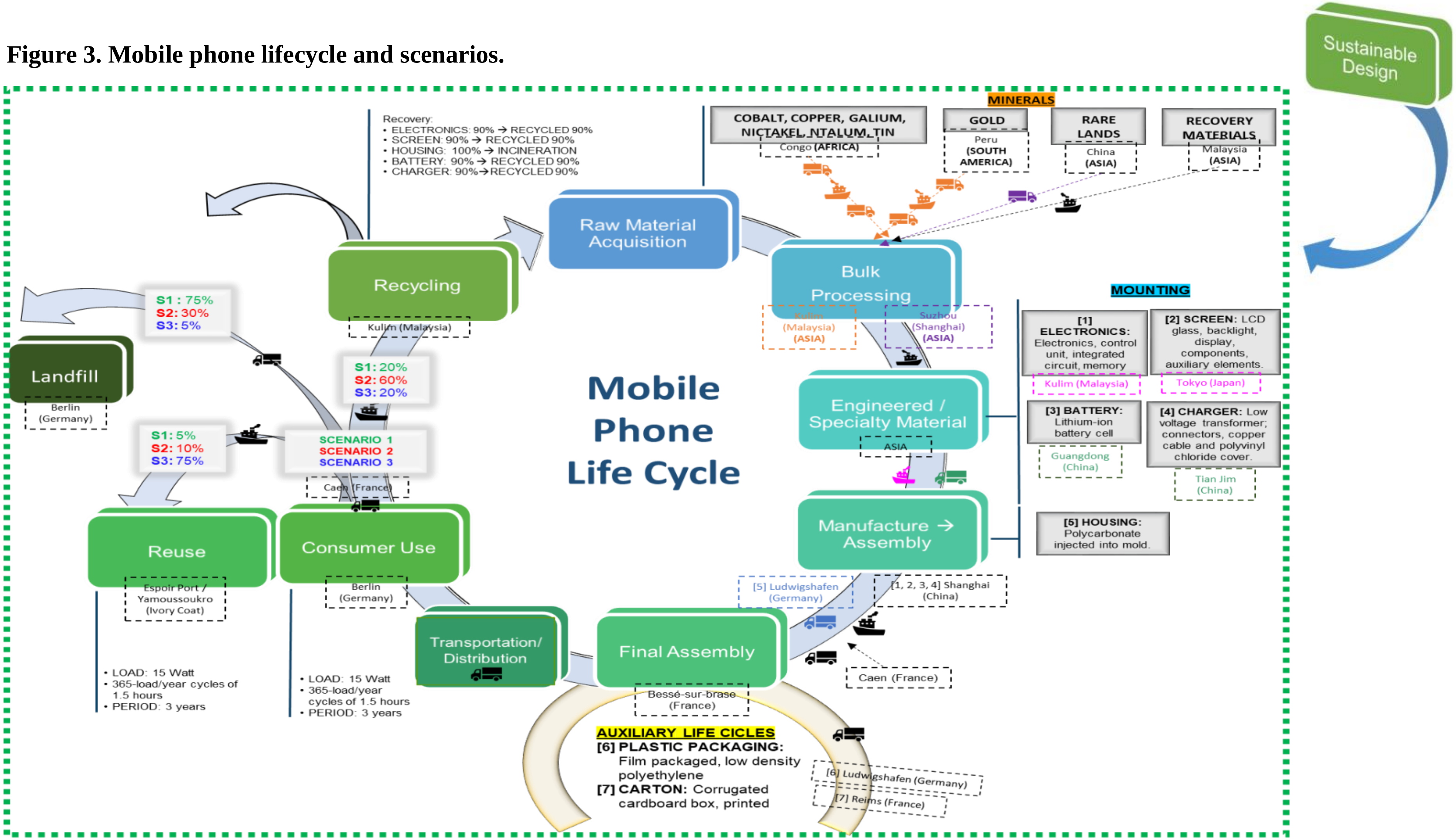
Organizational Environmental Footprint (EC, 2013) and Social Footprint based on the Social Life Cycle Assessment method of UNEP-SETAC (2009a, 2013) are calculated using the three scenarios and the technical tool SimaPro.

STEP 5: Sectoral hotspots

Mobile phone industry environmental and social hotspots are identified through the technical results obtained from footprints calculated using SimaPro and a group of 10 experts, belonging to the H2020 Project team, following the methodology of UNEP-SETAC (2017) hotspots analysis and EC (2013).

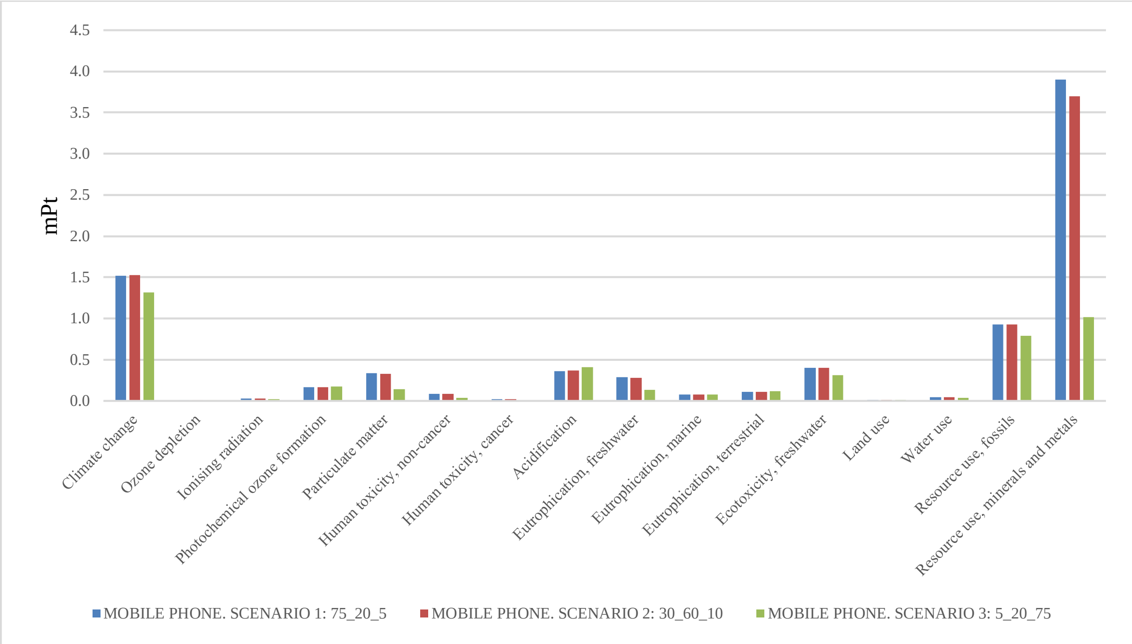
Source: Own Creation

Figure 3. Mobile phone lifecycle and scenarios.



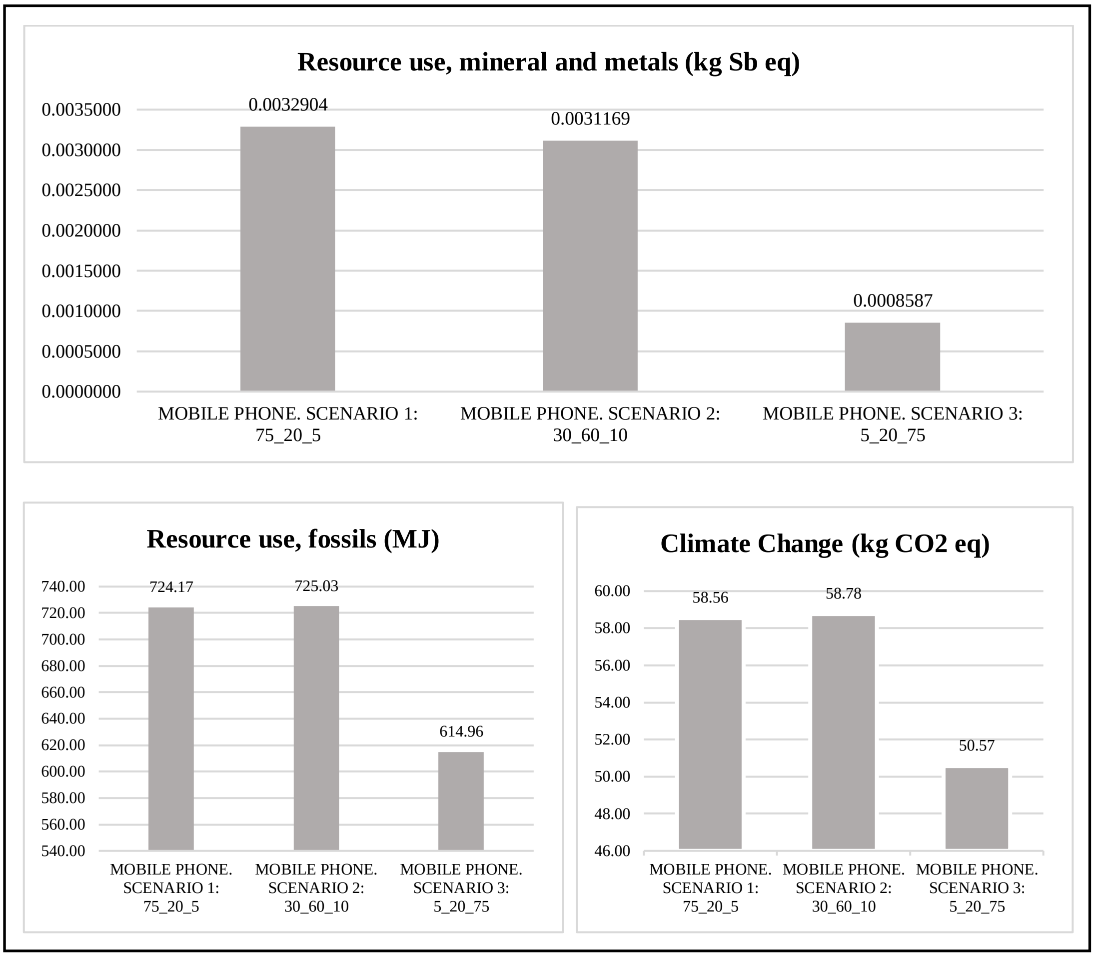
Source: Muñoz-Torres et al. (2018)

Figure 4. Environmental weighted results by scenarios.



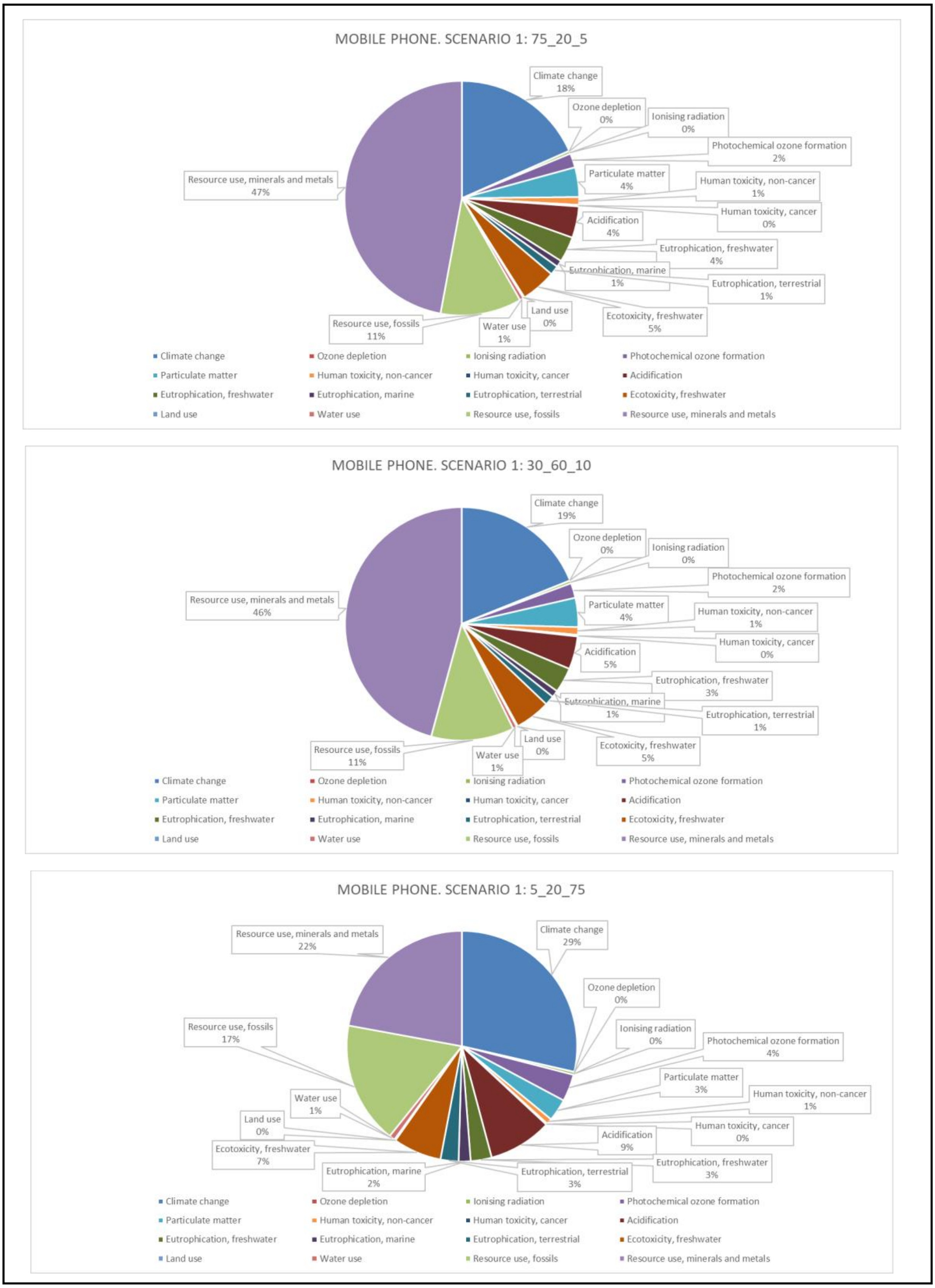
Source: SimaPro simulations (Simulation data: May 2021)

Figure 5. Results of the analysis of the environmental impact in the three main impact categories of the mobile phone industry by scenarios



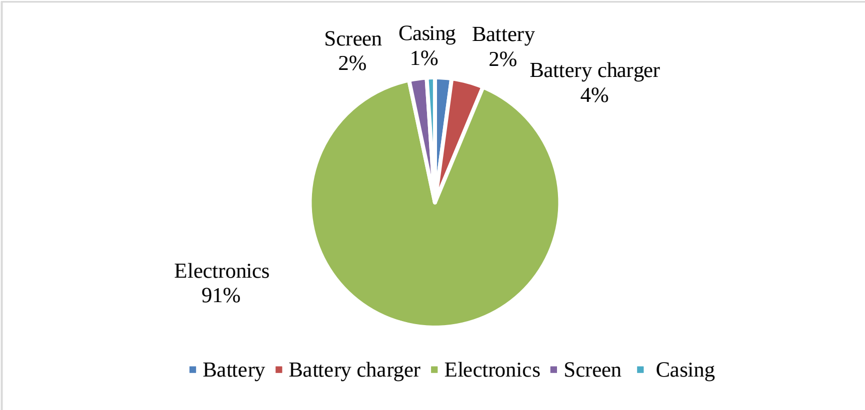
Source: SimaPro simulations (Simulation data: May 2021)

Figure 6. Cumulative environmental impact contribution of each life-cycle scenario.



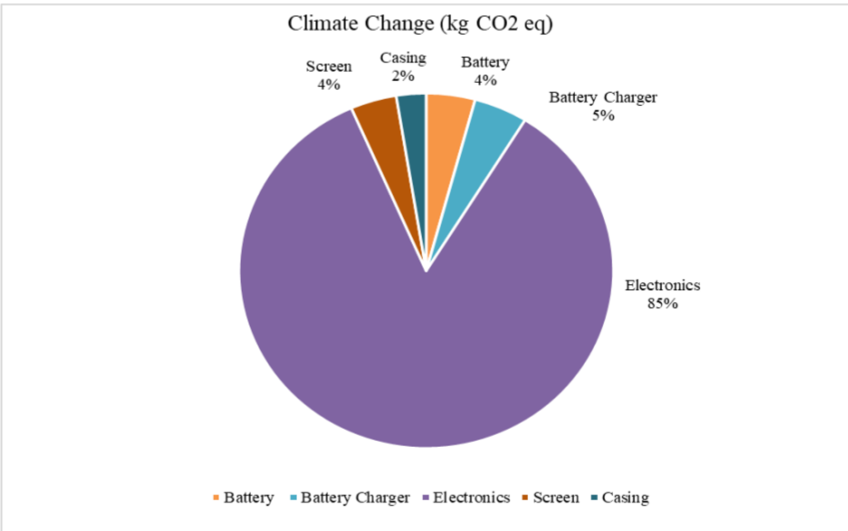
Source: SimaPro simulations (Simulation data: May 2021)

Figure 7. Environmental Impact contribution by component.



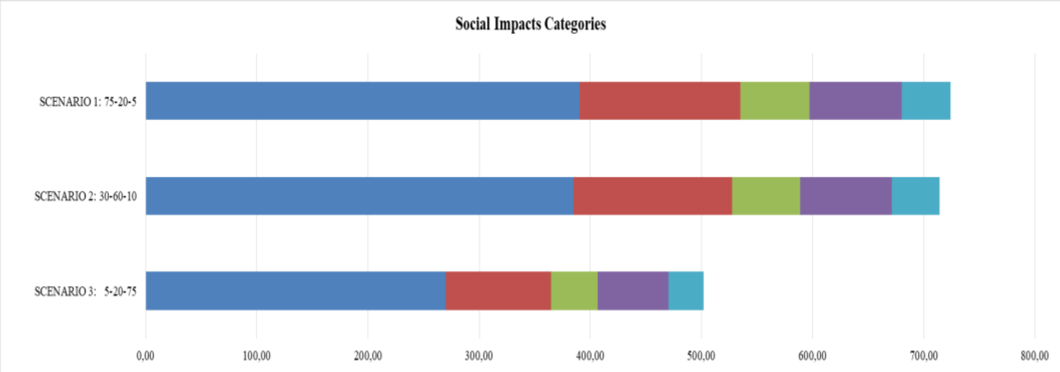
Source: SimaPro simulations (Simulation data: May 2021)

Figure 8. Environmental Impact contribution by component.



Source: SimaPro simulations (Simulation data: May 2021)

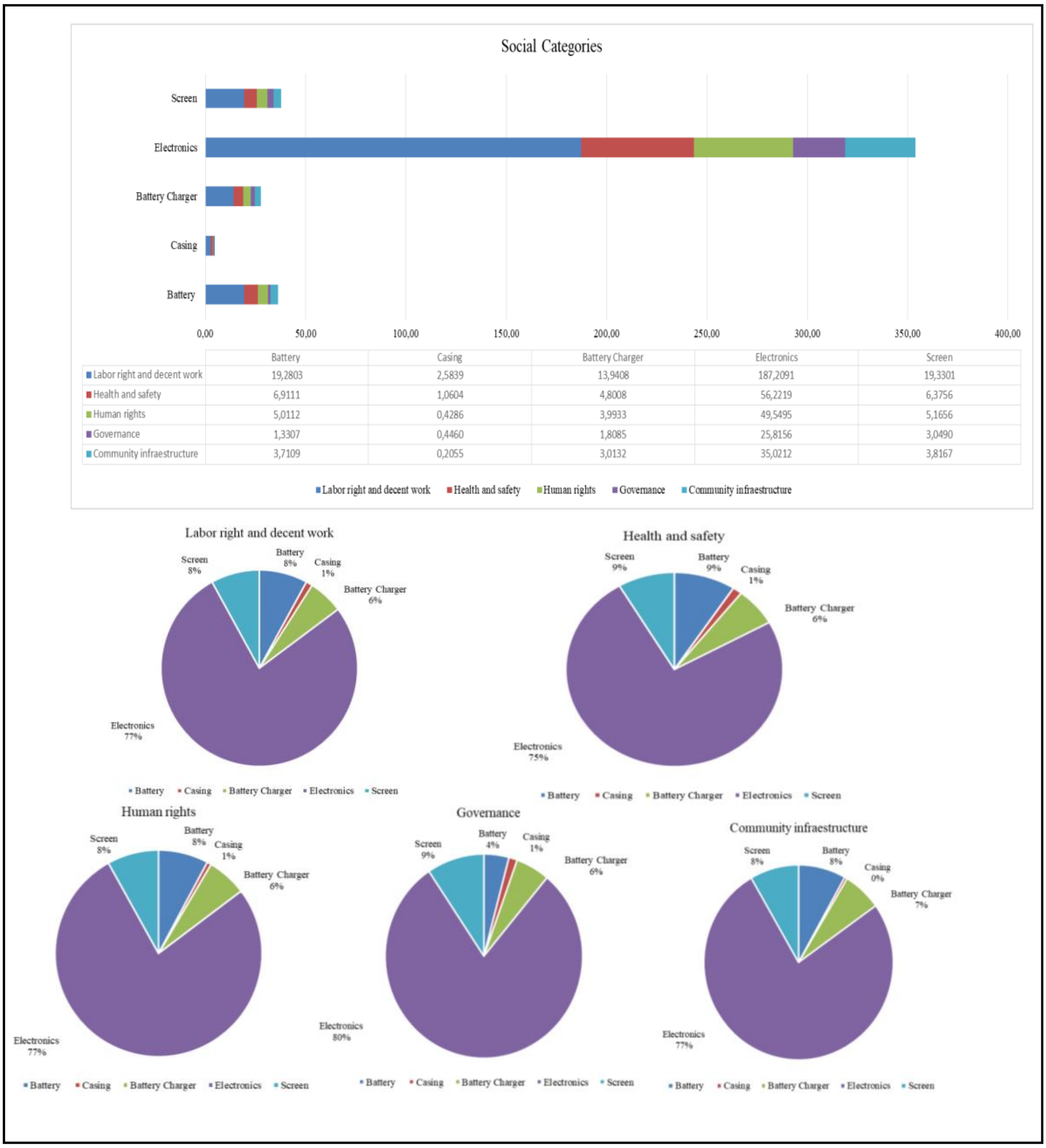
Figure 9. Social weighted results by scenarios.



	SCENARIO 3: 5-20-75	SCENARIO 2: 30-60-10	SCENARIO 1: 75-20-5
Labor right and decent work	269,8429	384,8045	390,5006
Health and safety	94,7986	142,5659	144,5419
Human right	42,0332	61,2761	62,0073
Governance	63,5576	82,3735	83,1340
Community infraestructure	31,7303	43,3639	43,8616

Source: SimaPro simulations (Simulation data: May 2021)

Figure 10. Social Impact contribution by component.



Source: SimaPro simulations (Simulation data: May 2021)

Table 1. Environmental impact analysis results considering a mobile phone lifecycle by scenarios

Impact category	Unit	MOBILE PHONE. SCENARIO 1: 75_20_5	MOBILE PHONE. SCENARIO 2: 30_60_10	MOBILE PHONE. SCENARIO 3: 5_20_75
Climate change	kg CO2 eq	58,56273	58,77811	50,57130
Ozone depletion	kg CFC11 eq	2,90E-06	2,84E-06	1,63E-06
Ionising radiation	kBq U-235 eq	2,61366	2,54165	1,51163
Photochemical ozone formation	kg NMVOC eq	0,13855	0,14121	0,14872
Particulate matter	disease inc.	2,25E-06	2,17E-06	9,57E-07
Human toxicity, non-cancer	CTUh	1,11E-06	1,07E-06	4,60E-07
Human toxicity, cancer	CTUh	1,42E-08	1,42E-08	6,93E-09
Acidification	mol H+ eq	0,32222	0,33027	0,36761
Eutrophication, freshwater	kg P eq	0,01676	0,01616	0,00781
Eutrophication, marine	kg N eq	0,05090	0,05141	0,05090
Eutrophication, terrestrial	mol N eq	0,50576	0,51599	0,55485
Ecotoxicity, freshwater	CTUe	893,81334	884,59126	694,85549
Land use	Pt	145,99445	143,04950	92,78715
Water use	m3 depriv.	6,00983	6,03460	5,07028
Resource use, fossils	MJ	724,16864	725,03117	614,96318
Resource use, minerals and metals	kg Sb eq	0,00329	0,00312	0,00086
CLIMATE CHANGE				
Climate change - Fossil	kg CO2 eq	58,16127535	58,43915032	50,36725314
Climate change - Biogenic	kg CO2 eq	0,295413923	0,231729538	0,128671704
Climate change - Land use and LU change	kg CO2 eq	0,1060384	0,107229659	0,075373246
HUMAN TOXICITY, NON CANCER				
Human toxicity, non-cancer - organics	CTUh	2,63418E-07	2,49793E-07	7,2677E-08
Human toxicity, non-cancer - inorganics	CTUh	9,39943E-08	9,10328E-08	4,30167E-08
Human toxicity, non-cancer - metals	CTUh	7,58385E-07	7,33741E-07	3,49172E-07
HUMAN TOXICITY, CANCER				
Human toxicity, cancer - organics	CTUh	4,40189E-09	4,67241E-09	2,41959E-09
Human toxicity, cancer - inorganics	CTUh	0	0	0
Human toxicity, cancer - metals	CTUh	9,84139E-09	9,51021E-09	4,51402E-09
ECOTOXICITY, FRESHWATER				
Ecotoxicity, freshwater - organics	CTUe	7,00589677	6,791975809	2,924362605
Ecotoxicity, freshwater - inorganics	CTUe	94,40520291	93,20852762	49,93029173
Ecotoxicity, freshwater - metals	CTUe	792,4022417	784,5907606	642,0008345

Source: SimaPro simulations (Simulation data: May 2021)

Table 2. Cumulative environmental impact contribution of each life-cycle phase of a mobile phone scenario.

Impact Category	Unit	MOBILE PHONE. SCENARIO 1: 75_20_5	MOBILE PHONE. SCENARIO 2: 30_60_10	MOBILE PHONE. SCENARIO 3: 5_20_75
Total	mPt	8,2912	8,0763	4,6045
Climate change	mPt	1,5232	1,5288	1,3153
Ozone depletion	mPt	0,0034	0,0033	0,0019
Ionising radiation	mPt	0,0310	0,0302	0,0179
Photochemical ozone formation	mPt	0,1631	0,1662	0,1751
Particulate matter	mPt	0,3387	0,3270	0,1441
Human toxicity, non-cancer	mPt	0,0887	0,0854	0,0368
Human toxicity, cancer	mPt	0,0180	0,0179	0,0087
Acidification	mPt	0,3596	0,3686	0,4102
Eutrophication, freshwater	mPt	0,2920	0,2815	0,1361
Eutrophication, marine	mPt	0,0771	0,0778	0,0771
Eutrophication, terrestrial	mPt	0,1062	0,1083	0,1165
Ecotoxicity, freshwater	mPt	0,4021	0,3979	0,3126
Land use	mPt	0,0141	0,0139	0,0090
Water use	mPt	0,0446	0,0448	0,0376
Resource use, fossils	mPt	0,9267	0,9278	0,7869
Resource use, minerals and metals	mPt	3,9028	3,6970	1,0185

Source: SimaPro simulations (Simulation data: May 2021)

Table 3. Environmental impact analysis by components.

Impact Category	Unit	Total	Battery	Battery Charger	Electronics	Screen	Casing	Electricity, medium voltage {CN}
Total	mPt	7,62686491	0,15809054	0,30643178	6,69816976	0,16827615	0,07832682	0,21756985
Climate change	mPt	1,09996242	0,04245938	0,04664167	0,85098293	0,04001709	0,0258706	0,09399074
Ozone depletion	mPt	0,00243897	0,00010264	0,00020861	0,00197307	0,00010261	3,8464E-05	1,3579E-05
Ionising radiation	mPt	0,0230527	0,00068653	0,00078357	0,01969047	0,00104074	0,0006146	0,00023679
Photochemical ozone formation	mPt	0,14016877	0,00590644	0,00806094	0,10562219	0,00714168	0,00254157	0,01089596
Particulate matter	mPt	0,3312847	0,01608699	0,01873558	0,2411588	0,01108619	0,00991873	0,03429842
Human toxicity, non-cancer	mPt	0,08579904	0,0039023	0,00984546	0,04355264	0,02604901	0,00132654	0,00112309
Human toxicity, cancer	mPt	0,01539132	0,00104253	0,00260712	0,0104701	0,00078591	0,0002551	0,00023056
Acidification	mPt	0,31796434	0,0148008	0,02431833	0,23900704	0,013096	0,00406655	0,02267562
Eutrophication, freshwater	mPt	0,2671812	0,00567062	0,01681196	0,24110765	0,00231312	0,00031655	0,00096131
Eutrophication, marine	mPt	0,06753389	0,00240945	0,0031101	0,04350545	0,01289963	0,00084367	0,00476559
Eutrophication, terrestrial	mPt	0,09120563	0,0037543	0,00504598	0,06835216	0,00553289	0,00127837	0,00724193
Ecotoxicity, freshwater	mPt	0,38324084	0,01469289	0,04242777	0,30010976	0,01431235	0,00842904	0,00326904
Land use	mPt	0,00883128	0,00024206	0,0004231	0,00751677	0,0002349	0,00011032	0,00030413
Water use	mPt	0,04032954	0,0014343	0,00421012	0,02915402	0,00277359	0,00222306	0,00053445
Resource use, fossils	mPt	0,63175954	0,02377066	0,02974185	0,49414707	0,0268052	0,02029597	0,0369988
Resource use, minerals and metals	mPt	4,12072073	0,02112867	0,09345963	4,00181965	0,00408525	0,00019769	2,9836E-05

Source: SimaPro simulations (Simulation data: May 2021)

Table 4. Total environmental impact by components.

Impact Category	Unit	Total	Battery	Battery Charger	Electronics	Screen	Casing
Climate change	kg CO2 eq	**38,6777**	1,6325	1,7933	32,7187	1,5386	0,9947
Ozone depletion	kg CFC11 eq	**2,06E-06**	8,73E-08	1,77E-07	1,68E-06	8,72E-08	3,27E-08
Ionising radiation	kBq U-235 eq	**1,9215**	0,0578	0,0660	1,6583	0,0877	0,0518
Photochemical ozone formation	kg NMVOC eq	**0,1098**	0,0050	0,0068	0,0897	0,0061	0,0022
Particulate matter	disease inc.	**1,97E-06**	1,07E-07	1,24E-07	1,60E-06	7,36E-08	6,59E-08
Human toxicity, non-cancer	CTUh	**1,06E-06**	4,87E-08	1,23E-07	5,44E-07	3,25E-07	1,66E-08
Human toxicity, cancer	CTUh	**1,20E-08**	8,27E-10	2,07E-09	8,31E-09	6,24E-10	2,02E-10
Acidification	mol H+ eq	**0,2646**	0,0133	0,0218	0,2142	0,0117	0,0036
Eutrophication, freshwater	kg P eq	**0,0153**	0,0003	0,0010	0,0138	0,0001	1,82E-05
Eutrophication, marine	kg N eq	**0,0414**	0,0016	0,0021	0,0287	0,0085	0,0006
Eutrophication, terrestrial	mol N eq	**0,4000**	0,0179	0,0240	0,3256	0,0264	0,0061
Ecotoxicity, freshwater	CTUe	**844,6521**	32,6613	94,3141	667,1241	31,8154	18,7372
Land use	Pt	**88,0285**	2,4988	4,3678	77,5980	2,4250	1,1389
Water use	m3 depriv.	**5,3633**	0,1933	0,5674	3,9292	0,3738	0,2996
Resource use, fossils	MJ	**464,7963**	18,5764	23,2428	386,1682	20,9478	15,8610
Resource use, minerals and metals	kg Sb eq	**0,0035**	1,78E-05	0,0001	0,0034	3,44E-06	1,67E-07
Climate change - Fossil	kg CO2 eq	**38,5281**	1,6301	1,7894	32,5803	1,5342	0,9940
Climate change - Biogenic	kg CO2 eq	**0,0707**	0,0012	0,0022	0,0647	0,0021	0,0005
Climate change - Land use and LU change	kg CO2 eq	**0,0788**	0,0011	0,0016	0,0737	0,0022	0,0002

Source: SimaPro simulations (Simulation data: May 2021)

Table 5. Social impact analysis results considering a mobile phone lifecycle by scenarios.

Social Categories	Impact Categories (Subcategories)	SCENARIO 1: 75-20-5	SCENARIO 2: 30-60-10	SCENARIO 3: 5-20-75
Labor rights and decent work	total - Child Labor	21,5890	21,9409	22,4404
	total - Forced Labor	24,0339	23,3995	14,2162
	total - Excessive Working Time	18,4189	17,9270	10,3555
	total - Wage Assessment	103,3894	101,6221	69,6441
	total - Poverty	26,3305	25,9753	19,6231
	total - Migrant Labor	48,3648	47,3274	32,9265
	total - Collective Bargaining	127,4268	126,0461	89,0266
	total - Social Benefits	20,9474	20,5662	11,6105
Health and safety	total - Injuries and Fatalities	36,7666	35,8812	21,4951
	total - Toxics and Hazards	107,7753	106,6847	73,3034
Human right	total - Indigenous Rights	9,3900	9,6759	9,6264
	total - Gender Equity	21,6821	21,0993	11,9802
	total - High Conflict	30,9352	30,5008	20,4266
Governance	total - Legal System	34,3129	33,8478	23,4728
	total - Corruption	48,8211	48,5257	40,0848
Community infrastructure	total - Drinking Water	8,3264	8,2110	6,2886
	total - Improved Sanitation	18,1906	17,7642	11,5394
	total - Hospital Beds	17,3446	17,3887	13,9024

Source: SimaPro simulations (Simulation data: May 2021)

Table 6. Social impact analysis by components.

Social Categories	Impact Categories (Subcategories)	Battery	Battery Charger	Casing	Electronics	Screen

Labor right and decent work	total - Child Labor	1,2656	0,0793	1,1732	12,8235	1,4933
	total - Forced Labor	1,3155	0,1048	1,2050	15,2088	1,5738
	total - Excessive Working Time	1,8124	0,0745	0,9055	10,6359	1,1653
	total - Wage Assessment	1,0700	0,1534	1,4092	24,8211	2,3567
	total - Poverty	5,9688	0,8529	3,4550	43,8342	4,3859
	total - Migrant Labor	4,0488	0,8179	3,1033	44,0547	4,7739
	total - Collective Bargaining	1,3519	0,0955	1,3073	16,8234	1,7449
	total - Social Benefits	2,4474	0,4055	1,3822	19,0075	1,8363
Health and safety	total - Injuries and Fatalities	6,5210	1,0374	4,3552	50,0503	5,9769
	total - Toxics and Hazards	0,3901	0,0230	0,4456	6,1716	0,3987
Human rights	total - Indigenous Rights	1,2373	0,0818	1,0086	13,8599	1,2826
	total - Gender Equity	2,2991	0,1143	1,6226	19,2235	1,9564
	total - High Conflict	1,4748	0,2325	1,3621	16,4661	1,9266
Governance	total - Legal System	0,9680	0,4219	1,2449	20,2695	2,2755
	total - Corruption	0,3627	0,0242	0,5636	5,5462	0,7735
Community infrastructure	total - Drinking Water	1,2028	0,0812	0,9613	10,7843	1,1798
	total - Improved Sanitation	1,2028	0,0453	0,9687	11,3636	1,1709
	total - Hospital Beds	1,3053	0,0790	1,0832	12,8733	1,4660

Source: SimaPro simulations (Simulation data: May 2021)

Table 7. Total social impact by components.

	Battery	Casing	Battery Charger	Electronics	Screen	Total
Labor right and decent work	19,2803	2,5839	13,9408	187,2091	19,3301	242,344079
Health and safety	6,9111	1,0604	4,8008	56,2219	6,3756	75,369763
Human rights	5,0112	0,4286	3,9933	49,5495	5,1656	64,148148
Governance	1,3307	0,4460	1,8085	25,8156	3,0490	32,449823
Community infraestructure	3,7109	0,2055	3,0132	35,0212	3,8167	45,767528

Source: SimaPro simulations (Simulation data: May 2021)