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ECO-INNOVATION MEASUREMENT OF ENTERPRISES – VALIDATION OF THE LCA-BASED APPROACH

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Purpose: The primary aim of the article is to present, examine and discuss an alternative approach to the eco-innovation measurement of enterprises, based on the methodology of life cycle assessment (LCA).
Design/methodology/approach: The simplified three-step approach, based on the LCA methodology, was applied to perform the analysis. It consists of the following subsequent stages: environmental assessment, environmental profile of an enterprise and contribution analysis. The environmental profile of the enterprise was calculated using the ReCiPe Midpoint (H) method.
Findings: A medium size enterprise manufacturing rubber granulates (ethylene-propylene-diene monomer, EPDM and styrene-butadiene rubber, SBR) was covered by the research. The research proved that the analysed enterprise has the most detrimental impact on the environment in the following impact categories: marine ecotoxicity, natural land transformation and freshwater ecotoxicity. These result predominantly from SBR rubber granulate production. Consequently, due to the specificity of the manufacturing process to be more eco-innovative, the enterprise needs to apply more energy-efficient technologies.
Originality/value: This is a fully original research paper that validates an alternative approach to measure and stimulate the implementation of eco-innovation at the micro-level. It complements the currently existing methodologies by taking life cycle and the supply chain perspective into consideration, and thus supports decision-makers in the implementation of the principles of circular economy.

Keywords: eco-innovation, enterprise, life cycle assessment (LCA), rubber granulates.

Category of the paper: Research paper, Technical paper.

1. Introduction

The concept of eco-innovation has its origin in the definition of innovation, which is defined as: “a new or improved product or process (or combination thereof) that differs significantly from the previous products or processes” (OECD and Eurostat, 2018). Eco-innovations, however, have one distinctive feature: they lead to the improvement of environmental performance, either via the effective control of emission to prevent environmental pollution (reactive eco-innovative action) or via the reduction of consumption of natural resources (proactive eco-innovative action).

Following the Oslo Manual, two types of eco-innovation can be distinguished: product eco-innovation and business process eco-innovation (OECD and Eurostat, 2018). The first type, product eco-innovations, involves two generic types of products: goods and services. The implementation of product eco-innovation requires a broad spectrum of actions from enterprises, including the reduction of consumption of natural resources at all stages (the manufacturing stage, the use phase and end-of-life management), increased product performance (products with extended life cycle) and the use of materials having lower environmental impacts (eco-design) (Marcon et al., 2017). The second type, business process eco-innovations, encompasses six different types of functions performed by companies: production of goods or services, distribution and logistics, marketing and sales, information and communication systems, administration and management and, finally, product and business process development. The implementation of business process eco-innovations within the production of goods and services requires a broad spectrum of actions, including the reduction of consumption of natural resources and waste prevention, materials savings, use of cleantech technologies and, finally, using renewable energy resources (Marcon et al., 2017).

The eco-innovation measurement is performed at three different levels, i.e. a micro-level, a meso-level and, finally, a macro-level. Each of these levels requires different measurement mechanism and different eco-innovation indicators. Although methodologies for measuring eco-innovation at the micro-level are still very much in their infancy, there are a few approaches applied, including the Community Innovation Survey (CIS) and own proposals of authors researching eco-innovation (e.g. Cheng, and Shiu, 2012). Taking into account the current challenges of the circular economy, the eco-innovation measurement at the micro-level ought to refer to the life cycle perspective.

The aim of the article is to present the results of the eco-innovation measurement of the medium-size enterprise representing the rubber granulates market. The research was conducted with the use of a simplified stepwise LCA-based methodology, allowing for the identification and prioritisation of environmental impacts, proposed by Rybaczewska-Błażejowska (2017), as well as Rybaczewska-Błażejowska and Sulerz (2017). The stepwise LCA-based approach constitutes a complement of the currently applied eco-innovation measurement methods related to products and processes.

2. Methods

The eco-innovation measurement of the enterprise was performed with the use of the simplified stepwise LCA-based methodology. The three-step approach consists of the following:

1. an environmental assessment of products and production processes through the application of the life cycle assessment (LCA) technique,
2. formulation of the environmental profile of the enterprise on the basis of the results achieved in the first step and presenting it in a matrix form (MAT_{LCA}),
3. diagnosis, including calculation of the contribution of individual processes in the selected environmental impact categories.

The LCA, applied in the first step, is a quantitative management technique that evaluates inputs, outputs and potential environmental impacts associated with a product system throughout its life cycle (ISO 2006a; ISO 2006b). It can be applied either in the conventional format, as cradle-to-grave and cradle-to-cradle analyses, or a modernised format, as cradle-to-gate, gate-to-gate and gate-to-grave analyses. The third variant of the LCA analysis, i.e. cradle-to-gate, which covers selected stages of the life cycle of a product system with the addition of upstream environmental impacts, was selected for the research. The LCA methodology comprises four distinct phases that are subsequently split into several operational steps. These are: goal and scope definition, the collection and validation of input and output data (life cycle inventory, LCI), the calculation of the impact assessment (life cycle impact assessment, LCIA) with the use of a selected single-impact or multi-impact LCIA method and, finally, interpretation (Barański et al., 2011).

Subsequently, the results of the LCA analysis, multiplied by the enterprise's yearly production capacity or weighted following the production structure of a given company, are presented in the matrix form (MAT_{LCA}) to illustrate the environmental profile of a company. The rows in the matrix represent product systems (products and related production processes) ($i = 1, \ldots, n$), whereas the columns represent a quantifiable representation of environmental impact categories of the selected LCIA method ($j = 1, \ldots, m$). Consequently, it is a set of sums S of matrix elements a_{ij} for each j = const.

Finally, a diagnosis of the causes of environmental impacts is performed by the calculation of contribution analysis, also taking into account the input-related upstream processes. This, in consequence, enables one to prioritise the eco-innovative actions on products and/or production processes with the highest negative impacts on the environment throughout their life cycles. However, Motta et al. (2015) argue that the implemented eco-innovative actions, although effective in one life cycle phase, may create new environmental problems in other life cycle phases.

3. Results and discussion

3.1. Environmental assessment

The goal of the LCA research is to analyse the potential environmental burdens of two types of rubber granulates: ethylene-propylene-diene monomer (EPDM) and styrene-butadiene rubber (SBR), within the variant cradle-to-gate. The gate is the production process of the aforementioned granulates. The proposed methodology and obtained results can be applied to measure and stimulate the implementation of eco-innovation by enterprises manufacturing rubber granulates. These types of research projects are meant for internal communication. The functional unit is 1 Mg of final product, i.e. EPDM and SBR granulates.

EPDM granulate is produced through the recycling process of different types of EPDM-based rubber waste, predominantly car seals. It has very good physico-chemical properties (high durability and UV- and weatherproof) and a quality closed to the virgin material. It occurs in the following grain sizes: 0.0-0.5 mm, 0.5-1.5 mm and 1.0-3.5 mm. SBR granulate is produced through the recycling of different types of SBR-based rubber waste, predominantly waste tyres. The SBR production process encompasses the following unit processes: shredding, crushing, wire and fibre separation, further shredding into fine rubber granulates, hierarchical screening and, finally, packaging into large 1000 kg bags. The SBR granulate occurs in the following grain sizes: 0.5-2.5 mm, 1.0-4.0 mm and 2.0-6.0 mm. The granulates are used as bound floor covering systems in sport surfaces, leisure surfaces and commercial flooring, as well as in road building and maintenance.

A life cycle inventory (LCI) of EPDM and SBR rubber granulates covers two types of environmental data, input-based and output-based. The first cover materials and energy, whereas the second includes waste. Materials and waste are product related, whereas energy is production process related. The EPDM rubber granulate is manufactured from ethylene-propylene-diene monomer with the following additives: soot, silica, petroleum oil, textiles, anti-aging agents, sulphur, stearic acid, steel and zinc oxide (Figure 1). The SBR rubber granulate is manufactured from styrene-butadiene rubber with the following additives: natural rubber, butadiene rubber, soot, steel, silica, mineral oils, zinc oxide, sulphur, stearic acid, resin and textiles (Figure 2). Comparable amounts of energy are used in EPDM and SBR production processes. All LCI data was collected from the enterprise manufacturing rubber granulates and Bilitewski et al. (2009).

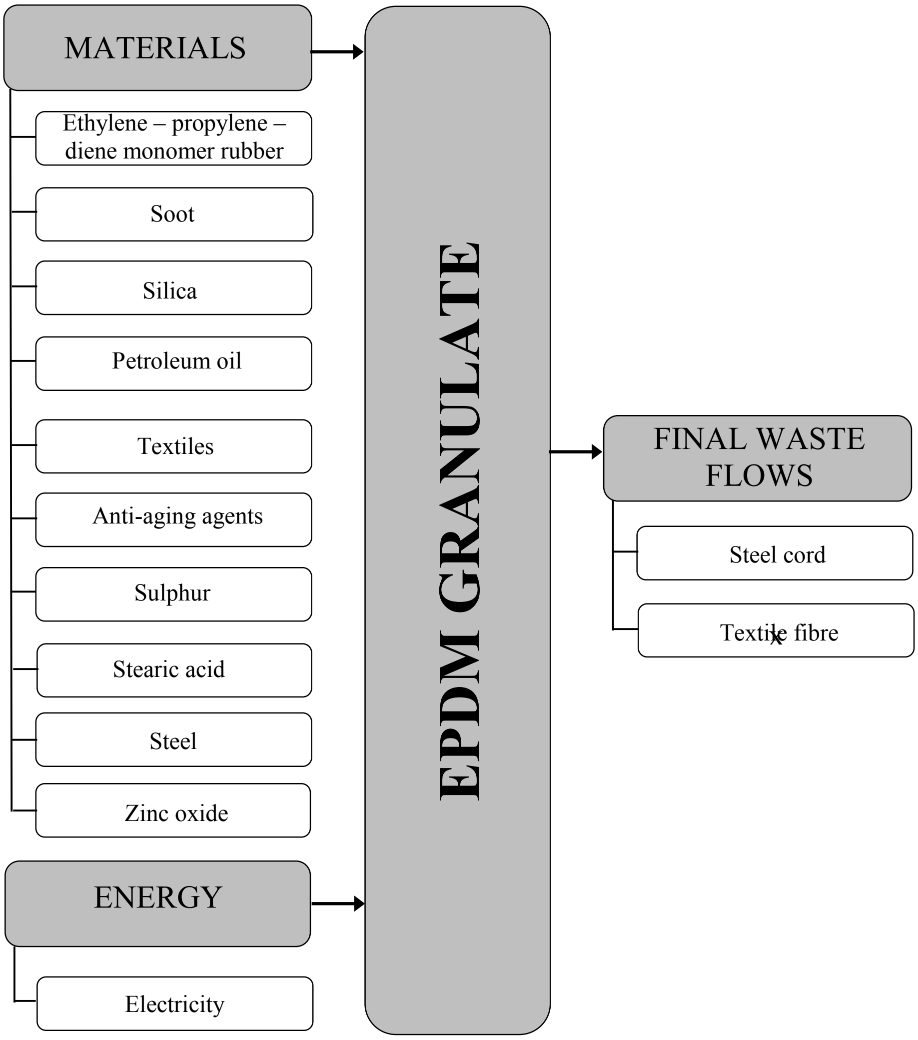

Figure 1. General scheme of the life cycle inventory of the EPDM rubber granulate and its production process.

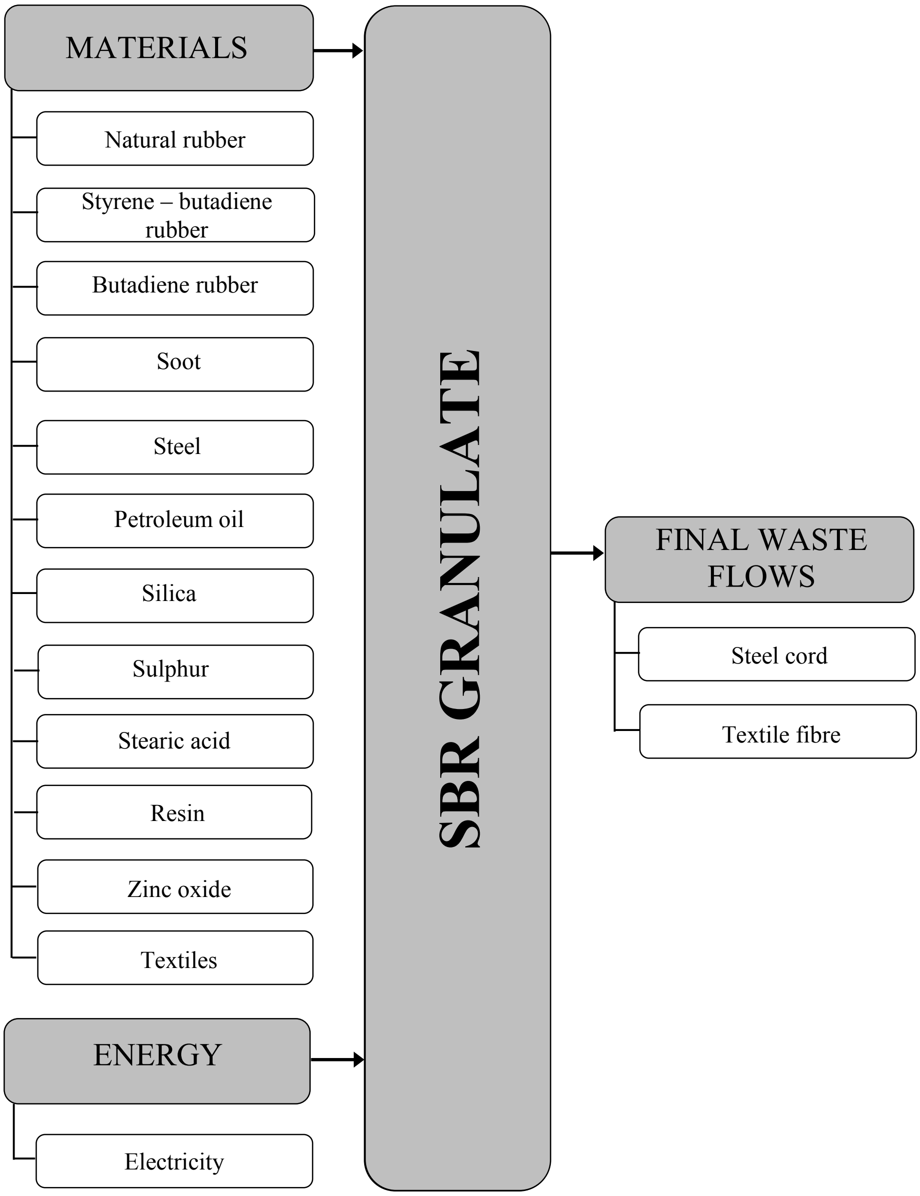

Figure 2. General scheme of the life cycle inventory of the SBR rubber granulate and its production process.

A life cycle impact assessment (LCIA) of EPDM and SBR rubber granulates was performed using specialised software (SimaPro) and the ReCiPe Midpoint (H) method. Consequently, the LCI results were assessed at the midpoint level and classified into 18 impact categories: climate change, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation, ionising radiation, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion and fossil depletion (Goedkoop et al., 2013). The hierarchist (H) perspective was chosen on the assumption that the environmental damages are reversible if proper technological changes are introduced. The indicator values of the impact category were normalised in relation to the average load per one inhabitant in Europe. The LCIA results were not weighted.

Comparative LCIA of normalised environmental profiles of 1 Mg of the analysed rubber granulates proved that, notwithstanding the impact category, the SBR rubber granulate has the most detrimental impact on the environment (Figure 3). It achieves the highest value in the following impact categories: natural land transformation (3.90), marine ecotoxicity (3.58), freshwater ecotoxicity (3.08), freshwater eutrophication (1.82) and photochemical oxidant formation (1.47). The second of the analysed, EPDM rubber granulate, achieves the highest value in the following impact categories: marine ecotoxicity (2.10), freshwater ecotoxicity (1.81), natural land transformation (1.27), freshwater eutrophication (1.25) and fossil depletion (0.85).

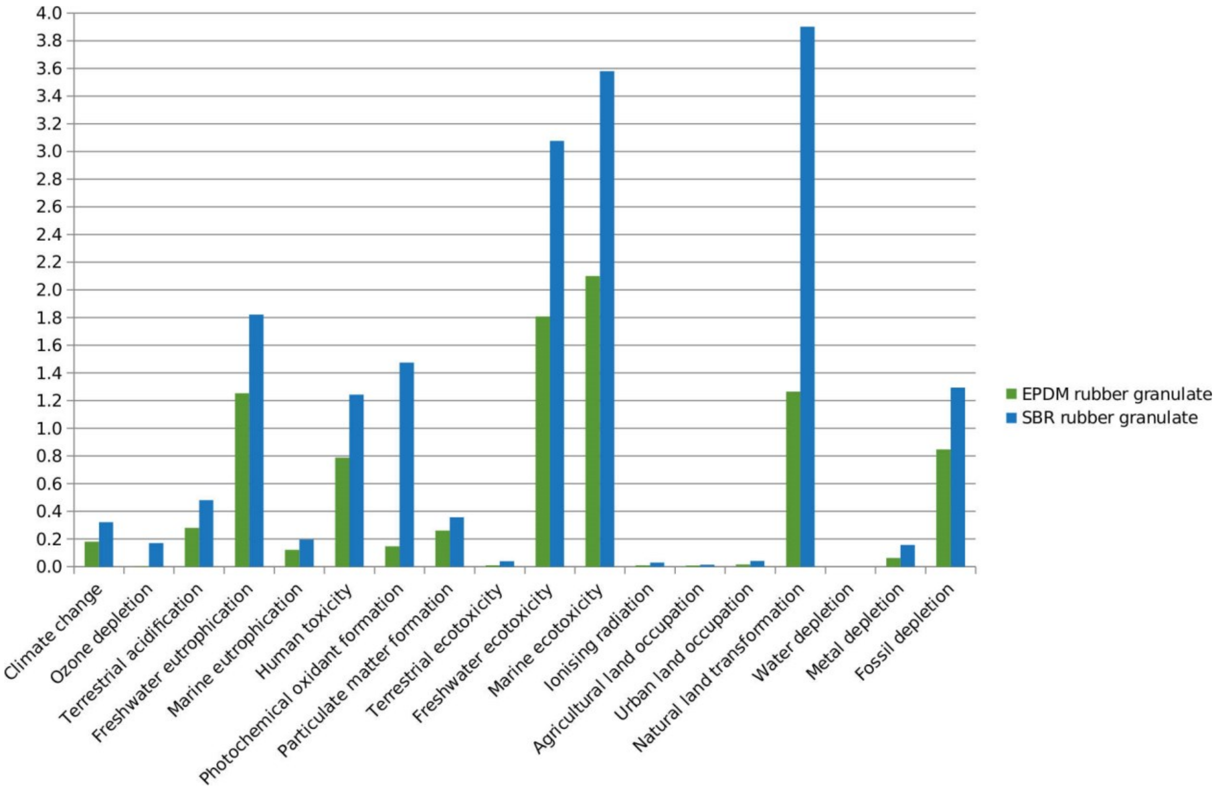

Figure 3. Life cycle impact assessment of the EPDM and SBR rubber granulates and their production processes.

3.2. Environmental profile of an enterprise

The environmental profile of the enterprise manufacturing rubber granulates is presented in a matrix form (MAT_{LCA}) (Figure 4). The rows correspond to individual rubber granulates: EPDM and SBR, whereas the columns correspond to particular impact categories of the ReCiPe Midpoint (H) method. In order to reflect the production structure of the analysed enterprise, weights were assigned to individual rubber granulates and their production. They reflect the relative proportion of a particular granulate in the enterprise's production.

$$MAT_{LCA} = \begin{bmatrix} 0.060 & 0.002 & 0.094 & 0.417 & 0.041 & 0.263 & 0.049 & 0.087 & 0.004 & 0.602 & 0.699 & 0.003 & 0.003 & 0.005 & 0.422 & 0.000 & 0.021 & 0.282 \\ 0.107 & 0.057 & 0.160 & 0.607 & 0.066 & 0.414 & 0.491 & 0.119 & 0.014 & 1.024 & 1.192 & 0.010 & 0.005 & 0.014 & 1.299 & 0.000 & 0.052 & 0.431 \end{bmatrix}$$

where the rows $i \in (1, 2)$ represent products and their production processes: 1 – EPDM, 2 – SBR; whereas the columns $j \in (1 \ldots 20)$ represent environmental impacts categories: 1 – climate change, 2 – ozone depletion, 3 – terrestrial acidification, 4 – freshwater eutrophication, 5 – marine eutrophication, 6 – human toxicity, 7 – photochemical oxidant formation, 8 – particulate matter formation, 9 – terrestrial ecotoxicity, 10 – freshwater ecotoxicity, 11 – marine ecotoxicity, 12 – ionising radiation, 13 – agricultural land occupation, 14 – urban land occupation, 15 – natural land transformation, 16 – metal depletion, 17 – fossil depletion.

Figure 4. Weighted environmental profile of the enterprise manufacturing rubber granulates.

3.3. Contribution analysis

The weighted environmental profile of the enterprise manufacturing rubber granulates proved to have considerable impacts in the following impact categories: marine ecotoxicity (1.89), natural land transformation (1.72) and freshwater ecotoxicity (1.63), being predominantly the result of SBR rubber granulate production. Consequently, the potential contributions of individual inputs and outputs in the aforementioned impact categories were calculated.

Both the category marine ecotoxicity and freshwater ecotoxicity, some of the midpoint indicators of ecotoxicity, reflect the fate, exposure and effect of toxic substances, mainly heavy metals, on the marine and freshwater environment, respectively (Acero et al., 2015). Their characterisation factors in the ReCiPe method are expressed using the reference unit kg 1,4-dichlorobenzene equivalent (1,4-DB). The marine toxic effect of 1 tonne of SBR rubber granulate is estimated at a level of 28.3 1,4-DB eq, whereas the freshwater toxic effect of 1 tonne of SBR rubber granulate is estimated at a level of 30.8 1,4-DB eq. The marine ecotoxicity results primarily from the consumption of electricity (35%) in the production process, followed by the content of natural rubber (21.2%) and steel (15%) in the product (Figure 5). The freshwater ecotoxicity results analogously to the marine ecotoxicity primarily from consumption of electricity (35.5%) in the production process, followed by the content of natural rubber (21.6%) and steel (14%) in the product (Figure 6).

The category natural land transformation, one of the midpoint indicators of land use, illustrates the impact on the land being the result of the conversion of the existing land-use type into another type, for instance agriculture, anthropogenic settlement and resources extractions, which, as a consequence, damage ecosystems (Goedkoop et al., 2013). The characterisation factor of natural land transformation in the ReCiPe method is expressed using the reference unit m^2a. The production of 1 tonne of SBR rubber granulate is associated with the transformation of 17.9 m^2 of natural land annually, which mainly results from the content of soot (60%) and natural rubber (26.9%) in the product (Figure 7).

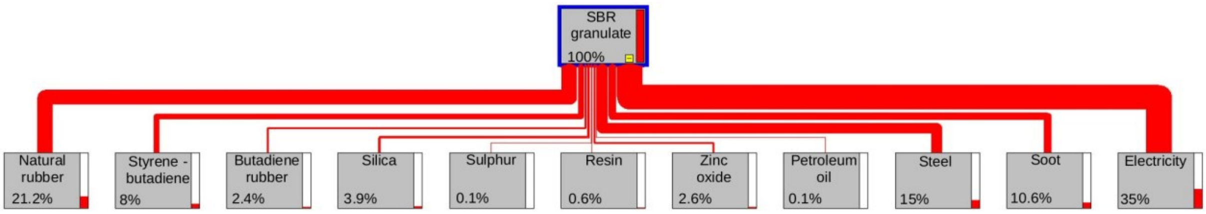

Figure 5. The process tree of the SBR rubber granulate in the category marine eco-toxicity.

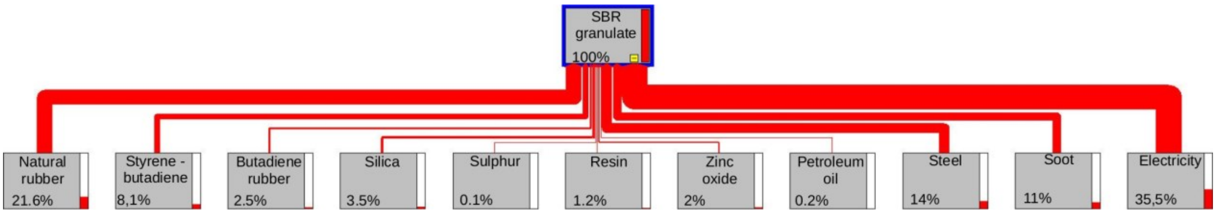

Figure 6. The process tree of the SBR rubber granulate in the category freshwater eco-toxicity.

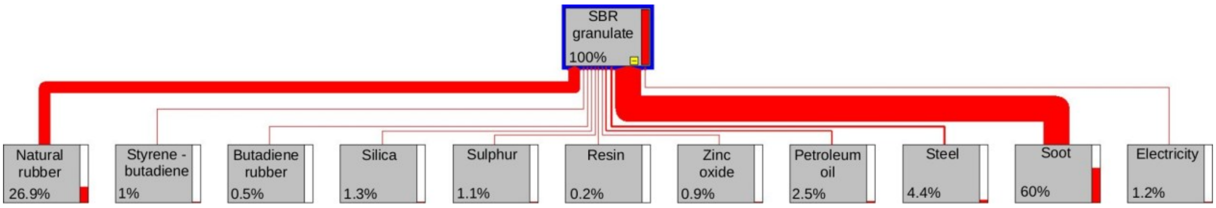

Figure 7. The process tree of the SBR rubber granulate in the category natural land transformation

4. Conclusions

The article presents an alternative approach for measuring eco-innovation at the micro-level with the consideration of eco-innovative indicators associated with life cycle and the supply chain perspective. Regarding the above, a comprehensive analysis of the enterprise manufacturing rubber granulates (EPDM and SBR) was made with the use of the simplified stepwise LCA-based methodology. It revealed not only the enterprise's life cycle impacts on the environment, but also their sources. Consequently, due to the specificity of the manufacturing process, to be more eco-innovative, the analysed enterprise needs to move towards more energy-efficient technologies, depicted in the BREF document (2007).

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