Chapter N (please do not write anything in this line. Editors will annotate the chapter number)

Material Flow Analysis and Life Cycle Assessment of Waste Electrical and Electronic Equipment Recovery in a Regional Circular Economy Scenario

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**Abstract.** This study analyses the waste electrical and electronic equipment (WEEE) management system of Campania Region assessing the input and output material flows to and from the system and the environmental impacts of the recovery of the materials and components of WEEE after their first step separation in a treatment plant located outside the Region. This study also aims at improving the traceability of the life cycle of WEEE of Campania Region. The midpoint and endpoint preliminary results evidence the environmental impacts of the collection and treatment of R1 and R2 category of WEEE. Moreover, the comparison of the environmental impacts for the recovered materials having the highest weight share of the functional unit (e.g., iron in R1 and mixed iron & steel in R2) show that the recovery of WEEE secondary materials generates lower environmental impacts than the production of the primary materials. This LCA confirms the importance of evaluating the environmental impacts of the implementation of the European WEEE Management system established in compliance of the EU WEEE directives towards better understanding the social and just implications of the circular economy model.

**Keywords.** Material Flow Analysis, Life Cycle Assessment, Waste Electrical and Electronic Equipment, Circular Economy, Recycling.

* 1. **Introduction**

Currently, the traceability of products at the end-of-life is a critical factor for key product value chains in European Union and their waste streams such as Waste Electrical and Electronic Equipments (WEEE) due to the lack of comprehensive data about their treatment and the related environmental and social impacts (Berežni et al., 2021; Ghisellini et al., 2019; European Union, 2017; Umair et al., 2015). For the treatment processes of waste including WEEE it is not valid the principle of proximity as applied in the case of waste disposal[[1]](#footnote-1). As a result, WEEE are treated where they are recovered in the most cost-efficient way. This implies that they can be transported and recovered far from where they are generated, as in the case of WEEE collected in Campania Region (Campania Region, 2022) challenging the aspect of sustainability and social and environment justice to which the current CE transition is expected to contribute (Arauzo-Carod et al., 2022; Abalansa et al., 2021).

WEEE as a waste stream is a very heterogeneous category consisting of many products and materials also including hazardous ones that need for a proper treatment to prevent damages to people and environment. The EU has adopted since the year 2002 two important directives in order to regulate and improve the management of WEEE. In Italy, the Ministerial Decree 185/2007 transposed the first WEEE directive identifying the main actors of the WEEE management system, their functions and the adoption for the collection centres of a classification system for the WEEE consisting in the following five categories:

* R1: Refrigerators and air conditioning systems;
* R2: Large household appliances;
* R3: TV sets and displays;
* R4: Small household appliances, consumer electronics, office automation, computer appliances, lighting devices;
* R5: Light sources (excluding incandescent lamps).

The WEEE directive[[2]](#footnote-2) aims to introduce substantially the CE principles in the sector by preventing WEEE generation, promoting a more efficient use of the resources/products by means of their reuse or recovery into secondary raw materials as well asimprove the environmental performances of all the stakeholders involved in the WEEE life cycle (European Commission, 2019).

This study proposes a joint application of MFA and LCA and is aimed to evaluate:

* The life cycle of the legal WEEE management system of Campania Region established in compliance with the Italian legislation and European Directives improving its traceability;
* The environmental impacts from the collection and treatment of WEEE;
* The opportunities for improving the environmental performances of the regional WEEE management system.

The organization of this study comprises in the next Section 1.2 a review of previous literature evaluating regional WEEE management systems followed by section 1.3 (Materials and Methods) that summarizes the main key feature of the regional system under investigation and the methodological framework (MFA+LCA) adopted to achieve the goals of this study. Results are showed and discussed in section 1.4 while conclusions and future perspectives in section 1.5.

* 1. **Review of the Literature**

The international literature shows a few cases of studies that assess the environmental performances of regional or national WEEE management systems by means of Life Cycle Assessment (LCA) and Material Flow Analysis (MFA). Indeed, in the WEEE sector, the use of both these tools seems still low (in particular in the research of e-waste generation and management life cycle stages) despite the fact the contribution of LCA is recognized as important since its early applications when the LCA was used to evaluate the environmental benefits of the implementation of the first WEEE directive (Huisman et al., 2008). A recent literature review (Withanage and Habib, 2021) highlights the need for increasing the number of studies focusing on a “cradle to grave” and “cradle to cradle” window of analysis to enhance the knowledge about their life cycle and providing useful feedbacks to improve the current practices, policies and regulatory frameworks (Withanage and Habib, 2021).

The international literature shows two recent cases of joint application of both MFA and LCA to study WEEE management in Italy (Fiore et al., 2019; Biganzoli et al., 2015). Beyond the Italian context a recent paper applies both LCA and MFA to study the WEEE management in UK whereas Souza et al. (2016) uses the LCA for the analysis of the sustainability of WEEE management options in the Metropolitan Region of Rio De Janeiro. Finally, Angouria-Tsorochidou et al., (2018) applies the MFA to map the life cycle stages of WEEE in Denmark and integrating such method with an economic analysis for the purpose of evaluating the opportunities for reuse rather than recycling. They found that a management system based on reuse is economically viable and has the potential of providing environmental and social benefits.

* 1. **Material and Methods**

This section provides a brief introduction to the Life Cycle Assessment Method that is adopted in the present study jointly with the MFA. The system under investigation is the Regional WEEE management system of Campania Region for the five categories of collected WEEE (R1, R2, R3, R4 and R5) in the year 2020.

As applied by the previous literature (Biganzoli et al., 2015) each one of the five categories of WEEE have been analyzed separately as well as jointly. The present study shows the preliminary results of the recovery processes for the categories R1 and R2 of WEEE and considers the treatment process performed in the first treatment plants involving the dismantling of the WEEE, the separation of the main components (such as e.g., cables, compressors, motors, capacitors, etcetera) and the recovery of the materials. Actually, the study aims at providing the results for all the other WEEE categories (R3, R4 and R5) in Campania Region and additional processing stages after those performed in the first treatment plants, also showing the separation of all the above-mentioned components into their constituent materials (iron, steel, copper, plastic, precious materials, etcetera). Further results will be presented later on.

* + 1. ***Life Cycle Assessment***

The Life Cycle Assessment Method is performed taking into account the standard ISO 14040:2006 that is the reference framework for applying the LCA. The ISO 14040:2006 suggests the following four stages for an LCA study: Goal and scope, Inventory analysis, Impact Assessment and Interpretation.

* + - 1. *Goal and Scope Definition*

The main goals of this LCA study are the evaluation of the environmental impacts associated to the collection of the five categories of WEEE of Campania Region and their recovery and by this improving the transparency of the life cycle of the WEEE collected at Regional level in a perspective of sustainability according to the three dimensions and a just transition to the circular economy.

The stages included in this LCA study are the following:

* Collection of the WEEE in the five provinces of Campania Region (Naples, Caserta, Benevento, Avellino and Salerno) and their transport outside the Region towards the first treatment plants;
* Recovery of the WEEE in the first treatment plants mainly located in Balvano (Potenza) and Sessano del Molise (Isernia). In overall these two plants treat a relevant share of the WEEE collected in Campania Region. In the year 2020, they treated about 75% of the total WEEE collected in Campania Region. Due to the lack of data about the other plants treating the residual 25%, we assumed that they have been treated in plants with similar characteristics of the plants of Balvano and Sessano del Molise.

The considered functional unit is 1 tonne of collected and recovered WEEE.

*1.3.1.2 Life Cycle Inventory*

The second stage of the LCA involves the definition of the boundaries of the system, to point out the relations between the economic system and the environment (de Bruijn, H. et al., 2002), the material and energy inventory of investigated processes as well as the definition of the product system. The main steps in this stage include material flow data collection and the adoption of allocation procedures in case of multifunctional processes (de Bruijn, H. et al., 2002). The input and output inventories are quantified according to the selected functional unit.

The data collected in this study are both primary and secondary data. The first ones regard the annual flows of WEEE collected in Campania Region in the five provinces as well as the data about the material input and output flows in the treatment plants while the secondary data regard in particular the transport stage of the collected WEEE from each province of Campania to the treatment plants of Balvano and Sessano del Molise modelled using Ecoinvent and the electricity consumption in the treatement plants for the recovery operations from Biganzoli et al. (2015). Table 1 and Table 2 show the primary and secondary data of the collection and treatment stages for the R1 and R2 WEEE category. The data have been collected on the basis of a functional unit of 1 tonne of treated R1 or R2 WEEE. The allocation of the environmental impacts on the basis of the economic value of the materials and components has been implemented in this study. Most of the prices have been collected from Borsino dei Rifiuti.[[3]](#footnote-3)

Table 1. Material and energy inventory data for 1 tonne of R1 WEEE category collected in Campania Region and treated in Balvano and Sessano del Molise treatment plants.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Flows**  | **Data Sources**  | **Amount**  | **Unit**  |
| **INPUT** | WEEE collected and treated  |  | 1 | Tonne  |
|  | Transport from Regional collection points to treatment plants | Transport, freight, lorry 3.5-7.5 metric tonne (Ecoinvent 3.8) | 133.5 | Tonne\*Km |
|  | Electricity, medium voltage – IT  | Ecoinvent 3.8 and Biganzoli et al., (2015) | 100 | kWh/Tonne |
|  | Landfilling of residual waste and poliurethane from WEEE  | Ecoinvent 3.8 (Waste treatment and disposal) | 186.5 | Kg/Tonne |
| **OUTPUT** | Recovered Aluminium  |  | 4.8 | Kg/tonne |
|  | Recovered Cables  |  | 2.3 | Kg/tonne |
|  | Recovered Compressors  |  | 140 | Kg/tonne  |
|  | Recovered Electronic Boards  |  | 0.90 | Kg/tonne |
|  | Recovered Glass  |  | 10.60 | Kg/tonne |
|  | Recovered Wood  |  | 1.20 | Kg/tonne |
|  | Recovered Plastic  |  | 160.30 | Kg/tonne |
|  | Recovered Oil |  | 2.90 | Kg/tonne |
|  | Recovered Gas  |  | 5.30 | Kg/tonne |
|  | Recovered Lamps  |  | 0.20 | Kg/tonne |
|  | Recovered Capacitors |  | 0.20 | Kg/tonne |
|  | Recovered Copper  |  | 0.40 | Kg/tonne |
|  | Polyurethane, to be disposed of in landfill |  | 166.00 | Kg/tonne |
|  | Residual Waste, to be disposed of in landfill |  | 20.50 | Kg/tonne |

Sources: Elaboration of the Authors

Table 2. Material and energy inventory data for 1 tonne of collected WEEE R2 category in Campania Region and treated in the plants of Balvano and Sessano del Molise.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Flow**  | **Data Sources**  | **Amount**  | **Unit**  |
| **INPUT** | WEEE collected and treated  |  | 1 | Tonne  |
|  | Transport from Regional collection points to treatment plants | Transport, freight, lorry 3.5-7.5 metric tonne (Ecoinvent 3.8) | 133.5 | Tonne\*Km |
|  | Electricity, medium voltage – IT  | Ecoinvent 3.8 and Biganzoli et al., (2015) | 66 | kWh/Tonne |
| **OUTPUT** | Recovered Steel and Iron |  | 648.10 | Kg/tonne |
|  | Recovered Concrete  |  | 274. 00 | Kg/tonne |
|  | Recovered Motors |  | 70.00 | Kg/tonne  |
|  | Recovered Cables  |  | 5.00 | Kg/tonne |
|  | Recovered Capacitors  |  | 1.20  | Kg/tonne |
|  | Recovered Electronic boards |  | 1.70 | Kg/tonne |

Sources: Elaboration of the Authors

*1.3.1.3 Life Cycle Impact Assessment*

This stage consists in the processing of the input and output data from the Inventory, which translates into specific impact categories by means of specific characterization methods, highlighting the potential contribution that the system provides to each environmental aspect considered in the analysis.

* 1. **Results and Discussion**

Table 3 shows the midpoint results per functional unit (1 tonne) for the R1 category of WEEE, assessed by means of the ReCiPe 2016 Assessment Method (Midpoint H). The Table 3 reports the environmental impacts only for the materials and components that are the most representative in terms of weight in the functional unit excluding those with a weight below 3kg per tonne of functional unit (cables, electronic boards, oil, wood, lamps, copper and capacitors). However, the total impacts per each impact category (last column of Table 3) considers the results of the environmental impacts of the collection and recovery stages of all the materials and components. Table 3 shows that the e.g. recovery of Iron after dismantling the WEEE in R1 category contributes to climate change by 21.41 kg CO2 eq. The recovery of all the materials and components generate 32.97 kg CO2 eq.

Table 3. Total midpoint results per functional unit, 1 tonne collected and treated WEEE for the R1 category.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Impact Category**  | **Unit** | **Recov. Iron** | **Recov.****Aluminum** | **Recov. Glass** | **Recov.****Plastic** | **Recov. Gas** | **Recov.****Compressors** | **Total Impacts** |
| Terrestrial acidification | kg SO2 eq | 0.23 | 0.00 | 0.00 | 0.02 | 0.00 | 0.09 | 0.36 |
| Human toxicity | kg 1,4-DB eq | -30.96 | -0.48 | -0.09 | -2.27 | -0.01 | -11.88 | -47.68 |
| Marine eutrophication | kg N eq | 0.27 | 0.00 | 0.00 | 0.02 | 0.00 | 0.10 | 0.41 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Water depletion | m3 | 252.92 | 3.90 | 0.74 | 18.50 | 0.12 | 97.03 | 389.52 |
| Climate Change | kg CO2 eq | 21.41 | 0.33 | 0.06 | 1.57 | 0.01 | 8.21 | 32.97 |
| Photochemical oxidant formation | kg NMVOC | 0.15 | 0.00 | 0.00 | 0.01 | 0.00 | 0.06 | 0.23 |
| Freshwater ecotoxicity | kg 1,4-DB eq | -35.33 | -0.54 | -0.10 | -2.58 | -0.02 | -13.55 | -54.41 |
| Natural land transformation | m2 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 |
| Ionising radiation | kg U235 eq | 10.35 | 0.16 | 0.03 | 0.76 | 0.00 | 3.97 | 15.94 |
| Agricultural land occupation | m2\*a | 2.18 | 0.03 | 0.01 | 0.16 | 0.00 | 0.84 | 3.36 |
| Freshwater eutrophication | kg P eq | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Marine ecotoxicity | kg 1,4-DB eq | -34.19 | -0.53 | -0.10 | -2.50 | -0.02 | -13.12 | -52.66 |
| Particulate matter formation | kg PM10 eq | 0.09 | 0.00 | 0.00 | 0.01 | 0.00 | 0.03 | 0.13 |
| Ozone depletion | kg CFC-11 eq | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Metal depletion | kg Fe eq | 2.86 | 0.04 | 0.01 | 0.21 | 0.00 | 1.10 | 4.41 |
| Fossil depletion | kg oil eq | 26.90 | 0.41 | 0.08 | 1.97 | 0.01 | 10.32 | 41.43 |
| Urban land occupation | m2\*a | 1.53 | 0.02 | 0.00 | 0.11 | 0.00 | 0.59 | 2.35 |

Sources: Elaboration of the Authors

The Table 4 shows the Endpoint results per functional unit for the most representative materials and components, calculated by means of the same Impact Assessment ReCiPe Endpoint Method, evidencing that the total impacts contribute to the depletion of the ecosystems by 3.97E-07 species-yr, to the resource depletion by 7.17 US$ and to damages to human health by 4.86E-05 DALY (Disability Adjusted Life Years).

Table 4. Total endpoint results per functional unit (1 tonne collected and treated) for the R1 WEEE category.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Impact Category** | **Unit** | **Recov. Iron** | **Recov. Aluminium** | **Recov. Glass** | **Recov. Plastic** | **Recov. Gas** | **Recov. compressors** | **Total Impacts** |
| Ecosystems-total | species.yr | 2.58E-07 | 3.97E-09 | 7.55E-10 | 1.89E-08 | 1.19E-10 | 9.89E-08 | 3.97E-07 |
| Resources-total | $ | 4.66 | 0.07 | 0.01 | 0.34 | 0.00 | 1.79 | 7.17 |
| Human Health-total | DALY | 3.15E-05 | 4.86E-07 | 9.23E-08 | 2.31E-06 | 1.46E-08 | 1.21E-05 | 4.86E-05 |

Source: Elaboration of the Authors

The Table 5 shows the midpoint results per functional unit (1 tonne) for the R2 category of WEEE, assessed by means of the ReCiPe 2016 Assessment Method (Midpoint H) as in the case of WEEE R1. Table 5 shows the environmental impacts for all the materials and components recovered per functional unit. The recovery of Steel and Iron after dismantling the WEEE in R2 category has the highest share in total climate change impact category (110.01 kg CO2 eq.) contributing by 86.33 kg CO2 eq.

Table 5. Total midpoint results per functional unit (1 tonne collected and treated) for the R2 WEEE category.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Impact Category** | **Unit** | **Recover. steel and iron** | **Recover. Cables** | **Recover. Motors** | **Recover.****Concrete** | **Recover. Capacitors** | **Recover.****Elec. Boards** | **Total Impacts**  |
| Terrestrial acidification | kg SO2 eq | 0.298 | 0.017 | 0.053 | 0.010 | 3.01E-05 | 4.14E-05 | 0.379 |
| Human toxicity | kg 1,4-DB eq | 17.512 | 1.028 | 3.151 | 0.617 | 1.79E-03 | 2.45E-03 | 22.312 |
| Marine eutrophication | kg N eq | 0.227 | 0.013 | 0.041 | 0.008 | 2.33E-05 | 3.20E-05 | 0.290 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 0.018 | 0.001 | 0.003 | 0.001 | 1.85E-06 | 2.54E-06 | 0.023 |
| Water depletion | m3 | 219.933 | 12.913 | 39.589 | 7.749 | 2.24E-02 | 3.08E-02 | 280.237 |
| Climate Change | kg CO2 eq | 86.333 | 5.069 | 15.541 | 3.041 | 0.009 | 0.012 | 110.01 |
| Photochemical oxidant formation | kg NMVOC | 0.272 | 0.016 | 0.048 | 0.010 | 2.75E-05 | 3.78E-05 | 0.346 |
| Freshwater ecotoxicity | kg 1,4-DB eq | 0.518 | 0.030 | 0.093 | 0.018 | 5.27E-05 | 7.25E-05 | 0.660 |
| Natural land transformation | m2 | 0.024 | 0.001 | 0.004 | 0.001 | 2.45E-06 | 3.36E-06 | 0.031 |
| Ionising radiation | kg U235 eq | 9.903 | 0.582 | 1.783 | 0.348 | 1.01E-03 | 1.39E-03 | 12.618 |
| Agricultural land occupation | m2\*a | 1.938 | 0.114 | 0.349 | 0.069 | 1.92E-04 | 2.72E-04 | 2.470 |
| Freshwater eutrophication | kg P eq | 0.010 | 0.001 | 0.002 | 0.000 | 1.03E-06 | 1.41E-06 | 0.013 |
| Marine ecotoxicity | kg 1,4-DB eq | 0.557 | 0.033 | 0.101 | 0.020 | 5.69E-05 | 7.83E-05 | 0.711 |
| Particulate matter formation | kg PM10 eq | 0.117 | 0.007 | 0.022 | 0.004 | 1.22E-05 | 1.68E-05 | 0.150 |
| Ozone depletion | kg CFC-11 eq | 0.000 | 0.000 | 0.000 | 0.000 | 1.41E-09 | 1.94E-09 | 0.000 |
| Metal depletion | kg Fe eq | 3.759 | 0.221 | 0.676 | 0.132 | 3.84E-04 | 5.27E-04 | 4.788 |
| Fossil depletion | kg oil eq | 28.737 | 1.687 | 5.173 | 1.011 | 2.93E-03 | 4.03E-03 | 36.615 |
| Urban land occupation | m2\*a | 1.944 | 0.114 | 0.349 | 0.069 | 1.92E-04 | 2.72E-04 | 2.477 |

Source: Elaboration of the Authors

The Table 6 shows the Endpoint results per functional unit for all the materials and components recovered in the R2 category, calculated by means of Impact Assessment ReCiPe Endpoint Method and evidencing that the total impacts of R2 treatment contribute to the depletion of the ecosystems by 1.04E+06 species-yr, to the resource depletion by 6.40E+00 US$ and to damages to human health by 2.10E-04 DALY (Disability Adjusted Life Years).

Table 6. Endpoint results per functional unit (1 tonne collected and treated) for the R2 WEEE category.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Impact category** | **Unit** | **Recover. Steel and iron**  | **Recover. Cables**  | **Recover. Motors** | **Recover.****Concrete**  | **Recover.****Capacitors**  | **Recover.****Elec. Boards** | **Total impacts per category**  |
| Ecosystems-total | species.yr | 8.16E-07 | 4.79E-08 | 1.470E-07 | 2.88E-08 | 8.32E-11 | 1.144E-10 | 1.04E-06 |
| Resources-total | $ | 5.02E+00 | 2.95E-01 | 9.044E-01 | 1.78E-01 | 5.16E-04 | 6.970E-04 | 6.40E+00 |
| Human Health-total | DALY | 1.64E-04 | 9.66E-06 | 2.960E-05 | 5.79E-06 | 1.68E-08 | 2.305E-08 | 2.10E-04 |

Source: Elaboration of the Authors

Finally, we compared the environmental impacts of one of the main recovered materials in the WEEE R1 and R2 categories, e.g. “Iron” and “Mixed iron and steel” respectively, with the primary materials from mining and industrial processing. In R1 category, the amount of iron recovered per ton of treated WEEE is 484.40 kg, whereas the amount of mixed “steel and iron” in R2 category is 648.10 kg per functional unit.

The Table 7 shows that the environmental impacts of the production of primary iron (1 kg) generates 0.18 kg CO2 eq. while the production of secondary iron from the R1 category of WEEE only generates 0.04 kg CO2 eq. The production of 1 kg of “mixed steel and iron” with similar percentage composition contributes to climate change by 2.44 kg CO2 eq. while the recovery of “mixed iron and steel” from WEEE R2 contributes a lower 0.13 kg CO2 eq. Similar results can be found also for the other impact categories. We expect that other WEEE recovered materials (copper, aluminium, glass, concrete, etc) may show the same impact behaviour and work is in progress to finalize these calculations.

Table 7. Midpoint results per kg of primary iron and secondary iron from WEEE of R1 category and steel and iron and secondary iron and steel from WEEE of R2 category.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Impact Category**  | **Unit** | **Primary iron**  | **Secondary iron (R1)**  | **Primary iron and steel**  | **Secondary iron and steel (R2)**  |
| Terrestrial acidification | kg SO2 eq | 1.01E-03 | 4.80E-04 | 1.40E-02 | 4.60E-04 |
| Human toxicity | kg 1,4-DB eq | 2.58E-02 | -6.39E-02 | 1.38E+00 | 2.70E-02 |
| Marine eutrophication | kg N eq | 1.10E-04 | 5.50E-04 | 2.29E-03 | 3.50E-04 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 8.77E-06 | 1.12E-05 | 4.24E-04 | 2.80E-05 |
| Water depletion | m3 | 2.37E+00 | 5.22E-01 | 5.86E+01 | 3.39E-01 |
| Climate Change | kg CO2 eq | 0.18 | 0.04 | 2.44 | 0.13 |
| Photochemical oxidant formation | kg NMVOC | 9.00E-04 | 3.10E-04 | 9.66E-03 | 4.20E-04 |
| Freshwater ecotoxicity | kg 1,4-DB eq | 8.90E-04 | -7.29E-02 | 1.92E-01 | 8.00E-04 |
| Natural land transformation | m2 | 1.60E-04 | 4.70E-05 | 2.95E-04 | 3.70E-05 |
| Ionising radiation | kg U235 eq | 1.30E-02 | 2.14E-02 | 2.47E-01 | 1.53E-02 |
| Agricultural land occupation | m2\*a | 2.21E-03 | 4.51E-03 | 1.83E-01 | 2.99E-03 |
| Freshwater eutrophication | kg P eq | 2.46E-05 | 1.19E-05 | 7.77E-04 | 1.55E-05 |
| Marine ecotoxicity | kg 1,4-DB eq | 8.70E-04 | -7.06E-02 | 1.96E-01 | 8.60E-04 |
| Particulate matter formation | kg PM10 eq | 4.80E-04 | 1.80E-04 | 1.23E-02 | 1.80E-04 |
| Ozone depletion | kg CFC-11 eq | 1.18E-08 | 2.68E-08 | 1.50E-07 | 2.13E-08 |
| Metal depletion | kg Fe eq | 8.92E-01 | 5.91E-03 | 7.26E+00 | 5.80E-03 |
| Fossil depletion | kg oil eq | 3.03E-02 | 5.55E-02 | 5.82E-01 | 4.43E-02 |
| Urban land occupation | m2\*a | 6.23E-03 | 3.15E-03 | 4.61E-02 | 3.00E-03 |

Source: Elaboration of the Authors

* 1. **Conclusions and future perspectives**

This study was aimed at evaluating the environmental impacts of the WEEE management system of Campania region in the stages of collection and treatment and by this improving the traceability of the system. In that, the LCA confirm its importance in evaluating the implementation of the European model of WEEE management tracing the WEEE from their collection until their transport to the first treatment plants and their treatment. The latter stage results in the recovery of a wide range of materials and components depending on the category of WEEE. The preliminary results of this LCA shows that the recovery of the materials in WEEE is beneficial for the environment. The environmental impacts for example of the recovery of iron from WEEE in R1 category generate a much lower contribution to climate change and the other impact categories compared to the primary iron. The analysis will be further advanced towards the evaluation of the environmental impacts of the life cycle of the other WEEE categories (R3, R4, R5) and the comparison of the impacts with the most representative recovered materials in the functional unit with the same materials produced by virgin materials. In this perspective, this LCA can also be considered a useful tool for improving the understanding of policy makers of Campania Region about the environmental impacts of the Regional WEEE system and cycle as well as on the social and just implications.

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