Environmental analysis of a hypothetical WEEE management system

-The WEEE Models Life Project-

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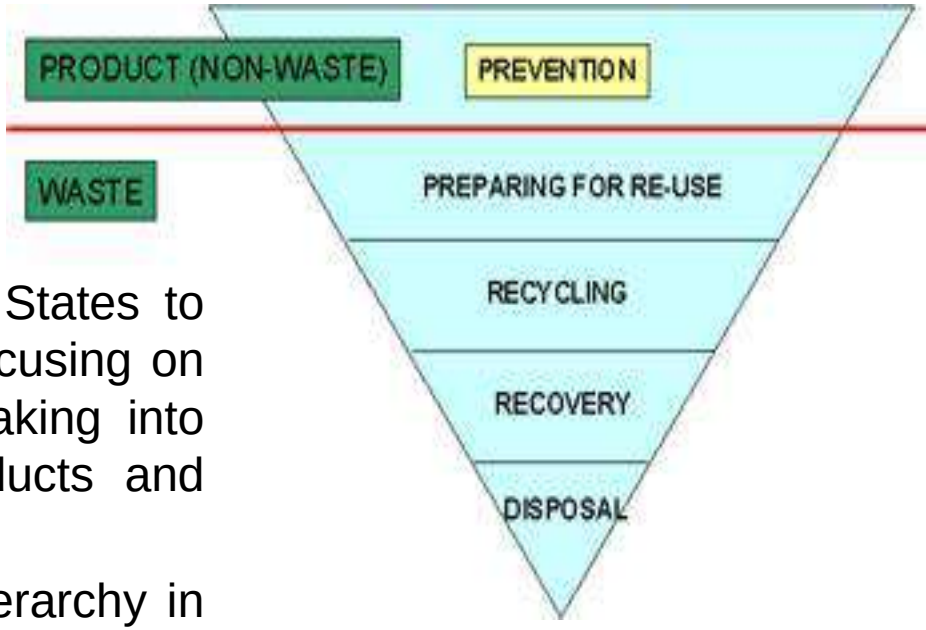
Waste framework directive

- Waste management in Europe: Directive 2008/98/EC (Waste Framework Directive). Waste management in Italy: D.Lgs. 205/2010.
- **Directive 2008/98/EC**:
  - ✓defines the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery/reuse;
  - ✓introduces the obligation for Member States to develop *waste prevention programs* focusing on the *key environmental impacts* and taking into account the whole *life cycle* of products and materials;
  - ✓establishes the waste management hierarchy in five points to be applied in order of priority.



WEEE: the reuse activity issue legislative background

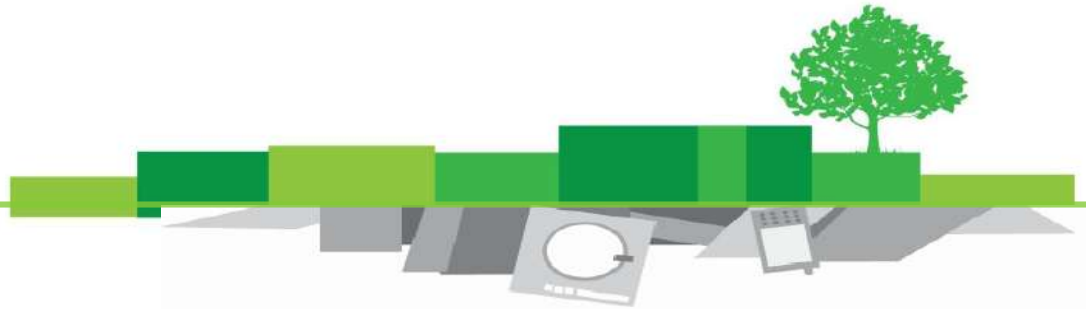
- **Directive 2012/19/EU** completes Directive 2008/98/EC on **WEEE** treatment and promotes the *eco-design* approach, which aims to facilitate the reuse of WEEE since the design stage.
- **Directive 2012/19/U** emphasizes on the issues of the reuse of WEEE and encourages the development and improvement of activities such as reconditioning, recycling, recovery, reuse of EEE. These activities extend the life span of products and components used, ensuring their re-entry into the market.
- Europe: *3.5 million tons/year* (6.5 kg/inhabitant) of WEEE
  Italy: *230'000 tons/year* (3.8 kg/inhabitant) of WEEE

WEEEN MODELS

Life

Waste Electric and Electronic Equipment New MODELs for Logistic Solutions

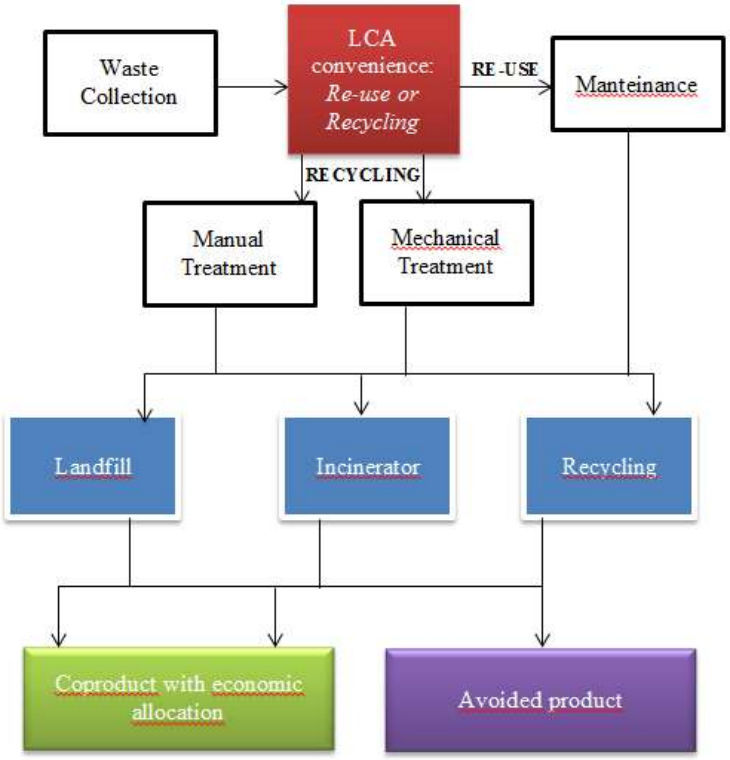
Progetto WEEENmodels LIFE12 ENV/IT/001058



www.weeenmodels.eu

WEEE management system

Criteria adopted for the LCA modeling



- Scenario: Genoa City (592'507 inhabitants).
- Reuse rate of WEEE: 10%.
- For each WEEE typology, a representative product has been considered, assuming that it generates the same environmental damage of the other products belonging to the same category:
  - R1 - refrigerator
  - R2 – washing machine
  - R3 – CRT
  - R4 – laptop
  - R5 – fluorescent lamp
- The life time of the reused product has been assumed equal to half of the life time of an equivalent new product. The energy consumption of EEE increases compared to that of the new one.
- The social benefits derived from the introduction of a new activity (Reuse activity) have been assessed (e.g. the increasing of employment).

LCA of WEEE management and their potential reuse

ISO 14040/44

Goal and scope definition The goal of this study is to assess the environmental performance of an hypothetical WEEE management and their reuse. Genoa city has been taken into consideration as case study.

System function The function of the system is the management of WEEE and it considers both the part that is conferred to the reuse activity and the one that goes to the end of life treatment.

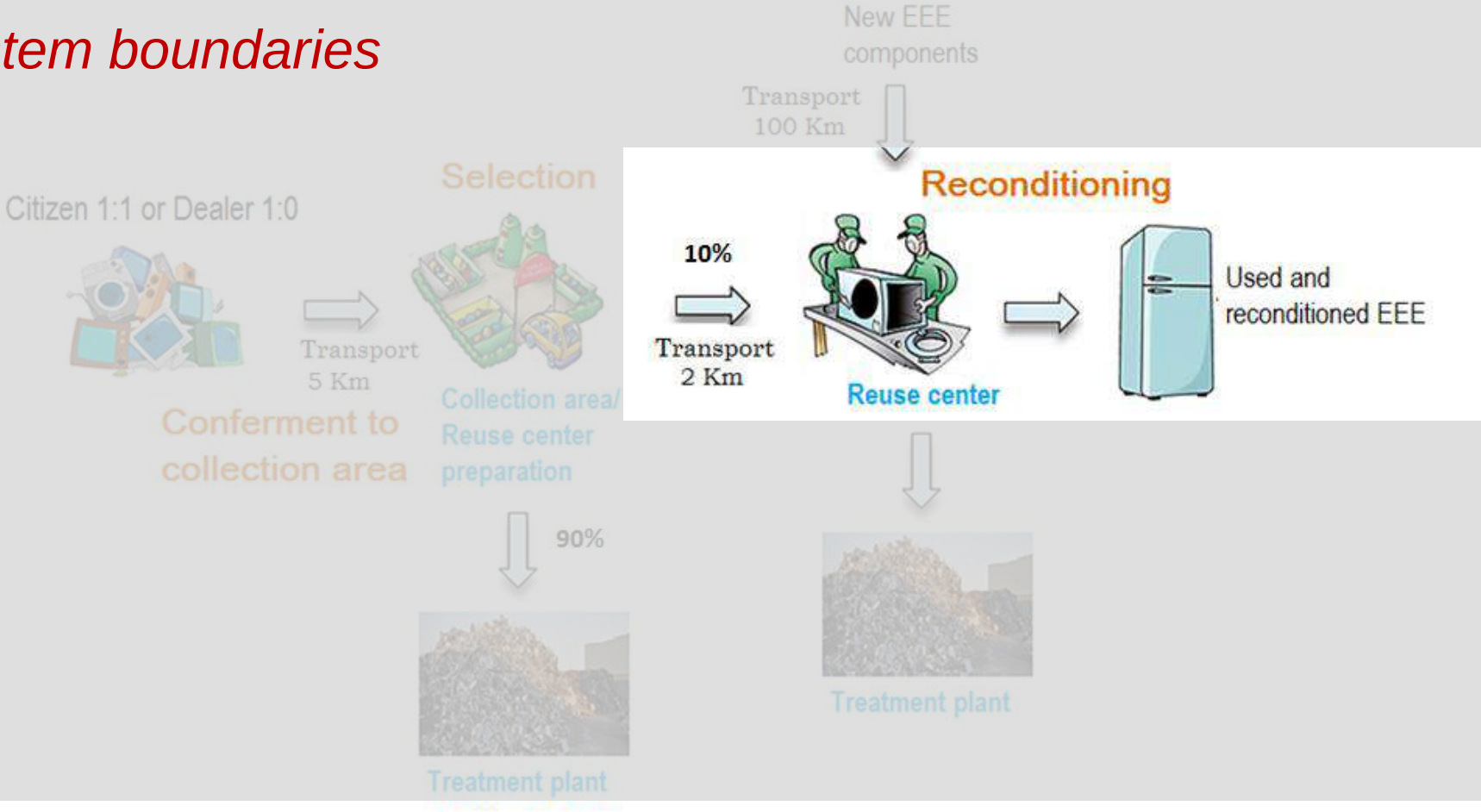
Studied system The studied system is the one hypothesized for Genoa city.

Functional unit:The functional unit is refered to the amount of WEEE produced per day by Genoa city (**9326,4 kg/d**).

System boundaries The system boundaries cover the entire life cycle from collection of WEEE to selection, maintenance of product to reuse, treatment of product to disposal, landfill and incinerator and whenever possible and environmentally convenient, recycling of materials.

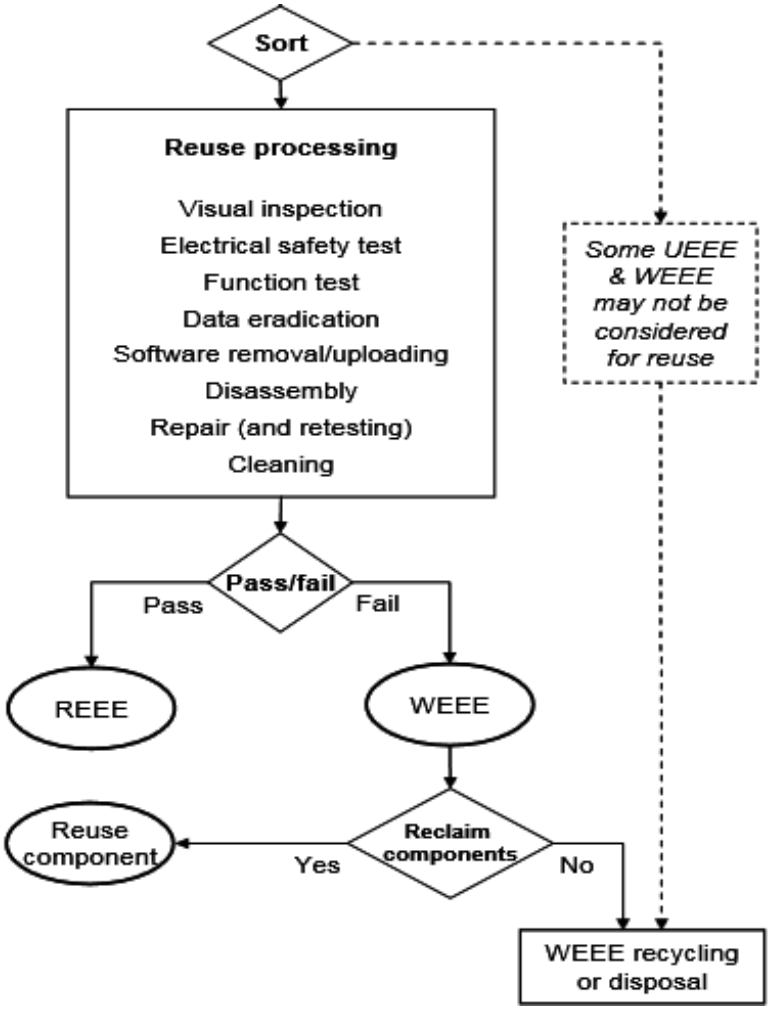
LCA of WEEE management and their potential reuse

System boundaries



Reconditioning

- Conferment to reuse center preparation (25% car –citizens- and 75% trucks - distributor-)
- Energy for disassembly and replacement of damaged components.
- Energy for assembly of new components and for the operation check.
- Separation of damaged components
- End of Life treatment damaged components
- Containers
- Labors



LCA of WEEE management and their potential reuse

ISO 14040/44

Data quality The primary data refer to the flow of the decommissioned WEEE in Genoa city.

The secondary data refer to: 1) the end of life treatments → Database *Ecoinvent v3.1*; 2) reconditioning activity of R1 (refrigerator) and R2 (washing machine), of which the replaced components have been modelled ad hoc or it has been used processes belong to *LCA_DatabaseUNIMORE*. The replaced components of WEEE have been chosen following according feasibility criteria and economic/environmental compatibility.

Software Simapro 8.0.4

Life cycle impact assessment method: modified IMPACT 2002+

New indicator -*number of new employees*- has been calculated in order to assess the increase of employment that will be generated by the new reuse activity.

Product (2014)	WEEE amount kg/day	Reuse rate %	Replaced components
R1 -Refrigerator	2486,8	10	Compressor Refrigerator liquid Gaskets
R2 -Washing machine	3972,9	10	1 printed wiring board Engine Belt
R3 - CRT	1930,8	10	4 Printed wiring board Electron gun
R4 - Laptop	915,92	10	Li-ion battery NiMH battery 4 Printed wiring board
R5 – Fluorescent lamp	19,98	10	2 Capacitor

LCA models

The choice of LCA model influence the environmental damage

Models proposed by Ecoinvent v3.1

- **Allocation Default**: It is a multi-output model but does not show nor co-products or avoided products. It only indicates the product representing the system function to which will be assigned the total damage.
- **Allocation Recycled**: It does not consider recycling processes that are part of the multi-output process, namely it considers them without impact on the system.
- **Consequential**: It expands the reference system considering the co-products as avoided products.

Model created and adopted by this study

- **Multi-output**: the processes have been built on the basis of Consequential model which expresses the co-products that are produced by the process, but in this case are not considered as avoided products but as co-products. The damage is distributed to each product and co-product.

Comparison between life cycle of new EEE and reused one

Definition of LCA model

1. system expansion (Consequential)
2. multi-output: economic allocation -100% on function
3. **multi-output: economic allocation – reference to the function**
4. multi-output: economic allocation – reference to the co-product (reused EEE)
5. multi-output: mass allocation – reference to the function

Function costs

1. electric energy
2. labour
3. plants
4. costs of replaced components and their transports
5. transport of new components

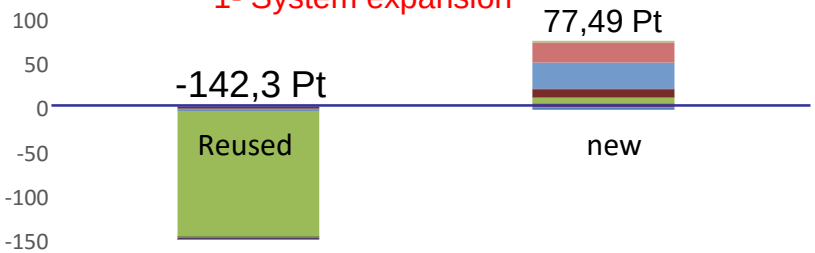
Co-product cost

1. market cost

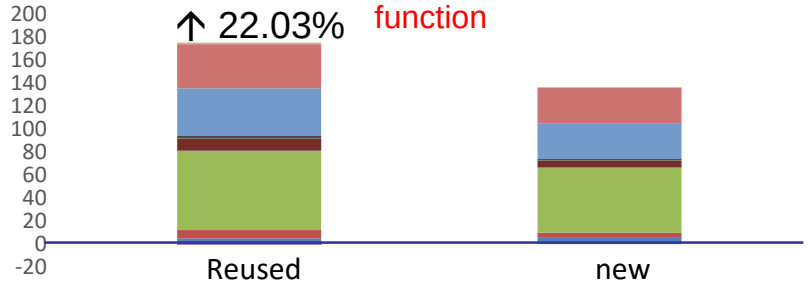
Comparison between life cycle of new and reused

R4 - laptop

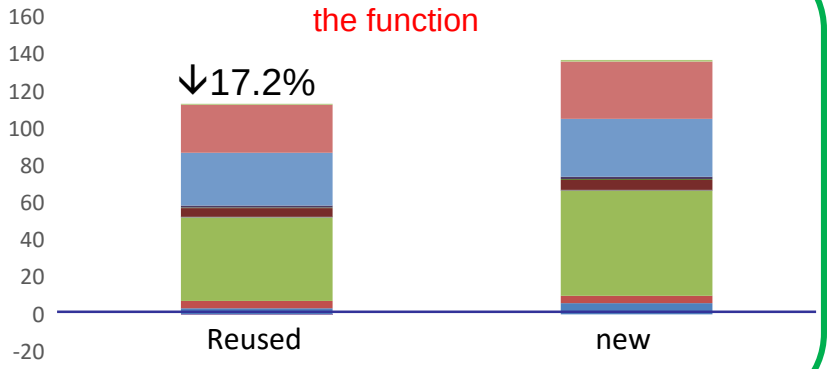
1- System expansion



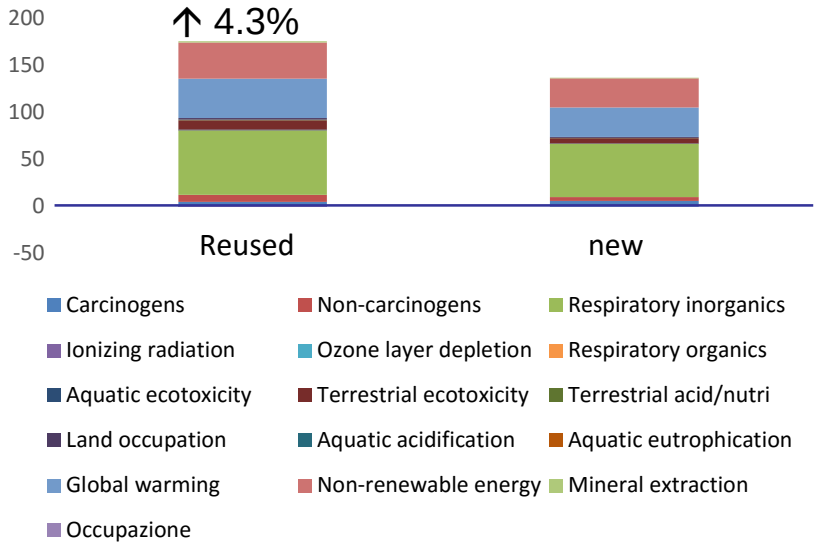
2- multi-output: economic allocation -100% on function



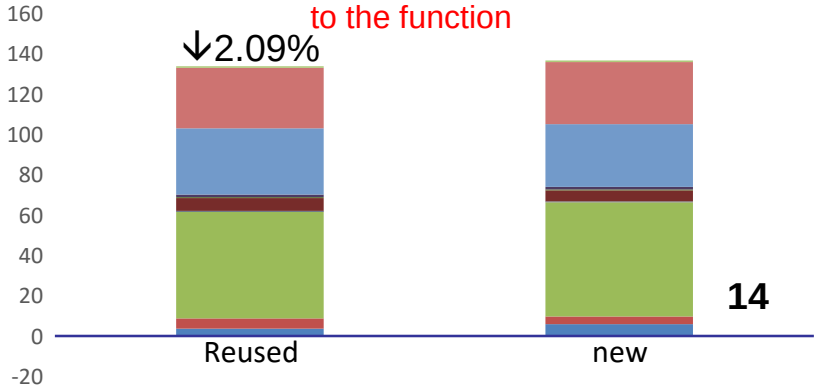
3- multi-output: economic allocation - reference to the function



4- multi-output: economic allocation – reference to the co-product (reused EEE)



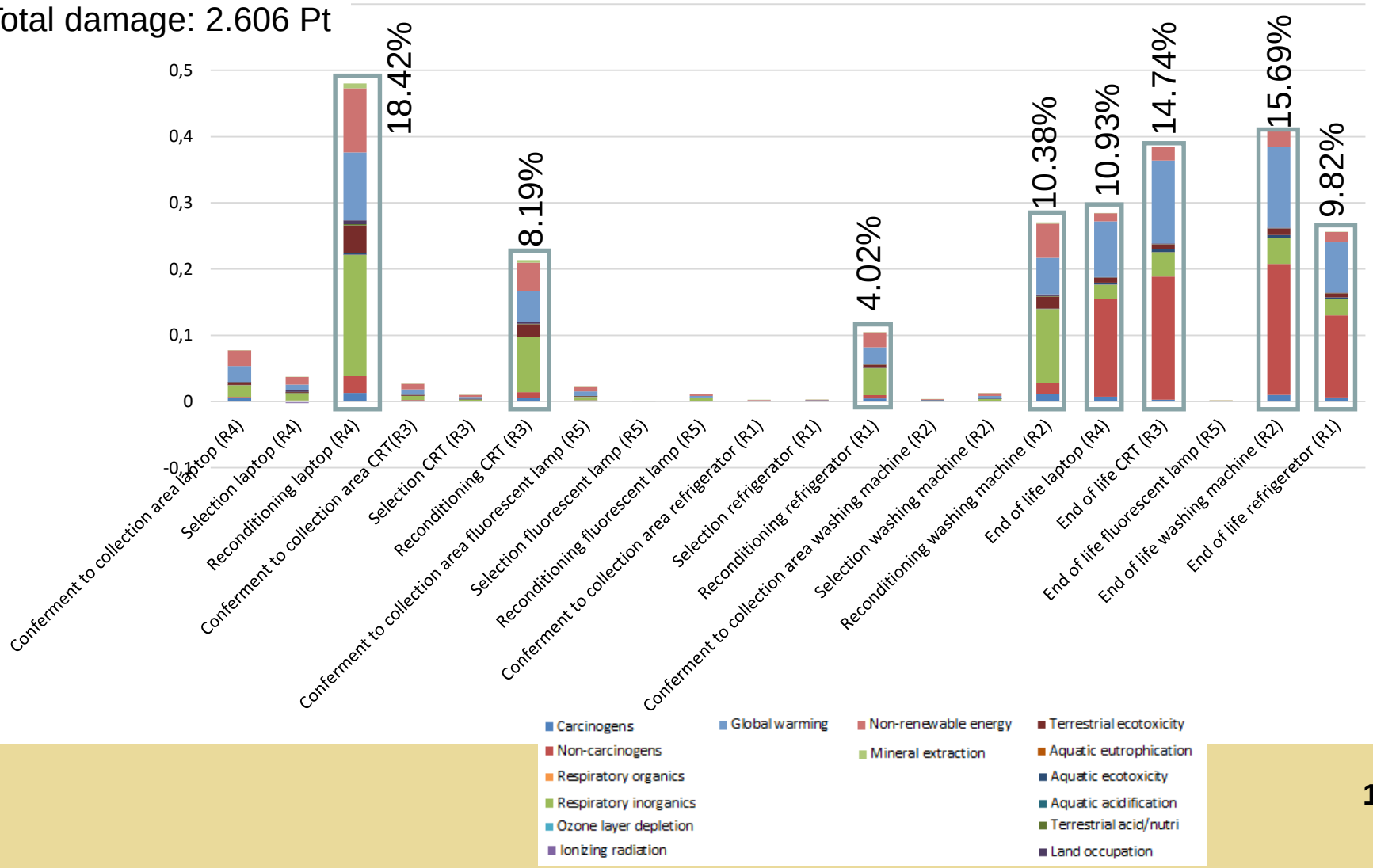
5- multi-output: mass allocation – reference to the function



Environmental results of the WEEE management system of Genoa city (UF 9326.4 kg/d)

Modello multi-output

Total damage: 2.606 Pt



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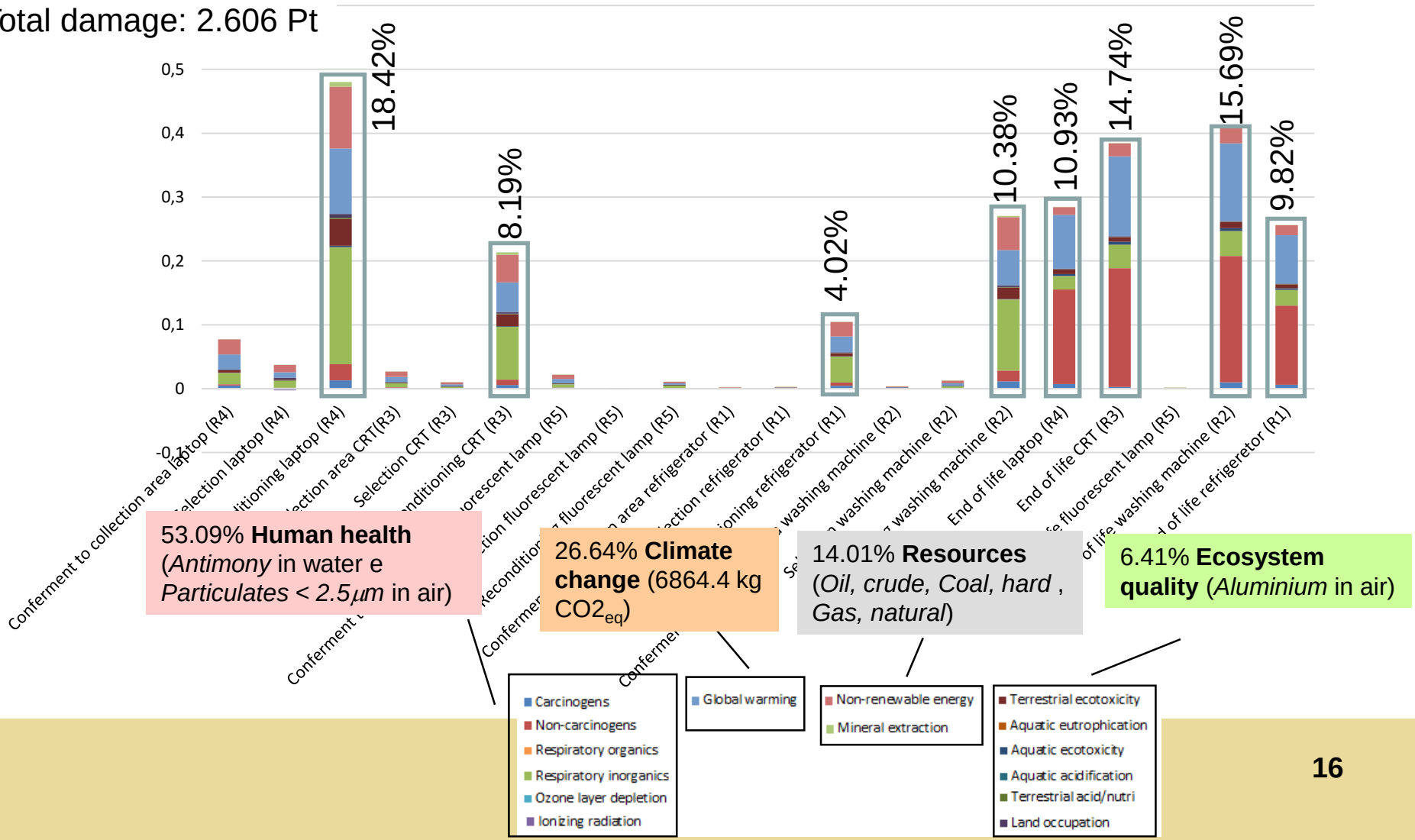

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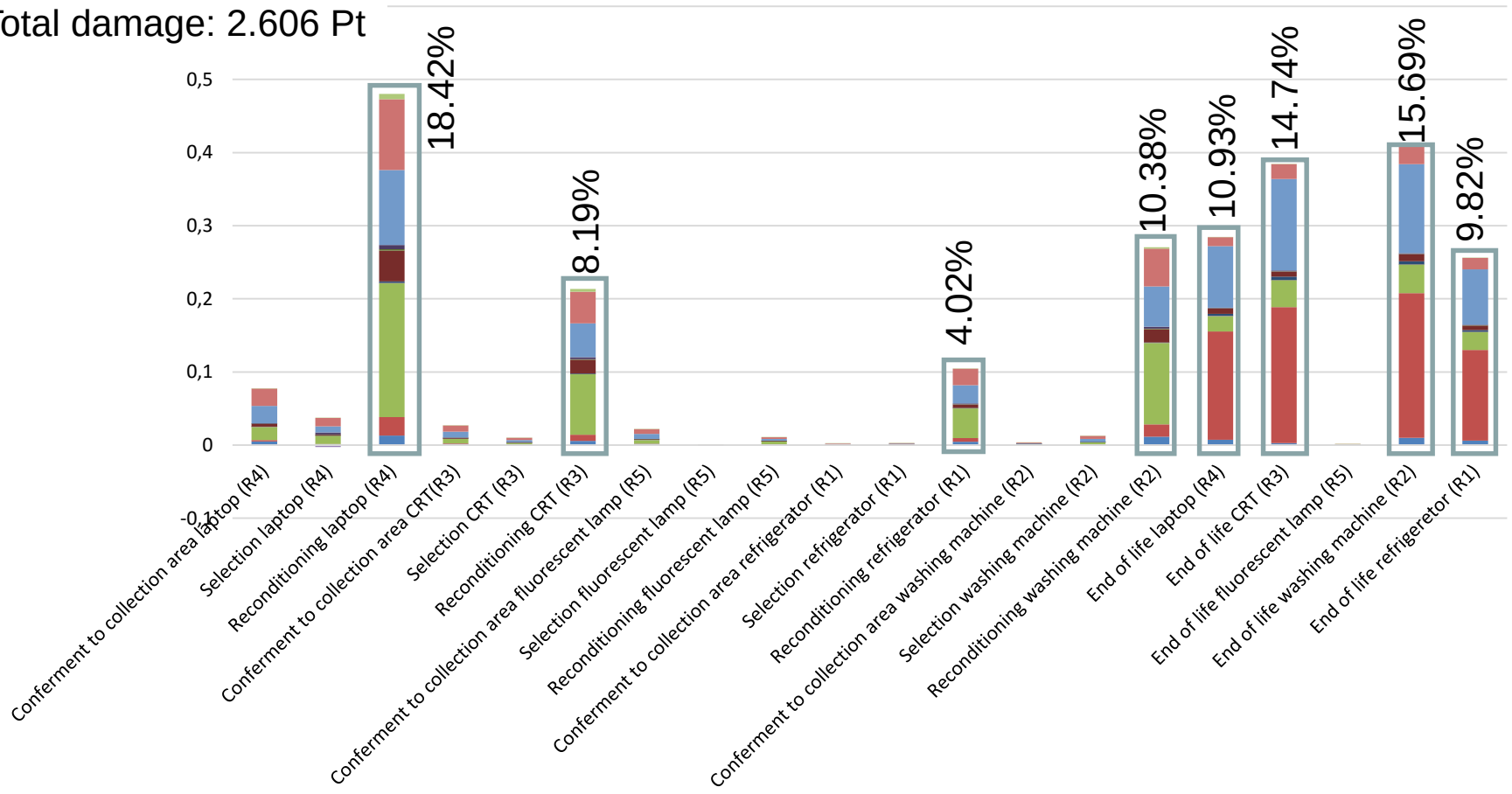
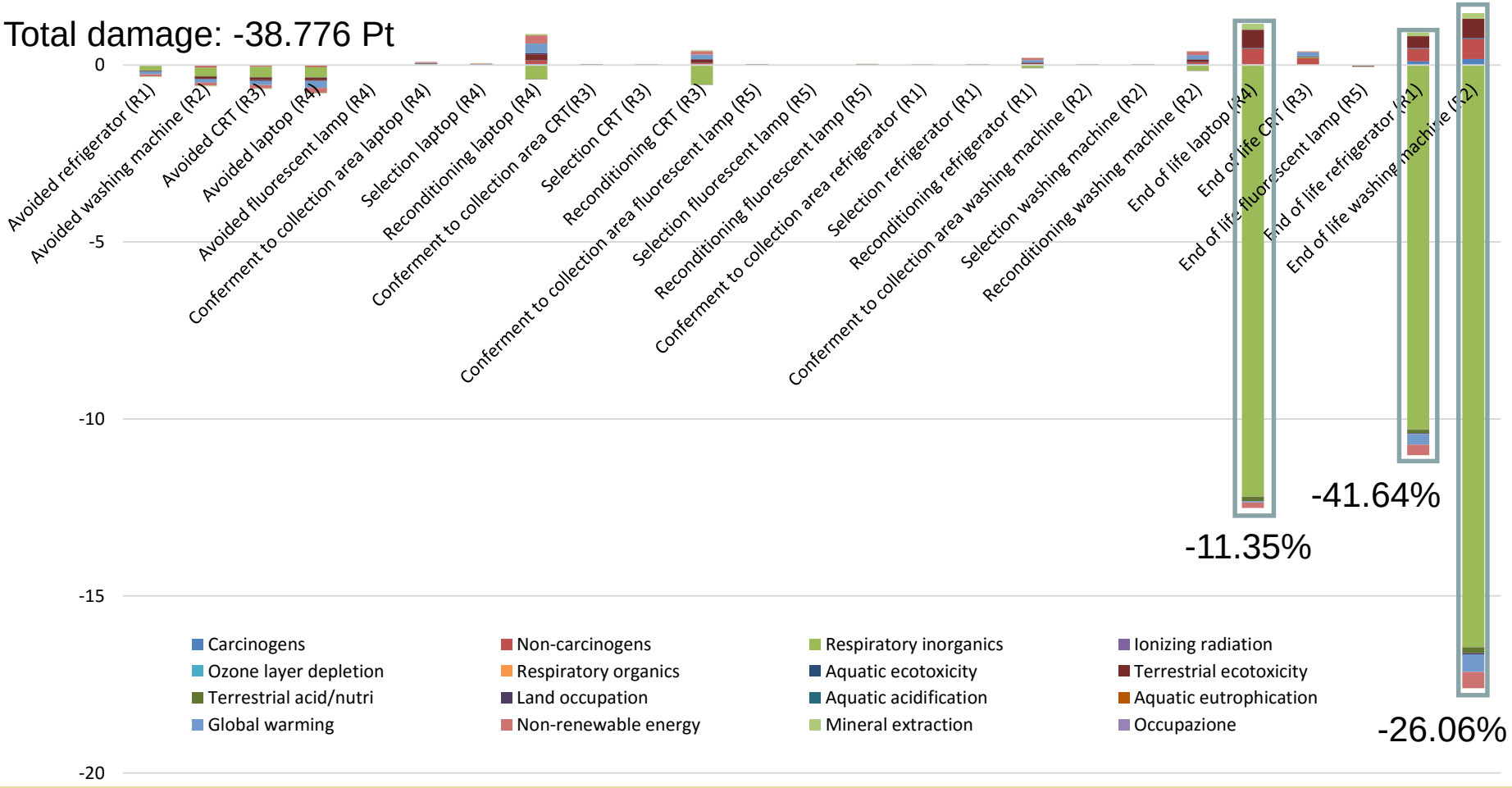


Environmental load of only reuse activity: 42.16% (1.09 Pt)

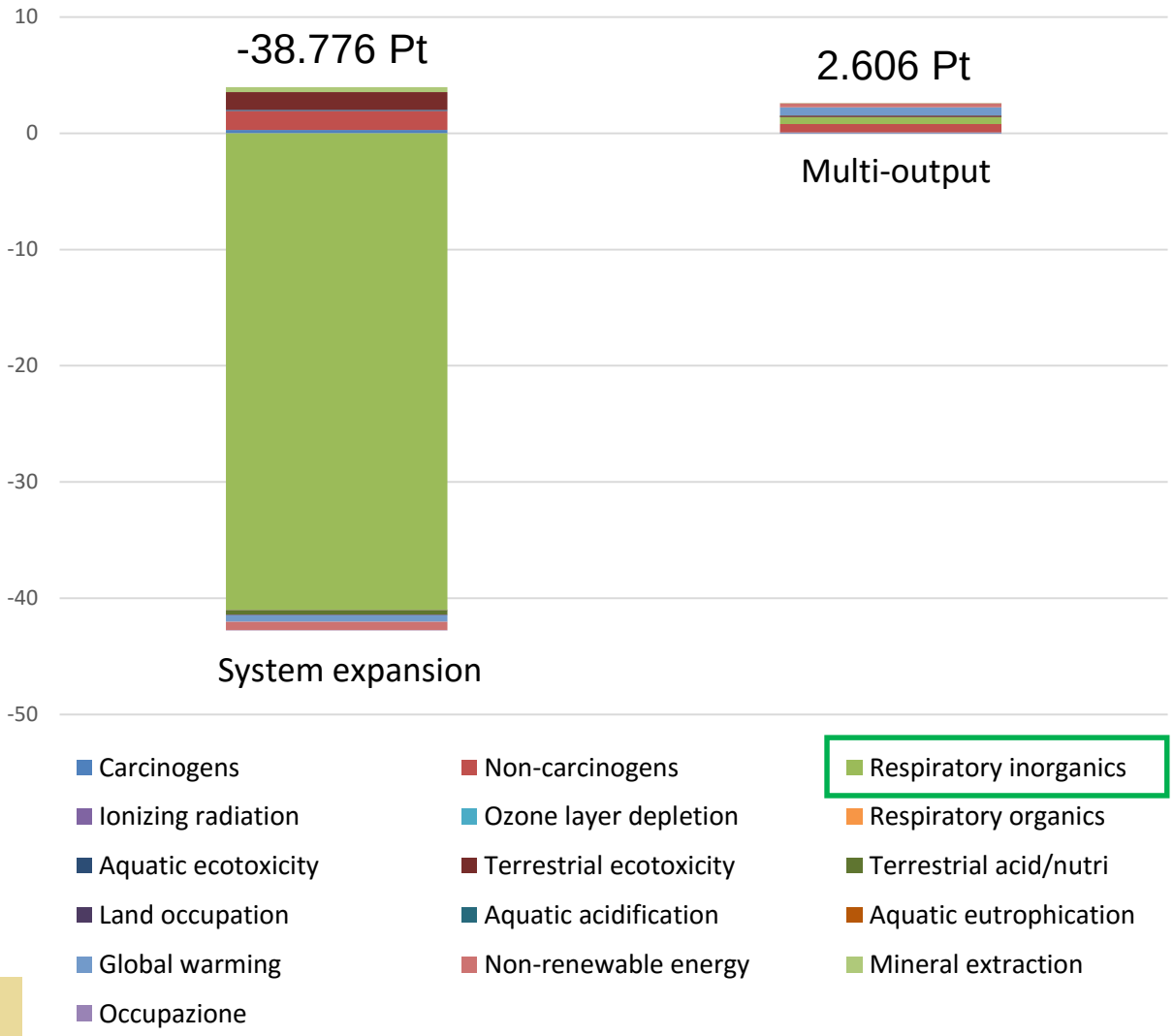
Number of jobs obtained by the new reuse activity: 100.74

Environmental results of the WEEE management system of Genoa city (UF 9326.4 kg/d)

Modello Espansione del sistema



LCA models comparison

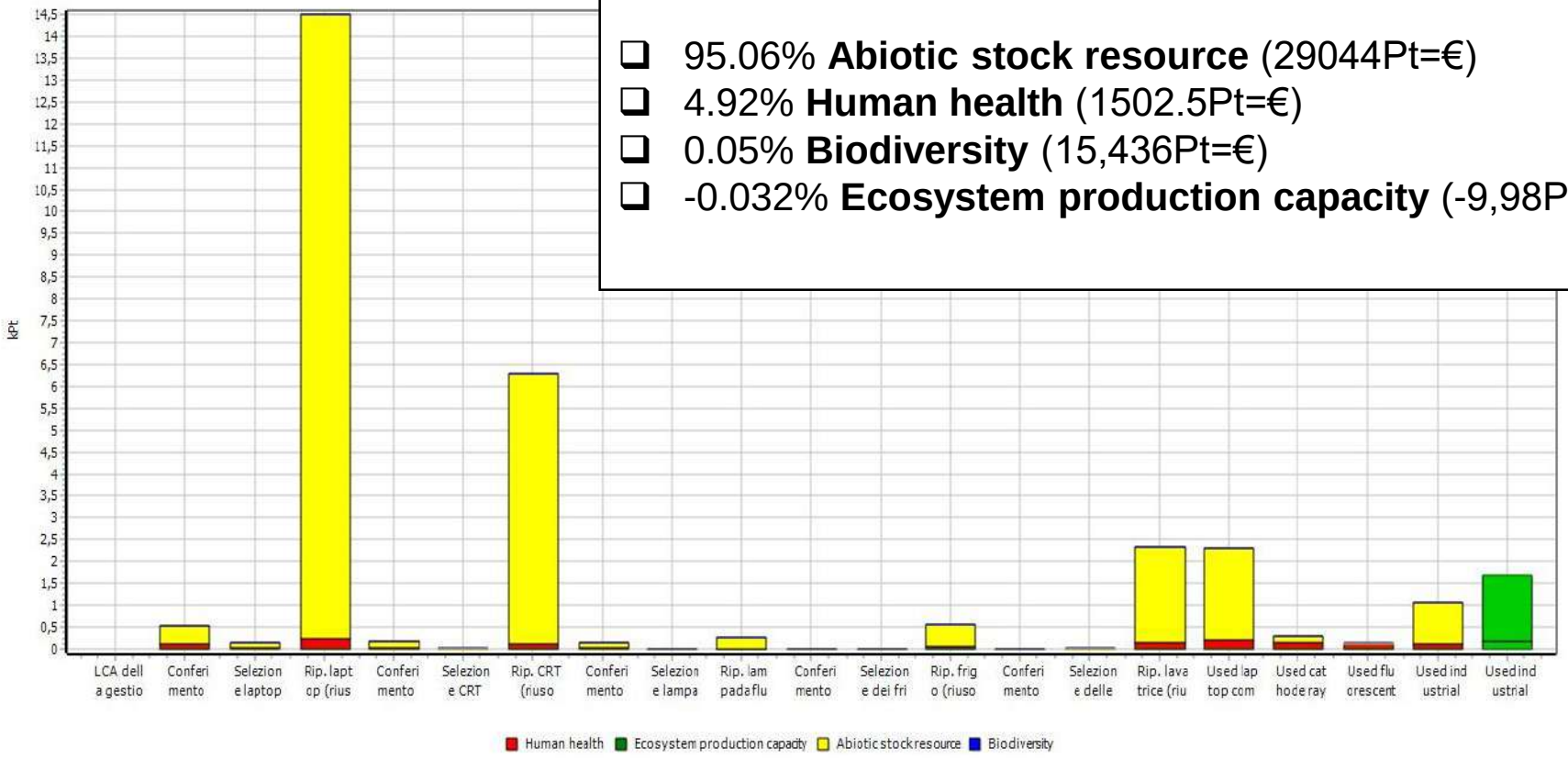


External costs analysis

LCIA method: EPS 2000

Total external cost: 30551.93€/d

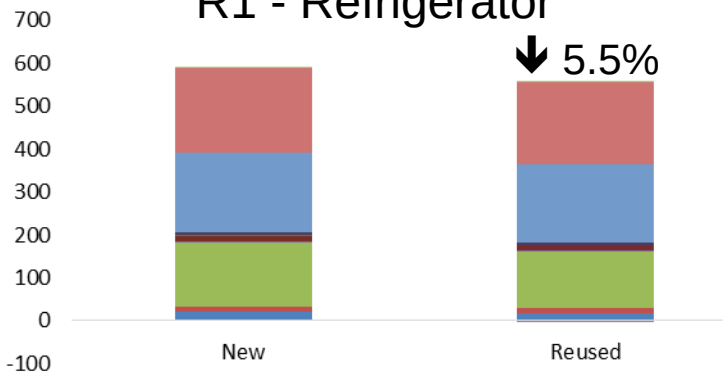
- 95.06% **Abiotic stock resource** (29044Pt=€)
- 4.92% **Human health** (1502.5Pt=€)
- 0.05% **Biodiversity** (15,436Pt=€)
- -0.032% **Ecosystem production capacity** (-9,98Pt=€)



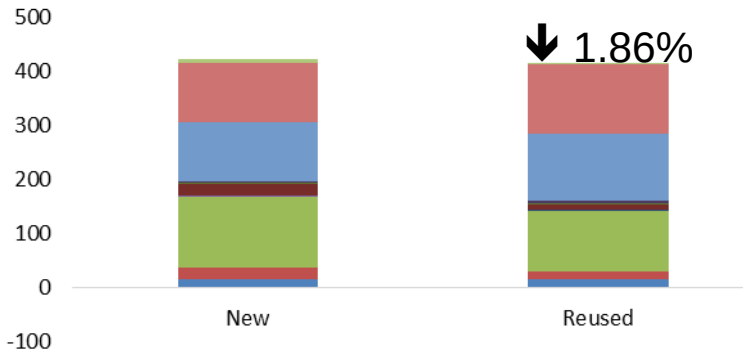
Environmental comparison between New and Reused

multi-output: economic allocation - reference to the function

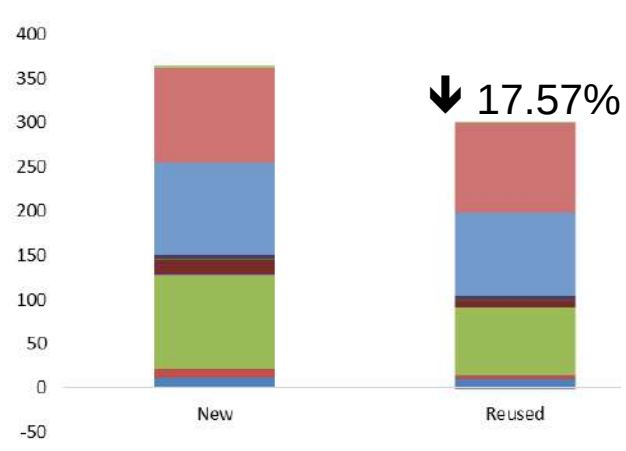
R1 - Refrigerator



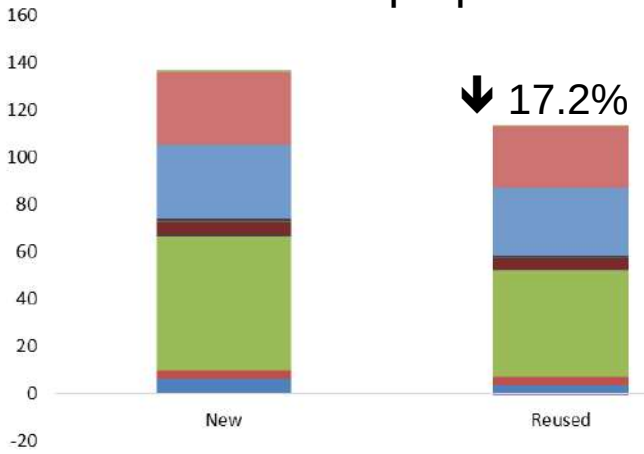
R2 – Washing machine



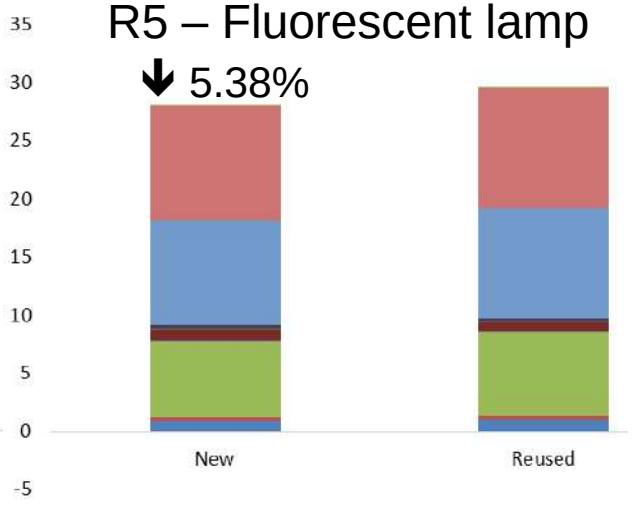
R3 - CRT



R4 - Laptop



R5 – Fluorescent lamp

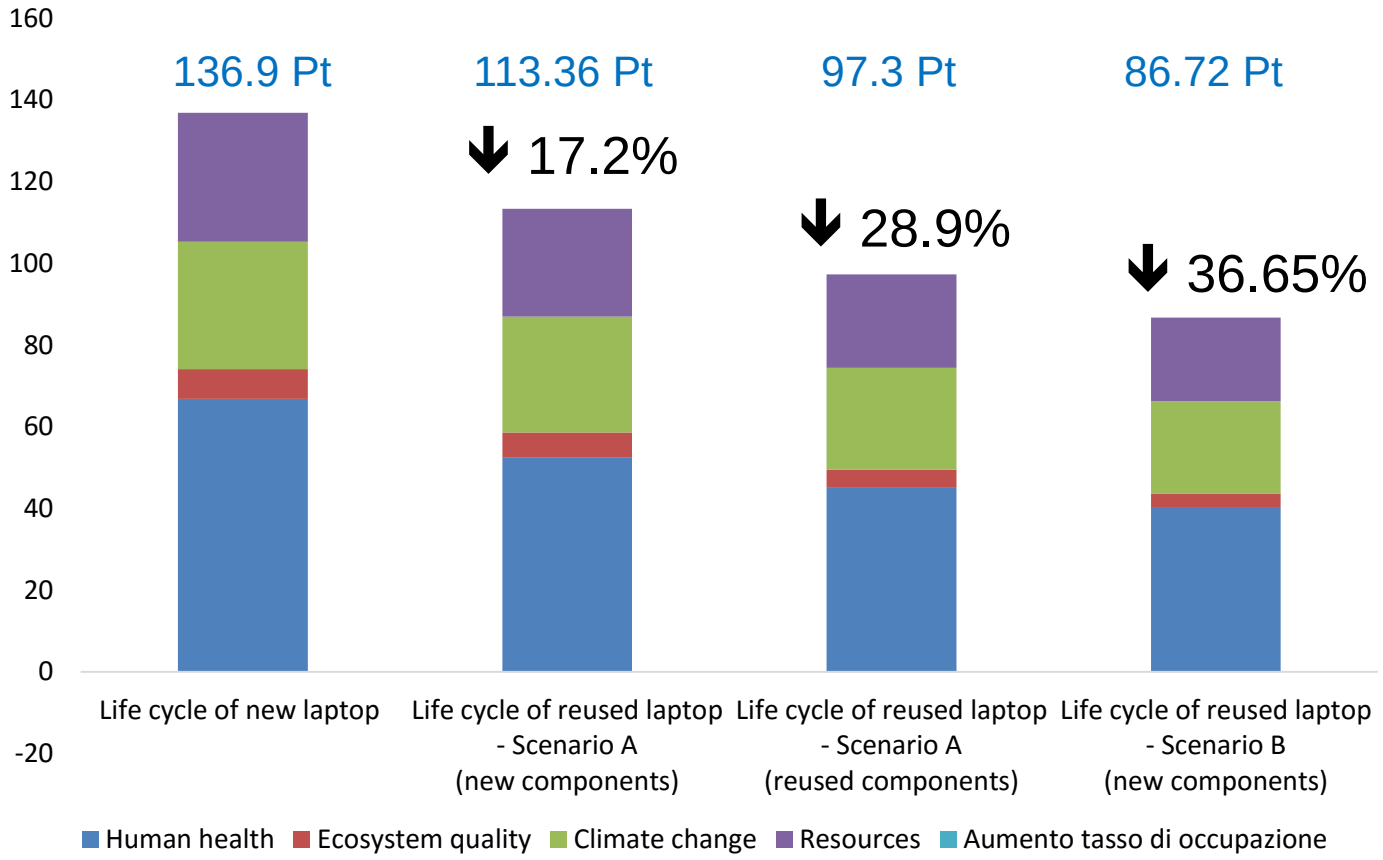


Carcinogens | Non-carcinogens | Respiratory inorganics | Ionizing radiation | Ozone layer depletion | Respiratory organics
Aquatic ecotoxicity | Terrestrial ecotoxicity | Terrestrial acid/nutri | Land occupation | Aquatic acidification | Aquatic eutrophication
Global warming | Non-renewable energy | Mineral extraction | Occupazione

Different scenarios of replaced components

Product	Scenario A Replaced components	Scenario B Replaced components
R1 -Refrigerator	Compressor Refrigerator liquid Gaskets	1 printed wiring board Resistor Thermostat
R2 -Washing machine	1 printed wiring board Engine Belt	1 printed wiring board Water pump Filter
R3 - CRT	4 Printed wiring board Electron gun	Funnel glass Panel glass
R4 - Laptop	Li-ion battery NiMH battery 4 Printed wiring board	Power pack Hard disk
R5 – Fluorescent lamp	2 Capacitor	Inductor Resistor

Environmental impacts of different scenarios of replaced components



Conclusions

- Total damage of hypothetical WEEE management in Genoa city: 2.6061Pt (multi-output model).
  - Processes: 18.42% Reuse activity of R4 and 15.7% End of Life of R2
  - Damage category: 53.09% Human health (End of life of R3 and Reuse activity of R4)
- The reuse activity determines a enviromental advantage of 0.15%.
- The total damage generated by the only reuse activity contributes to 42.16% on the total damage of WEEE management in Genoa city.
- In the reuse changing the replaced components or using replaced components already used the environmental performance decreases.
- The choice of LCA model for the reuse activity leads to differents of the environmental performance.
- External cost analysis (EPS 2000): the total external cost is equal to 30551.93 €/day (95.06% Resources).

Challenges

- A campaign should be launched which aims to raise awareness about of the positive effects that could generate the reconditioning of EEE

AMS - Montemurlo (PO)

- Installation of specific collection points outside populated places: commercial centers, schools, hospitals, municipal offices, etc.
- No business opportunity
- No authorizations are still defined to regulate the centers for preparation for reuse of WEEE

Preliminary framework to calculate the damage on human health caused by local and indoor emissions

- This method has been build following Eco-indicator 99 framework and the *Gaussian Plume Modeling* - a stationary model used to simulate the air pollutants dispersion into air emitted from a chimney-
- Damage local factor: $DF_{loc}=(DF_{EI99}/FF_{EI99}/PD_{EI99})\cdot FF_{loc}\cdot PD_{loc}$ [DALY/kg]
- Damage indoor factor: $DF_{indoor}=(DF_{EI99}/FF_{EI99}/PD_{EI99})\cdot FF_{indoor}\cdot PD_{indoor}$
- Where $FF_{loc/indoor}$= $C_{loc/indoor}$ /$E_{loc/indoor}$ is the local/indoor fate factor, $E_{loc/indoor}$ is the local/indoor emission calculated by Eco-indicator 99 formule- and $C_{loc/indoor}$ is the local/indoor concentration -calculated by Gaussian Plume Modeling formule-.
- The emitted area has been assumend 1 km^2 for local emissions and of 400 m^2 for indoor emissions.

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- Damage indoor fac PD_{indoor}
- Where $FF_{loc/indoor}$= e factor, $E_{loc/indoor}$ is the local/indoor em rmule- and $C_{loc/indoor}$ is the local/indoor c lume Modeling formule-.
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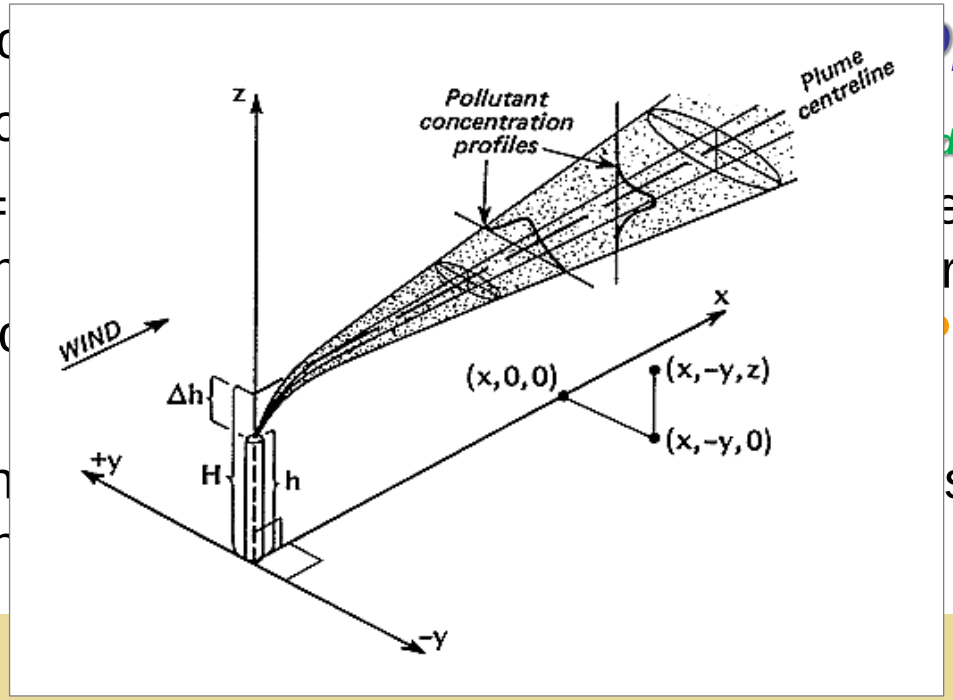

Preliminary framework to calculate the damage on human health caused by local and indoor emissions

- The environmental damage of WEEE management (10% of reuse rate) in Genoa city has been calculated by IMPACT 2002+ Method.
- The air emissions generated by the processes with greater environmental impacts have been taken into account.
- For each emissions first the maximum local emission concentration (C_{max}) and then the average emission concentration in urban area ($\bar{C}_{loc}$) have been calculated following the GPM method.

$$C_{max} = \frac{Q \cdot 10^6}{\pi \, v_z \, \sigma_y \, \sigma_z} \cdot \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

$$\bar{C}_{loc} = \frac{C_{max} \cdot 10^{-9}}{2}$$

- Final local and indoor human damages [DALY/d] have been calculated by a specific spreadsheet.

Processes with greater environmental impact

	WEEE treatment		Reuse activity	
Processes	Pt	kg	Pt	kg
Waste electric and electronic equipment {GLO}| treatment of, shredding	8,45E-03	6322,86	6,87E-06	51,38
Electronics scrap {SE}| treatment of, metals recovery in copper smelter	7,12E-02	347,87	2,01E-03	9,77
Non-Fe-Co-metals, from used Li-ion battery, pyrometallurgical processing {GLO}| treatment of non-Fe-Co-metals, from used Li-ion battery, pyrometallurgical processing	7,53E-03	0,59	7,53E-03	0,59
Precious metal from electronics scrap, in anode slime {RoW}+{SE}| treatment of, precious metal extraction	2,71E-02	2,11	7,63E-04	0,0595

Local and Indoor

Waste electric and electronic equipment {GLO}| treatment of, shredding

		WEEE management		Reuse activity		**WEEE management**	**Reuse activity**
Emission	Impact category in Human Health	Local emission concentration	Indoor emission concentration	Local emission concentration	Indoor emission concentration	Damage (Locale+Indoor) DALY/d	Damage(Locale+Indoor) DALY/d
		[µg/m3]	[µg/m3]	[µg/m3]	[µg/m3]	[DALY/d]	[DALY/d]
Aluminium	Carcinogens	3,5391E-02	1,3971E+03	2,8760E-04	1,13534E+01	2,2099E-05	1,79588E-07
	Non-carcinogens	3,5391E-02	1,3971E+03	2,8760E-04	1,13534E+01	3,5508E-06	2,88552E-08
Antimony	Non-carcinogens	3,0083E-03	1,1875E+02	2,4447E-05	9,65008E-01	2,3198E-02	1,88519E-04
Bromine	Not harmful to Human Health	6,0165E-03	2,3751E+02	4,8892E-05	1,93010E+00	0,0000E+00	0,00000E+00
Cadmium	Carcinogens	6,0165E-04	2,3751E+01	4,8892E-06	1,93010E-01	1,6462E-02	1,33778E-04
Chlorine	Non-carcinogens	8,1400E-03	3,2133E+02	6,6149E-05	2,61125E+00	2,6291E-05	2,13650E-07
Chromium	Carcinogens	1,3095E-03	5,1693E+01	1,0642E-05	4,20077E-01	2,6268E-05	2,13468E-07
	Non-carcinogens	1,3095E-03	5,1693E+01	1,0642E-05	4,20077E-01	1,4599E-06	1,18636E-08
Copper	Non-carcinogens	1,0617E-02	4,1913E+02	8,6278E-05	3,40601E+00	3,1519E-06	2,56133E-08
Iron	Not harmful to Human Health	1,2210E-02	4,8200E+03	9,9223E-05	3,91692E+01	0,0000E+00	0,00000E+00
Lead	Carcinogens	1,0440E-02	4,1214E+02	8,4839E-05	3,34921E+00	6,5193E-06	5,29786E-08
Mercury	Carcinogens	3,0083E-06	1,1875E-01	2,4447E-08	9,65008E-04	1,8785E-09	1,52650E-11
	Non-carcinogens	3,0083E-06	1,1875E-01	2,4447E-08	9,65008E-04	8,8142E-08	7,16276E-10
Nickel	Carcinogens	4,0700E-03	1,6067E+02	3,3074E-05	1,30567E+00	6,8695E-05	5,58243E-07
Phosphorus	Not harmful to Human Health	3,5391E-04	1,3971E+01	2,8760E-06	1,13534E-01	0,0000E+00	0,00000E+00
Polychlorinated biphenyls	Carcinogens	2,4620E-05	9,7191E-01	2,0007E-07	7,89812E-03	2,5819E-06	2,09819E-08
	Respiratory organics	2,4620E-05	9,7191E-01	2,0007E-07	7,89812E-03	4,2758E-08	3,47468E-10
Tin	Carcinogens	7,6091E-03	3,0038E+02	6,1834E-05	2,44100E+00	4,7514E-06	3,86115E-08
Zinc	Carcinogens	3,3091E-01	1,3063E+03	2,6891E-03	1,06155E+01	2,0663E-05	1,67915E-07
	Non-carcinogens	3,3091E-01	1,3063E+03	2,6891E-03	1,06155E+01	4,0896E-04	3,32337E-06
						Total damage (Locale+Indoor)	Total damage (Locale+Indoor)
						4,02 E-02	3,27 E-04

Continental diffusion (Europe) WEEE management

Waste electric and electronic equipment {GLO}| treatment of, shredding

5.6 E-5 DALY/d

The damage is reduced of three orders of magnitude.

Thank for your attention