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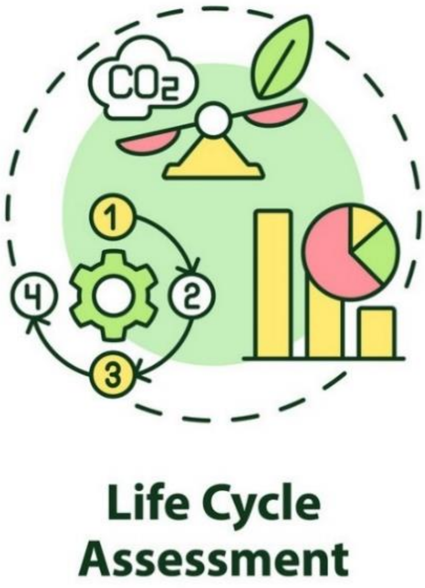
INDUSTRIAL MASTER

MASTER PROJECT

LIFE CYCLE ASSESSMENT OF MECHANICAL PLASTICS RECYCLING PROCESSES



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ABSTRACT

Since the advent of plastics in industry and in our daily lives, plastic pollution has caused significant damage to ecosystems and human health. As a result of economic and population growth, the use of plastics and the generation of plastic waste could almost triple worldwide in the 30 coming years. In addition, greenhouse gas emissions from the life cycle of plastics are expected to more than double, as are several related effects (ozone formation, acidification, human toxicity, etc.).

To counter these effects and to try to shift the projections of these grim predictions towards a healthier future for the environment and humans, it becomes essential to study the life cycle of the most widely used plastics today and more specifically their recycling processes. At present, 99% of recycled thermoplastic waste is recycled through a so-called "mechanical" recycling process. This recycling consists of several stages: collection, sorting, washing, grinding, extrusion and transformation.

Among the most used plastics in the world, we choose to study polypropylene, polyethylene terephthalate and high-density polyethylene. We will carry out an analysis of the environmental impacts of the mechanical recycling processes of these three plastics using the free software OpenLCA, in a Life Cycle Assessment approach.

By comparing the results obtained in our study, we hope to provide additional data and help other ongoing or future studies on these sensitive and important topics.

RESUMEN

Desde la aparición de los plásticos en la industria y en nuestra vida cotidiana, la contaminación por plásticos ha causado importantes daños a los ecosistemas y a la salud humana. Como consecuencia del crecimiento económico y demográfico, el uso de plásticos y la generación de residuos plásticos podrían casi triplicarse en todo el mundo en los 30 próximos años. Además, se prevé que las emisiones de gases de efecto invernadero derivadas del ciclo de vida de los plásticos aumenten más del doble, al igual que varios efectos relacionados (formación de ozono, acidificación, toxicidad humana, etc.).

Para contrarrestar estos efectos y tratar de cambiar las proyecciones de estas sombrías predicciones hacia un futuro más saludable para el medio ambiente y los seres humanos, resulta esencial estudiar el ciclo de vida de los plásticos más utilizados en la actualidad y, más concretamente, sus procesos de reciclado. En la actualidad, el 99% de los residuos termoplásticos reciclados se reciclan mediante el denominado proceso de reciclado "mecánico". Este reciclaje consta de varias etapas: recogida, clasificación, lavado, trituración, extrusión y transformación.

Entre los plásticos más utilizados en el mundo, elegimos estudiar el polipropileno, el tereftalato de polietileno y el polietileno de alta densidad. Realizaremos un análisis de los impactos ambientales de los procesos de reciclado mecánico de estos tres plásticos utilizando el software libre OpenLCA, en un enfoque de evaluación del ciclo de vida.

Al comparar los resultados obtenidos en nuestro estudio, esperamos aportar datos adicionales y ayudar a otros estudios en curso o futuros sobre estos temas tan delicados e importantes.

RÉSUMÉ

Depuis l'arrivée des plastiques dans l'industrie et dans notre vie quotidienne, la pollution plastique porte largement atteinte aux écosystèmes et à la santé humaine. Sous l'effet de la croissance économique et démographique, l'utilisation de plastique et la production de ses déchets pourraient quasiment tripler au niveau mondial dans les 30 prochaines années. En outre, les émissions de gaz à effet de serre imputables au cycle de vie des plastiques devraient plus que doubler et il en est de même pour plusieurs effets qui en sont liés (formation d'ozone, acidification, toxicité humaine…).

Pour contrer ces effets et tenter de dévier les projections de ces prédictions sinistres vers un avenir plus sain pour l'environnement et l'humain, il devient primordial d'étudier le cycle de vie des plastiques les plus largement utilisés aujourd'hui et plus spécifiquement leurs processus de recyclage. A l'heure actuelle, 99% des déchets thermoplastiques qui sont recyclés le sont selon un recyclage dit « mécanique ». Ce recyclage se décompose en plusieurs étapes : collecte, tri, lavage, broyage, extrusion et transformation.

Parmi les plastiques les plus utilisés dans le monde, nous choisissons d'étudier le polypropylène, le polyéthylène de téréphtalate et le polyéthylène à haute densité. Nous réaliserons une analyse des impacts environnementaux des processus de recyclage mécanique de ces trois plastiques via le logiciel gratuit OpenLCA, dans une démarche d'analyse de cycle de vie.

En comparant les résultats obtenus lors de notre étude, nous espérons apporter des données supplémentaires et aider d'autres études en cours ou à venir sur ces sujets sensibles et majeurs.

Table of Contents

ABSTRACT 4

RESUMEN 4

RÉSUMÉ 5

ACKNOWLEDGEMENTS 18

1 INTRODUCTION 19

1.1 Definition of plastic 21

1.2 Definition of polyethylene terephthalate 22

1.3 Definition of high-density polyethylene 22

1.4 Definition of polypropylene 22

1.5 Life Cycle Assessment 23

2 CONTEXT 29

2.1 Recyclable plastics 29

2.2 Mechanical recycling 30

2.2.1 Technology description 31

2.2.2 Sorting 31

2.2.3 Reprocessing 32

2.2.4 Quality of the recycled plastic 32

2.2.5 Economic viability 32

2.2.6 Environmental impact and comparison with other end-of-life treatments 33

2.2.7 Advantages 34

3 OBJECTIVES 35

4 BENEFITS 36

5 STATE OF THE ARTS ANALYSIS 37

6 METHODOLODY 38

6.1 Analysis of alternatives 38

6.2 Goal and scope 39

6.3 Impact analysis 39

7 PROPOSED SOLUTION 45

7.1 List of inputs/outputs ... 45
7.2 Flowcharts ... 47
7.2.1 PET detailed flowchart ... 47
7.2.2 HDPE detailed flowchart ... 47
7.2.3 PP detailed flowchart ... 48
7.3 List of inputs/outputs - final version ... 48
7.4 Flowcharts - final version ... 50
7.4.1 PET final flowchart ... 50
7.4.2 HDPE final flowchart ... 50
7.4.3 PP final flowchart ... 51
7.5 Material and energy inventory ... 52
7.5.1 PET inventory ... 52
7.5.2 HDPE inventory ... 53
7.5.3 PP inventory ... 54
8 RESULTS AND DISCUSSION ... 55
8.1 Global Warming Potential ... 57
8.2 Terrestrial Acidification Potential ... 62
8.3 Marine Eutrophication Potential ... 67
8.4 Human Toxicity (carcinogenic) Potential ... 72
8.5 Ozone Depletion Potential ... 76
8.6 Sensitivity analysis: Nuclear energy vs Renewable energies ... 80
8.6.1 Global Warming Potential ... 83
8.6.2 Terrestrial Acidification Potential ... 88
8.6.3 Marine Eutrophication Potential ... 93
8.6.4 Human Toxicity (carcinogenic) Potential ... 98
8.6.5 Ozone Depletion Potential ... 103
8.7 Comparative study ... 107
9 PROJECT PLANIFICATION ... 109
10 COST OF THE PROJECT ... 114
11 CONCLUSIONS ... 115

12 REFERENCES 117

13 ANNEXES 120

13.1 Nuclear energy 120

13.1.1 PET 121

13.1.2 HDPE 125

13.1.3 PP 127

13.2 Renewable energies 130

13.2.1 PET 131

13.2.2 HDPE 134

13.2.3 PP 137

Table of Figures

Figure 1. Projection of global plastics use in Mt (1950 and 2060) - (OCDE, 2022)............................ 19
Figure 2. Share of plastics treated by waste management category, after disposal of recycling residues and collected litter (2019) - (OCDE, 2022)... 20
Figure 3.Share of plastics treated by waste management category, after disposal of recycling residues and collected litter (2060) - (OCDE, 2022)... 20
Figure 4. Concept of the perspective of a Life Cycle Assessment and the phases considered............. 24
Figure 5. Product system and unit processes... 24
Figure 6. LCA steps.. 25
Figure 7. Calculation properties - OpenLCA 27
Figure 8. The different parts of Life Cycle Assessment (LCA) 27
Figure 9. Chart of the approximate proportion of PET, HDPE, PP and PS in lightweight packaging waste - (Deutschland, 2015) 30
Figure 10. Steps of the mechanical recycling.. 31
Figure 11. Global Warming Potential (GWP) comparison for different types of recycling, for 1 kg of plastic 33
Figure 12. Terminology related to the scope of a LCA.. 38
Figure 13. Menu - OpenLCA 40
Figure 14. New database - OpenLCA 40
Figure 15. Restore database - OpenLCA.. 41
Figure 16. Database - OpenLCA 41
Figure 17. Database ecoinvent_391_cutoff_upr - OpenLCA.. 42
Figure 18. Inputs/Outputs - OpenLCA 42
Figure 19. Calculation properties - OpenLCA 43
Figure 20. Model graph - OpenLCA 43
Figure 21. PET flowchart (detailed).. 47
Figure 22. HDPE flowchart (detailed)... 47
Figure 23. PP flowchart (detailed)... 48
Figure 24. PET flowchart (final version) 50
Figure 25. HDPE flowchart (final version) 50
Figure 26. PP flowchart (final version) 51
Figure 27. Stacked bar chart of the environment impact, considering 1 kg of material as base unit (using renewable energies).. 56
Figure 28. Pie chart of the categories having impact on GWP for 1 kg of recycled PET (using nuclear energy).. 59

Figure 29. Pie chart of the categories having impact on GWP for 1 kg of recycled HDPE (using nuclear energy) 60
Figure 30. Pie chart of the categories having impact on GWP for 1 kg of recycled PP (using nuclear energy) 61
Figure 31. Comparison of GWP (kg CO_2-Eq) for PET, HDPE and PP (using nuclear energy) 62
Figure 32. Pie chart of the categories having impact on TAP for 1 kg of recycled PET (using nuclear energy) 64
Figure 33. Pie chart of the categories having impact on TAP for 1 kg of recycled HDPE (using nuclear energy) 65
Figure 34. Pie chart of the categories having impact on TAP for 1 kg of recycled PP (using nuclear energy) 66
Figure 35. Comparison of TAP (kg SO2-Eq) for PET, HDPE and PP (using nuclear energy) 67
Figure 36. Pie chart of the categories having impact on MEP for 1 kg of recycled PET (using nuclear energy) 69
Figure 37. Pie chart of the categories having impact on MEP for 1 kg of recycled HDPE (using nuclear energy) 70
Figure 38. Pie chart of the categories having impact on MEP for 1 kg of recycled PET (using nuclear energy) 71
Figure 39. Comparison of MEP (kg N-Eq) for PET, HDPE and PP (using nuclear energy) 72
Figure 40. Pie chart of the categories having impact on HTPc for 1 kg of recycled PET (using nuclear energy) 73
Figure 41. Pie chart of the categories having impact on HTPc for 1 kg of recycled HDPE (using nuclear energy) 74
Figure 42. Pie chart of the categories having impact on HTPc for 1 kg of recycled PP (using nuclear energy) 75
Figure 43. Comparison of HTPc (kg 1,4-DCB-Eq) for PET, HDPE and PP (using nuclear energy) ... 76
Figure 44. Pie chart of the categories having impact on ODP for 1 kg of recycled PET (using nuclear energy) 77
Figure 45. Pie chart of the categories having impact on ODP for 1 kg of recycled HDPE (using nuclear energy) 78
Figure 46. Pie chart of the categories having impact on ODP for 1 kg of recycled PP (using nuclear energy) 79
Figure 47. Comparison of ODP (kg CFC-11-Eq) for PET, HDPE and PP (using nuclear energy) 80
Figure 48. Stacked bar chart of the environment impact, considering 1 kg of material as base unit (using nuclear energy) 82
Figure 49. Pie chart of the categories having impact on GWP for 1 kg of recycled PET (using renewable energies) 83

Figure 50. Pie chart of the categories having impact on GWP for 1 kg of recycled HDPE (using renewable energies) ... 84
Figure 51. Pie chart of the categories having impact on GWP for 1 kg of recycled PP (using renewable energies) ... 85
Figure 52. Comparison of GWP (kg CO2-Eq) for PET, HDPE and PP (using renewable energies) ... 86
Figure 53. Clustered bar chart of the elements having an impact on GWP for PET, HDPE and PP ... 86
Figure 54. Comparison of the pie charts for GWP ... 87
Figure 55. Pie chart of the categories having impact on TAP for 1 kg of recycled PET (using renewable energies) ... 88
Figure 56. Pie chart of the categories having impact on TAP for 1 kg of recycled HDPE (using renewable energies) ... 89
Figure 57. Pie chart of the categories having impact on TAP for 1 kg of recycled PP (using renewable energies) ... 90
Figure 58. Comparison of TAP (kg SO_2-Eq) for PET, HDPE and PP (using renewable energies) ... 91
Figure 59. Clustered bar chart of the elements having an impact on TAP for PET, HDPE and PP ... 91
Figure 60. Comparison of the pie charts for TAP ... 92
Figure 61. Pie chart of the categories having impact on MEP for 1 kg of recycled PET (using renewable energies) ... 93
Figure 62. Pie chart of the categories having impact on MEP for 1 kg of recycled HDPE (using renewable energies) ... 94
Figure 63. Pie chart of the categories having impact on MEP for 1 kg of recycled PP (using renewable energies) ... 95
Figure 64. Comparison of MEP (kg N-Eq) for PET, HDPE and PP (using renewable energies) ... 96
Figure 65. Clustered bar chart of the elements having an impact on MEP for PET, HDPE and PP ... 96
Figure 66. Comparison of the pie charts for MEP ... 97
Figure 67. Pie chart of the categories having impact on HTPc for 1 kg of recycled PET (using renewable energies) ... 98
Figure 68. Pie chart of the categories having impact on HTPc for 1 kg of recycled HDPE (using renewable energies) ... 99
Figure 69. Pie chart of the categories having impact on HTPc for 1 kg of recycled PP (using renewable energies) ... 100
Figure 70. Comparison of HTPc (1,4-DCB-Eq) for PET, HDPE and PP (using renewable energies) 101
Figure 71. Clustered bar chart of the elements having an impact on HTPc for PET, HDPE and PP .. 101
Figure 72. Comparison of the pie charts for HTPc ... 102
Figure 73. Pie chart of the categories having impact on ODP for 1 kg of recycled PET (using renewable energies) ... 103

Figure 74. Pie chart of the categories having impact on ODP for 1 kg of recycled HDPE (using renewable energies) 104
Figure 75. Pie chart of the categories having impact on ODP for 1 kg of recycled PP (using renewable energies) 105
Figure 76. Comparison of ODP (kg CFC-11-Eq) for PET, HDPE and PP (using renewable energies) 106
Figure 77. Clustered bar chart of the elements having an impact on ODP for PET, HDPE and PP ... 106
Figure 78. Comparison of the pie charts for ODP 107
Figure 79. Gantt affectation of the project 113

Table of Tables

Table 1. Main characteristics of PET, HDPE and PP 23
Table 2. Impact categories ReCiPe 2016 Midpoint (H) 26
Table 3. Definition of LCA terminologies 28
Table 4. List of inputs/outputs (detailed) 46
Table 5. List of inputs/outputs (final version) 49
Table 6. PET inventory - inputs 52
Table 7. PET inventory – outputs 52
Table 8. HDPE inventory - inputs 53
Table 9. HDPE inventory – outputs 53
Table 10. PP inventory - inputs 54
Table 11. PP inventory - outputs 54
Table 12. Environmental impact, considering 1 kg of material as base unit (using renewable energies) 56
Table 13. List of elements having impact on GWP for 1 kg of recycled PET (using nuclear energy) 59
Table 14. List of elements having impact on GWP for 1 kg of recycled HDPE (using nuclear energy) 60
Table 15. List of elements having impact on GWP for 1 kg of recycled PP (using nuclear energy) 61
Table 16. List of elements having impact on TAP for 1 kg of recycled PET (using nuclear energy) 64
Table 17. List of elements having impact on TAP for 1 kg of recycled HDPE (using nuclear energy) 65
Table 18. List of elements having impact on TAP for 1 kg of recycled PP (using nuclear energy) 66
Table 19. List of elements having impact on MEP for 1 kg of recycled PET (using nuclear energy) 69
Table 20. List of elements having impact on MEP for 1 kg of recycled HDPE (using nuclear energy)70
Table 21. List of elements having impact on MEP for 1 kg of recycled PP (using nuclear energy) 71
Table 22. List of elements having impact on HTPc for 1 kg of recycled PET (using nuclear energy) 73
Table 23. List of elements having impact on HTPc for 1 kg of recycled HDPE (using nuclear energy) 74
Table 24. List of elements having impact on HTPc for 1 kg of recycled PP (using nuclear energy) 75
Table 25. List of elements having impact on ODP for 1 kg of recycled PET (using nuclear energy) 77
Table 26. List of elements having impact on ODP for 1 kg of recycled HDPE (using nuclear energy)78
Table 27. List of elements having impact on ODP for 1 kg of recycled PP (using nuclear energy) 79
Table 28. Environmental impact, considering 1 kg of material as base unit 82
Table 29. List of elements having impact on GWP for 1 kg of recycled PET (using renewable energies) 83
Table 30. List of elements having impact on GWP for 1 kg of recycled HDPE (using renewable energies) 84

Table 31. List of elements having impact on GWP for 1 kg of recycled PP (using renewable energies) 85
Table 32. List of elements having impact on TAP for 1 kg of recycled PET (using renewable energies) 88
Table 33. List of elements having impact on TAP for 1 kg of recycled HDPE (using renewable energies) 89
Table 34. List of elements having impact on TAP for 1 kg of recycled PP (using renewable energies) 90
Table 35. List of elements having impact on MEP for 1 kg of recycled PET (using renewable energies) 93
Table 36. List of elements having impact on MEP for 1 kg of recycled HDPE (using renewable energies) 94
Table 37. List of elements having impact on MEP for 1 kg of recycled PP (using renewable energies) 95
Table 38. List of elements having impact on HTPc for 1 kg of recycled PET (using renewable energies) 98
Table 39. List of elements having impact on HTPc for 1 kg of recycled HDPE (using renewable energies) 99
Table 40. List of elements having impact on HTPc for 1 kg of recycled PP (using renewable energies) 100
Table 41. List of elements having impact on ODP for 1 kg of recycled PET (using renewable energies) 103
Table 42. List of elements having impact on ODP for 1 kg of recycled HDPE (using renewable energies) 104
Table 43. List of elements having impact on ODP for 1 kg of recycled PP (using renewable energies) 105
Table 44. Comparative table of the studies 108
Table 45. Milestones of the project 111

Glossary

LCA: Life Cycle Assessment

PET: Polyethylene terephthalate

HDPE: High Density Polyethylene

PP: Polypropylene

GWP: Global Warming Potential

TAP: Terrestrial Acidity Potential

MEP: Marine Eutrophication Potential

HTPc: Human Toxicity Potential (carcinogenic)

ODP: Ozone Deplation Potential

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Finally, I would like to thank my parents for their unwavering support and encouragement.

1 INTRODUCTION

The global use and production of plastics has been growing steadily over the past decades. Their use is very diverse, and plastics production has more than doubled between 2000 and 2019 to reach 460 million tonnes (Mt). This trend will not slow down in the absence of new measures, with plastics use expected to triple from the 2019 level, reaching 1230 Mt in 2060.

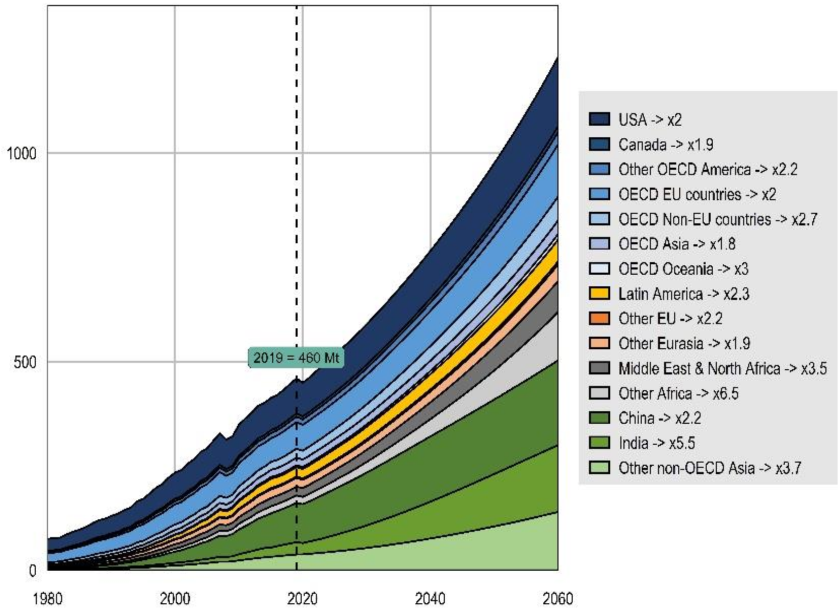

Figure 1. Projection of global plastics use in Mt (1950 and 2060) - (OCDE, 2022)

The increase of plastic production influences plastic waste generation, as it increased from 156 Mt to 353 Mt between 2000 and 2019, and is expected to almost triple by 2060, reaching 1014 Mt.

In 2019, only 55 Mt of waste was collected worldwide for recycling, but 22 Mt ended up as recycling residues to be disposed of again. In the end, 9% of plastic waste was recycled in the world, 19% was incinerated and almost 50% ended up in landfills. The remaining 22% was dumped in landfills, burned in the open or released into the environment. According to (OCDE, 2022), the recycling rate is projected to increase to 17% by 2060, growing faster than any other waste management method. However, recycling would still represent a smaller share of waste management than incineration (18%) and landfill (50%).

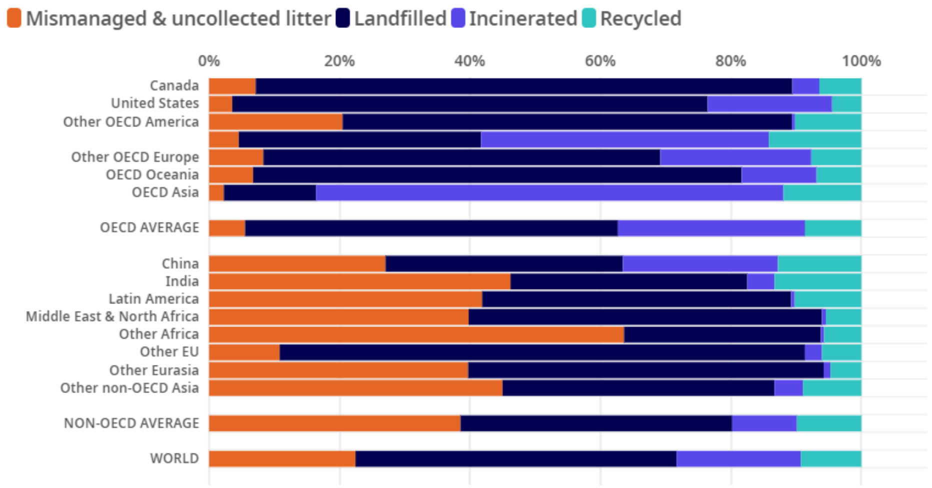

Figure 2. Share of plastics treated by waste management category, after disposal of recycling residues and collected litter (2019) - (OCDE, 2022)

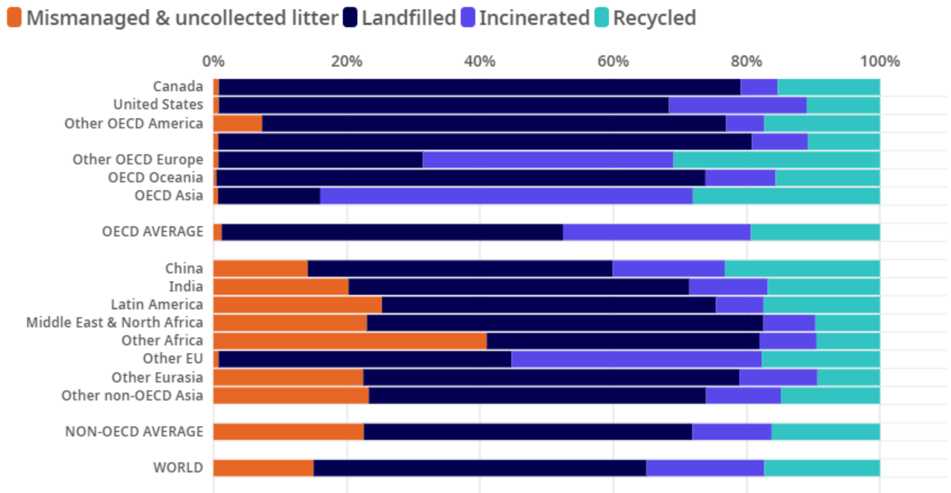

Figure 3.Share of plastics treated by waste management category, after disposal of recycling residues and collected litter (2060) - (OCDE, 2022)

The management of plastics and their impact on the environment includes the management of their production, use and end-of-life. In order to protect and respect the environment, scientists and policy makers are seeking to increase the recycling rate of plastics and to optimise new or existing recycling processes.

In our study we will perform a Life Cycle Assessment of the mechanical recycling processes of three of the most used plastics: polypropylene, polyethylene terephthalate and high-density polyethylene.

Subsequently, we will highlight several previously discussed concepts that we will use in our study.

1.1 Definition of plastic

Plastic is a polymeric material that has the capability of being moulded or shaped, usually by the application of heat and pressure. This property of plasticity, often found in combination with other special properties such as low density, low electrical conductivity, transparency, and toughness, allows plastics to be made into a great variety of products (Rodriguez, 2023).

There are three main families of plastics (OPCA DEFi, 2022):

- Thermoplastics: These are heat-formable without chemical modification. Polyethylene, polypropylene, polyvinyl chloride and polystyrene are thermoplastics. In France, more than 90% of the production of plastic materials is made of thermoplastics, 80% of which is made of the three thermoplastics: Polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC).
- Thermosets: they are heat-formable with chemical modification. Phenoplasts, aminoplasts and epoxy resins are thermosets.
- Elastomers: These have the properties of natural rubber, mainly high elasticity and stretchability

The properties of plastics depend on the different types of plastics considered. However, plastics have several interesting general properties which explain their wide use in the manufacture of technical objects (Industrie plastique, 2023):

- They are lightweight
- They are corrosion resistant
- They can be shaped and moulded by heat or pressure
- They have excellent durability
- They are good thermal and electrical insulators
- They have high strength
- They are economical

On the other hand, plastics have a major drawback: they are often obtained from a non-renewable fossil resource, namely oil. Plastics are subject to progressive degradation as they age. Degradation can be seen in the appearance of cracks or a change in colour. This degradation is slow, but often irreversible. There are various causes for the degradation of a plastic. For example, liquid phase substances, such as water, can penetrate some plastics and dissolve some of their chemical additives. Also, the polymers in plastics can degrade under the effect of ultraviolet radiation, especially that emitted by the sun. Finally, some plastics can oxidise on contact with certain gases (Les matières plastiques, 2022).

1.2 Definition of polyethylene terephthalate

Polyethylene terephthalate (PET or PETE) is a strong, stiff synthetic fibre and resin and a member of the polyester family of polymers. PET is spun into fibres for permanent-press fabrics and blow-molded into disposable beverage bottles (Gregersen, 2023).

PET is produced by the polymerization of ethylene glycol and terephthalic acid. Ethylene glycol is a colourless liquid obtained from ethylene, and terephthalic acid is a crystalline solid obtained from xylene. When heated together under the influence of chemical catalysts, ethylene glycol and terephthalic acid produce PET in the form of a molten, viscous mass that can be spun directly to fibres or solidified for later processing as a plastic.

1.3 Definition of high-density polyethylene

High-density polyethylene (HDPE) is a linear version of polyethylene, a light versatile synthetic resin made from the polymerization of ethylene. Polyethylene is one of the simplest and cheapest polymers, it belongs to the family of polyolefins (Tikkanen, 2023).

HDPE is manufactured at low temperatures and pressures. With a melting point more than 20 °C (36 °F) higher than low-density polyethylene, it can withstand repeated exposure to 120 °C (250 °F) so that it can be sterilized. Products include blow-molded bottles for milk and household cleaners; blow-extruded grocery bags, construction film, and agricultural mulch; and injection-molded pails, caps, appliance housings, and toys.

1.4 Definition of polypropylene

Polypropylene (PP) is a synthetic resin built up by the polymerization of propylene. One of the important family of polyolefin resins, polypropylene is molded or extruded into many plastic products in which toughness, flexibility, light weight, and heat resistance are required. It is also spun into fibres for employment in industrial and household textiles. Propylene can also be polymerized with ethylene to produce an elastic ethylene-propylene copolymer (Gregersen, Polypropylene, 2017).

	PET	HDPE	PP
Symbol	1 PET	2 HDPE	05 PP
Melting temperature	245°C	85-140°C	145-175°C
Solubility	Not resistant to hot water Not resistant to solvents: Oxidizing mineral acids, concentrated bases, cresols, phenols	Insoluble in water at 60-80°C Not resistant to solvents: Aromatic hydrocarbons, halogenated hydrocarbons	Insoluble in water at 80°C Not resistant to solvents: Aromatic hydrocarbons, halogenated hydrocarbons
Density	1.38 g/cm^3	0.91 g/cm^3	0.94-0.97 g/cm^3
Aspect	Transparent or semi-opaque	Translucent	Translucent to opaque
Advantages	Lightweight Strong Long life CO_2-tight	Soft and flexible Resistant to high and low temperatures	Hard to semi-hard Resistant to high and low temperatures Hydrophobic Highly abrasion resistant
Common use	Food packaging Water bottles Stuffing of cushions or pillows Credit card	Household products Plastic crates Cans Milk bottles Shampoo bottles	Butter packaging Synthetic carpets Straws Microwaveable dishes

Table 1. Main characteristics of PET, HDPE and PP

(Carrega, 2009) (JP Trotignon, 2006) (Hilado, 1982) (MJ Forrest, 1995) (Recyclage des déchets plastiques : tout comprendre, 2022)

1.5 Life Cycle Assessment

Life Cycle Assessment (LCA) is a tool for assessing environmental aspects and associated potential impacts throughout the entire life cycle of a product, from the extraction and acquisition of raw materials, through manufacturing, distribution and use, to final disposal. It is characterised by its holistic approach, which emphasises the need for full integration of all aspects involved in the entire life cycle.

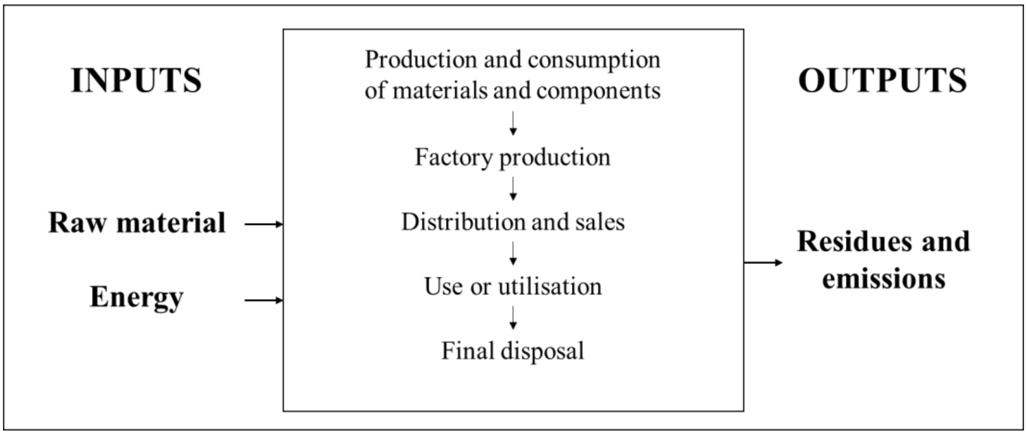

Figure 4. Concept of the perspective of a Life Cycle Assessment and the phases considered

LCA models the life cycle of a product as a product system, broken down into different unit processes linked to each other through intermediate flows, to other product systems through product flows and to the environment through elementary flows. These elementary flows comprise the resources, emissions to air and discharges to land and water associated with the system.

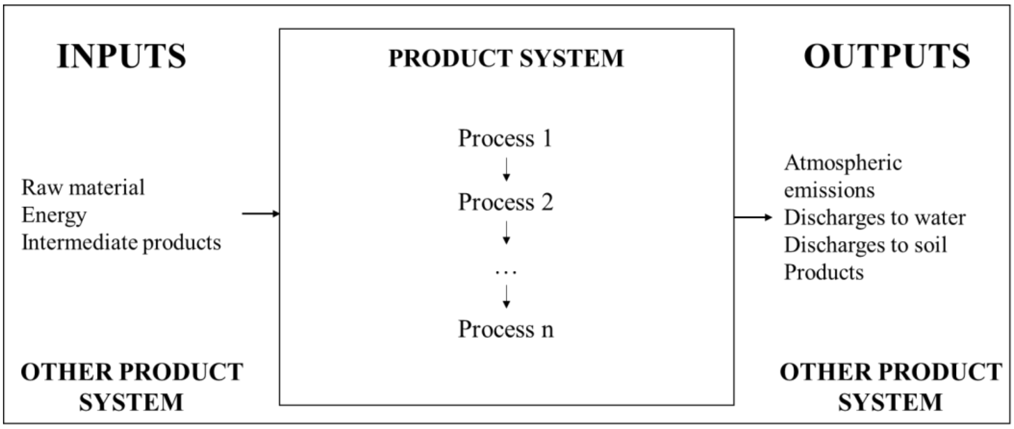

Figure 5. Product system and unit processes

In this way, it is necessary to compile input flows - such as raw materials, energy, and intermediate products - and output flows - such as air emissions, discharges to water, discharges to land and products, to and from nature - in order to obtain results that show the potential environmental impacts associated with these flows. It is based on a relative approach organised around a functional unit, which defines what is being studied, so that subsequent analyses are relative to this functional unit, establishing a reference to relate the inputs and outputs of the system considered.

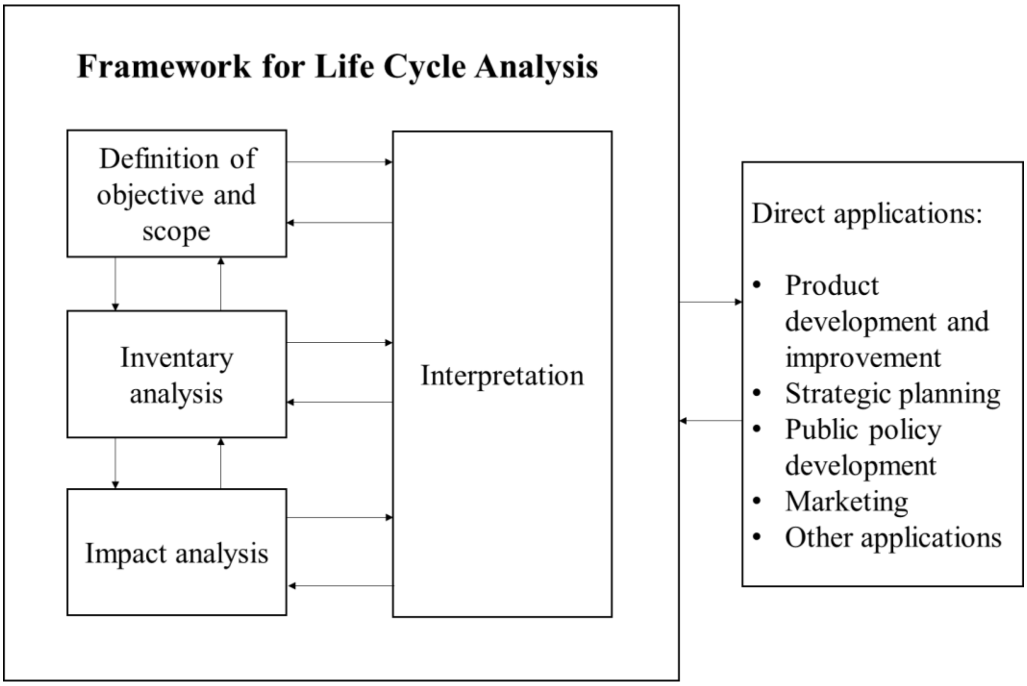

Figure 6. LCA steps

According to the UNE-EN ISO 14040:2006 standard and UNE-EN ISO 14044:2006, and as shown in Figure 6, LCA studies are composed of four phases:

1. Definition of the objective and scope. This consists of defining the objective and scope of the study carried out in relation to the system limits imposed, the functional unit chosen and the input and output flows within the life cycle considered, as well as the quality of the data obtained and the technological and evaluation parameters to be met.
2. Life cycle inventory (LCI) assessment. This consists of collecting and quantifying inputs and outputs of the product throughout its life cycle.
3. Life Cycle Environmental Impact Assessment (LCIA). This consists of understanding and assessing the magnitude and significance of the potential environmental impacts of a product system throughout the entire product life cycle. This phase is the core of the LCA and is further divided into the following phases:
    a. Selection of impact categories, category indicators and characterisation models. The selected categories represent the environmental impacts of interest, i.e. for which the results of the LCIA are to be assigned.
    b. Classification. LCI substances are assigned to the corresponding impact categories.

The normalisation, grouping and weighting phases are not mandatory, but recommended.

4. Life cycle interpretation. This consists of assessing the results of the LCI and/or LCIA assessment, in relation to the defined objective and scope, in order to arrive at a set of conclusions and recommendations.

During the LCIA, the impacts of the system are classified into different impact categories, transforming them into quantifiable and objective indicators. The classification and characterisation phases can be carried out under a midpoint view, where the impacts are relative to the environmental problem, or under an endpoint view, where the impacts are relative to the damage on tangible values for society, such as the impact on human health, biodiversity and resources. The impact categories considered in this study are based on the ReCiPe 2016 Midpoint (H) methodology.

Impact category	**Reference unit**
Terrestrial acidification potential	kg SO_2-Eq
Global warming potential	kg SO_2-Eq
Freshwater ecotoxicity potential	kg 1,4-DCB-Eq
Marine ecotoxicity potential	kg 1,4-DCB-Eq
Terrestrial ecotoxicity potential	kg 1,4-DCB-Eq
Fossil fuel potential	kg oil-Eq
Freshwater eutrophication potential	kg P-Eq
Marine eutrophication potential	kg N-Eq
Human toxicity potential - carcinogenic	kg 1,4-DCB-Eq
Human toxicity potential - non-carcinogenic	kg 1,4-DCB-Eq
Ionising radiation potential	kBq Co-60-Eq
Agricultural land occupation	m^2*a crop-Eq
Surplus ore potential	kg Cu-Eq
Ozone depletion potential	CFC-11-Eq
Particulate matter formation potential	kg PM2.5-Eq
Photochemical oxidant formation potential: humans	kg Nox-Eq
Photochemical oxidant formation potential: ecosystems	kg Nox-Eq
Water cosumption potential	m^3

Table 2. Impact categories ReCiPe 2016 Midpoint (H)

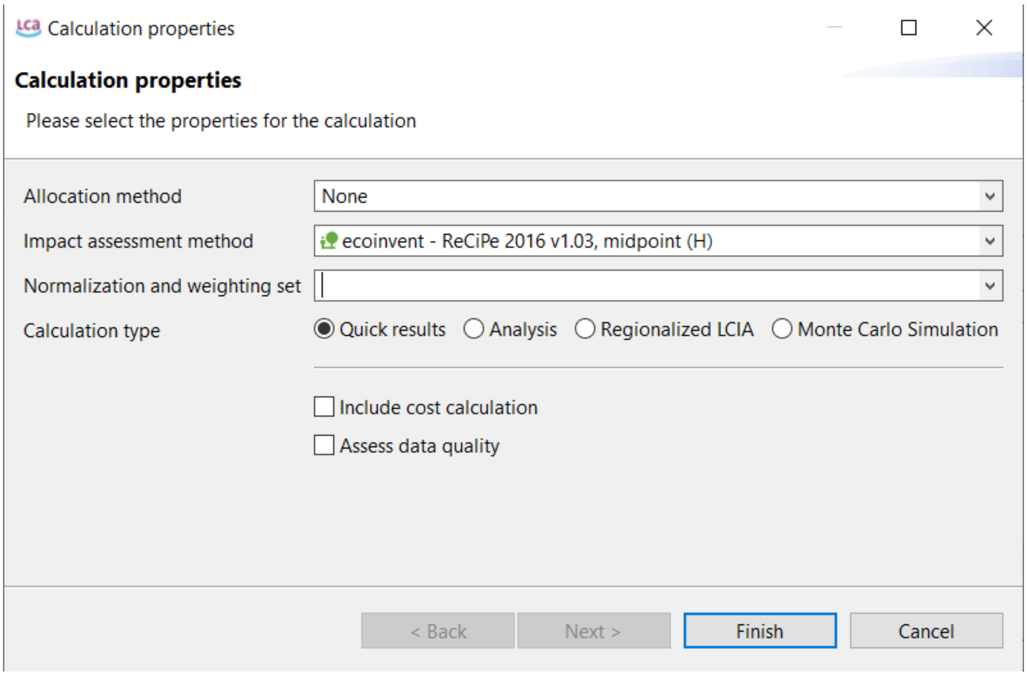

Figure 7. Calculation properties - OpenLCA

The study of LCA considers several types of life cycle. Once the consumer has utilized the product, the material can follow through two pathways. The first includes grave, which is the disposal of plastics for no further use. In this specific scenario, the plastics would be sent to a landfill. The other option is to send the products back to the cradle, to be re-processed into a new product. This would be considered recycling of the plastics. Each of these steps requires energy and emits waste.

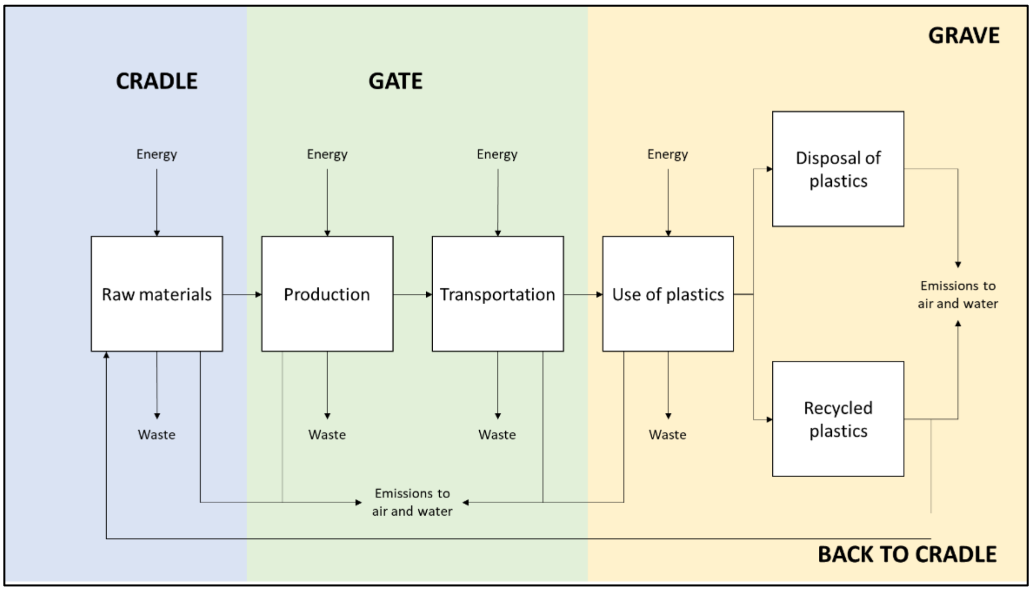

Figure 8. The different parts of Life Cycle Assessment (LCA)

A Life Cycle Assessment (LCA) is differentiated amongst several parts, including cradle, gate, and grave. If the recycling process is to be evaluated, the product would be generated from the cradle and would be sent back to the cradle for production again.

LCA terminology	Definition	Example
Assembly	Formation of the product of interest	Formation of a disposable water bottle
Subassembly	Formation of parts of the product of interest	Formation of the cap and the plastic wrapper found on a disposable water bottle
Cradle	Production of the product	Production of the water bottle, cap, labelling, etc. and ready for use
Gate	Transportation and handling of the product	Delivering and stocking the water bottle in the market
Grave	Disposal of the product	Landfill of incineration
Cradle-to-Cradle	Refers to the life cycle from the production of the product, including gate, and sending the product back to production (i.e., recycling product	Following the production of the disposable water bottle, to being stocked in the store, mechanically recycled, and ready for re-production
Cradle-to-Gate	Refers to life cycle from the production of product to transportation and handling	Following the production of the disposable water bottle to being stocked in the store, ready for purchase or use
Cradle-to-Grave	Refers to life cycle from the production of the product to the disposal of the product (end-of-life)	Following the production of the disposable water bottle, to being stocked in the store, and sent to the landfill or incinerated

Table 3. Definition of LCA terminologies

2 CONTEXT

As mentioned above, plastic pollution has become one of the most pressing environmental problems, as the production of single-use plastic products is rapidly increasing and outstripping the world's capacity to deal with it.

Fossil plastics are over a century old, the production and development of thousands of new plastic products accelerated 70 years ago and changed our way of life. In fact, half of the plastic ever produced has been produced in the last 15 years. They have revolutionised many areas such as medicine, transport, technology... But the convenience that plastics offer has led to a disposable culture that reveals a pressing issue.

Today, single-use plastics account for 40% of plastics produced annually. Many of these products, such as plastic bags and food packaging, have a lifespan of minutes to hours, but can remain in the environment for hundreds of years. Plastics often contain additives that increase strength, flexibility and durability. However, many of these additives can extend the life of products when discarded, with some estimates taking up to 400 years to degrade (Parker, 2019).

2.1 Recyclable plastics

Of all the plastics in existence, only a fraction is recyclable. Generally, the lower the resin code, the more likely the type of plastic is to be easily recyclable. Many types of plastic can be recycled, although the process is not widespread, but many plastics are not recycled simply because they are not easily recyclable. In addition, some plastic waste remains difficult to process in practice. This is the case with packaging that is too thin or too light, such as plastic film or plastic bags. Toys and tableware made of hard plastic are also not recyclable.

The difference in recyclability of plastic types may be due to the way they are manufactured; thermoset plastics contain polymers that form irreversible chemical bonds and cannot be recycled, whereas thermoplastics can be remelted and remoulded. Thermoplastics have the property that they soften when heated and harden when cold. They can therefore be reshaped repeatedly, almost without affecting their original mechanical properties. This feature makes it easier to recycle this type of plastic than the other types. Thermoplastics are by far the most widely used plastics, accounting for more than three quarters of all plastics produced in the world.

Today, the most recycled plastics are the following thermoplastics:

1. Polyethylene terephthalate (PET)
2. High density polyethylene (HDPE)

3. Polypropylene (PP)

These are the three plastics we have chosen to study for the reason given above. Indeed, the PET packaging market alone is expected to reach USD 74.2 billion by 2026 (Marché des emballages PET - Croissance, tendances, impact du COVID-19 et prévisions (2023-2028), 2019). The interest in limiting their ecological impact is all the more important as they represent the majority of plastics used in the world.

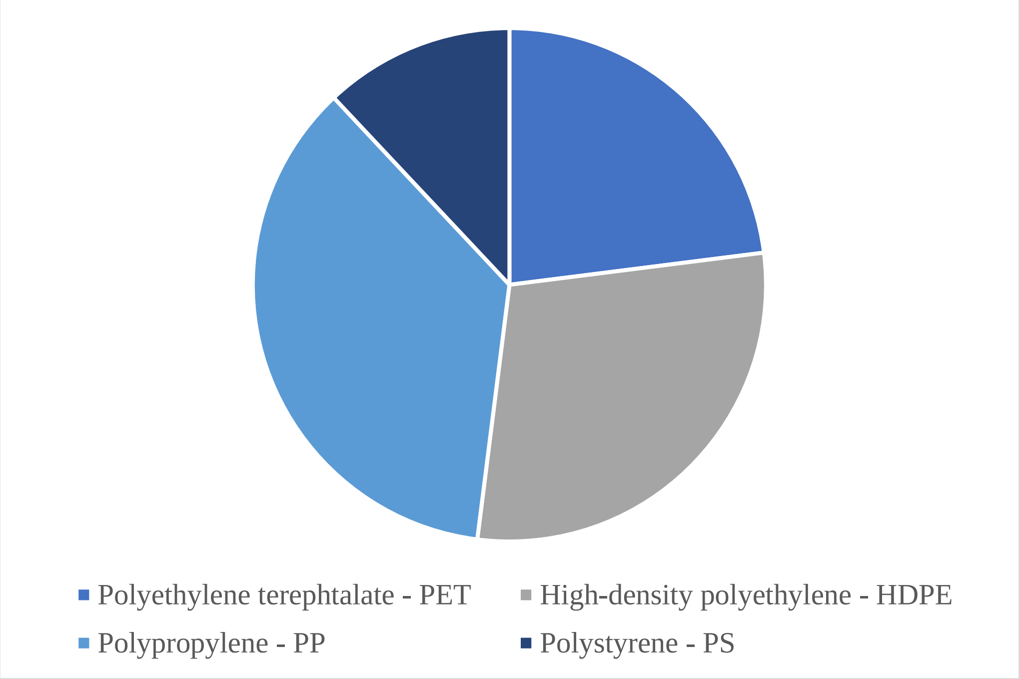

Figure 9. Chart of the approximate proportion of PET, HDPE, PP and PS in lightweight packaging waste - (Deutschland, 2015)

Before being recycled, plastics are sorted according to their resin type, either manually or using automated mechanised processes, or even by colour. After sorting, there are two main ways to have a recyclable plastic: mechanical recycling, where the plastic is washed, shredded and melted, or chemical recycling, where the plastic is usually broken down into monomers to form new polymers for reuse.

In our study we will therefore focus on the mechanical recycling processes of these three plastics (Quels sont les plastiques qui sont recyclables ?, 2021).

2.2 Mechanical recycling

Mechanical recycling is currently the dominant recycling technique for post-consumer plastic packaging waste.

2.2.1 Technology description

Mechanical recycling refers to operations that aim to recover plastics via mechanical processes (grinding, washing, separating, drying, re-granulating and compounding), thus producing recyclates that can be converted into plastics products, substituting virgin plastics.

In mechanical recycling, plastic waste (sorted by material type) is milled and washed, passes a flotation separation, and is dried. The plastic flakes are then either used directly to produce new plastic materials or they are processed into granulates beforehand.

It is used for the recovery of pre-consumer (post-industrial) material as well as for post-consumer plastic waste. For mechanical recycling, only thermoplastic materials are of interest. It is a well-established technology for the material recovery of the three plastics that are going to be studied here.

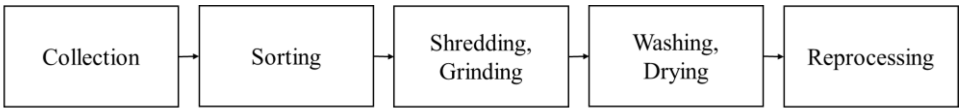

Figure 10. Steps of the mechanical recycling

2.2.2 Sorting

Post-consumer plastic waste is usually a very inhomogeneous and contaminated waste fraction. It comprises a huge range of material types (e.g. multilayer films, blends, and composites) with shape, colour and size varying widely. Therefore, in a first step, the plastic waste passes extensive manual and/or automated mechanical sorting processes in specialised facilities, designed to separate the different materials.

The proper identification of the materials is essential for achieving a maximised purity of recyclates. For this purpose, various technologies such as near infrared (NIR), laser, or x-ray-based techniques are available.

Although sorting technology has increased its accuracy, sorting efficiency never reaches 100% due to separation flaws and laminated or blended products that cannot be separated into their original materials. This often leads to contamination of recycled plastics with other plastics and all kinds of additives. The quality of sorting processes is also dependent on the efficiency of collection schemes, which vary widely even within EU member states.

In order to be recycled, plastics have to be sorted according to their material type. The initial sorting of plastics can be manual, which is associated with extensive labour, or automated. Sorting techniques include:

- Float-Sink Sorting (based on density)

- Froth–Flotation Sorting
- Near-Infrared Sorting
- X-Ray Fluorescence
- Laser-Aided Identification
- Marker Systems

2.2.3 Reprocessing

After cleaning and grinding processes, the materials are recovered through remelting and regranulating. The resulting recyclates can be processed with all common technologies for plastics conversion. During melting and reprocessing, high temperatures and shear forces can cause thermal and mechanical degradation of polymers, affecting polymer chain length and distribution. This may influence material properties, such as crystallinity or mechanical strength. If the quality is sufficient after sorting and reprocessing, the recycled materials can be reused in the same or similar products. By recovering plastic materials for reuse, virgin plastic materials are replaced, contributing to a circular economy. However, the resulting quality often only allows the use in lower value applications (so-called down-cycling).

2.2.4 Quality of the recycled plastic

The quality of the reclaimed materials is dependent on the quality of the plastic waste stream. Plastics undergo physical and chemical changes during their service life as well as during processing and recycling steps. Polymers suffer from oxidative reactions and these oxidative processes enhance the thermal and photo-degradation of the recyclate. Formation of the oxidative moieties further consumes the significant part of the polymer stabilisers, which results in the decrease of the long-term stability as well as mechanical properties. Determination of the degradation degree of the waste plastic is important as it influences the mechanical properties, stability and future performance of the recycled products (F Vilaplana, 2008).

In terms of the waste stream composition, the plastic stream that provides the clean, single type thermoplastic is the best for mechanical recycling. The contaminated mixed plastic waste streams that are hard to sort and separate present a challenge as they require additional washing and sorting steps to remove impurities and contaminants.

2.2.5 Economic viability

Mechanical recycling is generally the most cost-effective approach, however with limitations. The profitability and economic viability depend on the material that is being recycled and the degree of contamination of the waste stream. Other factors that affect overall costs and should be considered include collection fees, transportation fees, efficiency of the process, type of material, etc. Although cost effective, if not combined with additional techniques, there are limitations on the quality of the material obtained. In this respect, cost efficiency is strongly associated with the purity and material type.

2.2.6 Environmental impact and comparison with other end-of-life treatments

According to a study conducted by (Jeswani, 2021), environmental burdens of plastic waste collection, transportation, and the recycling process usually are less than the environmental burdens associated with the production of virgin material.

His study compared environmental impacts of producing mixed commodity plastics with their end-of-life treatment via chemical (pyrolysis), mechanical recycling and energy recovery, which consisted of 30% municipal solid waste incineration and 70% combustion of refuse-derived fuel. The study showed that the Global Warming Potential was the lowest for mechanical recycling (1.99 kg CO_2 eq./kg plastics) compared to other treatments (Figure 11).

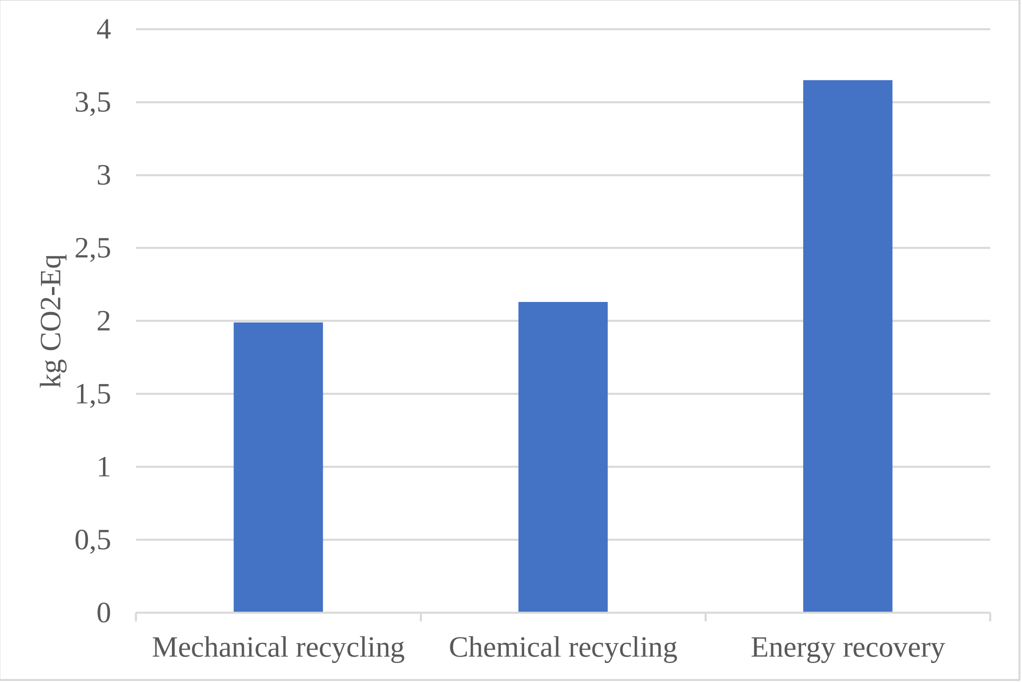

Figure 11. Global Warming Potential (GWP) comparison for different types of recycling, for 1 kg of plastic

These results are interesting for our study since we will later use the same indicator, i.e. the Global Warming Potential.

2.2.7 Advantages

To conclude this part, advantages of the mechanical recycling can be listed:

- Less waste is sent to landfills
- Resources used to produce virgin polymers are reduced
- Reduction in plastic pollution and associated environmental impacts
- Reduction of greenhouse gas emissions

(Plastics – the Facts 2020. Enable a sustainable future., 2020) (European Bioplastics, 2020)

3 OBJECTIVES

In this study, we will try to optimise the mechanical recycling processes of the three plastics mentioned above: PP, PET and HDPE.

For this purpose, we will carry out an analysis of these recycling processes with the help of the OpenLCA software.

Secondary or derived objectives include the advancement of a deeper understanding of the functioning of this software used to carry out life cycle analyses, and the development of a study that can serve as a basis for future research related to mechanical recycling processes, facilitating the transition towards a sustainable energy system and a model based on the circular economy.

4 BENEFITS

As we have seen above, the production and consumption of plastics are current issues that we need to address.

In this way, the main benefit of this work is to provide support to researchers in the field of plastic materials and in the field of recycling and to help future progress in the development of sustainable plastics.

The interest of this work is to highlight the environmental impacts that the method of mechanical recycling of plastics can have. It is important today to consider how best to reuse our materials.

In this way, we seek to encourage progress towards a sustainable recycling method, which will be part of a new, more sustainable way of consuming and producing.

5 STATE OF THE ARTS ANALYSIS

Before embarking on the study of the ecological and environmental impacts of the mechanical recycling process, it is important to be aware of the different works that have been done previously to take their results into account. This will increase the added value of our work.

In the OpenLCA software, there are already processes of the production of several types of plastics, included the three plastics we are interested in. These processes are part of the database that we will use later in our study, their input and output data will be interpreted to serve our needs.

On the other hand, there are very extensive studies on the Life Cycle Assessment of mechanical recycling of our plastics (Neeti Gandhi, 2021). This study does not consider the same parameters and data as ours. However, we will consider the approach used in these studies in order to be able to make a qualitative analysis and a comparison between their results and ours.

6 METHODOLODY

The development of the work has been based on the following essential steps:

- Reading general articles dedicated to Life Cycle Assessment and general information about plastics.
- Study of the processes of mechanical recycling for the three concerned plastics.
- Insertion of processes in OpenLCA, a free and open-source software for Life Cycle Assessment with numerous functionalities.
- Collection, interpretation and analysis of the data provided by OpenLCA.
- Drafting of the final document.

It should be noted that learning OpenLCA has been necessary as part of the project development. The Life Cycle Assessment and mechanical recycling as well as this software were new notions at the beginning of the study.

6.1 Analysis of alternatives

Depending on the defined scope, the assessment made or the impacts environmental studies, there are different ways of performing a stroke: from cradle to cradle, from the cradle to grave, from cradle to gate and from gate to gate.

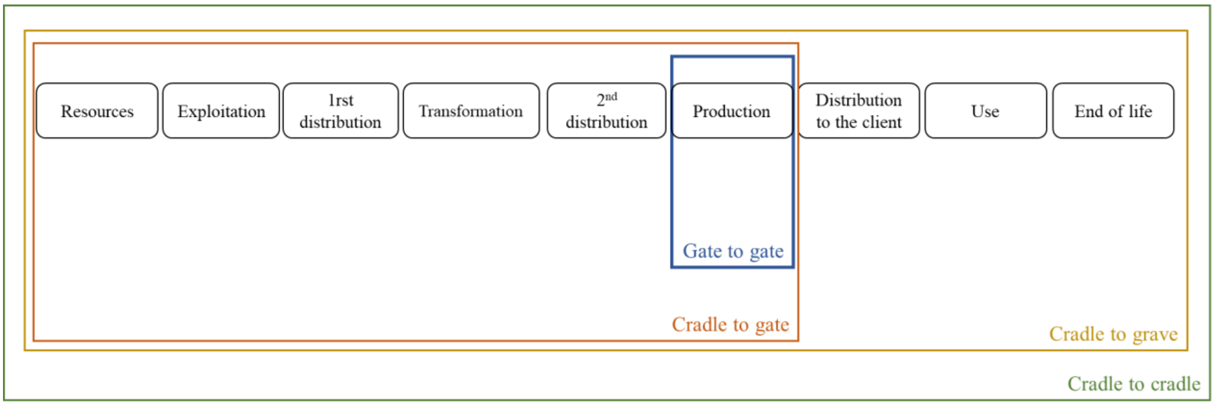

Figure 12. Terminology related to the scope of a LCA

- From cradle to grave: Used in reference to perspective on impact created by a particular product, service or activity since extraction resources (cradle) until its end of life (grave). Its goal is to reduce waste.
- From cradle to gate: Used in reference to partial perspective on impact created by a particular product, service or activity since extraction of resources (cradle) to production (gate), omitting the phases of customer, use and end of life.

- Gate to gate: Used in reference to the partial perspective on impact created by a particular product, service or activity from a point of defined over the life cycle to a second point defined later in the cycle.
- From cradle to cradle: Used in reference to the cyclical perspective on impact created by a particular product, service, or activity, rather than the linear perspective "from cradle to grave". In this case, the goal is to completely eliminate waste.

6.2 Goal and scope

In order to be able to study and compare the results obtained with an LCA, all the quantities obtained for the impact categories are obtained for 1 kg of recycled plastic. We will use this scale as a basis for comparing the three plastics with each other and for completing our comparative study.

6.3 Impact analysis

The tool used in this work is OpenLCA, a free and open-source software for Life Cycle Assessment that has numerous functionalities. Specifically, OpenLCA version 1.10.2 has been used in conjunction with the ecoinvent 3.8 database.

Over the last decade, ecoinvent has established itself as a world leader in the creation of life cycle inventory databases, due to its relevance, transparency, consistency and reliability. It provides a wide range of well-documented process data for thousands of products, making it possible to make informed and informed decisions about their environmental impact. The data provided can be used for different environmental assessment studies (Life Cycle Assessment, carbon footprint, environmental product declaration, etc.) and in different software tools (OpenLCA, MS Excel, SimaPro, etc.). Although it is a paid database, the Life Cycle Thinking Research Group of the UPV/EHU in charge of this study has a licence.

Figure 13. Menu - OpenLCA

As for OpenLCA, the first step consists of linking the database to the software so that it can work. The databases are in files with the extension ".zolca", which are inserted into the software by means of a wizard enabled for this purpose.

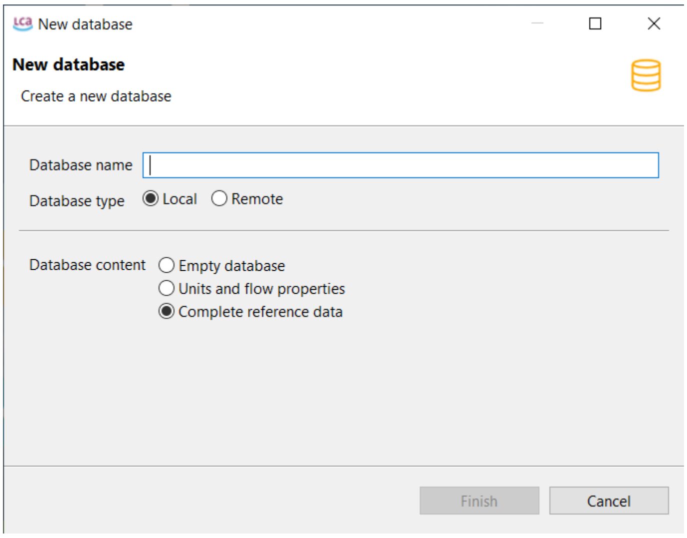

Figure 14. New database - OpenLCA

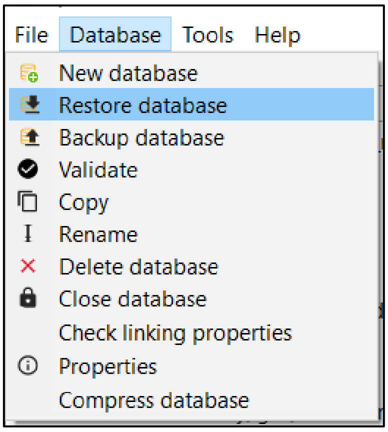

Figure 15. Restore database - OpenLCA

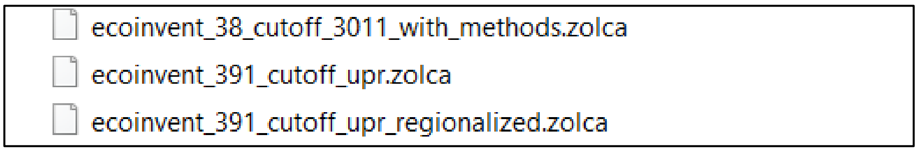

Figure 16. Database - OpenLCA

In the same way, it is necessary to insert a file with the same extension ".zolca" that establishes the method to determine the environmental impacts of each of the impact categories, i.e. the LCIA (life cycle impact assessment).

For the realisation of the work, a ".zolca" file has been inserted with the database and the methods.

Before inserting the components into the software, and according to the LCA methodology, the life cycle inventory (LCI) assessment must be carried out, i.e. the inputs and outputs of the systems considered must be collected and quantified on the basis of the functional unit considered.

After the inventories have been carried out, the data are inserted into the software. In the OpenLCA environment, and within the databases, there are three main collections: product systems, processes and flows. In each of the three proposed methods, a series of processes are developed with inputs and outputs (flows) already identified in the inventory. Together, these processes constitute the product system against which the environmental impact of the method is assessed.

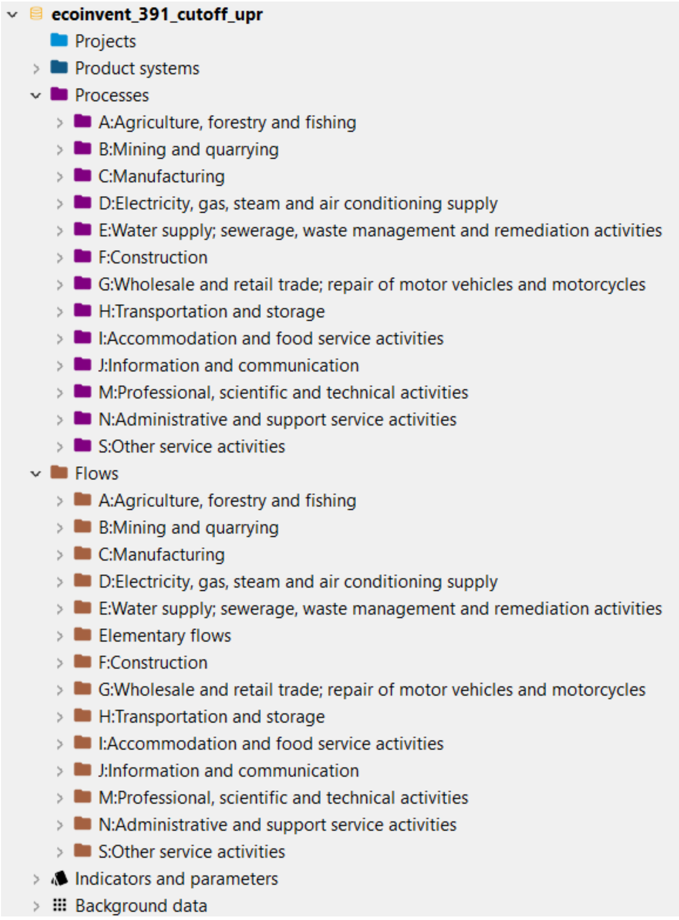

Figure 17. Database ecoinvent_391_cutoff_upr - OpenLCA

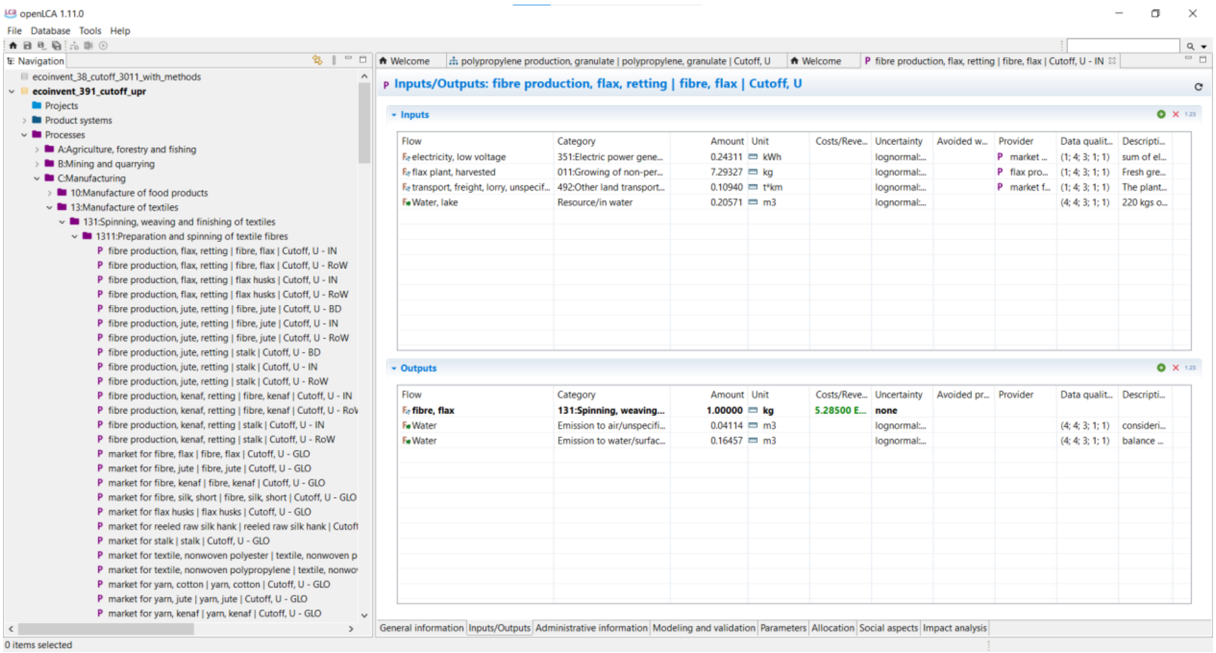

Figure 18. Inputs/Outputs - OpenLCA

Figure 18 shows the collections within the database mentioned above and an example of a process with its respective inputs and outputs, identified and calculated in the inventory.

The outputs of some processes are the inputs of others, so the processes are related to each other through these flows. After the creation of the different processes with their interrelationships through the flows that connect them, a product system is created for the last process that constitutes the method. The impact data of the product system are calculated, as can be seen in **Error! Reference source not found.** and **Error! Reference source not found.**, by means of the function Direct calculation, based on the output of the last process, i.e. the output of the system, which corresponds to the recycled plastic.

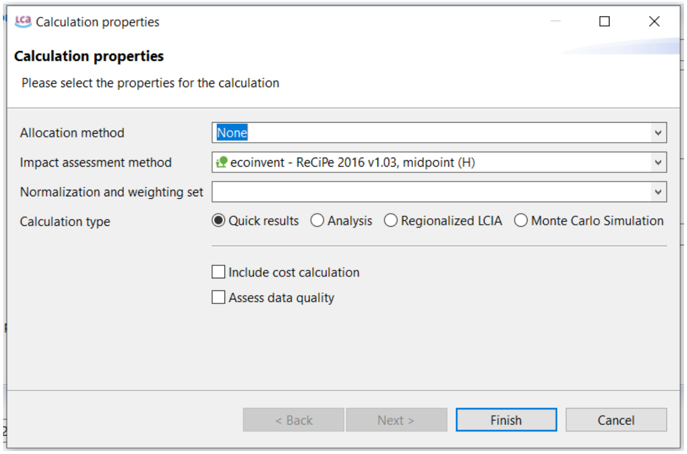

Figure 19. Calculation properties - OpenLCA

After the creation of the product system, the software allows us to create a diagram of the global process in which it is possible to observe the connections between the unitary processes and the inputs and outputs of each one of them.

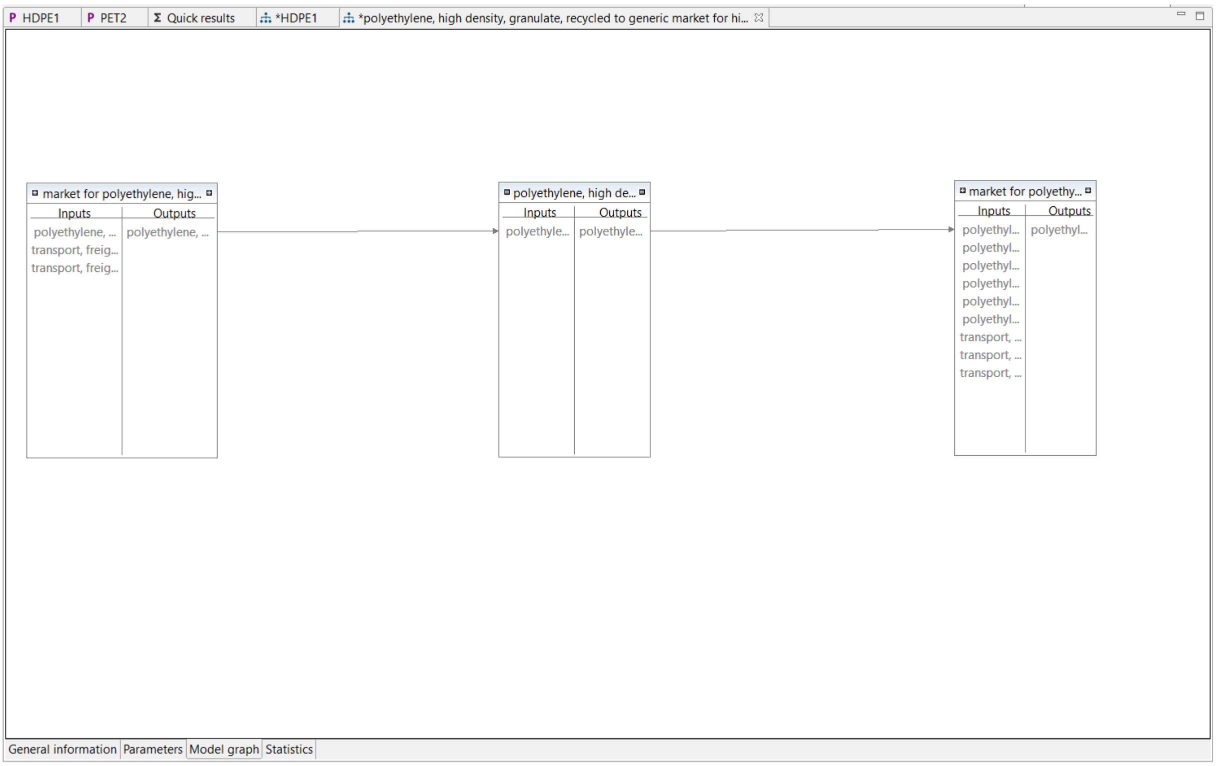

Figure 20. Model graph - OpenLCA

OpenLCA provides the option to export the results to an Excel file, which is used as a basis for the management, analysis, and comparison of the data of the three proposed methods. Moreover, it can export pictures of figures, that will be shown later on the study.

7 PROPOSED SOLUTION

In this section, we present the input and output data used in our subsequent study. The approach used is explained in order to better understand the inputs and outputs of the analysis that will follow.

7.1 List of inputs/outputs

The list of inputs and outputs that we have detailed below is based on scientific research carried out in previous studies. In order to give an approximation of the embodied energy, we use the approximation calculated by (Bataineh, 2020). The list of materials involved in the mechanical recycling of our plastics is deduced from the study of (Zoe Schyns, 2021). We multiply the amount of embodied energy by 0.17 to take into account only the energy used in the melt blending step. Similarly, the inputs and outputs quantities are determined only for this stage.

Legend:

- Existent in OpenLCA
- Non-existent in OpenLCA

Plastic	**Inputs**	**Outputs**
Melt Blending (general)	Embodied energy (melt blending ≈ 17% total process): - PET = 38 * 0,17 MJ = 6,45 MJ - HDPE = 40 * 0,17MJ = 6,8 MJ - PP = 50 * 0,17 MJ = 8,5 MJ	
PET	vPET (80%) rPET (20%) Contaminants (traces of): - Polyvinyl alcohol (PVA) - Polylactic acid (PLA) - PVC Metal-based stabilizers: - Tin mercaptide - Lead phthalate Radical scavengers: - Organic phosphates Chain extender: - Triphenyl phosphite (TPP) - Pyromellitic dianhydride (PMDA) - Bis-oxazolines - Di-isocyanates - Di-epoxides	rPET (100%) Side products: - Carbon dioxide - Water - Carboxylic acid - Aldehyde end groups
HDPE	HDPE Initiators/polymerizable monomers: - Parabenzoquinone - Vinyl silanes - Maleic anhydrides	rHDPE

	- Styrenics - Oxazolines - Acrylics Trimethylol propane triacrylate (TMPTA)	
PP	PP Stabilizers: - Phenolic amine systems PHENOL - Hindered amine systems Antioxidants: - Tannin wine seed extracts - Seed polyphenol extracts - Virgin wine wastes - Lignin Thymol Carvacrol	rPP Peroxyradicals

Table 4. List of inputs/outputs (detailed)

7.2 Flowcharts

7.2.1 PET detailed flowchart

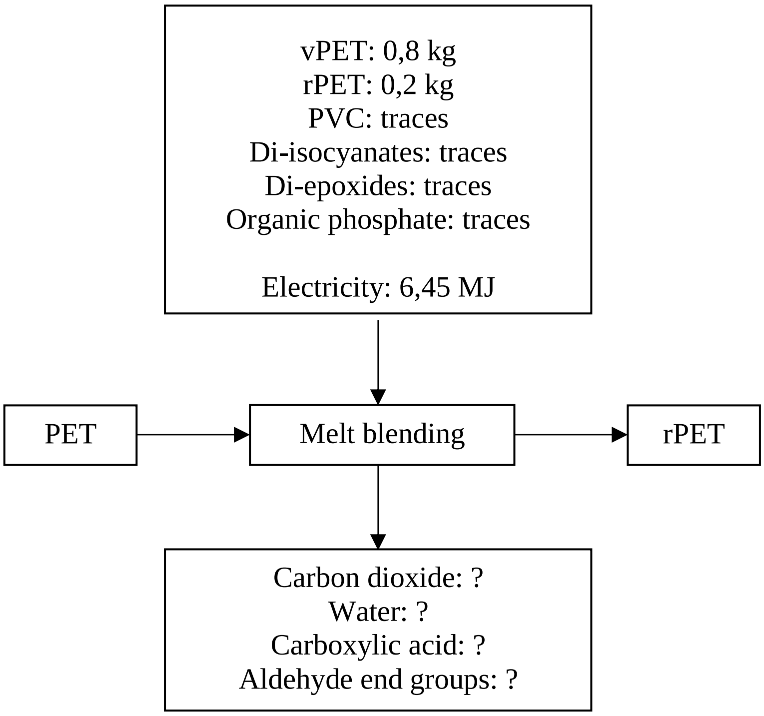

Figure 21. PET flowchart (detailed)

7.2.2 HDPE detailed flowchart

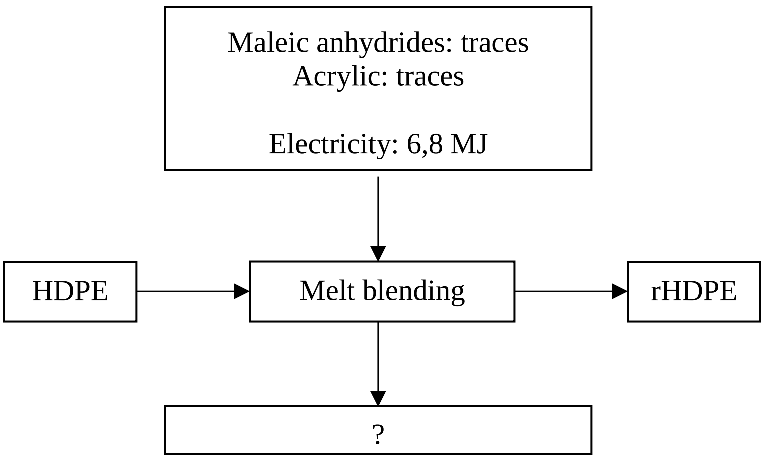

Figure 22. HDPE flowchart (detailed)

7.2.3 PP detailed flowchart

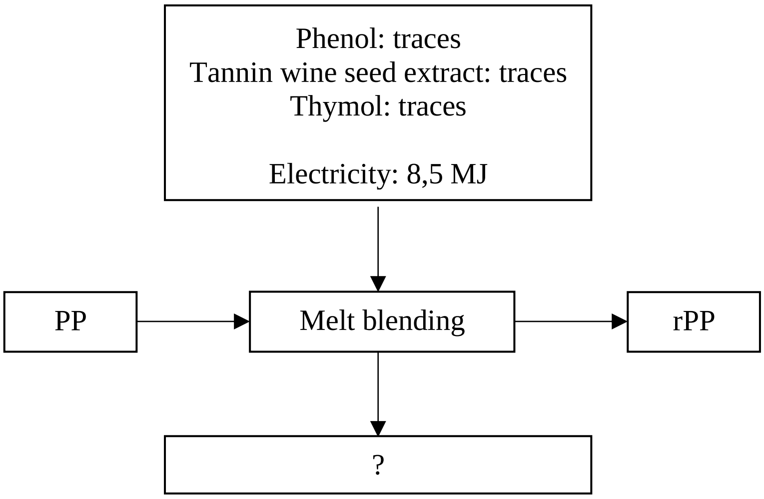

Figure 23. PP flowchart (detailed)

7.3 List of inputs/outputs - final version

The above flowcharts highlight missing data. Not only do some products not exist in the database we have access to, but we almost never know the exact quantities of the products - present or not in this database.

For this reason, we decided to simplify and group the inputs and outputs in order to make a more complete study that is closer to what is actually happening. We compared our data with those used in similar Life Cycle Assessment and thus we obtained the following table and flowcharts.

Plastic	Inputs	Outputs
Melt Blending (general)	Embodied energy: - PET = 38 * 0,17 MJ = 6,45 MJ - HDPE = 40 * 0,17MJ = 6,8 MJ - PP = 50 * 0,17 MJ = 8,5 MJ	
PET	vPET (80%) = 0.8 kg rPET (20%) = 0.2 kg Water: 5.627 m^3 Gas natural: 0.435 kg Chemical organics: 0.692 kg Coal: 0.334 kg	rPET (100%) = 1 kg Side products: - Water: 5.823 m^3 - Carbon dioxide: 0.968 kg - Chemical organics: 0.166 kg
HDPE	HDPE Water: 3.137 m^3 Gravel: 0.279 kg Oxygen: 0.248 kg	rHDPE Side products: - Water: 3.213 m^3 - Carbon dioxide: 0.700 kg
PP	PP Water: 2.531 m^3 Oil: 1.003 kg	rPP Side products: - Water: 2.592 m^3

	Coal: 1.142 kg Gangue: 1.541 kg	- Carbon dioxide: 1.527 kg

Table 5. List of inputs/outputs (final version)

For embodied energy, the calculation remains unchanged. It is the input and output materials that are modified between this part and the previous one. As explained above, in order to ensure that the data in the OpenLCA software was available, we used the manufacturing processes of the plastics studied. The software offers several processes for these plastics. By cross-checking this data with the information we have previously retrieved, we group the inputs and outputs into the following materials:

- Water
- Oxygen
- Natural gas
- Carbon dioxide
- Oil
- Coal
- Gravel
- Gangue
- Chemical organics

These groupings facilitate the study while remaining representative of reality. They are based on the bibliographical research carried out beforehand and take into account the materials that are present in greater quantities in the processes already existing in the software.

7.4 Flowcharts - final version

7.4.1 PET final flowchart

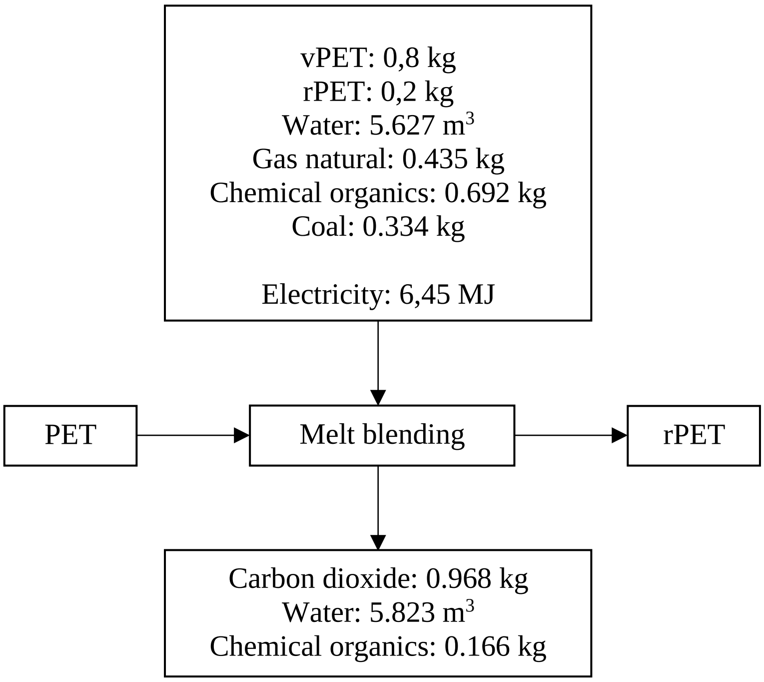

Figure 24. PET flowchart (final version)

7.4.2 HDPE final flowchart

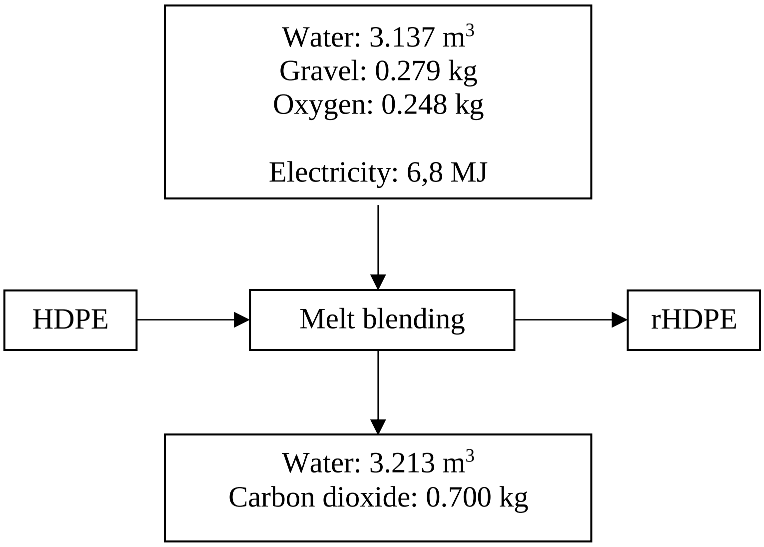

Figure 25. HDPE flowchart (final version)

7.4.3 PP final flowchart

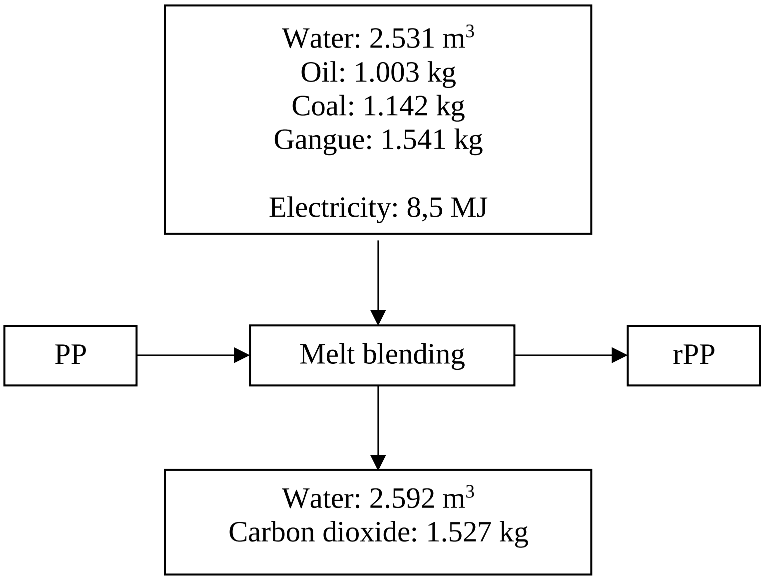

Figure 26. PP flowchart (final version)

7.5 Material and energy inventory

7.5.1 PET inventory

<u>Inputs</u>:

Item	Amount	Provider
rPET - polyethylene terephthalate, granulate, amorphous	0.8 kg	polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | polyethylene terephthalate, granulate, amorphous | Cutoff, U - Europe without Switzerland
vPET - polyethylene terephthalate, granulate, amorphous	0.2 kg	polyethylene terephthalate production, granulate, amorphous | polyethylene terephthalate, granulate, amorphous | Cutoff, U - RER
Water - Water, cooling, unspecified natural origin	5.627 m^3	
Gas natural - Gas, natural/kg	0.435 kg	
Chemical organics – chemical, organic	0.692 kg	chemical production, organic | chemical, organic | Cutoff, U - GLO
Coal – Coal, brown	0.334 kg	
Electricity - electricity, high voltage	6.45 MJ	electricity production, nuclear, pressure water reactor | electricity, high voltage | Cutoff, U - FR

Table 6. PET inventory - inputs

<u>Outputs</u>:

Item	Amount	Provider
rPET - polyethylene terephthalate, granulate, amorphous	1 kg	polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | polyethylene terephthalate, granulate, amorphous | Cutoff, U - Europe without Switzerland
Carbon dioxide – Carbon dioxide	0.968 kg	
Water - Water, cooling, unspecified natural origin	5.823 m^3	
Chemical organics – chemical, organic	0.166 kg	chemical production, organic | chemical, organic | Cutoff, U - GLO

Table 7. PET inventory – outputs

7.5.2 HDPE inventory

Inputs:

Item	Amount	Provider
HDPE - polyethylene, high density, granulate	1 kg	market for polyethylene, high density, granulate | polyethylene, high density, granulate | Cutoff, U - GLO
Water - Water, cooling, unspecified natural origin	3.137 m^3	
Oxygen	0.248 kg	
Gravel – gravel, round	0.279 kg	market for gravel, round | gravel, round | Cutoff, U - RoW
Electricity - electricity, high voltage	6.8 MJ	electricity production, nuclear, pressure water reactor | electricity, high voltage | Cutoff, U - FR

Table 8. HDPE inventory - inputs

Outputs:

Item	Amount	Provider
rHDPE - polyethylene, high density, granulate, recycled	1 kg	
Water - Water, cooling, unspecified natural origin	3.213 m^3	
Carbon dioxide – Carbon dioxide	0.700 kg	

Table 9. HDPE inventory – outputs

7.5.3 PP inventory

Inputs:

Item	Amount	Provider
PP - polypropylene, granulate	1 kg	market for polypropylene, granulate | polypropylene, granulate | Cutoff, U - GLO
Water - Water, cooling, unspecified natural origin	2.531 m^3	
Oil – Oil, crude	1.003 kg	
Coal – Coal, brown	1.142 kg	
Gangue - Gangue	1.541 kg	
Electricity - electricity, high voltage	8.5 MJ	electricity production, nuclear, pressure water reactor | electricity, high voltage | Cutoff, U - FR

Table 10. PP inventory - inputs

Outputs:

Item	Amount	Provider
rPP	1 kg	
Water - Water, cooling, unspecified natural origin	2.592 m^3	
Carbon dioxide – Carbon dioxide	1.527 kg	

Table 11. PP inventory - outputs

8 RESULTS AND DISCUSSION

This section presents and analyses the environmental impacts based on the ReCiPe 2016 Midpoint (H) methodology of the mechanical recycling of the three plastics studied.

In order to properly analyse the data received by OpenLCA, it is necessary to understand what it means. OpenLCA is a fairly powerful software that returns a lot of information. The information we have retained is the impacts in each category for the 3 plastics studied.

The **Error! Reference source not found.** presents the environmental impacts of the mechanical recycling of these plastics, considering 1 kg of material as a functional unit. Using a cradle-to-gate LCA approach, impacts are normalised to 1 kg of material.

Each of the categories has its own unit, standardised to 1 kg of material, and its own meaning.

Name	PET	HDPE	PP	Unit
water use - water consumption potential (WCP)	0.04222	0.02604	0.02479	m^3
photochemical oxidant formation: terrestrial ecosystems - photochemical oxidant formation potential: ecosystems (EOFP)	0.00679	0.00572	0.00537	kg NOx-Eq
photochemical oxidant formation: human health - photochemical oxidant formation potential: humans (HOFP)	0.00633	0.00531	0.00501	kg NOx-Eq
particulate matter formation - particulate matter formation potential (PMFP)	0.00334	0.00256	0.00245	kg PM2.5-Eq
ozone depletion - ozone depletion potential (ODPinfinite)	4.52872E-6	3.65202E-7	2.79224E-7	kg CFC-11-Eq
material resources: metals/minerals - surplus ore potential (SOP)	0.04282	0.02125	0.02324	kg Cu-Eq
land use - agricultural land occupation (LOP)	0.05245	0.02004	0.01900	m^2*a crop-Eq
ionising radiation - ionising radiation potential (IRP)	1.53709	1.42018	1.74924	kBq Co-60-Eq
human toxicity: non-carcinogenic - human toxicity potential (HTPnc)	4.23212	1.36006	1.37468	kg 1,4-DCB-Eq
human toxicity: carcinogenic - human toxicity potential (HTPc)	0.18162	0.10804	0.09305	kg 1,4-DCB-Eq
eutrophication: marine - marine eutrophication potential (MEP)	0.00023	6.55979E-5	7.04551E-5	kg N-Eq

eutrophication: freshwater - freshwater eutrophication potential (FEP)	0.00075	0.00041	0.00040	kg P-Eq
energy resources: non-renewable, fossil - fossil fuel potential (FFP)	1.45936	1.68284	1.71719	kg oil-Eq
ecotoxicity: terrestrial - terrestrial ecotoxicity potential (TETP)	13.37035	6.14294	5.93817	kg 1,4-DCB-Eq
ecotoxicity: marine - marine ecotoxicity potential (METP)	0.27928	0.07664	0.07612	kg 1,4-DCB-Eq
ecotoxicity: freshwater - freshwater ecotoxicity potential (FETP)	0.21097	0.05732	0.05691	kg 1,4-DCB-Eq
climate change - global warming potential (GWP100)	3.03563	2.42634	2.39780	kg CO_2-Eq
acidification: terrestrial - terrestrial acidification potential (TAP)	0.00785	0.00646	0.00638	kg SO_2-Eq

Table 12. Environmental impact, considering 1 kg of material as base unit (using renewable energies)

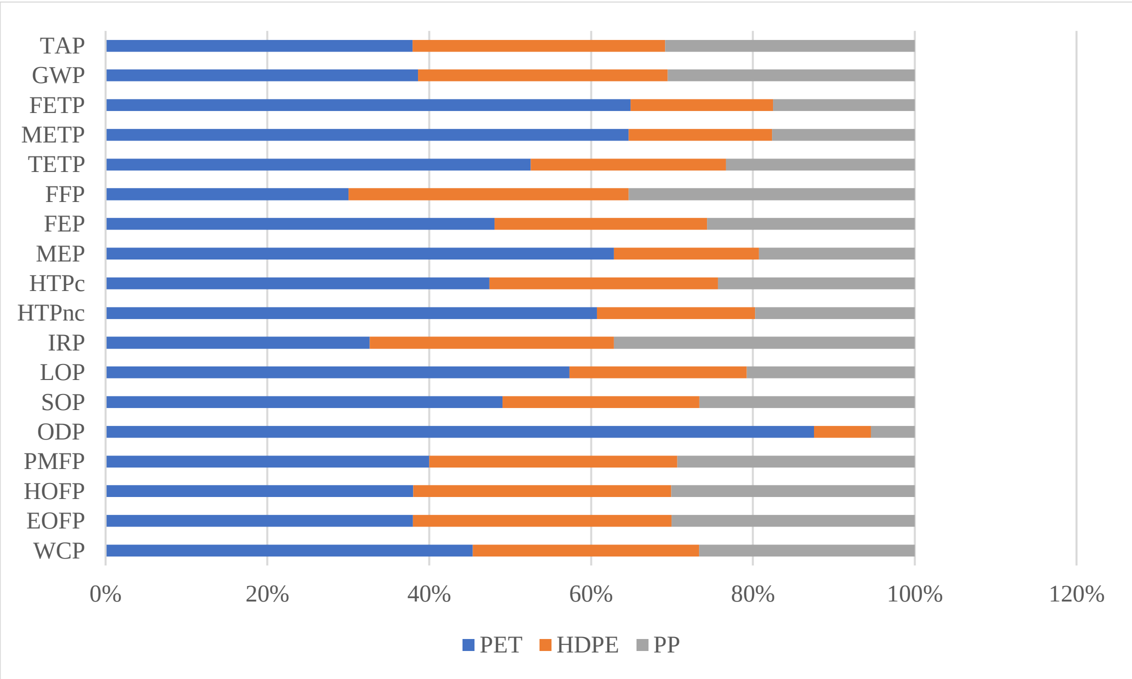

Figure 27. Stacked bar chart of the environment impact, considering 1 kg of material as base unit (using renewable energies)

At first sight, we notice that PET values are higher than HDPE and PP values by a factor of 2 or even 10 for some impact categories. On the other hand, the values for HDPE and PP are very close, with HDPE being slightly higher.

For the sake of clarity, we will focus on four impact categories:

- Global Warming Potential (GWP)

- Terrestrial Acidification Potential (TAP)
- Marine Eutrophication (MEP)
- Human Toxicity (carcogenic) Potential (HTPc)
- Ozone Depletion Potential (ODP)

These categories have different interests that will allow us to have an overview of the impacts that our processes can have. We have chosen to study the impact of our processes in a global way in the first instance, and then to consider the impacts on the soil and the sea and finally on the human species. The last studied impact is needed to complete the study to incorporate the impact on the ozone depletion. In this way, we manage to have a complete spectrum of data and our study will take many kinds of impact into account.

8.1 Global Warming Potential

Given its predominant relevance for compliance with legally binding international climate change treaties, the impact category of Global Warming Potential (GWP) is studied first.

The GWP is an index that defines the integrated warming effect of a 1 kg release of a greenhouse gas compared to the warming caused by CO_2. It measures the amount of energy absorbed by one tonne of gas emitted into the atmosphere over a given period of time. The GWP of a gas always takes carbon dioxide (CO_2) as a reference. The GWP of CO_2 is therefore always 1. It is an important indicator to consider nowadays to analyse the environmental feasibility of a process.

Not all greenhouse gases contribute equally to the Earth's energy balance because the amount of energy absorbed or the lifetime in the atmosphere differs from one gas to another. The main greenhouse gases, carbon dioxide (CO_2), water vapour (H_20), methane (CH_4), nitrous oxide (N_2O), to name but a few, therefore, have different workings, and thus a specific impact on global warming.

In order to assess climate change and make climate forecasts, it is therefore necessary to find a common unit to assess the effect of these different gases on the climate. With a common unit, we can better assess the impact of the emission of one tonne of CO_2 or one tonne of CH_4.

The GWP is therefore a homogenisation and comparison tool for public institutions, research and private organisations. The GWP makes it possible, particularly in the context of the Paris Agreements, to be able to account for greenhouse gas emissions during national inventories (Pouvoir de réchauffement global (PRG / GWP) : définition, utilité et limites, 2023).

The results of our study follow. We see the list of elements that influence GWP, and the percentage share of each type of element with a GWP impact. The elements are divided into five categories:

- Energy
- Chemical production
- Manufacture of refined petroleum
- Other.

For each of the impact categories we have chosen to study, we will look at the same indicators. Details of these categories are given in the section ANNEXES.

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						3,03563	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,29447	kg	1	kg CO2-Eq/kg	1,29447	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,81647	kg	1	kg CO2-Eq/kg	0,81647	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,28718	kg	1	kg CO2-Eq/kg	0,28718	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,00695	kg	36	kg CO2-Eq/kg	0,25013	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00643	kg	36	kg CO2-Eq/kg	0,23145	kg CO2-Eq
Methane, non-fossil	Emission to air / low population density	0,00351	kg	34	kg CO2-Eq/kg	0,1195	kg CO2-Eq

Table 13. List of elements having impact on GWP for 1 kg of recycled PET (using nuclear energy)

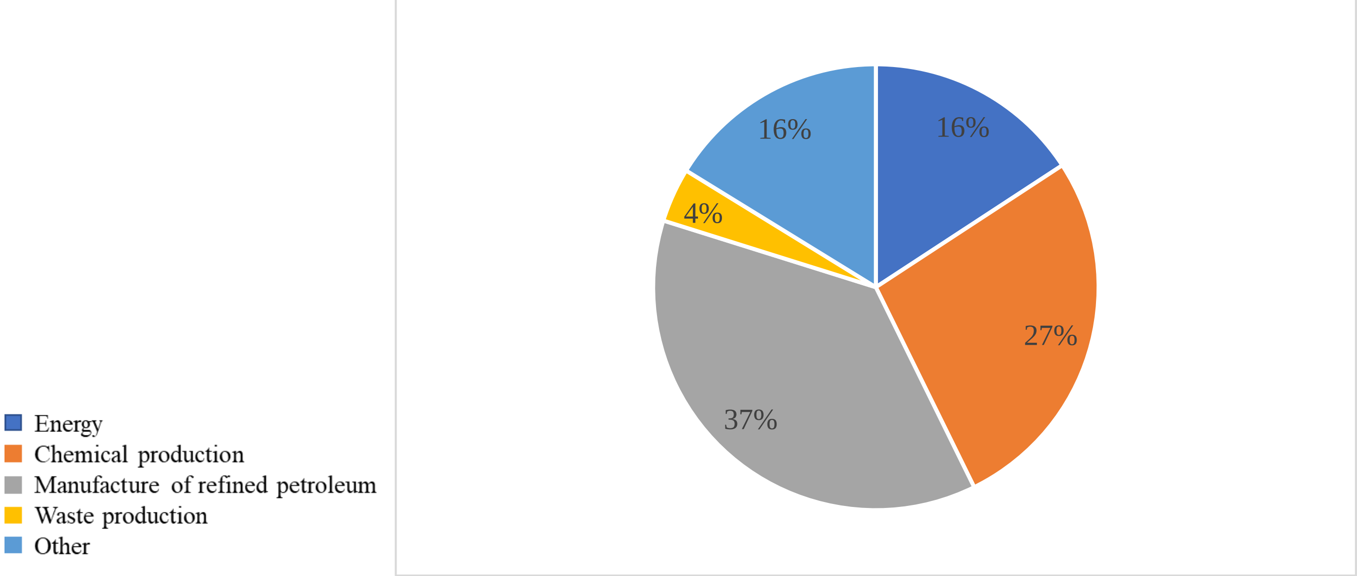

Figure 28. Pie chart of the categories having impact on GWP for 1 kg of recycled PET (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						2,42634	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,29199	kg	1	kg CO2-Eq/kg	1,29199	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,51299	kg	1	kg CO2-Eq/kg	0,51299	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01063	kg	36	kg CO2-Eq/kg	0,38262	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,12895	kg	1	kg CO2-Eq/kg	0,12895	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00254	kg	36	kg CO2-Eq/kg	0,09159	kg CO2-Eq

Table 14. List of elements having impact on GWP for 1 kg of recycled HDPE (using nuclear energy)

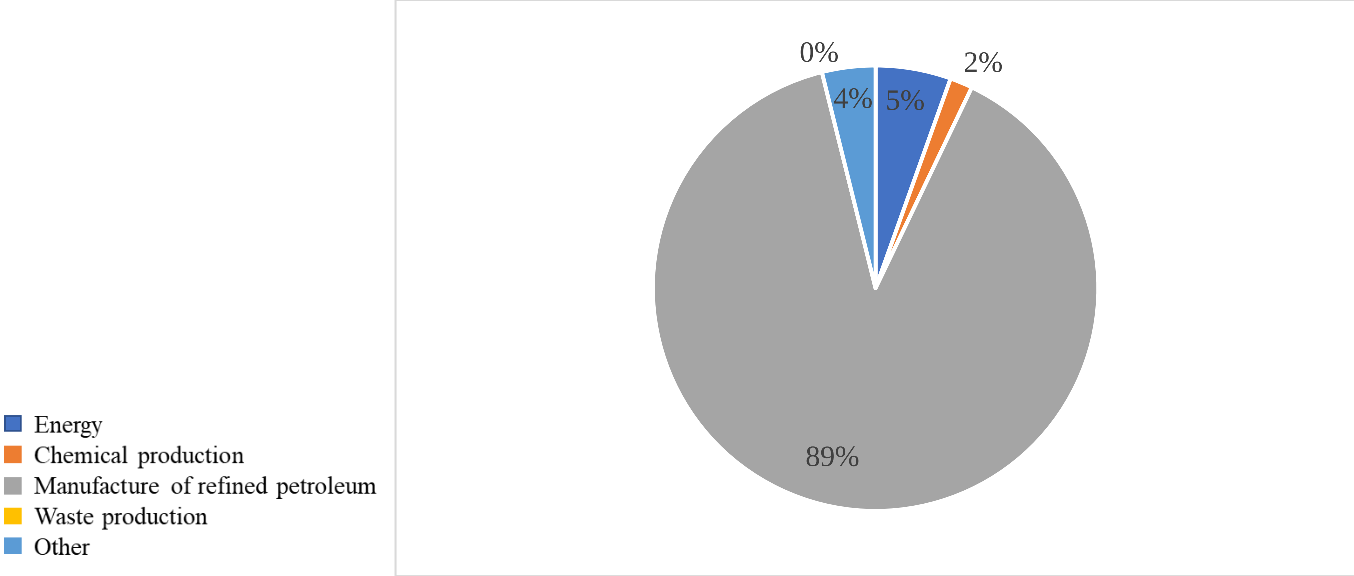

Figure 29. Pie chart of the categories having impact on GWP for 1 kg of recycled HDPE (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						2,3978	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,28758	kg	1	kg CO2-Eq/kg	1,28758	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,47035	kg	1	kg CO2-Eq/kg	0,47035	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01164	kg	36	kg CO2-Eq/kg	0,41907	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,13062	kg	1	kg CO2-Eq/kg	0,13062	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00209	kg	36	kg CO2-Eq/kg	0,07514	kg CO2-Eq

Table 15. List of elements having impact on GWP for 1 kg of recycled PP (using nuclear energy)

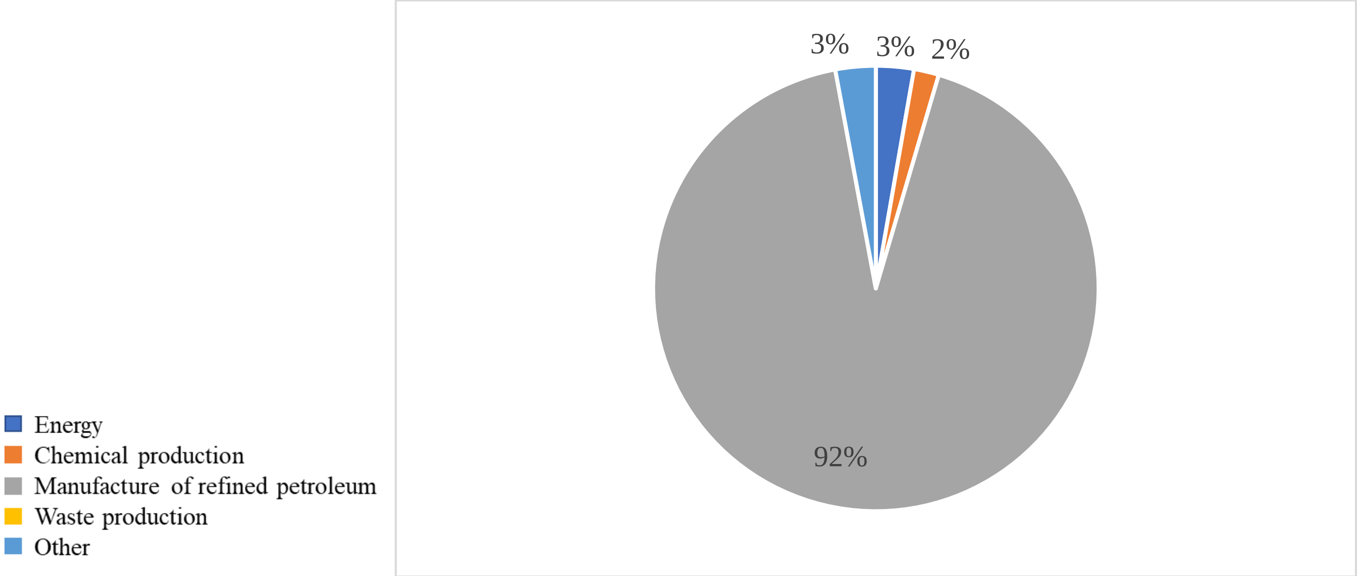

Figure 30. Pie chart of the categories having impact on GWP for 1 kg of recycled PP (using nuclear energy)

The components with the greatest impact on GWP here are carbon dioxide and methane, the two elements listed by OpenLCA. By definition, the impact factor of CO_2 is equal to 1, much less important than that of methane which is 36.

In the case of our 3 plastic recycling processes, it is carbon dioxide that is in greater quantity as an emission into the air. In total, between 1 and 2 kg of carbon dioxide were emitted in each case. On the other hand, although methane emissions to air are in smaller quantities, the impact factor being 36 to 1, its resultant impact becomes almost as important, around 0.5 kg CO_2-Eq for each plastic while barely 0.01 kg of methane is emitted to air.

In general, it can be observed that the emissions of the components are more important in areas with high population density.

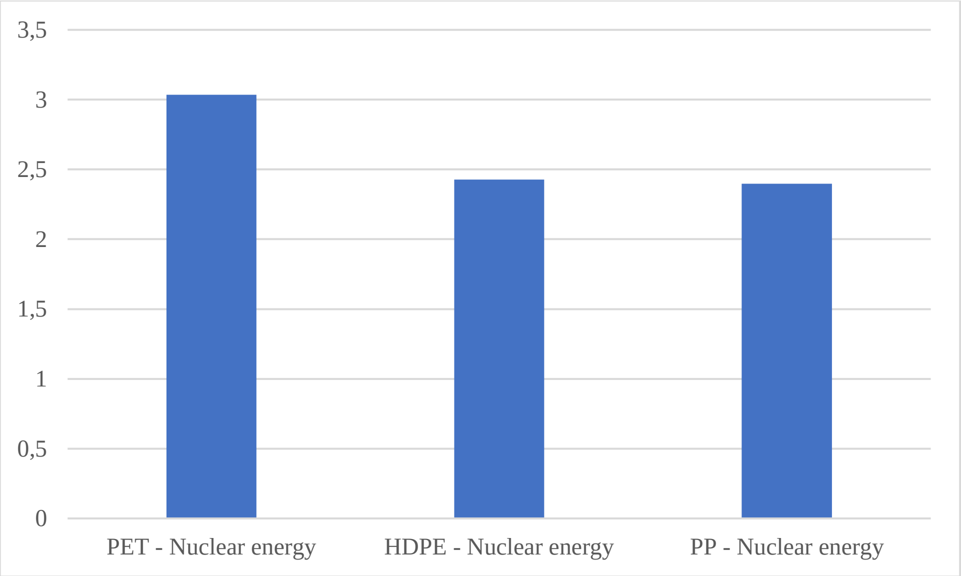

Figure 31. Comparison of GWP (kg CO_2-Eq) for PET, HDPE and PP (using nuclear energy)

If we compare our results with Figure 11 mentioned at the beginning of this document, the values obtained by our study are of the same order of magnitude or even slightly higher, they are between 2 and 3 kg CO_2-Eq. PET remains the plastic with the highest GWP.

8.2 Terrestrial Acidification Potential

Terrestrial acidification is characterized by changes in soil chemical properties following the deposition of nutrients in acidifying forms.

Soil acidification is a natural, unavoidable, and slow phenomenon. It occurs in both natural and cultivated environments, but the use of acid fertilisers without tillage concentrates acidity on the surface. It is the quantity of H+ ions present in the soil solution that characterises the pH of a soil, and therefore its acidity. The more H+, the more acidic the soil and the lower the pH. The variability of the pH is due in particular to the nature of the rocks and the season. Biological activity is also a source of pH modification.

Acidification has several consequences on the functioning of a soil. The protons will bind strongly to the clay-humus complex and take the place of the cations. The latter are found in large proportions in the soil solution and are likely to be leached out. In addition, if the soil is very acidic (pH<5), some aluminium-containing minerals may solubilise while others may be blocked. The presence of some elements in the soil can be toxic to plants. Acidity can disrupt physical fertility: increase in the risk of capping with dispersion of aggregates and therefore poor water infiltration.

Finally, acidification affects biological fertility: biological activity prefers neutral pH. It is known that fungi appreciate acidic pH levels more than basic ones; the latter being more favourable to the development of bacterial populations (Maëva Bourgeois, 2010).

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00785	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00285	kg	1	kg SO2-Eq/kg	0,00285	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00257	kg	1	kg SO2-Eq/kg	0,00257	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00207	kg	0,36	kg SO2-Eq/kg	0,00075	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00194	kg	0,36	kg SO2-Eq/kg	0,0007	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00155	kg	0,36	kg SO2-Eq/kg	0,00056	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	0,00022	kg	1	kg SO2-Eq/kg	0,00022	kg SO2-Eq
Ammonia	Emission to air / high population density	5,13E-05	kg	1,96	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Ammonia	Emission to air / unspecified	4,25E-05	kg	1,96	kg SO2-Eq/kg	8,34E-05	kg SO2-Eq

Table 16. List of elements having impact on TAP for 1 kg of recycled PET (using nuclear energy)

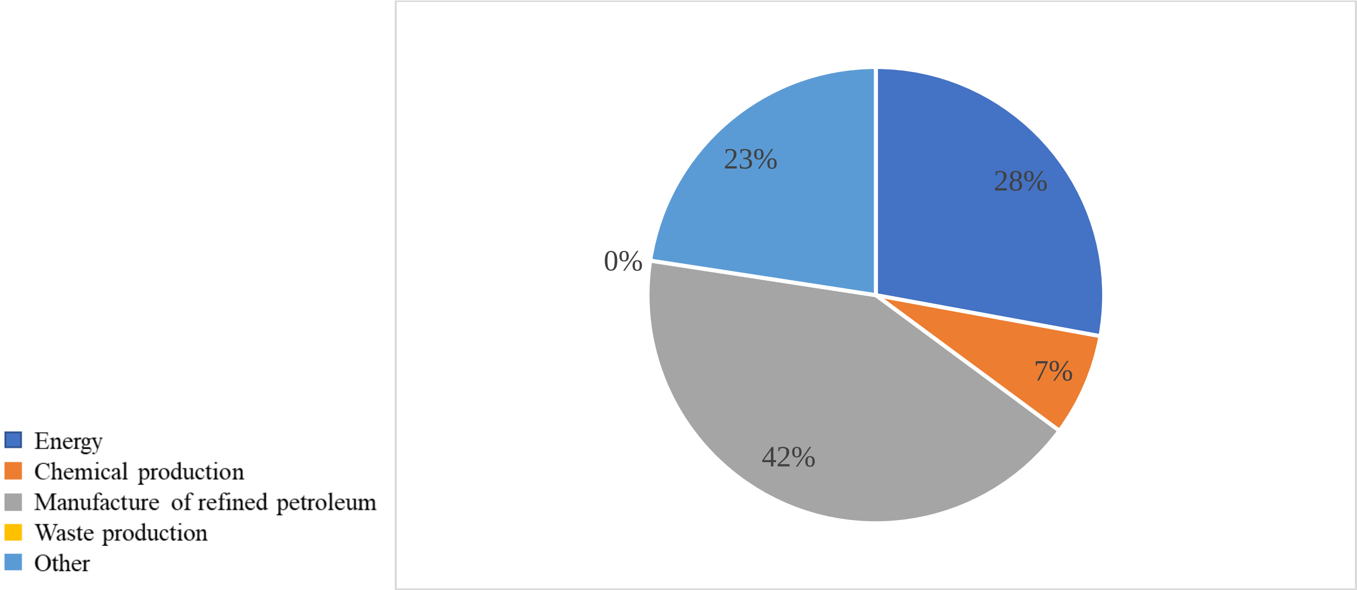

Figure 32. Pie chart of the categories having impact on TAP for 1 kg of recycled PET (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00646	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,0027	kg	1	kg SO2-Eq/kg	0,0027	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,0019	kg	1	kg SO2-Eq/kg	0,0019	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	0,0001	kg	1	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00252	kg	0,36	kg SO2-Eq/kg	0,00091	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00142	kg	0,36	kg SO2-Eq/kg	0,00051	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00069	kg	0,36	kg SO2-Eq/kg	0,00025	kg SO2-Eq

Table 17. List of elements having impact on TAP for 1 kg of recycled HDPE (using nuclear energy)

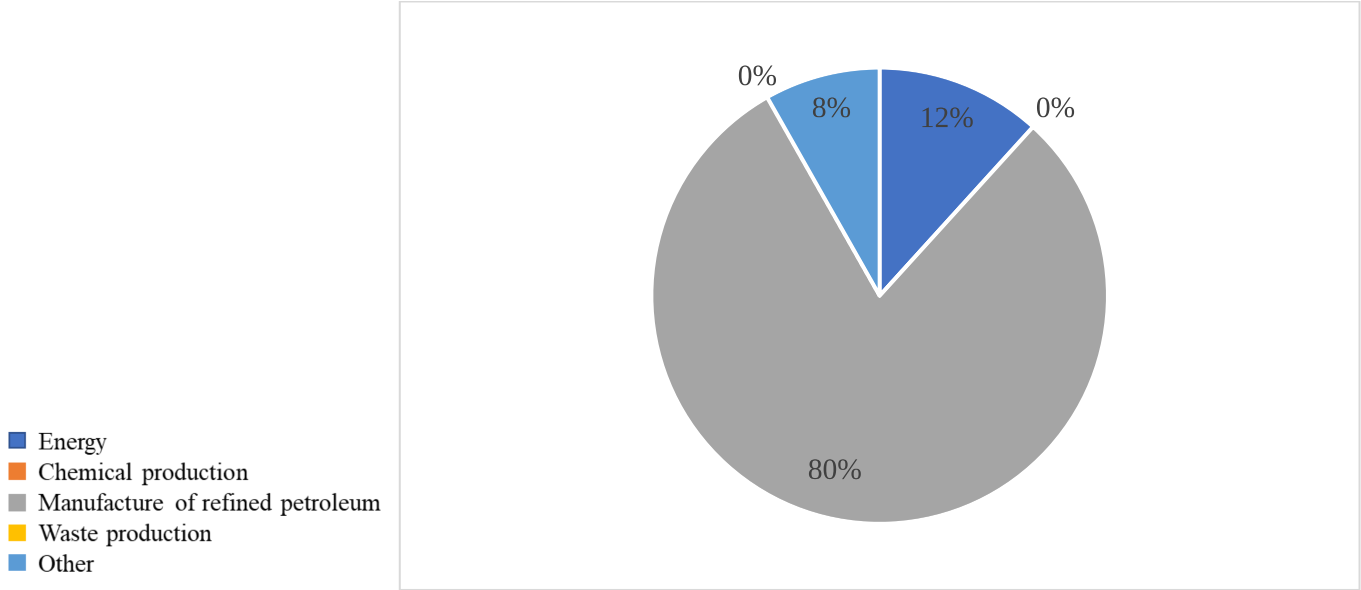

Figure 33. Pie chart of the categories having impact on TAP for 1 kg of recycled HDPE (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00638	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00277	kg	1	kg SO2-Eq/kg	0,00277	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00184	kg	1	kg SO2-Eq/kg	0,00184	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00242	kg	0,36	kg SO2-Eq/kg	0,00087	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00134	kg	0,36	kg SO2-Eq/kg	0,00048	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00068	kg	0,36	kg SO2-Eq/kg	0,00025	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	9,41E-05	kg	1	kg SO2-Eq/kg	9,41E-05	kg SO2-Eq

Table 18. List of elements having impact on TAP for 1 kg of recycled PP (using nuclear energy)

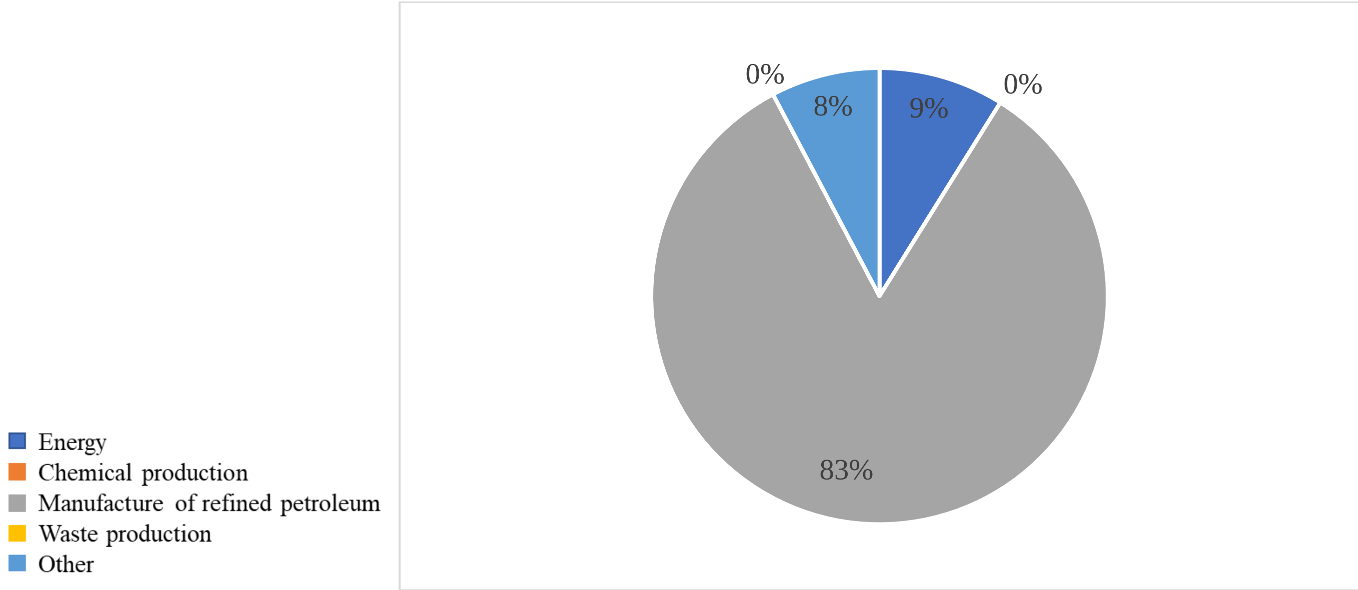

Figure 34. Pie chart of the categories having impact on TAP for 1 kg of recycled PP (using nuclear energy)

The most impactful elements for TAP are sulphur dioxide, nitrogen oxides and ammonia, the latter only being cited in the PET recycling process. The impact factor for sulphur dioxide is 1, for nitrogen oxides 0.36 and for ammonia 1.96.

Ammonia is present in very small quantities in the PET study and its impact is only taken into account because its impact factor is high. Nevertheless, it is the component with the lowest impact result of all the components mentioned above.

In terms of quantity, the quantities of sulphur dioxide and nitrogen oxides are almost the same in the three studies. For the former, we find almost 0.005 kg emitted and 0.004 kg for the latter.

In general, it can be seen once again that dense populations are the most affected.

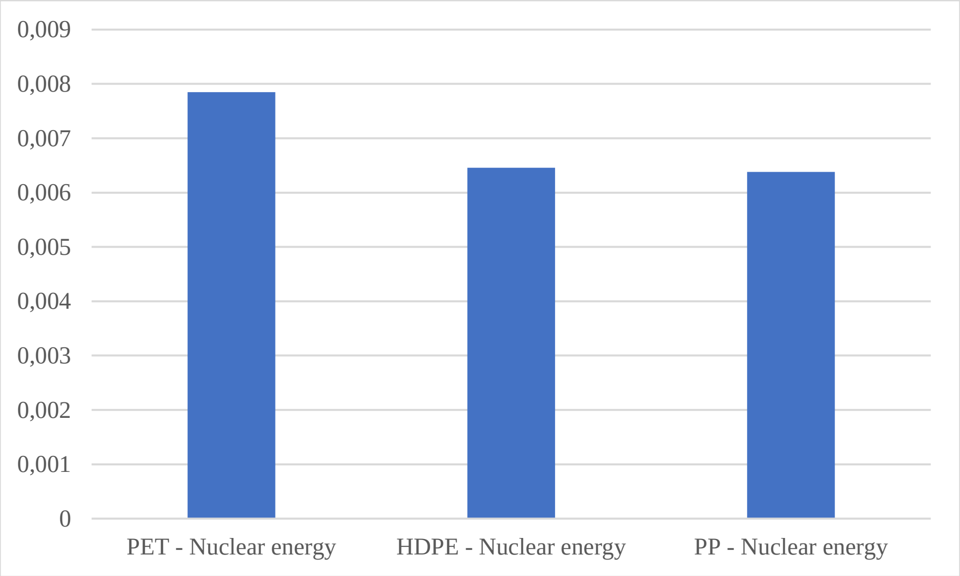

Figure 35. Comparison of TAP (kg SO2-Eq) for PET, HDPE and PP (using nuclear energy)

Again, PET is in first place with a TAP value of 0.00785 kg SO_2-Eq, followed by HDPE and PP which have very similar values, respectively 0.00646 and 0.00638 kg SO_2-Eq.

8.3 Marine Eutrophication Potential

Marine eutrophication is an imbalance in the environment caused by excessive inputs of nutrients, particularly nitrogen and phosphorus. It is characterised by a significant growth of plants, which causes dysfunctions within the ecosystem. (Gilles Pinay, 2013)

The consequences of marine eutrophication are numerous and variable: modification of physico-chemical characteristics or proliferation of planktonic algae and macro-algae for instance.

A distinction should be made between natural eutrophication, which corresponds to an increase in the production of organic matter linked to the evolution of an aquatic ecosystem and which extends over several thousand or million years, and eutrophication linked to human activities, known as anthropogenic eutrophication, which occurs on short time scales.

Anthropogenic water pollution is mainly attributed to phosphorus (contained in laundry detergents) and nitrogen (contained in fertilizers). The phenomenon of eutrophication is thus strongly correlated with agricultural, domestic or industrial discharges into watercourses. Due to their location at the interface between the ocean and the continent, coastal areas are the first to be affected by anthropogenic eutrophication.

This increase in nitrogen and phosphate inputs, combined with stable silicate inputs, modifies the proportions between these different elements, which influence the biological balance of the water. It has three potential consequences:

- An increase and accumulation of plant biomass, and therefore of the amount of organic matter, which can lead to adverse effects, such as significant drops in the oxygen concentration in the water.
- Changes in the dominance and abundance of macro-algae species and phytoplankton, which will have repercussions along the food chain and modify the relationships between organisms, and thus their life and survival.
- A disruption of the seasonal dynamics of phytoplankton in temperate waters, due to silicon limitation, which may cause a shift in dominance from siliceous species (diatoms) to non-siliceous species (flagellates and dinoflagellates). This results in the possible emergence of new types of algal growth (so-called blooms), whose characteristic species may be harmful or even toxic.

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						0,00023	kg N-Eq
Nitrate	Emission to water / ground water, long-term	0,00092	kg	0,0671	kg N-Eq/kg	6,18E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	0,00015	kg	0,297	kg N-Eq/kg	4,32E-05	kg N-Eq
Nitrate	Emission to water / surface water	0,00033	kg	0,0671	kg N-Eq/kg	2,22E-05	kg N-Eq
Ammonium	Emission to water / surface water	9,59E-05	kg	0,23	kg N-Eq/kg	2,21E-05	kg N-Eq
Nitrogen	Emission to water / surface water	7,16E-05	kg	0,297	kg N-Eq/kg	2,13E-05	kg N-Eq
Ammonium	Emission to water / ground water, long-term	8,93E-05	kg	0,23	kg N-Eq/kg	2,05E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water	4,91E-05	kg	0,297	kg N-Eq/kg	1,46E-05	kg N-Eq
Ammonium	Emission to water / ground water	3,05E-05	kg	0,23	kg N-Eq/kg	7,01E-06	kg N-Eq
Nitrate	Emission to water / ground water	0,0001	kg	0,0671	kg N-Eq/kg	6,87E-06	kg N-Eq
Ammonium	Emission to water / ocean	7,75E-06	kg	0,776	kg N-Eq/kg	6,01E-06	kg N-Eq

Table 19. List of elements having impact on MEP for 1 kg of recycled PET (using nuclear energy)

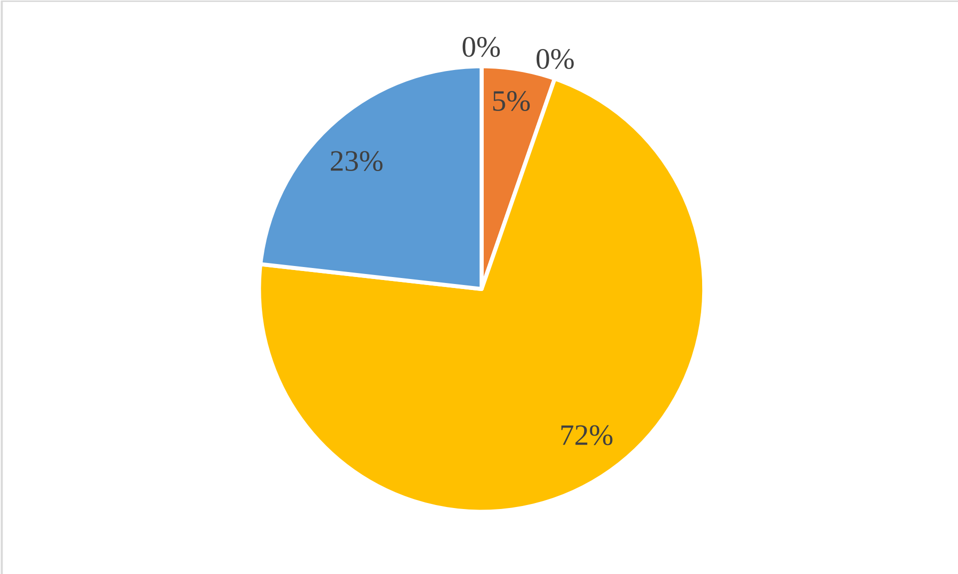

Figure 36. Pie chart of the categories having impact on MEP for 1 kg of recycled PET (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						6,56E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	6,56E-06	kg	0,297	kg N-Eq/kg	1,95E-06	kg N-Eq
Nitrogen	Emission to water / surface water	1,84E-05	kg	0,297	kg N-Eq/kg	5,45E-06	kg N-Eq
Nitrate	Emission to water / ground water, long-term	0,00061	kg	0,0671	kg N-Eq/kg	4,06E-05	kg N-Eq
Nitrate	Emission to water / ground water	8,50E-05	kg	0,0671	kg N-Eq/kg	5,70E-06	kg N-Eq
Nitrate	Emission to water / surface water	4,46E-05	kg	0,0671	kg N-Eq/kg	2,99E-06	kg N-Eq
Ammonium	Emission to water / surface water	1,36E-05	kg	0,23	kg N-Eq/kg	3,14E-06	kg N-Eq
Ammonium	Emission to water / ocean	2,86E-06	kg	0,776	kg N-Eq/kg	2,22E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	4,17E-06	kg	0,23	kg N-Eq/kg	9,59E-07	kg N-Eq

Table 20. List of elements having impact on MEP for 1 kg of recycled HDPE (using nuclear energy)

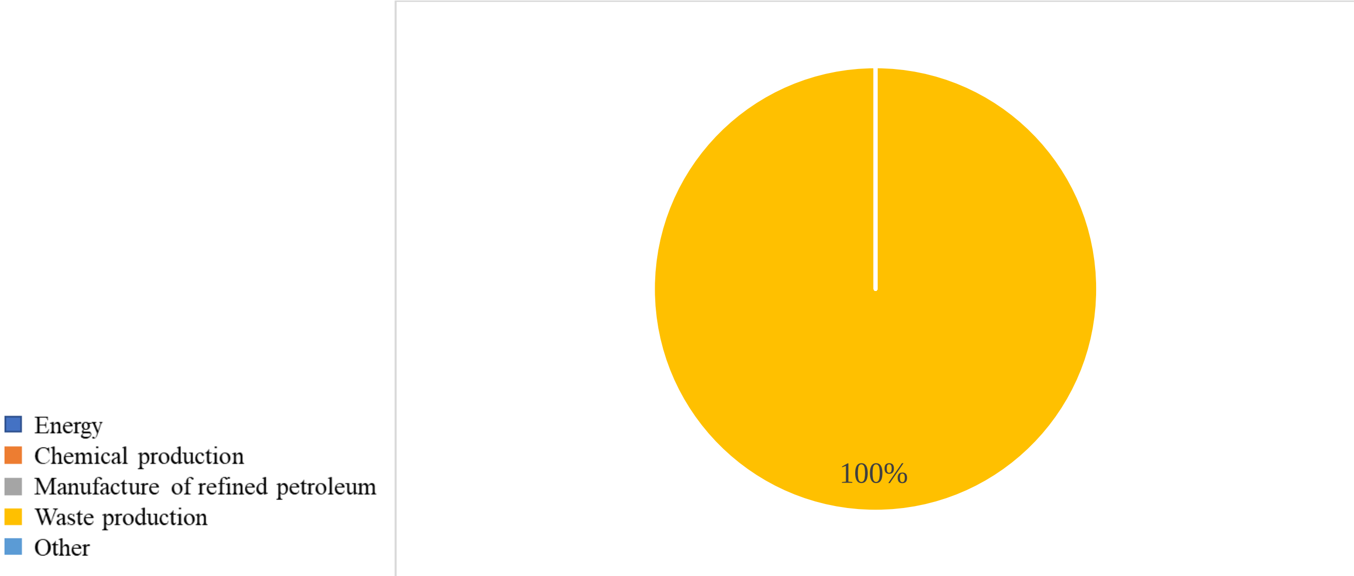

Figure 37. Pie chart of the categories having impact on MEP for 1 kg of recycled HDPE (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						7,05E-05	kg N-Eq
Nitrate	Emission to water / ground water, long-term	0,00066	kg	0,0671	kg N-Eq/kg	4,42E-05	kg N-Eq
Nitrate	Emission to water / ground water	9,95E-05	kg	0,0671	kg N-Eq/kg	6,68E-06	kg N-Eq
Nitrogen	Emission to water / surface water	1,74E-05	kg	0,297	kg N-Eq/kg	5,16E-06	kg N-Eq
Nitrate	Emission to water / surface water	4,50E-05	kg	0,0671	kg N-Eq/kg	3,02E-06	kg N-Eq
Ammonium	Emission to water / surface water	1,28E-05	kg	0,23	kg N-Eq/kg	2,95E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	8,09E-06	kg	0,297	kg N-Eq/kg	2,40E-06	kg N-Eq
Ammonium	Emission to water / ocean	2,16E-06	kg	0,776	kg N-Eq/kg	1,67E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	5,10E-06	kg	0,23	kg N-Eq/kg	1,17E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / unspecified	3,14E-06	kg	0,297	kg N-Eq/kg	9,31E-07	kg N-Eq

Table 21. List of elements having impact on MEP for 1 kg of recycled PP (using nuclear energy)

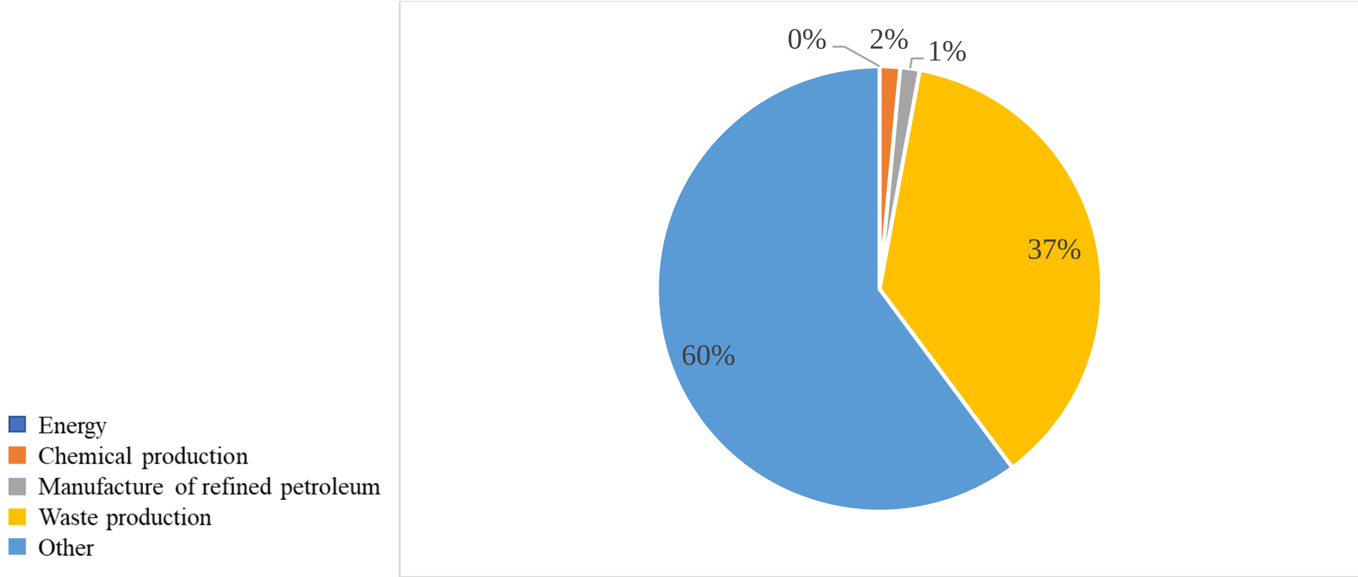

Figure 38. Pie chart of the categories having impact on MEP for 1 kg of recycled PET (using nuclear energy)

In the case of MEP, the elements of interest are nitrate, nitrogen and ammonium. Their impact factors are 0.0671, 0.297 and 0.23 respectively. Logically, the emissions here are not sent to the air but to the water, sometimes in the long term. Nitrate emissions are the most important, up to 0.001 kg in the case of PET. The other two elements do not reach quantities larger than 10E-4. Furthermore, it is the long-term impacts that are in greater quantities.

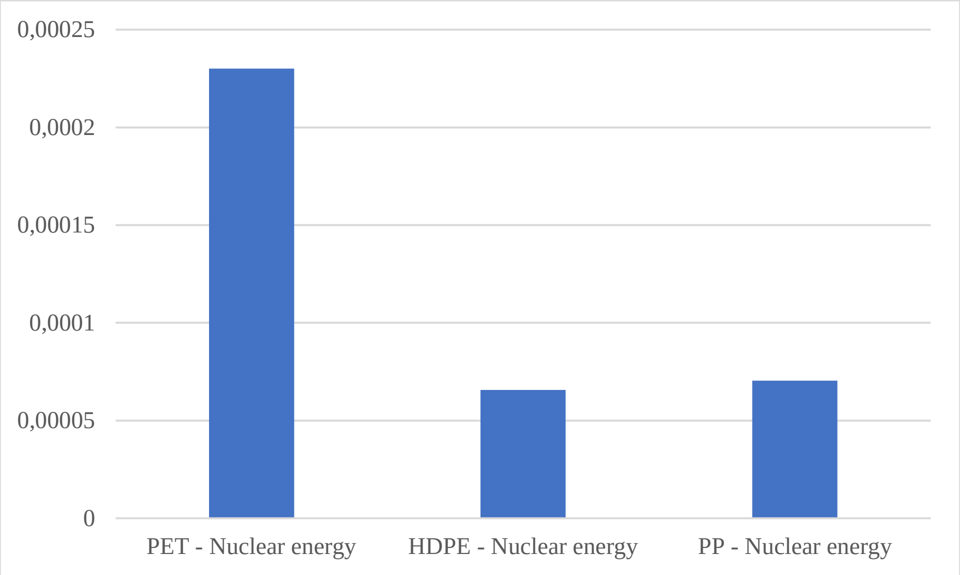

Figure 39. Comparison of MEP (kg N-Eq) for PET, HDPE and PP (using nuclear energy)

Once again, PET has the highest emissions. However, the difference is greater, there is a factor of 3 between the emissions of PET and PP.

8.4 Human Toxicity (carcinogenic) Potential

This category concerns the effects of toxic substances on the human environment. This indicator reflects the potential health damage of chemicals emitted into the atmosphere and the environment. For example, arsenic or hydrogen fluoride are potentially dangerous to human health through inhalation, ingestion and are carcinogenic. The measurement is in dichlorobenzene equivalent, a known carcinogen.

Health risks from exposure in the working environment are not considered. The characterisation factors, Human Toxicity Potentials (HTP), are calculated using the Uniform Substance Evaluation System adapted to LCA, which describes the fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance, the PTHs are expressed as 1,4-dichlorobenzene eq/kg emission. The geographical scope of this indicator depends on the fate of a substance and can vary from local to global.

In our study we differentiate between carcinogenic and non-carcinogenic hazards, and here we consider the former (Glossaires des Analyses de Cycles de Vie (ACV), s.d.).

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,18162	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,83E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,13644	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	4,40E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,03277	kg 1,4-DCB-Eq
Nickel II	Emission to water / ground water, long-term	9,96E-05	kg	22,8	kg 1,4-DCB-Eq/kg	0,00227	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	8,49E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00218	kg 1,4-DCB-Eq

Table 22. List of elements having impact on HTPc for 1 kg of recycled PET (using nuclear energy)

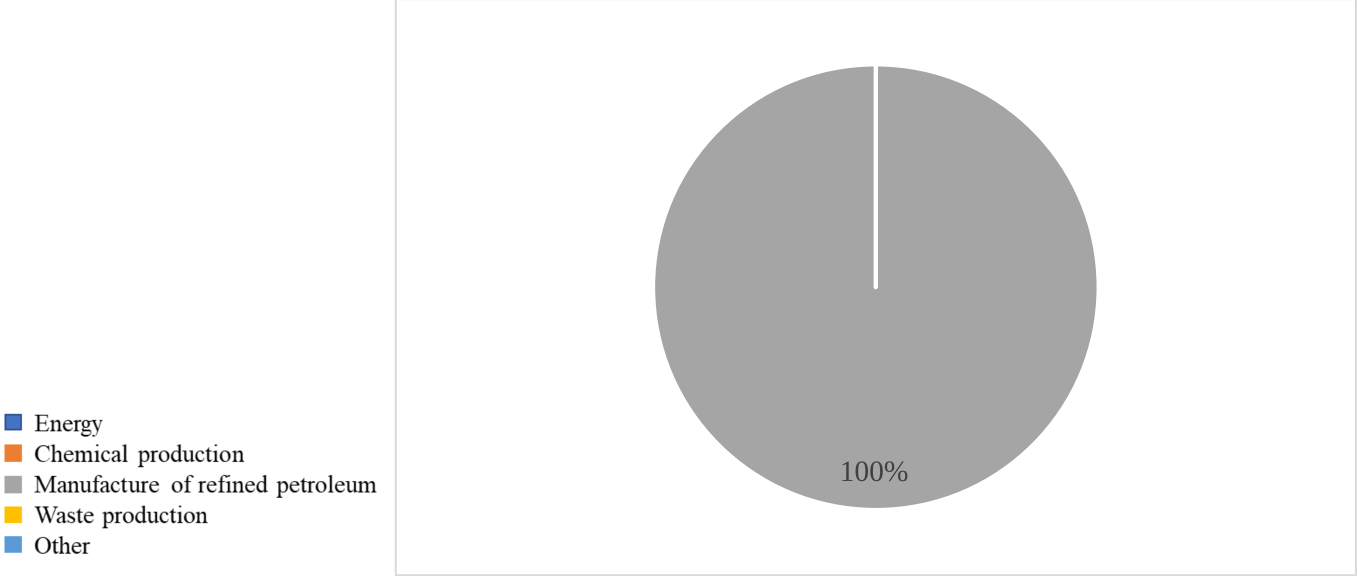

Figure 40. Pie chart of the categories having impact on HTPc for 1 kg of recycled PET (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,10804	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,10E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,08167	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	2,74E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,02036	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	5,00E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00129	kg 1,4-DCB-Eq

Table 23. List of elements having impact on HTPc for 1 kg of recycled HDPE (using nuclear energy)

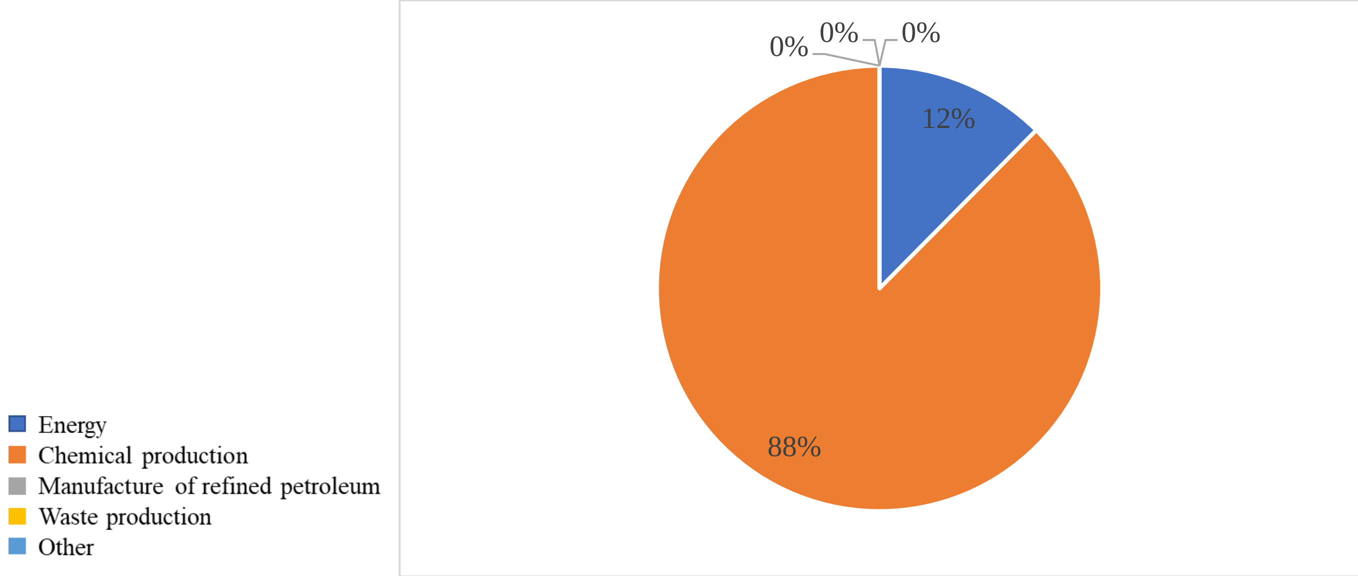

Figure 41. Pie chart of the categories having impact on HTPc for 1 kg of recycled HDPE (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,09305	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	9,42E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,07011	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	2,27E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,01689	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	5,02E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00129	kg 1,4-DCB-Eq
Arsenic ion	Emission to water / ground water, long-term	2,78E-06	kg	345	kg 1,4-DCB-Eq/kg	0,00096	kg 1,4-DCB-Eq

Table 24. List of elements having impact on HTPc for 1 kg of recycled PP (using nuclear energy)

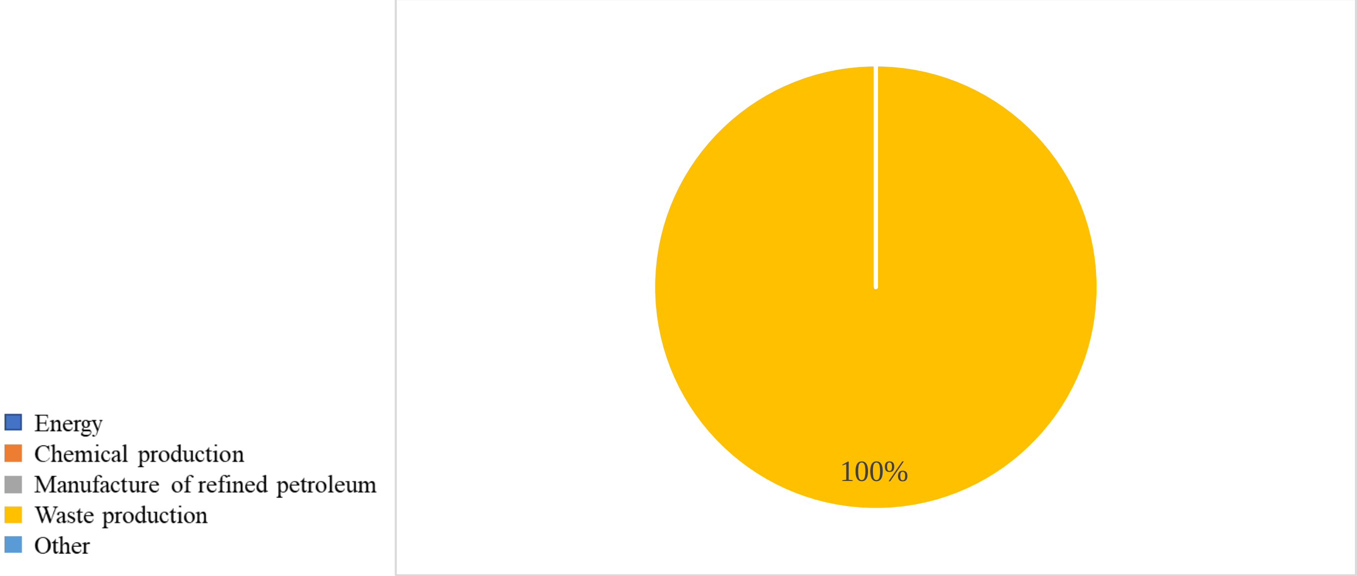

Figure 42. Pie chart of the categories having impact on HTPc for 1 kg of recycled PP (using nuclear energy)

For this impact we consider, chromium VI is listed, and in the case of PET, nickel II is also listed, while PP emits arsenic ion as well. The impact factor values are high enough to compensate for the very low emissions. For chromium VI, the impact factor has a value of 7440 in the case where it is emitted into water and it has a value of 2.57E4 in the case where the emissions are airborne. For nickel II, also emitted into water, the impact factor is 22.8. Finally, arsenic ion has an impact factor of 345 and is always emitted into water.

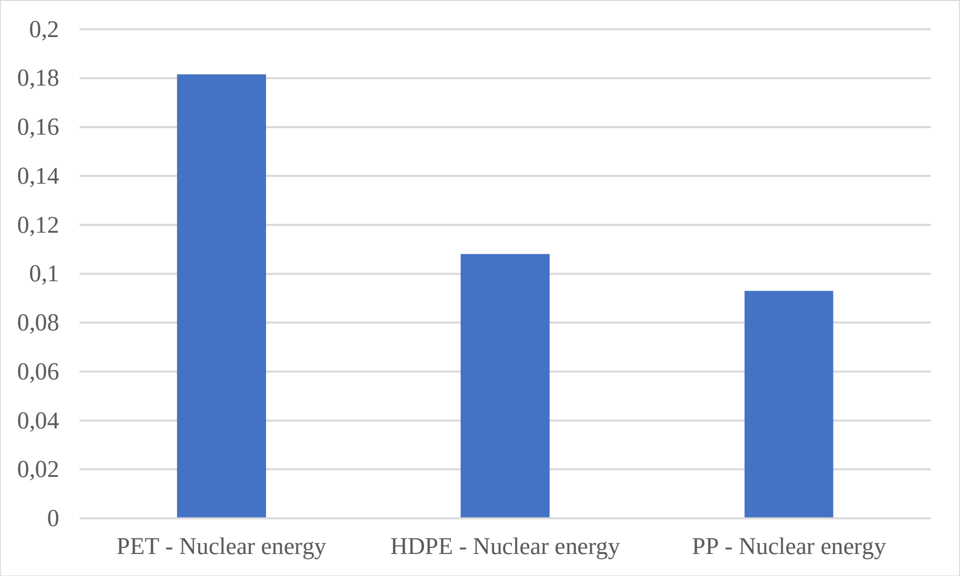

Figure 43. Comparison of HTPc (kg 1,4-DCB-Eq) for PET, HDPE and PP (using nuclear energy)

Then, PET is the plastic that is most harmful to humans in terms of carcinogenic toxicity.

8.5 Ozone Depletion Potential

The contribution of individual compounds to ozone depletion is characterized by the ozone depletion potential (ODP). The ODP of a compound as normally defined is the ratio of the global loss of ozone (i.e., integrated over latitude, altitude, and time) from that compound at steady state per unit mass emitted relative to the loss of ozone due to emission of unit mass of a reference compound, usually taken as CFC-11 ($CFCl_3$). The ODP thus provides a relative measure of the overall impact of a compound on ozone destruction over the long term. Values for ODPs have been derived using a variety of models (Wuebbles, 2015).

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						4,53E-06	kg CFC-11-Eq
Methane, bromo-, Halon	Emission to air / unspecified	5,27E-06	kg	0,734	kg CFC-11-Eq/kg	3,87E-06	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,84E-05	kg	0,011	kg CFC-11-Eq/kg	2,02E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,64E-05	kg	0,011	kg CFC-11-Eq/kg	1,81E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	1,45E-05	kg	0,011	kg CFC-11-Eq/kg	1,59E-07	kg CFC-11-Eq
Methane, tetrachloro-, R·	Emission to air / high population density	6,04E-08	kg	0,895	kg CFC-11-Eq/kg	5,41E-08	kg CFC-11-Eq

Table 25. List of elements having impact on ODP for 1 kg of recycled PET (using nuclear energy)

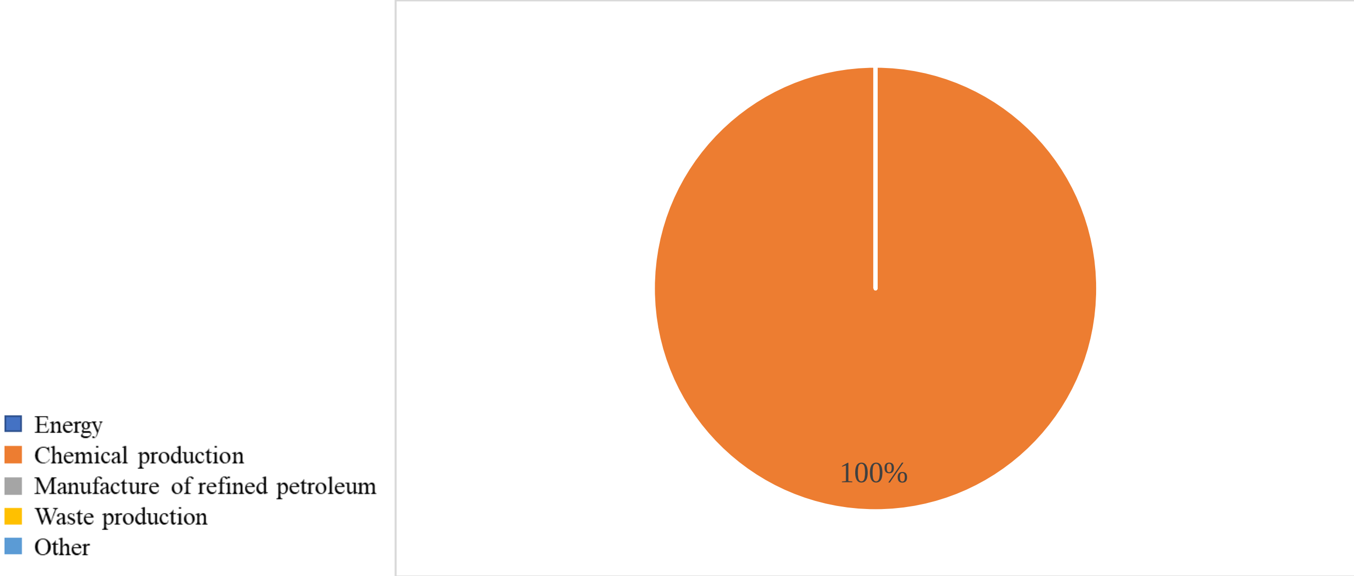

Figure 44. Pie chart of the categories having impact on ODP for 1 kg of recycled PET (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						3,65E-07	kg CFC-11-Eq
Methane, tetrachloro-, R-	Emission to air / high population density	4,20E-09	kg	0,895	kg CFC-11-Eq/kg	3,76E-09	kg CFC-11-Eq
Methane, bromotrifluoro-	Emission to air / low population density	4,26E-10	kg	14,1	kg CFC-11-Eq/kg	6,00E-09	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,47E-05	kg	0,011	kg CFC-11-Eq/kg	1,62E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,01E-05	kg	0,011	kg CFC-11-Eq/kg	1,11E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	7,17E-06	kg	0,011	kg CFC-11-Eq/kg	7,89E-08	kg CFC-11-Eq

Table 26. List of elements having impact on ODP for 1 kg of recycled HDPE (using nuclear energy)

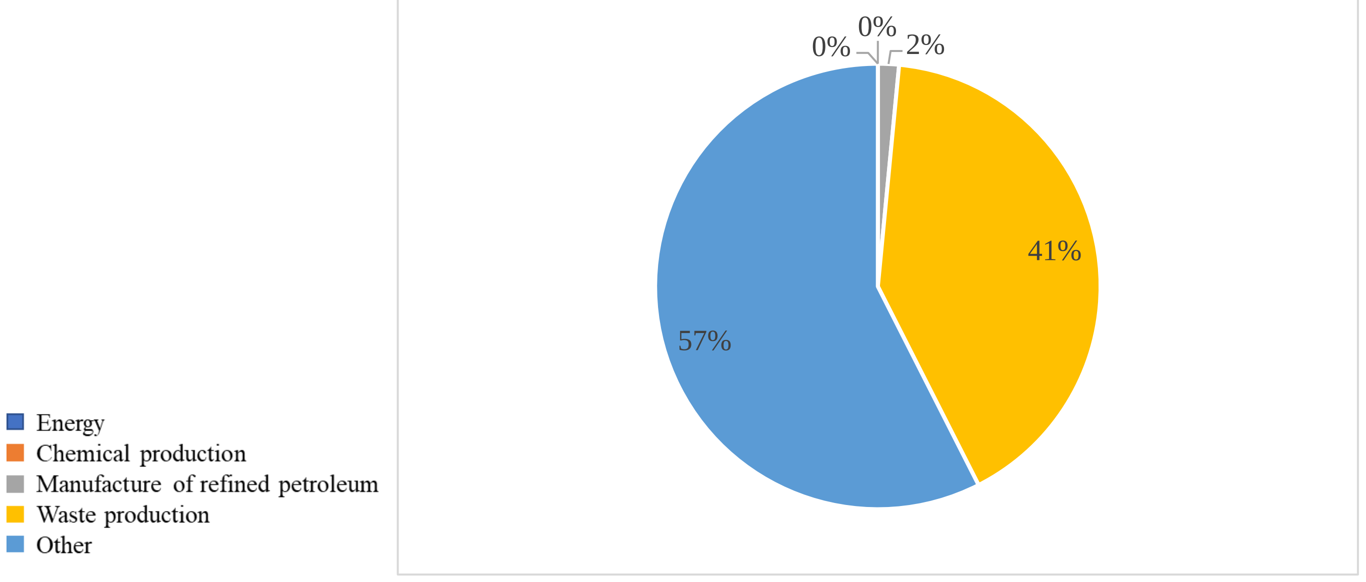

Figure 45. Pie chart of the categories having impact on ODP for 1 kg of recycled HDPE (using nuclear energy)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						2,79E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,07E-05	kg	0,011	kg CFC-11-Eq/kg	1,18E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	7,67E-06	kg	0,011	kg CFC-11-Eq/kg	8,43E-08	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	6,00E-06	kg	0,011	kg CFC-11-Eq/kg	6,60E-08	kg CFC-11-Eq
Methane, tetrachloro-, R	Emission to air / high population density	5,55E-09	kg	0,895	kg CFC-11-Eq/kg	4,97E-09	kg CFC-11-Eq
Methane, bromotrifluoro	Emission to air / low population density	3,22E-10	kg	14,1	kg CFC-11-Eq/kg	4,53E-09	kg CFC-11-Eq

Table 27. List of elements having impact on ODP for 1 kg of recycled PP (using nuclear energy)

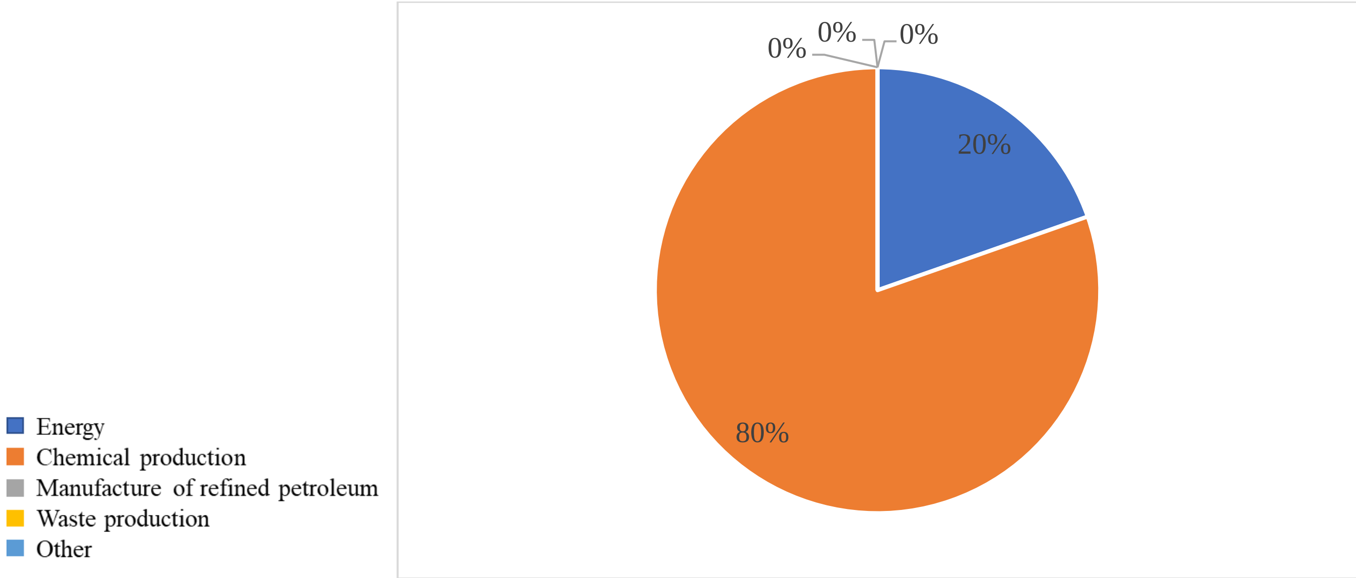

Figure 46. Pie chart of the categories having impact on ODP for 1 kg of recycled PP (using nuclear energy)

The main contributors to the impact category ozone depletion are: dinitrogen monoxide, with a factor of 0.0011, methane, with a factor of 0.895 or 14.1 depending on whether it is tethrachloro-methane or bromotrifluoro-methane. Dinitrogen monoxide has the greatest impact compared to methane, regardless of its type.

Of the plastics studied, the one with the highest ozone depletion potential is PET and it is far superior to the others. It reaches a value ten times higher than HDPE and PP, 4.5E-6 versus 3.5E-7 kg CFC-11-Eq).

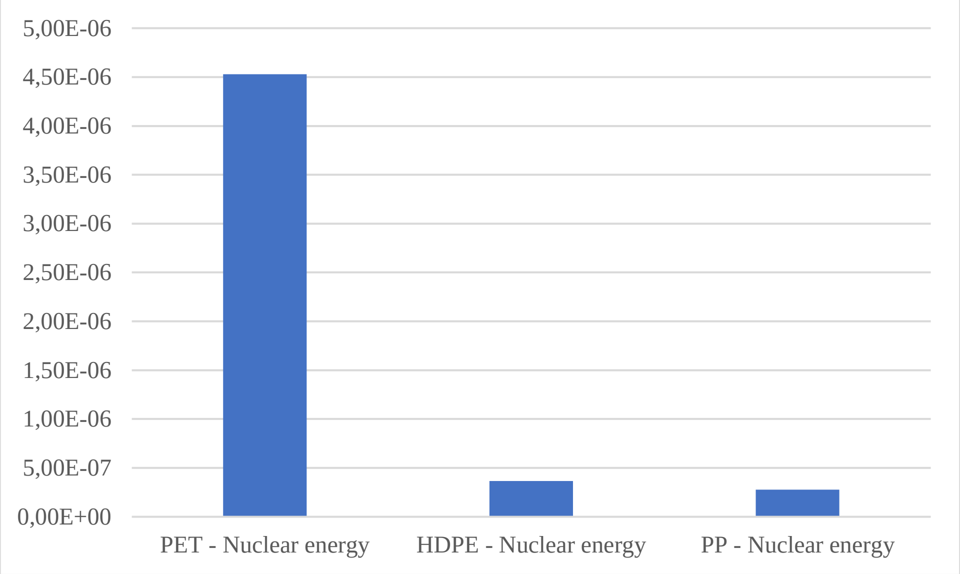

Figure 47. Comparison of ODP (kg CFC-11-Eq) for PET, HDPE and PP (using nuclear energy)

In general, the values we have obtained are low compared to those observed in the scientific literature for plastic production. However, it should be remembered that we are studying the recycling process and not the production of plastics from scratch. Indeed, in comparison with the PET LCA study conducted by (Brandon Kuczenski, 2011), we note a factor of 10 between our results for GWP and TAP and theirs. In particular, we note a much higher energy requirement than in our case.

8.6 Sensitivity analysis: Nuclear energy vs Renewable energies

Now we will look at the share of energy used in the recycling process. We have just seen the analysis of mechanical recycling of plastics using energy from a nuclear power plant. We have chosen this type of production because in France, almost 70% of the energy produced comes from a nuclear power station. Now we will look again at the mechanical recycling process by changing this energy to renewable energy.

The study will use the same parameters as those used previously and in the same quantities, but the energy used will be "*electricity, high voltage, renewable energy products*" from "*market for electricity, high voltage, renewable energy products | electricity, high voltage, renewable energy products | Cutoff, U – CH*".

Table 12 concatenates the impact analysis of this new study.

Name	PET	HDPE	PP	Unit
water use - water consumption potential (WCP)	0.06271	0.04764	0.09385	m^3
photochemical oxidant formation: terrestrial ecosystems - photochemical oxidant formation potential: ecosystems (EOFP)	0.00677	0.00570	0.00541	kg NOx-Eq
photochemical oxidant formation: human health - photochemical oxidant formation potential: humans (HOFP)	0.00631	0.00529	0.00505	kg NOx-Eq
particulate matter formation - particulate matter formation potential (PMFP)	0.00332	0.00254	0.00247	kg PM2.5-Eq
ozone depletion - ozone depletion potential (ODPinfinite)	4.63958E-6	4.82076E-7	2.85216E-7	kg CFC-11-Eq
material resources: metals/minerals - surplus ore potential (SOP)	0.04186	0.02023	0.02400	kg Cu-Eq
land use - agricultural land occupation (LOP)	0.05410	0.02179	0.01925	m^2*a crop-Eq
ionising radiation - ionising radiation potential (IRP)	0.24620	0.05924	1.75022	kBq Co-60-Eq
human toxicity: non-carcinogenic - human toxicity potential (HTPnc)	4.08812	1.20825	1.38809	kg 1,4-DCB-Eq
human toxicity: carcinogenic - human toxicity potential (HTPc)	0.18062	0.10698	0.09733	kg 1,4-DCB-Eq
eutrophication: marine - marine eutrophication potential (MEP)	0.00021	4.07194E-5	7.08319E-5	kg N-Eq
eutrophication: freshwater - freshwater eutrophication potential (FEP)	0.00074	0.00041	0.00040	kg P-Eq
energy resources: non-renewable, fossil - fossil fuel potential (FFP)	1.82425	1.68231	1.71949	kg oil-Eq
ecotoxicity: terrestrial - terrestrial ecotoxicity potential (TETP)	12.88095	5.62697	6.00287	kg 1,4-DCB-Eq

ecotoxicity: marine - marine ecotoxicity potential (METP)	0.27878	0.07611	0.07686	kg 1,4-DCB-Eq
ecotoxicity: freshwater - freshwater ecotoxicity potential (FETP)	0.21082	0.05717	0.05743	kg 1,4-DCB-Eq
climate change - global warming potential (GWP100)	3.04273	2.43382	2.41253	kg CO_2-Eq
acidification: terrestrial - terrestrial acidification potential (TAP)	0.00785	0.00645	0.00641	kg SO_2-Eq

Table 28. Environmental impact, considering 1 kg of material as base unit

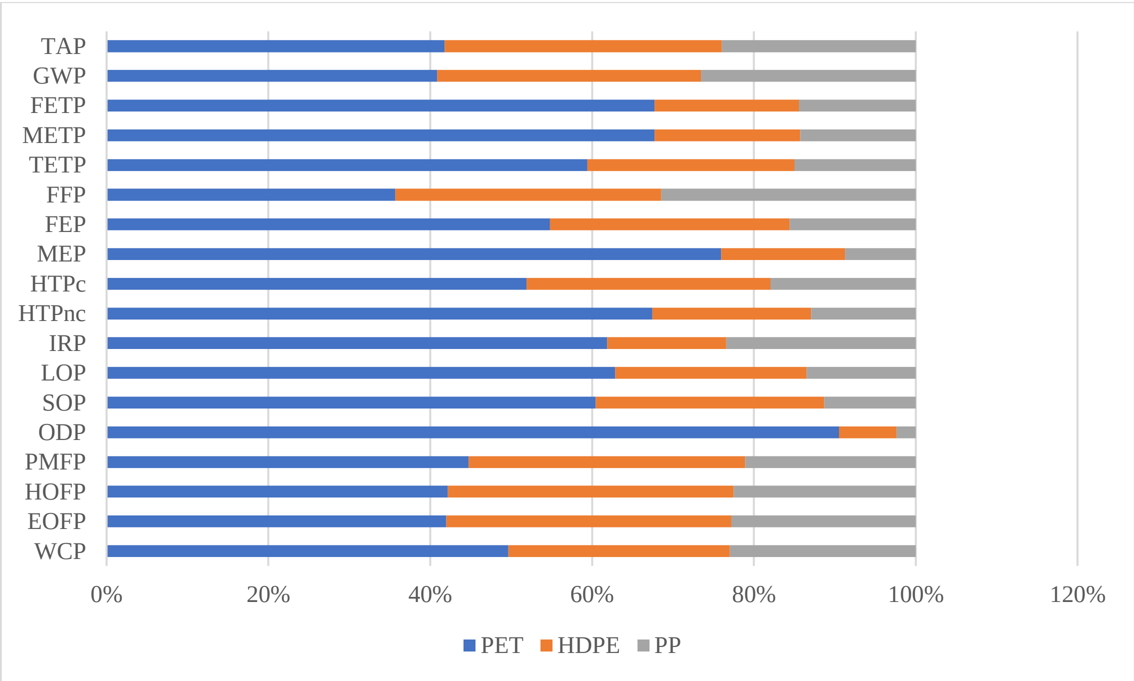

Figure 48. Stacked bar chart of the environment impact, considering 1 kg of material as base unit (using nuclear energy)

Subsequently, in order to conduct a comparative study, we will analyse the same impact categories as in the previous section, i.e. GWP, TAP, MEP, HTPc and ODP.

8.6.1 Global Warming Potential

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						3,02416	kg CO2-Eq
Methane, non-fossil	Emission to air / low population density	0,00351	kg	34	kg CO2-Eq/kg	0,11945	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,00695	kg	36	kg CO2-Eq/kg	0,2501	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,0064	kg	36	kg CO2-Eq/kg	0,23025	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,2925	kg	1	kg CO2-Eq/kg	1,2925	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,81024	kg	1	kg CO2-Eq/kg	0,81024	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,28545	kg	1	kg CO2-Eq/kg	0,28545	kg CO2-Eq

Table 29. List of elements having impact on GWP for 1 kg of recycled PET (using renewable energies)

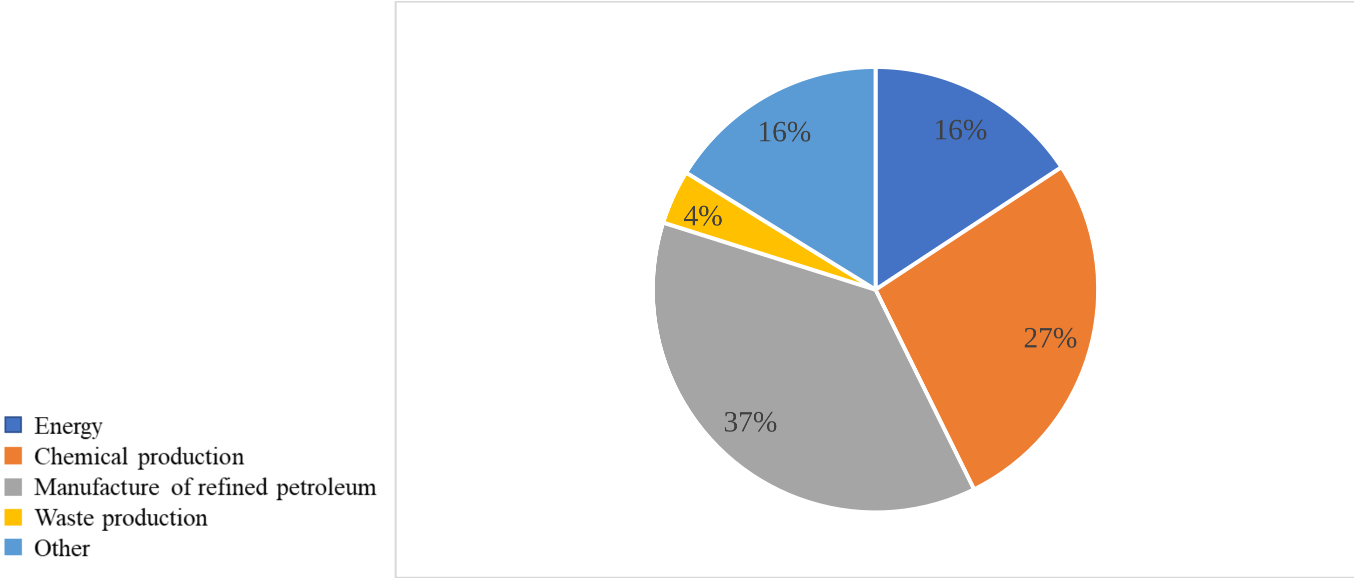

Figure 49. Pie chart of the categories having impact on GWP for 1 kg of recycled PET (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						2,41425	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01063	kg	36	kg CO2-Eq/kg	0,38258	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00251	kg	36	kg CO2-Eq/kg	0,09032	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,28992	kg	1	kg CO2-Eq/kg	1,28992	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,50642	kg	1	kg CO2-Eq/kg	0,50642	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,12713	kg	1	kg CO2-Eq/kg	0,12713	kg CO2-Eq

Table 30. List of elements having impact on GWP for 1 kg of recycled HDPE (using renewable energies)

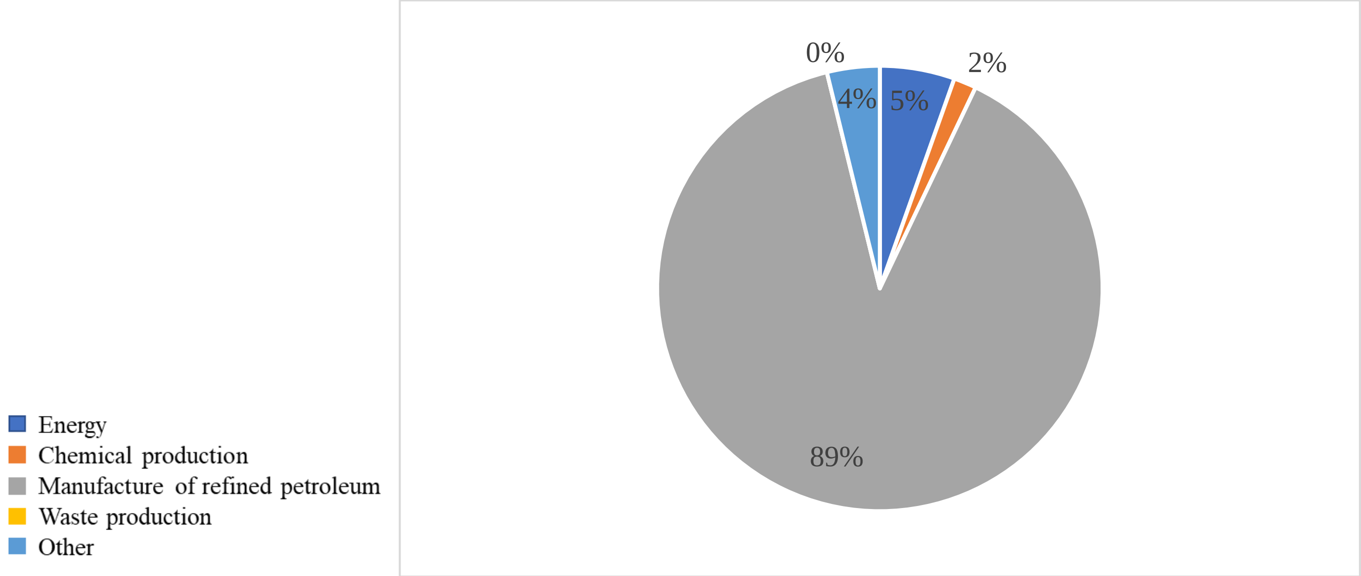

Figure 50. Pie chart of the categories having impact on GWP for 1 kg of recycled HDPE (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						1,96238	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01181	kg	36	kg CO2-Eq/kg	0,4252	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00075	kg	36	kg CO2-Eq/kg	0,02716	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,28166	kg	1	kg CO2-Eq/kg	1,28166	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,15687	kg	1	kg CO2-Eq/kg	0,15687	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,06297	kg	1	kg CO2-Eq/kg	0,06297	kg CO2-Eq

Table 31. List of elements having impact on GWP for 1 kg of recycled PP (using renewable energies)

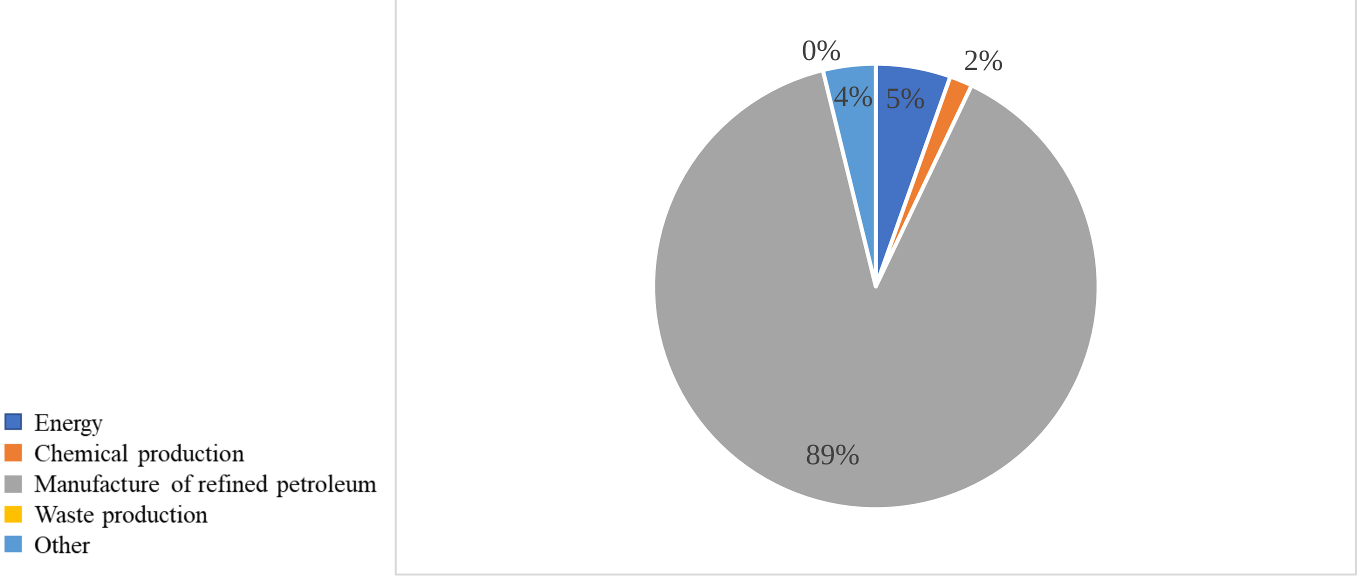

Figure 51. Pie chart of the categories having impact on GWP for 1 kg of recycled PP (using renewable energies)

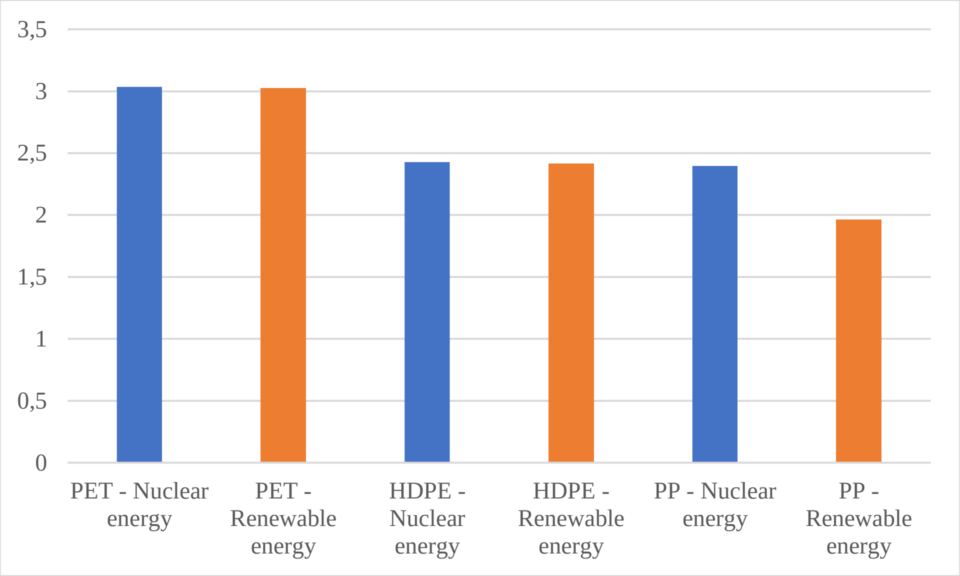

Figure 52. Comparison of GWP (kg CO2-Eq) for PET, HDPE and PP (using renewable energies)

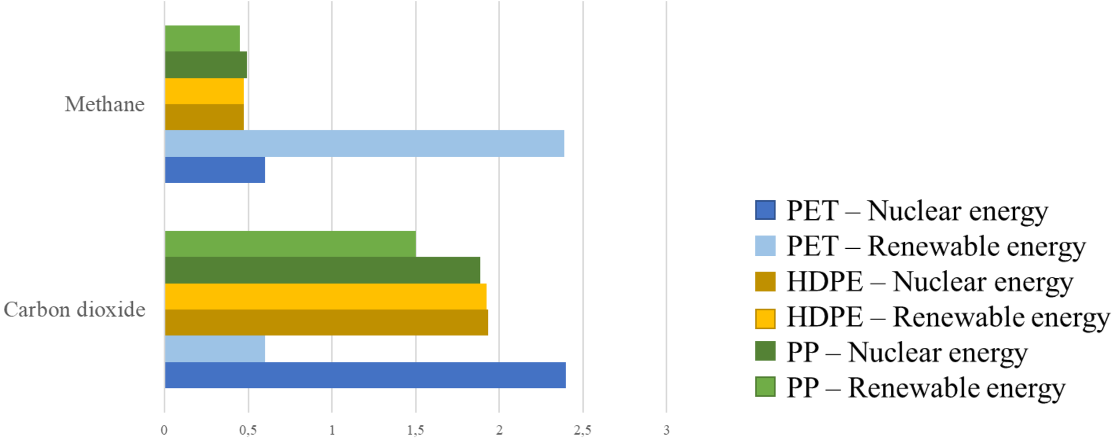

Figure 53. Clustered bar chart of the elements having an impact on GWP for PET, HDPE and PP

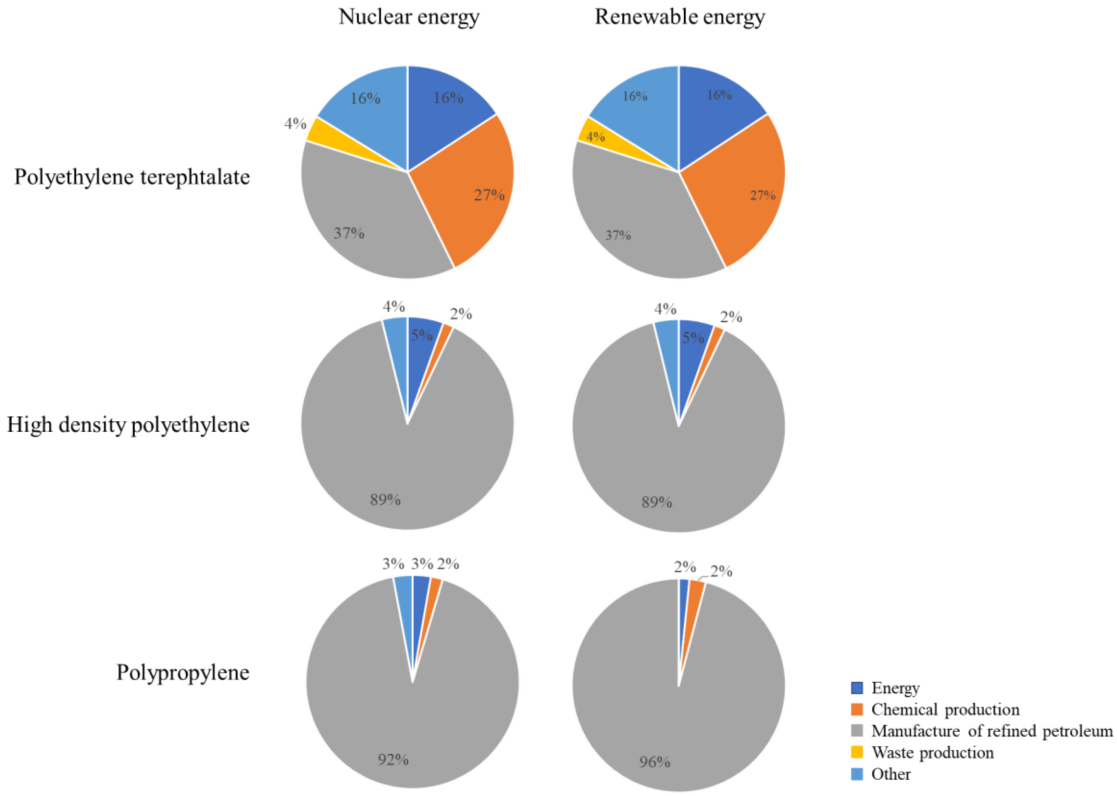

Figure 54. Comparison of the pie charts for GWP

As can be seen in Figure 52, PET is the plastic with the greatest GWP impact. On the other hand, we can also see that it has the highest percentages of energy and chemical production impact. These two comments are certainly linked, the main contribution in PET mechanical recycling being the energy required to produce chemicals and their extraction, which requires a lot of energy, the impact is elevated.

8.6.2 Terrestrial Acidification Potential

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00779	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00283	kg	1	kg SO2-Eq/kg	0,00283	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00256	kg	1	kg SO2-Eq/kg	0,00256	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	0,00021	kg	1	kg SO2-Eq/kg	0,00021	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00207	kg	0,36	kg SO2-Eq/kg	0,00074	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,0019	kg	0,36	kg SO2-Eq/kg	0,00068	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00154	kg	0,36	kg SO2-Eq/kg	0,00055	kg SO2-Eq
Ammonia	Emission to air / high population density	5,11E-05	kg	1,96	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Ammonia	Emission to air / unspecified	4,18E-05	kg	1,96	kg SO2-Eq/kg	8,19E-05	kg SO2-Eq

Table 32. List of elements having impact on TAP for 1 kg of recycled PET (using renewable energies)

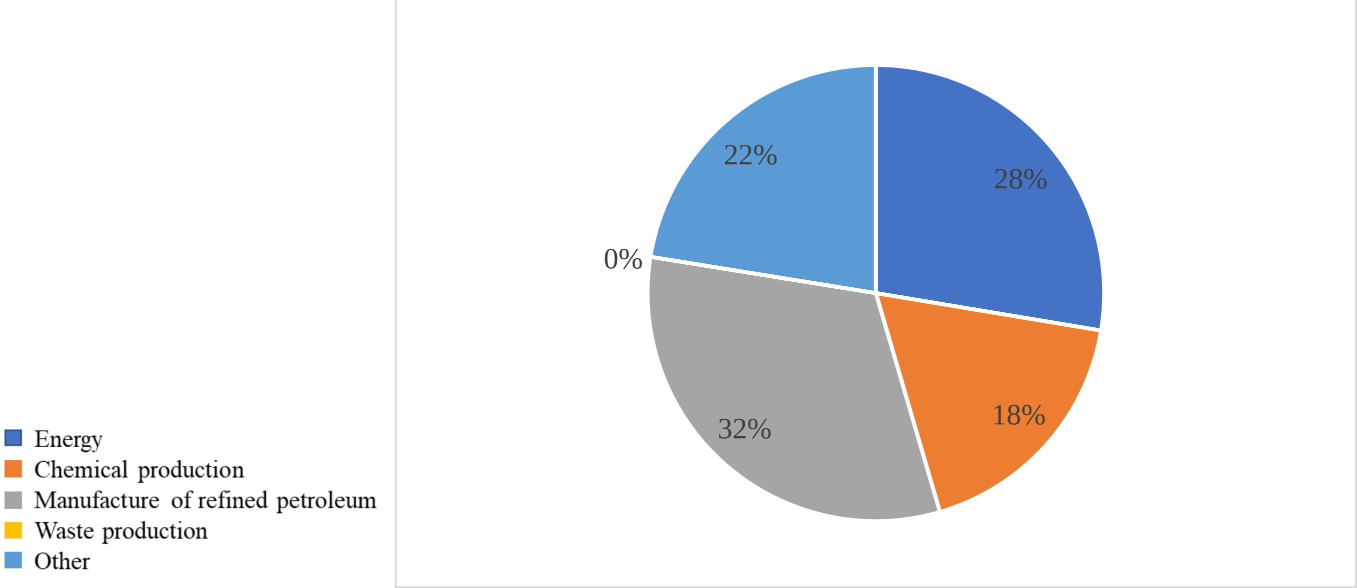

Figure 55. Pie chart of the categories having impact on TAP for 1 kg of recycled PET (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00639	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00269	kg	1	kg SO2-Eq/kg	0,00269	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00188	kg	1	kg SO2-Eq/kg	0,00188	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	9,71E-05	kg	1	kg SO2-Eq/kg	9,71E-05	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00251	kg	0,36	kg SO2-Eq/kg	0,0009	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00138	kg	0,36	kg SO2-Eq/kg	0,0005	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00068	kg	0,36	kg SO2-Eq/kg	0,00025	kg SO2-Eq

Table 33. List of elements having impact on TAP for 1 kg of recycled HDPE (using renewable energies)

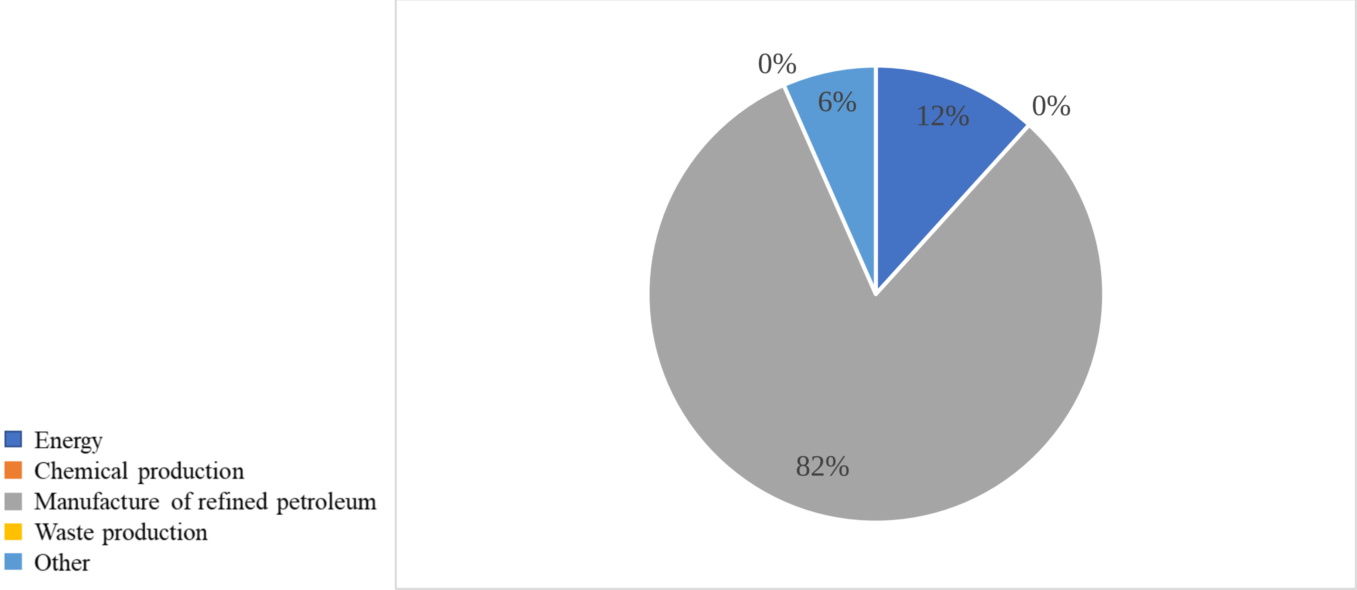

Figure 56. Pie chart of the categories having impact on TAP for 1 kg of recycled HDPE (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00447	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00265	kg	1	kg SO2-Eq/kg	0,00265	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00073	kg	1	kg SO2-Eq/kg	0,00073	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00239	kg	0,36	kg SO2-Eq/kg	0,00086	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00028	kg	0,36	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00015	kg	0,36	kg SO2-Eq/kg	5,50E-05	kg SO2-Eq

Table 34. List of elements having impact on TAP for 1 kg of recycled PP (using renewable energies)

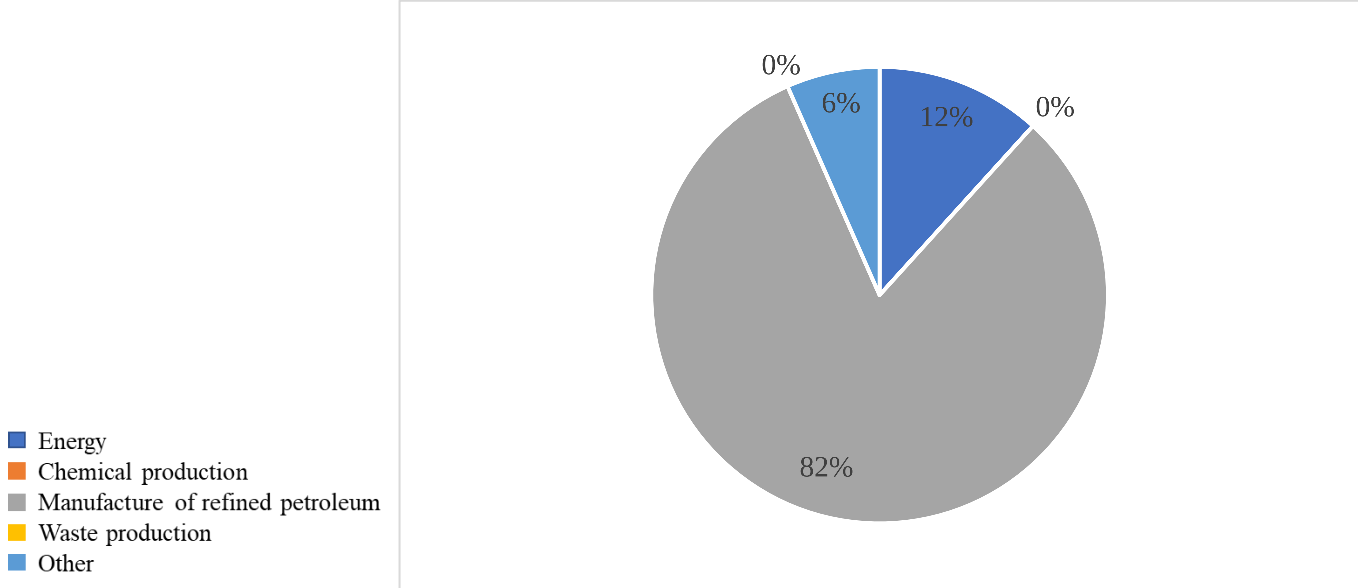

Figure 57. Pie chart of the categories having impact on TAP for 1 kg of recycled PP (using renewable energies)

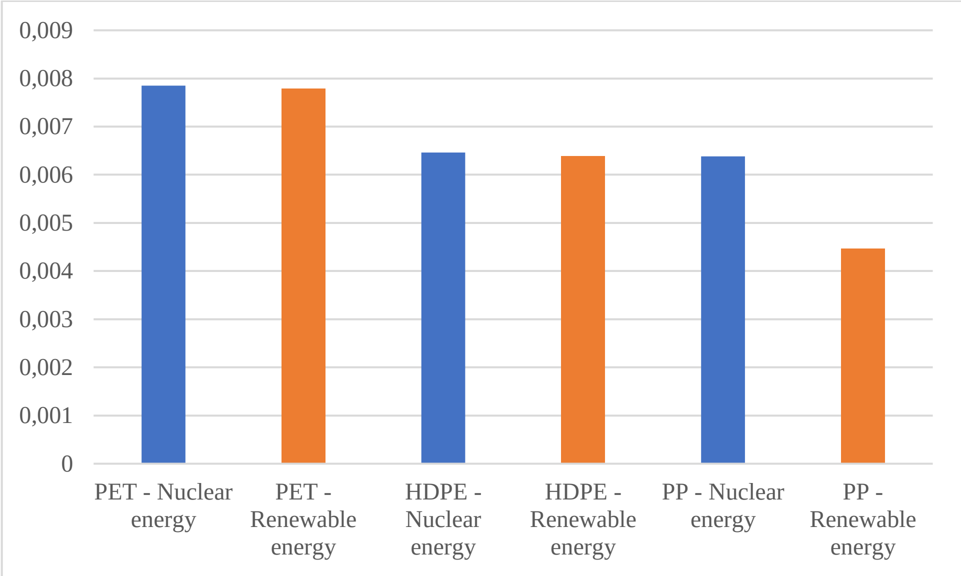

Figure 58. Comparison of TAP (kg SO_2-Eq) for PET, HDPE and PP (using renewable energies)

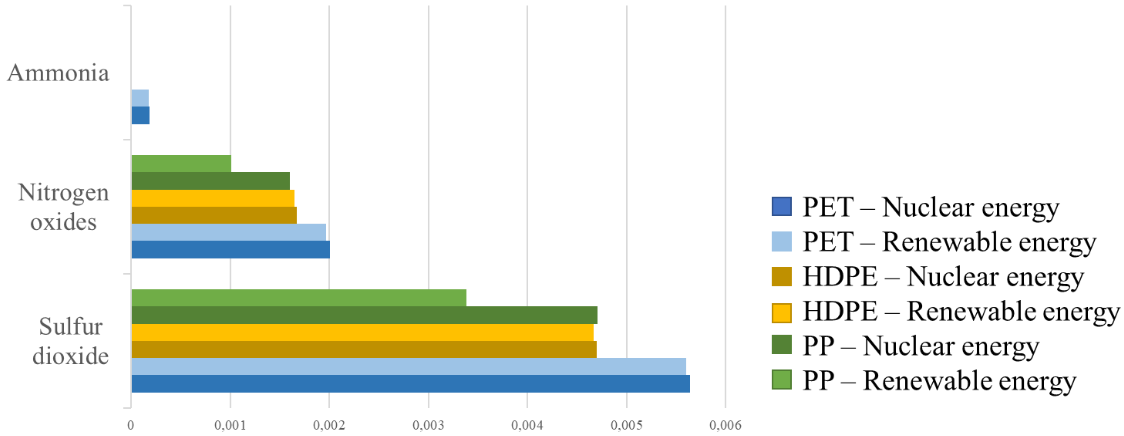

Figure 59. Clustered bar chart of the elements having an impact on TAP for PET, HDPE and PP

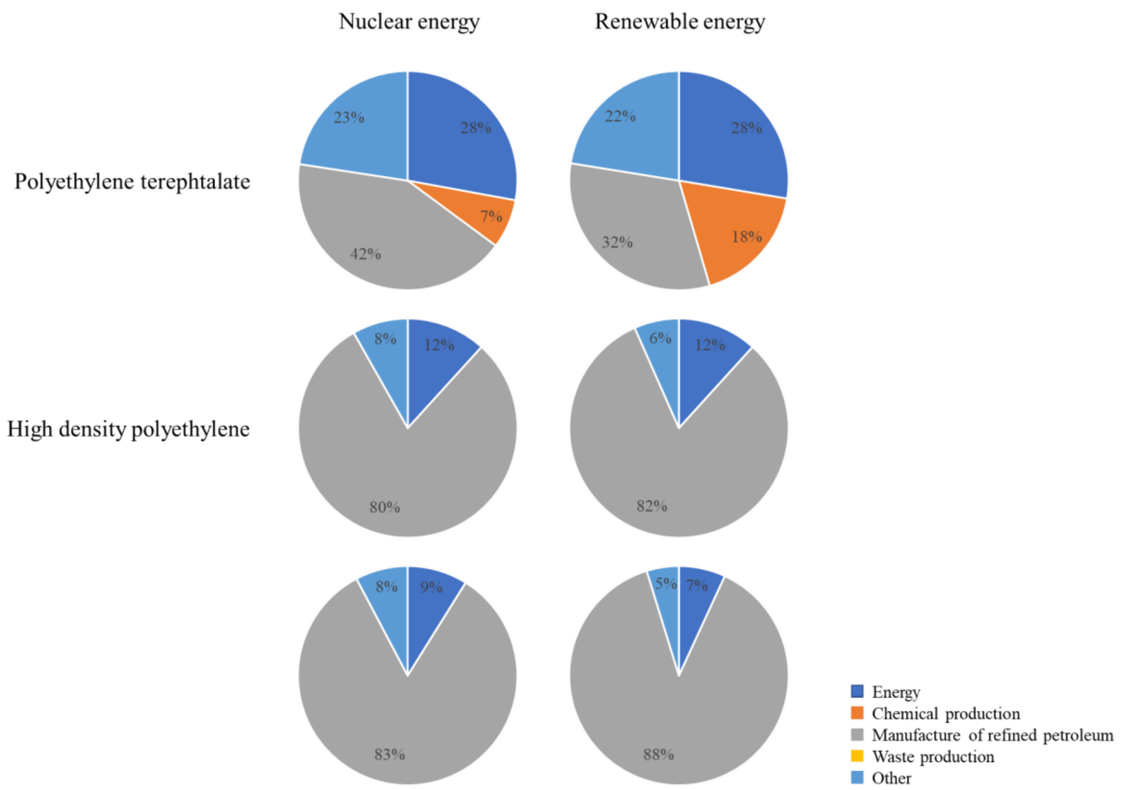

Figure 60. Comparison of the pie charts for TAP

Once again, as observed in Figure 58 and Figure 60, PET is the plastic with the greater impact and the greater percentages of contribution in energy and chemical production. This observation reenforce the link between these two results.

8.6.3 Marine Eutrophication Potential

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						0,0002	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	0,00015	kg	0,297	kg N-Eq/kg	4,32E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water	4,91E-05	kg	0,297	kg N-Eq/kg	1,46E-05	kg N-Eq
Nitrogen	Emission to water / surface water	7,11E-05	kg	0,297	kg N-Eq/kg	2,11E-05	kg N-Eq
Nitrate	Emission to water / ground water, long-term	6,50E-04	kg	0,0671	kg N-Eq/kg	4,37E-05	kg N-Eq
Nitrate	Emission to water / surface water	3,30E-04	kg	0,0671	kg N-Eq/kg	2,19E-05	kg N-Eq
Nitrate	Emission to water / ground water	4,15E-05	kg	0,0671	kg N-Eq/kg	2,79E-06	kg N-Eq
Ammonium	Emission to water / surface water	9,24E-05	kg	0,23	kg N-Eq/kg	2,13E-05	kg N-Eq
Ammonium	Emission to water / ground water, long-term	8,92E-05	kg	0,23	kg N-Eq/kg	2,05E-05	kg N-Eq
Ammonium	Emission to water / ground water	3,05E-05	kg	0,23	kg N-Eq/kg	7,01E-06	kg N-Eq
Ammonium	Emission to water / ocean	7,69E-06	kg	0,776	kg N-Eq/kg	5,97E-06	kg N-Eq

Table 35. List of elements having impact on MEP for 1 kg of recycled PET (using renewable energies)

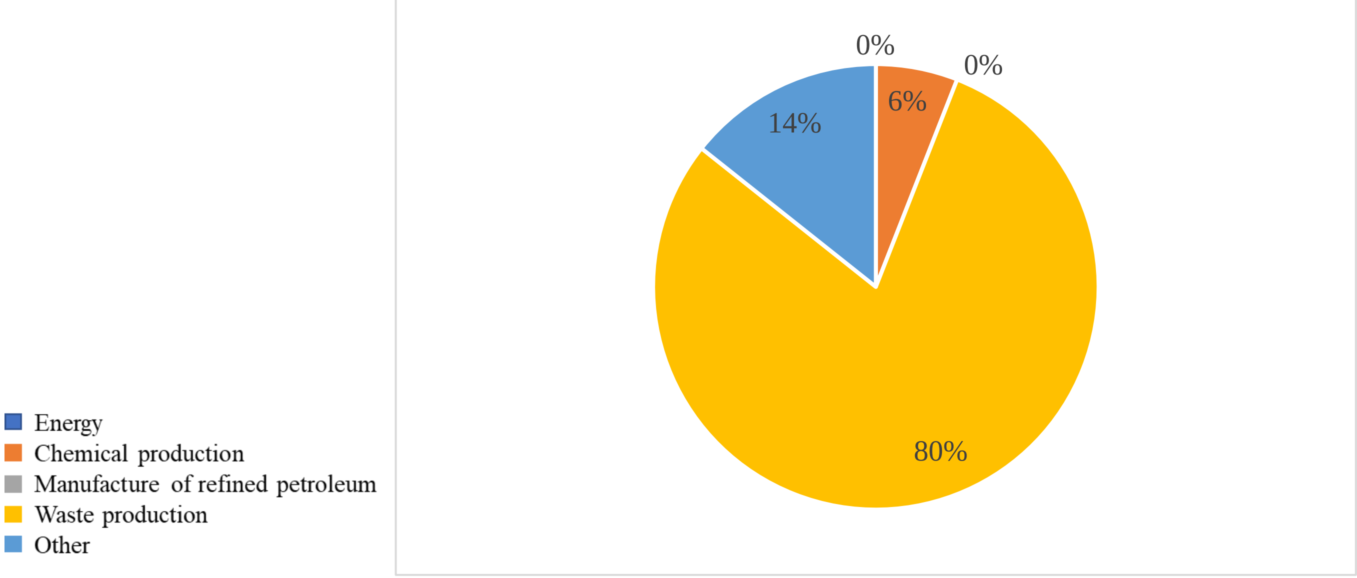

Figure 61. Pie chart of the categories having impact on MEP for 1 kg of recycled PET (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						4,03E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	6,52E-06	kg	0,297	kg N-Eq/kg	1,94E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / unspecified	2,16E-06	kg	0,297	kg N-Eq/kg	6,42E-07	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water	1,44E-06	kg	0,297	kg N-Eq/kg	4,28E-07	kg N-Eq
Nitrogen	Emission to water / surface water	1,78E-05	kg	0,297	kg N-Eq/kg	5,29E-06	kg N-Eq
Nitrate	Emission to water / ground water, long-term	3,20E-04	kg	0,0671	kg N-Eq/kg	2,15E-05	kg N-Eq
Nitrate	Emission to water / surface water	4,00E-05	kg	0,0671	kg N-Eq/kg	2,68E-06	kg N-Eq
Nitrate	Emission to water / ground water	2,08E-05	kg	0,0671	kg N-Eq/kg	1,40E-06	kg N-Eq
Ammonium	Emission to water / surface water	9,96E-06	kg	0,23	kg N-Eq/kg	2,29E-06	kg N-Eq
Ammonium	Emission to water / ocean	2,80E-06	kg	0,776	kg N-Eq/kg	2,17E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	4,14E-06	kg	0,23	kg N-Eq/kg	9,52E-07	kg N-Eq
Ammonium	Emission to water / unspecified	1,82E-06	kg	0,23	kg N-Eq/kg	4,18E-07	kg N-Eq

Table 36. List of elements having impact on MEP for 1 kg of recycled HDPE (using renewable energies)

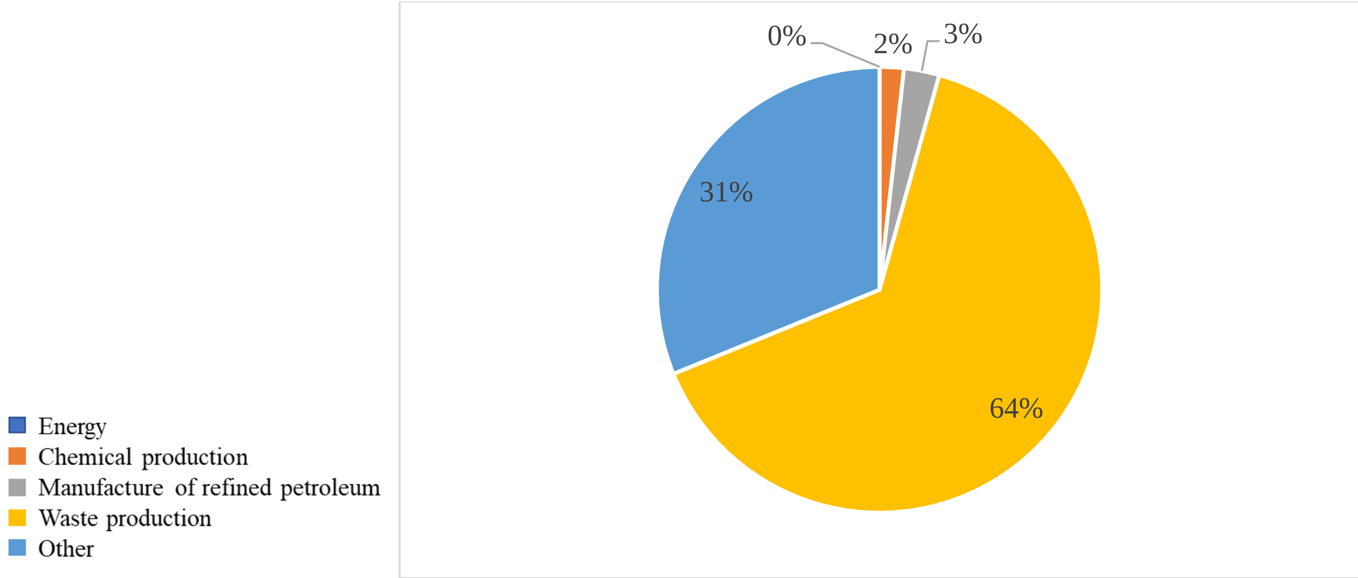

Figure 62. Pie chart of the categories having impact on MEP for 1 kg of recycled HDPE (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						2,30E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	5,08E-06	kg	0,297	kg N-Eq/kg	1,51E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / unspecified	3,13E-06	kg	0,297	kg N-Eq/kg	9,31E-07	kg N-Eq
Nitrogen	Emission to water / surface water	6,45E-06	kg	0,297	kg N-Eq/kg	1,92E-06	kg N-Eq
Nitrate	Emission to water / ground water, long-term	1,70E-04	kg	0,0671	kg N-Eq/kg	1,11E-05	kg N-Eq
Nitrate	Emission to water / surface water	5,66E-05	kg	0,0671	kg N-Eq/kg	3,80E-06	kg N-Eq
Nitrate	Emission to water / ground water	8,51E-06	kg	0,0671	kg N-Eq/kg	5,71E-07	kg N-Eq
Ammonium	Emission to water / surface water	4,99E-06	kg	0,23	kg N-Eq/kg	1,15E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	3,24E-06	kg	0,23	kg N-Eq/kg	7,46E-07	kg N-Eq
Ammonium	Emission to water / ocean	7,79E-07	kg	0,776	kg N-Eq/kg	6,05E-07	kg N-Eq

Table 37. List of elements having impact on MEP for 1 kg of recycled PP (using renewable energies)

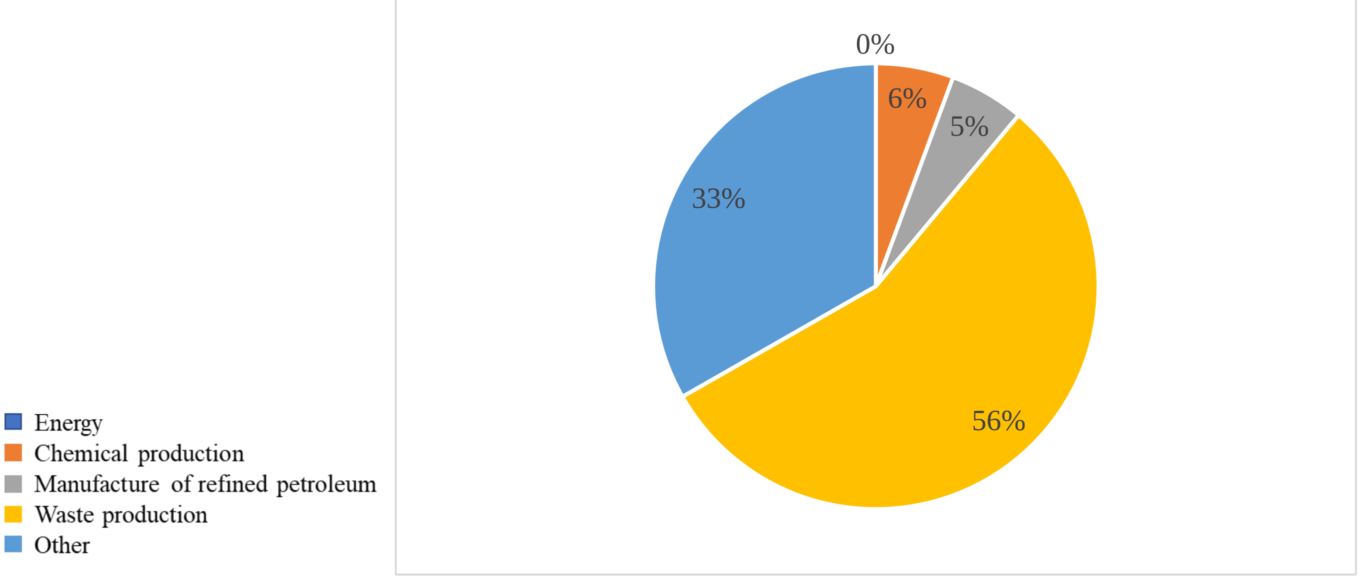

Figure 63. Pie chart of the categories having impact on MEP for 1 kg of recycled PP (using renewable energies)

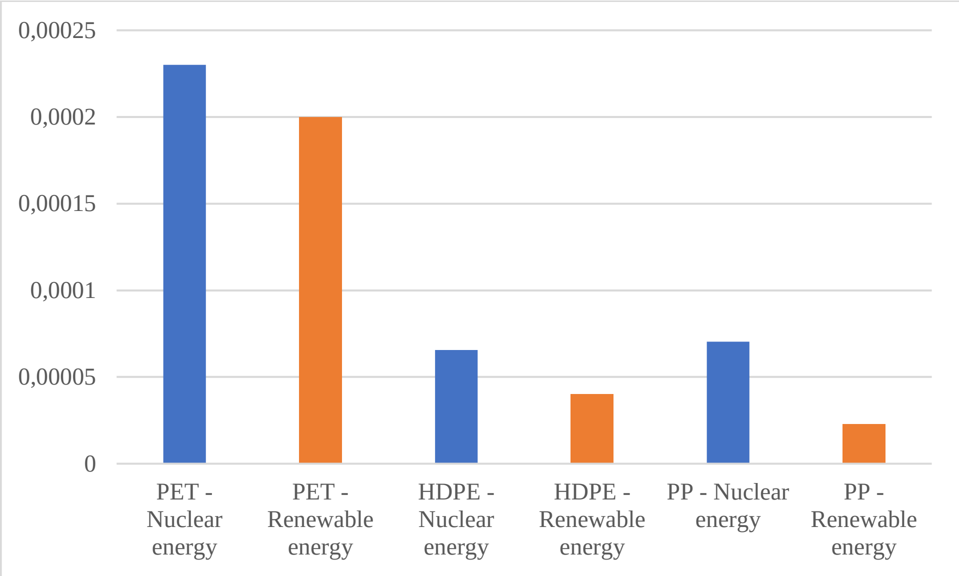

Figure 64. Comparison of MEP (kg N-Eq) for PET, HDPE and PP (using renewable energies)

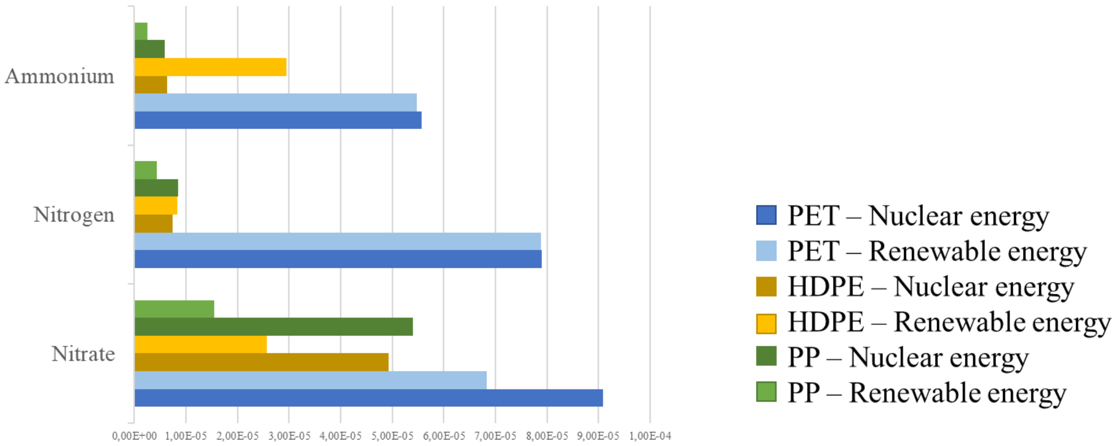

Figure 65. Clustered bar chart of the elements having an impact on MEP for PET, HDPE and PP

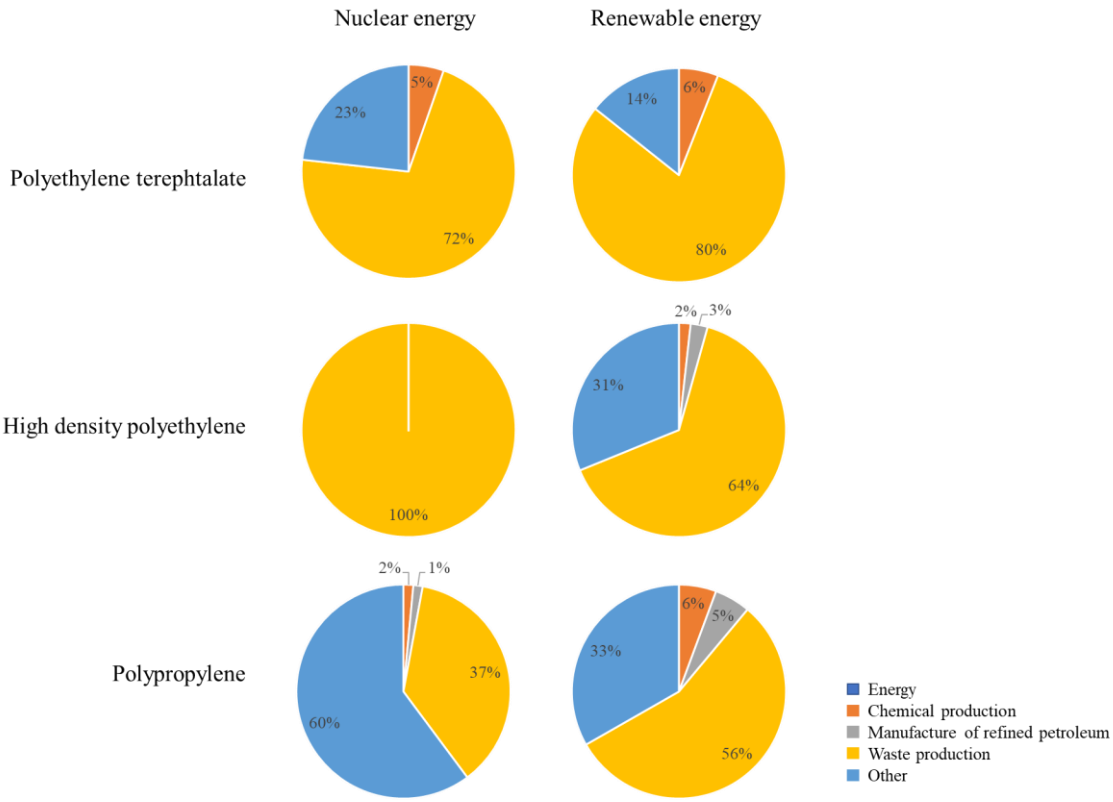

Figure 66. Comparison of the pie charts for MEP

8.6.4 Human Toxicity (carcinogenic) Potential

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,17605	kg 1,4-DCB-Eq
Nickel II	Emission to water / ground water, long-term	9,81E-05	kg	22,8	kg 1,4-DCB-Eq/kg	0,00224	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,78E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,13279	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	4,30E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,03199	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	7,87E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00202	kg 1,4-DCB-Eq

Table 38. List of elements having impact on HTPc for 1 kg of recycled PET (using renewable energies)

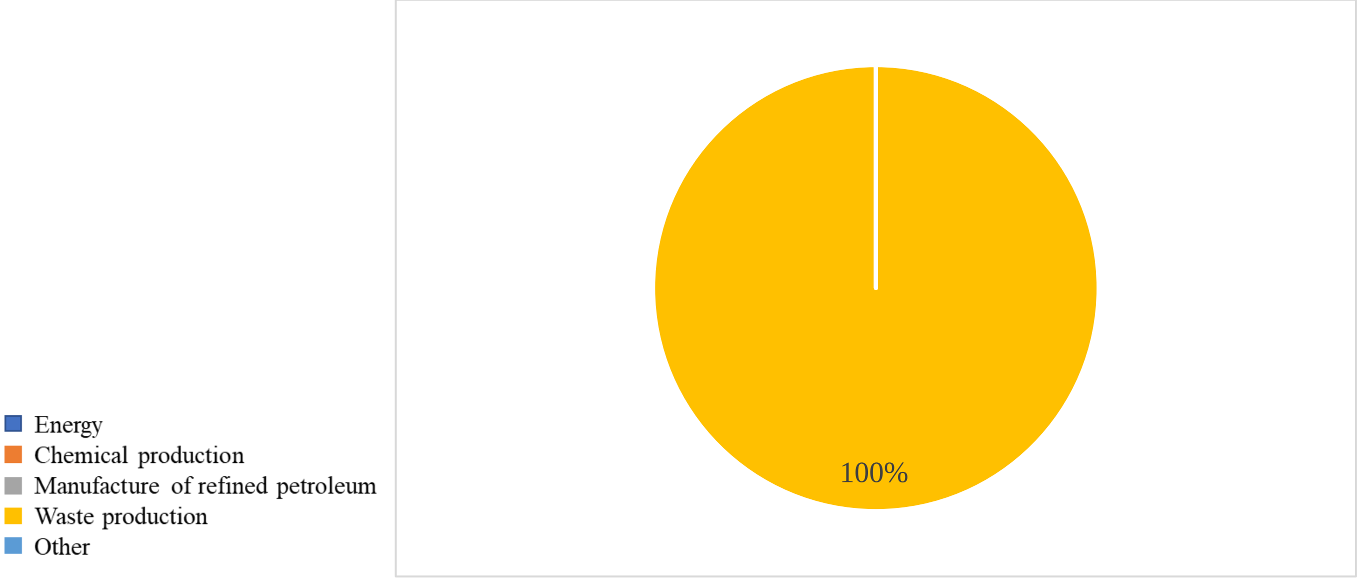

Figure 67. Pie chart of the categories having impact on HTPc for 1 kg of recycled PET (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,10216	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,05E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,07782	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	2,63E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,01954	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	4,35E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00112	kg 1,4-DCB-Eq

Table 39. List of elements having impact on HTPc for 1 kg of recycled HDPE (using renewable energies)

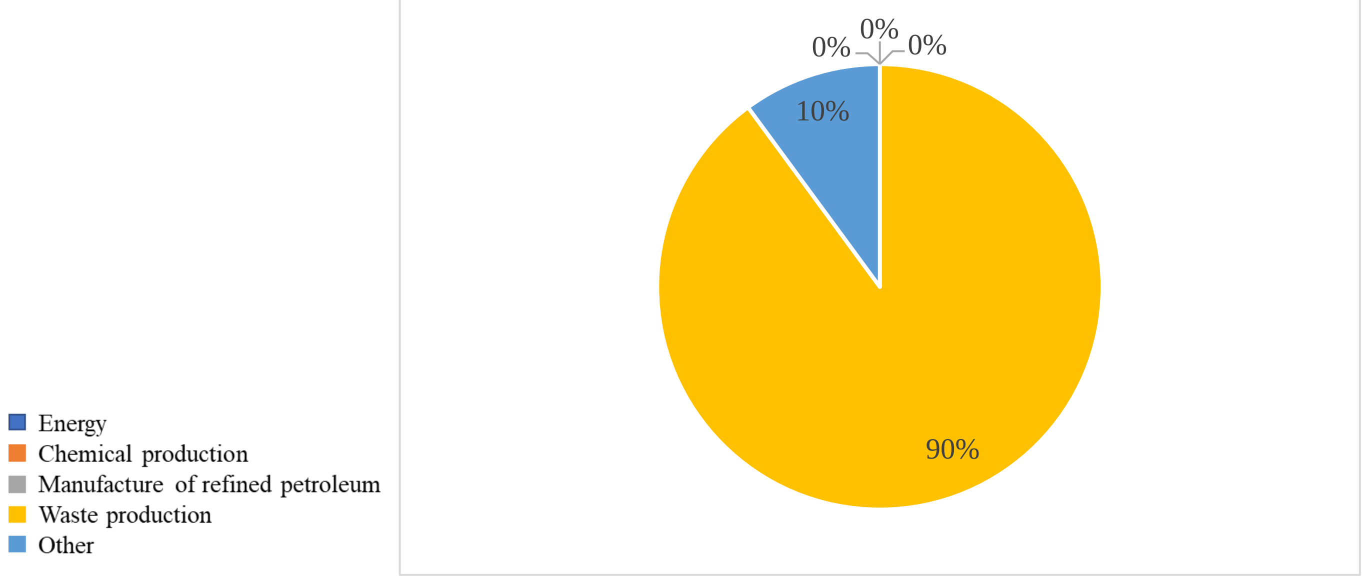

Figure 68. Pie chart of the categories having impact on HTPc for 1 kg of recycled HDPE (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,06084	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	6,10E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,04541	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	1,63E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,01209	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	3,91E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,001	kg 1,4-DCB-Eq

Table 40. List of elements having impact on HTPc for 1 kg of recycled PP (using renewable energies)

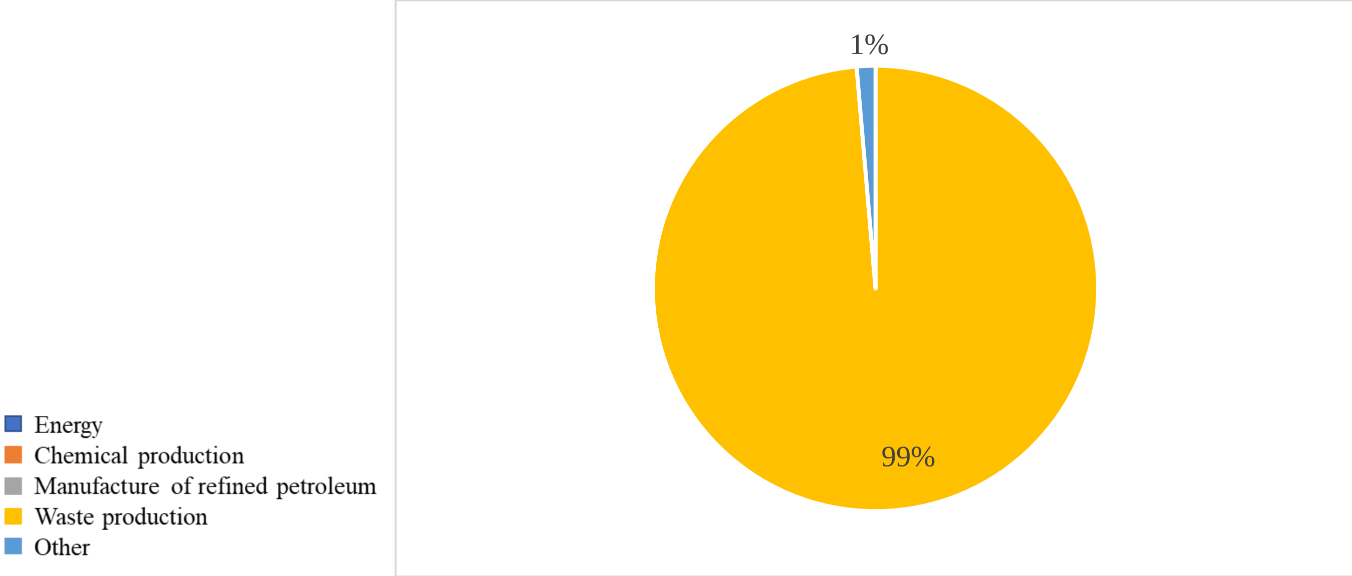

Figure 69. Pie chart of the categories having impact on HTPc for 1 kg of recycled PP (using renewable energies)

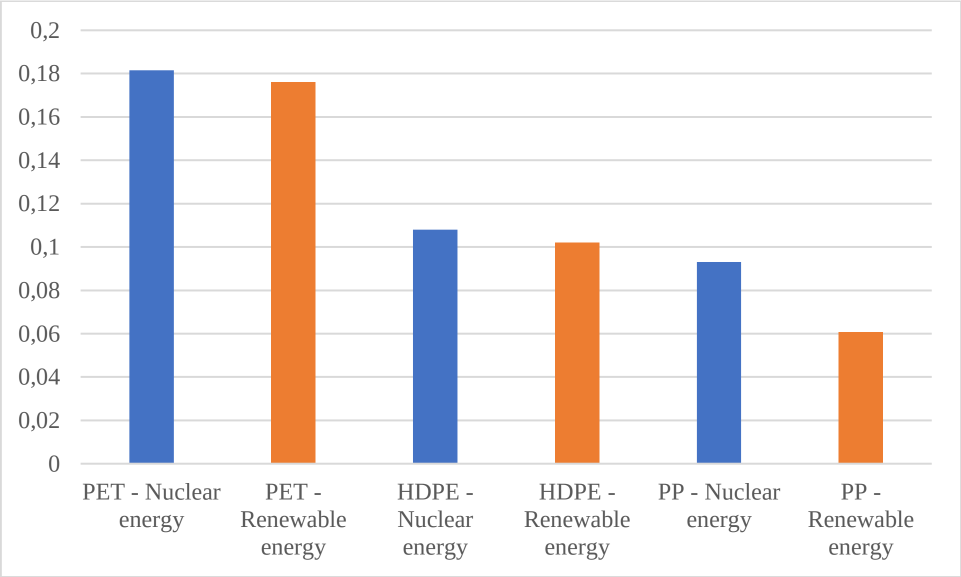

Figure 70. Comparison of HTPc (1,4-DCB-Eq) for PET, HDPE and PP (using renewable energies)

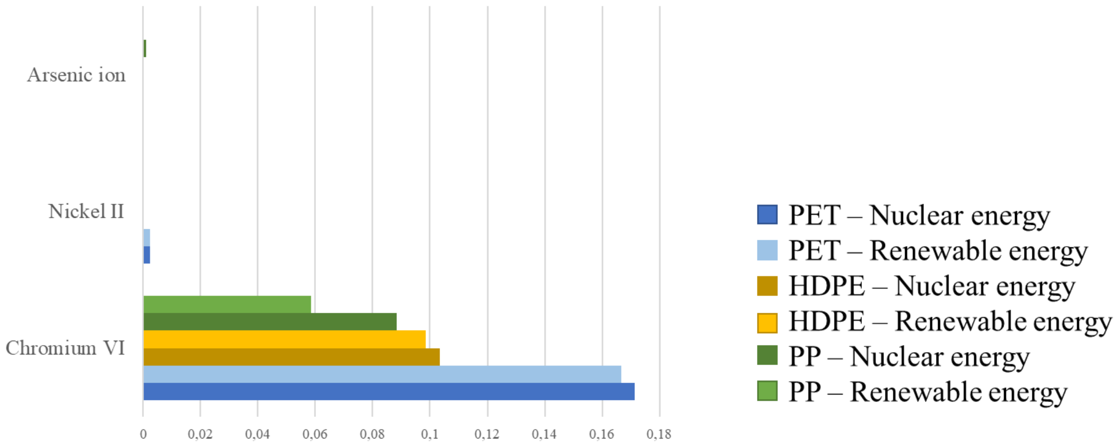

Figure 71. Clustered bar chart of the elements having an impact on HTPc for PET, HDPE and PP

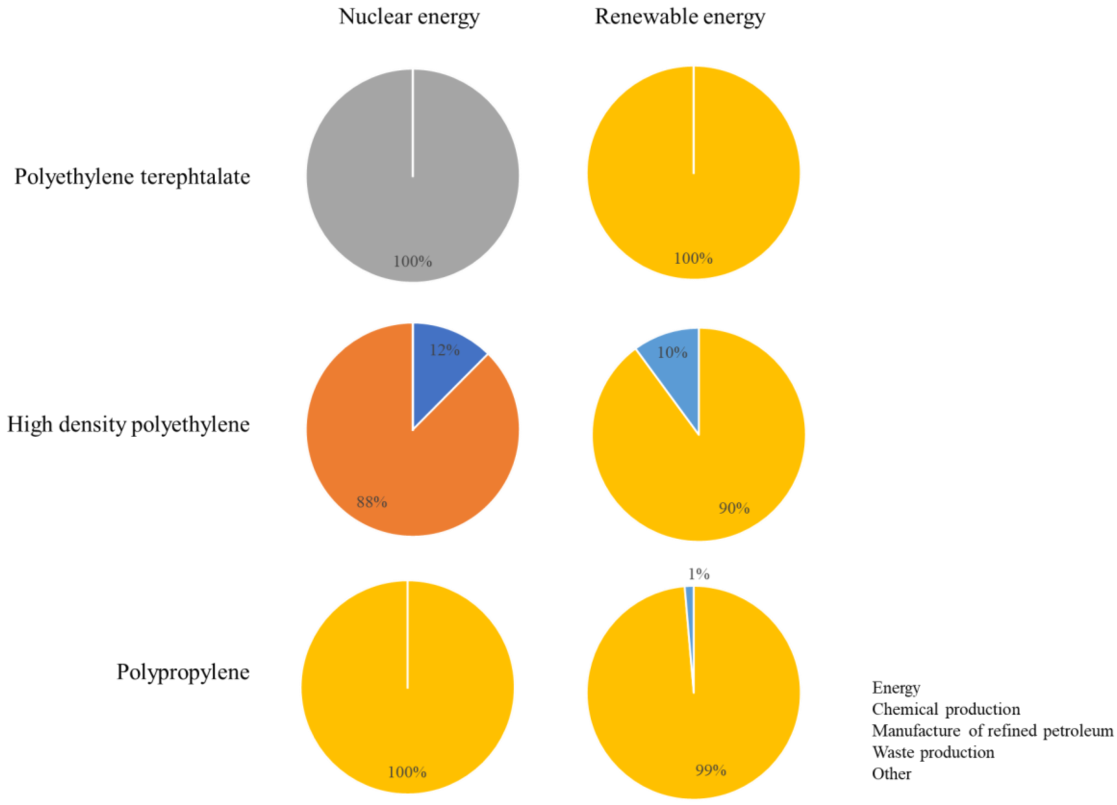

Figure 72. Comparison of the pie charts for HTPc

8.6.5 Ozone Depletion Potential

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						4,52E-06	kg CFC-11-Eq
Methane, tetrachloro-, R-10	Emission to air / high population density	6,03E-08	kg	0,895	kg CFC-11-Eq/kg	5,39E-08	kg CFC-11-Eq
Methane, bromo-, Halon 1001	Emission to air / unspecified	5,27E-06	kg	0,734	kg CFC-11-Eq/kg	3,87E-06	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,81E-05	kg	0,011	kg CFC-11-Eq/kg	1,99E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,63E-05	kg	0,011	kg CFC-11-Eq/kg	1,79E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	1,42E-05	kg	0,011	kg CFC-11-Eq/kg	1,56E-07	kg CFC-11-Eq

Table 41. List of elements having impact on ODP for 1 kg of recycled PET (using renewable energies)

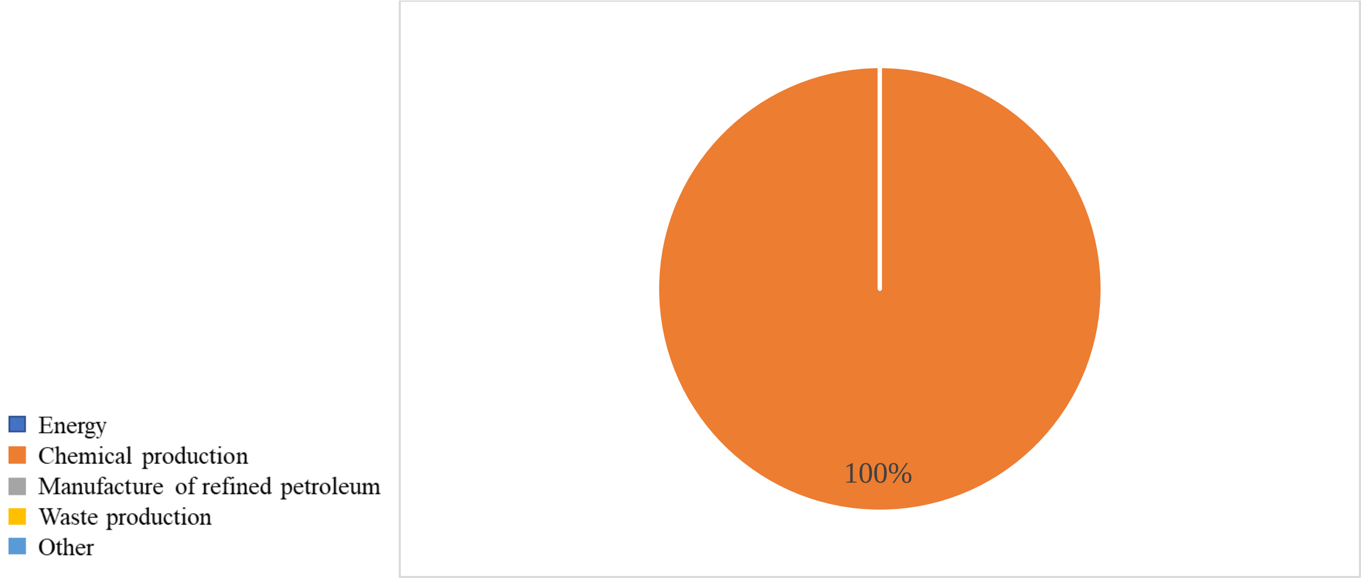

Figure 73. Pie chart of the categories having impact on ODP for 1 kg of recycled PET (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						3,57E-07	kg CFC-11-Eq
Methane, tetrachloro-, R-	Emission to air / high population density	4,04E-09	kg	0,895	kg CFC-11-Eq/kg	3,62E-09	kg CFC-11-Eq
Methane, bromotrifluoro-	Emission to air / low population density	4,18E-10	kg	14,1	kg CFC-11-Eq/kg	5,89E-09	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,46E-05	kg	0,011	kg CFC-11-Eq/kg	1,60E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	9,84E-06	kg	0,011	kg CFC-11-Eq/kg	1,08E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	6,89E-06	kg	0,011	kg CFC-11-Eq/kg	7,58E-08	kg CFC-11-Eq

Table 42. List of elements having impact on ODP for 1 kg of recycled HDPE (using renewable energies)

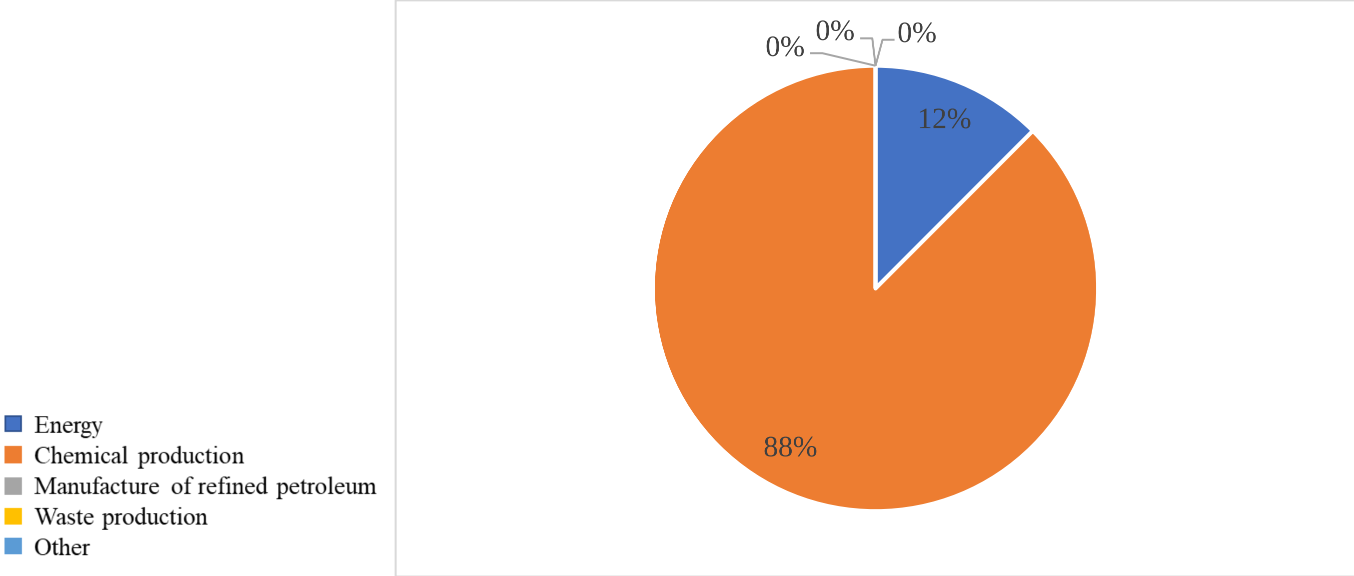

Figure 74. Pie chart of the categories having impact on ODP for 1 kg of recycled HDPE (using renewable energies)

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						1,17E-07	kg CFC-11-Eq
Methane, tetrachloro-, R-	Emission to air / high population density	3,86E-09	kg	0,895	kg CFC-11-Eq/kg	3,46E-09	kg CFC-11-Eq
Methane, bromotrifluoro-	Emission to air / low population density	2,61E-10	kg	14,1	kg CFC-11-Eq/kg	3,68E-09	kg CFC-11-Eq
Methane, bromochlorodi	Emission to air / low population density	1,66E-10	kg	8,78	kg CFC-11-Eq/kg	1,45E-09	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	4,15E-06	kg	0,011	kg CFC-11-Eq/kg	4,57E-08	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	3,08E-06	kg	0,011	kg CFC-11-Eq/kg	3,39E-08	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	2,53E-06	kg	0,011	kg CFC-11-Eq/kg	2,78E-08	kg CFC-11-Eq

Table 43. List of elements having impact on ODP for 1 kg of recycled PP (using renewable energies)

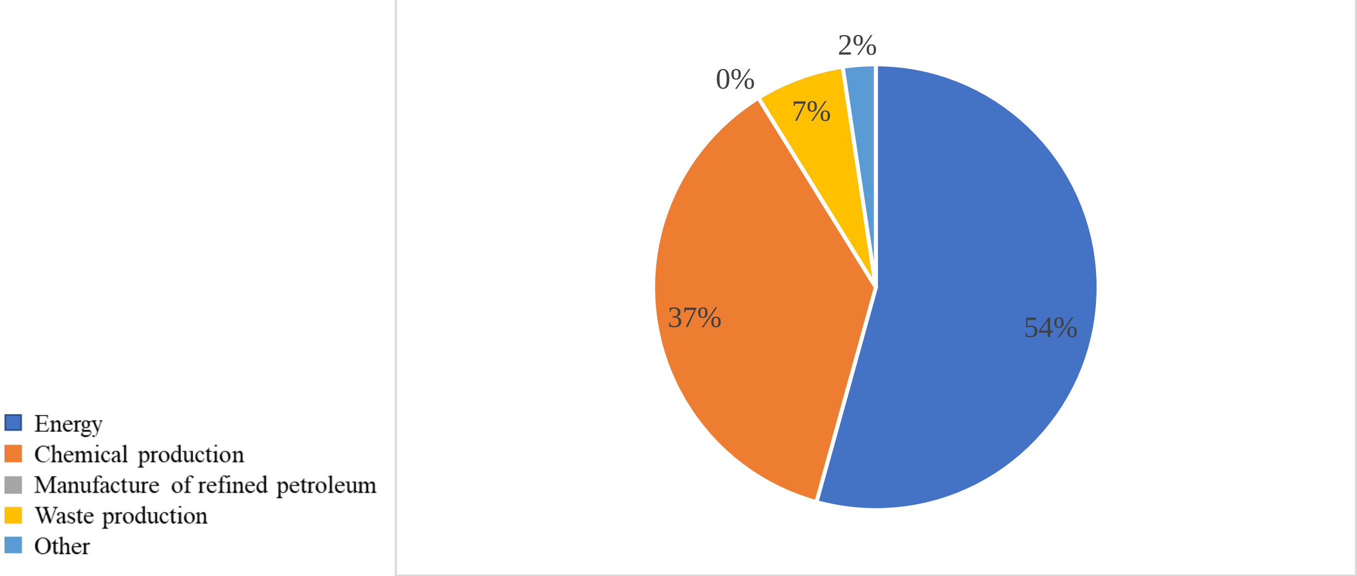

Figure 75. Pie chart of the categories having impact on ODP for 1 kg of recycled PP (using renewable energies)

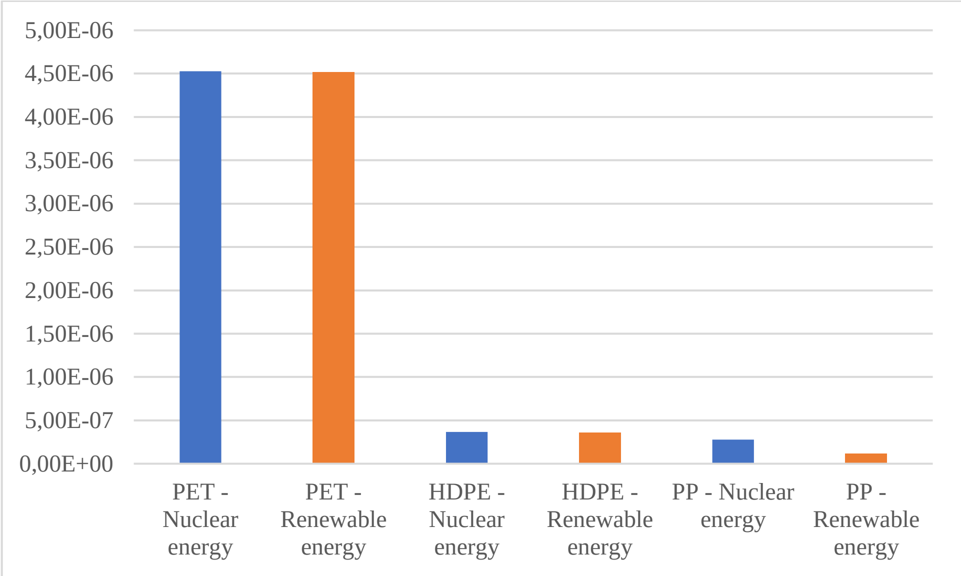

Figure 76. Comparison of ODP (kg CFC-11-Eq) for PET, HDPE and PP (using renewable energies)

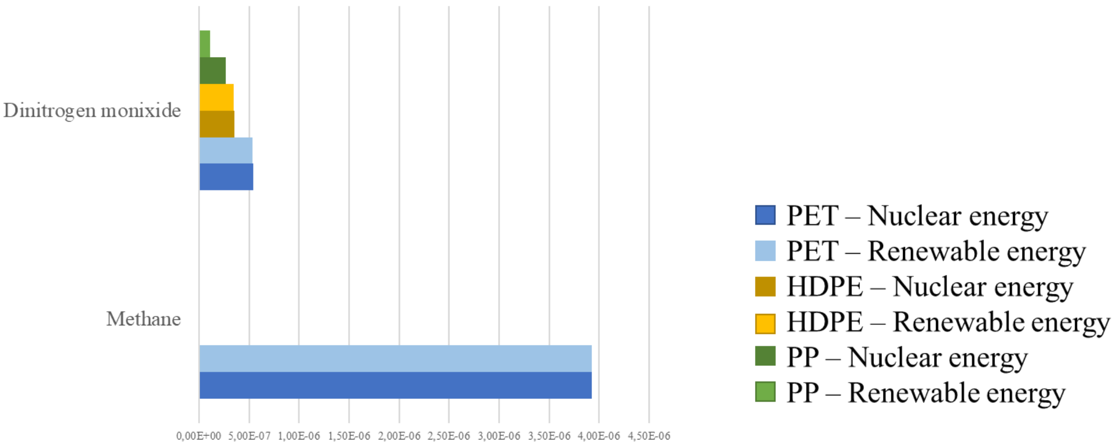

Figure 77. Clustered bar chart of the elements having an impact on ODP for PET, HDPE and PP

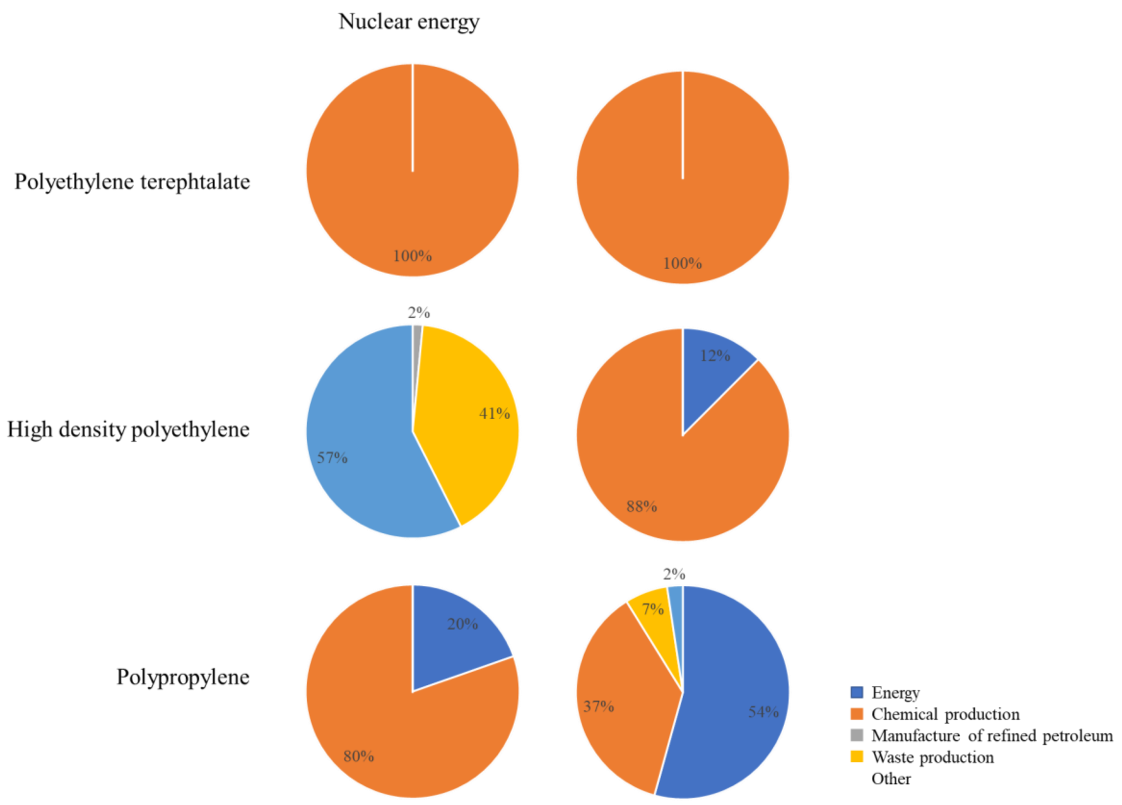

Figure 78. Comparison of the pie charts for ODP

8.7 Comparative study

First of all, PET remains the plastic with the greatest impact, all categories taken together. This is very probably due to the fact that the elements emitted during the mechanical recycling of PET are much greater in quantity than those emitted by the other two plastics.

Secondly, the differences between the two studies are relatively small, so the importance of the energy used should be put into perspective. The difference between the two studies would certainly have been even greater if the comparison had been made with energy production by coal-fired power stations, known for its large quantities of emissions, rather than with energy produced by nuclear plants. Nevertheless, several differences can be highlighted which are due to the change in energy consumed by the recycling process.

In the case of every studied impact category, the use of renewable energy shows a decrease of the impacts, they are lower than in the first study conducted. As we can see in Table 44, the differences are the smallest for ODP, GWP and TAP, they do not represent more than 5% of the total amount of emissions for each category in the case of PET and HDPE, and GWP has the smallest average difference percentage compared to other impact categories of PP. On the other hand, with a difference in emissions of up to 13% for the PET, 38% for HDPE and almost 70% for PP for MEP, it becomes interesting to note the decrease in emissions, especially with considerable differences for PP.

Overall, PP is the plastic that shows the most difference in its impacts with the change of energy production.

		PET		HDPE		PP		
		Nuclear energy	Renewable energies	Nuclear energy	Renewable energies	Nuclear energy	Renewable energies	
ODP	Analytical values	4,53E-06	4,52E-06	3,65E-07	3,57E-07	2,79E-07	1,17E-07	**kg CFC-11-Eq**
HTPc		0,18162	0,17605	0,10804	0,10216	0,09305	0,06084	**kg 1,4-DCB-Eq**
MEP		0,00023	0,0002	6,56E-05	4,03E-05	7,05E-05	2,30E-05	**kg N-Eq**
GWP		3,03563	3,02416	2,42634	2,41425	2,3978	1,96238	**kg CO2-Eq**
TAP		0,00785	0,00779	0,00646	0,00639	0,00638	0,00447	**kg SO2-Eq**
ODP	Average difference (unit)	7,33E-09		7,73E-09		1,62208E-07		**kg CFC-11-Eq**
HTPc		0,00557		5,88E-03		0,03221		**kg 1,4-DCB-Eq**
MEP		0,00003		2,53E-05		4,75018E-05		**kg N-Eq**
GWP		0,01147		1,21E-02		0,43542		**kg CO2-Eq**
TAP		6E-05		7,00E-05		0,00191		**kg SO2-Eq**
ODP	Average difference (%)	0,16%		2,12%		58,09%		**%**
HTPc		3,07%		5,44%		34,62%		**%**
MEP		13,04%		38,59%		67,42%		**%**
GWP		0,38%		0,50%		18,16%		**%**
TAP		0,76%		1,08%		29,94%		**%**

Table 44. Comparative table of the studies

As part of the drive to reduce the impact of the mechanical recycling process, taking all impact categories together, we have identified several areas for improvement.

Firstly, we recommend limiting the use of chemicals as much as possible. As we have seen, their contribution to the production of energy and chemicals has a major impact on the first two categories studied and the last, i.e. GWP, TAP and ODP. If the use of chemicals cannot be reduced to zero, try to introduce recirculation for the chemicals used. The same applies to the natural resources used in our processes, particularly water.

As for waste management, we note that it has a particularly significant impact on the HTPc and MEP categories, accounting for more than half of the percentages obtained in most cases. In an attempt to overcome this problem, it is recommended that recycled materials be used as much as possible. This comment is entirely in line with the approach of our study, since we are studying recycling processes.

9 PROJECT PLANIFICATION

This section describes the different task packages that make up the project. For each of them, the tasks that comprise it are listed, including their description, the resources required and their duration. A maximum daily working time of 2 hours, 5 days a week, has been considered.

P.T.1. Initial preparation

M.1. Preparatory meeting (29/11/22)

T.1.1 Overall scientific reading

Description: Reading of general articles on Life Cycle Assessment of plastics and mechanical recycling processes, with the aim of drawing general conclusions and establishing a starting context for the development of the project.

Human resources: Junior engineer (40 hours).

Duration: 3 weeks.

T.1.2 Selection of specific plastics

Description: Choice of plastics to be selected for further study, considering previous research. The recycling processes of these plastics will be studied.

Human resources: Junior engineer (10 hours)

Duration: 1 week.

M.2. Finalisation of the introduction (29/01/23)

Description: The research on the basic knowledge needed is completed and information on the different types of plastics, their uses, advantages/disadvantages as well as their recycling method is gathered.

P.T.2. Project development

T.2.1 Reading of specific articles

Description: More focused research on the selected recycling processes and obtaining quantified information to realise the flow diagrams.

Human resources: Junior engineer (50 hours)

Duration: 2 weeks.

M.3. Elaboration of the methodology (12/02/23)

P.T.3. Flow diagrams

T.3.1 Execution of the flow diagrams

Description: Approximate execution of the flow diagrams of the recycling processes.

Human resources: Junior engineer (50 hours), Project manager (10 hours).

Duration: 4 weeks.

M.4. Presentation of the flow diagrams (12/03/23)

P.T.4. OpenLCA

T.4.1 Data introduction into OpenLCA

Description: Introduction of the data collected during the scientific reading in the OpenLCA software.

Human resources: Junior engineer (30 hours), Project manager (5 hours)

Duration: 2 weeks.

M.5. Mid-term meeting (13/03/23)

M.6. Finalisation of OpenLCA (26/03/23)

P.T.5. Analysis of the results

T.5.1 Analysis of the results

Description: Analysis of the results obtained for the three studies conducted on the software.

Human resources: Junior engineer (40 hours), Project manager (10 hours).

Duration: 3 weeks.

M.7. Finalisation of the results analysis (16/04/23)

P.T.6. Report writing

T.6.1. Writing of the abstract

Description: Writing of the abstract of the project.

Human resources: Junior engineer (5 hours).

Duration: 1 week.

M.8. Delivery of the abstract (12/02/23)

T.6.2 Writing of the interim report

Description: Writing of the interim report of the project.

Human resources: Junior engineer (60 hours).

Duration: 4 weeks.

M.9. Delivery of the interim report (30/04/23)

T.6.3. Writing of the final report

Description: Writing of the final report of the project.

Human resources: Junior engineer (20 hours).

Duration: 2 weeks.

M.10. Delivery of the final report (14/05/23)

In the planning of any project, a series of milestones must be considered, i.e. the project's control points or critical dates. In this case, the milestones are presented in Table 45.

Code	Name	Date
M.1.	Preparatory meeting	29/11/2022
M.2.	Finalisation of the introduction	29/01/2023
M.3.	Elaboration of the methodology	12/02/2023
M.4.	Presentation of the flow diagrams	12/03/2023
M.5.	Mid-term meeting	13/03/2023
M.6.	Finalisation of OpenLCA	26/03/2023
M.7.	Finalisation of the results analysis	16/04/2023
M.8.	Delivery of the abstract	12/02/2023
M.9.	Delivery of the interim report	30/04/2023
M.10.	Delivery of the final report	14/05/2023

Table 45. Milestones of the project

The following Figure 79 shows the Gantt chart of the project. The total duration of the project, considering a maximum working day of 3 hours per day for 5 days per week, is 19 weeks. As can be seen, the project starts on 29/11/22 and ends on 14/05/23, with a shutdown period between 19/12/22 and 22/01/23 (5 weeks) due to holidays and examens.

Id.	Code	Name	Beginning	End	Duration
1	**P.T.1.**	**Initial preparation**	**29/11/2022**	**29/01/2023**	**9 weeks**
2	M.1.	Preparatory meeting	29/11/2022	29/11/2022	-
3	T.1.1	Overall scientific reading	29/11/2022	18/12/2022	3 weeks
4	T.1.2	Selection of specific plastics	23/01/2023	29/01/2023	1 week
5	M.2.	Finalisation of the introduction	29/01/2023	29/01/2023	-
6	**P.T.2.**	**Project development**	**30/01/2023**	**12/02/2023**	**2 weeks**
7	T.2.1	Reading of specific articles	30/01/2023	12/02/2023	2 weeks
8	M.3.	Elaboration of the methodology	12/02/2023	12/02/2023	-
9	**P.T.3.**	**Flow diagrams**	**13/02/2023**	**12/03/2023**	**4 weeks**
10	T.3.1	Execution of the flow diagrams	13/02/2023	12/03/2023	4 weeks
11	M.4.	Presentation of the flow diagrams	12/03/2023	12/03/2023	-
12	**P.T.4.**	**OpenLCA**	**13/03/2023**	**26/03/2023**	**2 weeks**
13	M.5.	Mid-term meeting	13/03/2023	13/03/2023	-
14	T.4.1	Data introduction into OpenLCA	13/03/2023	26/03/2023	2 weeks
15	M.6.	Finalisation of OpenLCA	26/03/2023	26/03/2023	-
16	**P.T.5.**	**Analysis of the results**	**27/03/2023**	**16/04/2023**	**3 weeks**
17	T.5.1	Analysis of the results	27/03/2023	16/04/2023	3 weeks
18	M.7.	Finalisation of the results analysis	16/04/2023	16/04/2023	-
19	**P.T.6.**	**Report writing**	**06/02/2023**	**14/05/2023**	**14 weeks**
20	T.6.1.	Writing of the abstract	06/02/2023	12/02/2023	1 week
21	M.8.	Delivery of the abstract	12/02/2023	12/02/2023	-
22	T.6.2	Writing of the interim report	03/04/2023	30/04/2023	4 weeks
23	M.9.	Delivery of the interim report	30/04/2023	30/04/2023	-
24	T.6.3	Writing of the final report	01/05/2023	14/05/2023	2 weeks
25	M.10.	Delivery of the final report	14/05/2023	14/05/2023	-

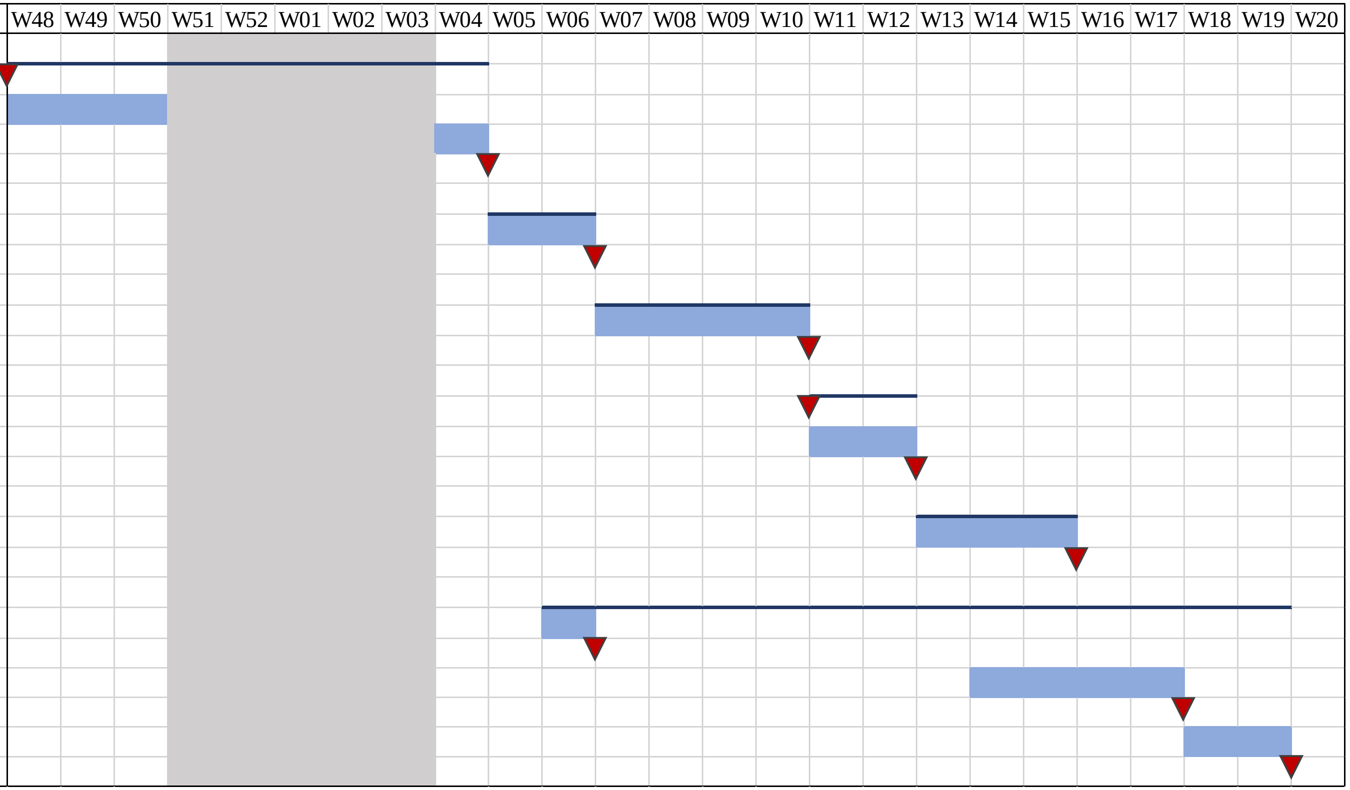

Figure 79. Gantt affectation of the project

10 COST OF THE PROJECT

This chapter presents the cost of the project, including internal hours, depreciation, and other expenses. Indirect costs are considered to be 10 % of the direct costs and we will not take any contingencies into account as this is a finished project. Thus, the total cost of the project amounts to 15 984,10 €.

Concept	Unit	N° units	Unit rate	Cost
INTERNAL HOURS				
Junior engineer	h	305	40,00 €	12 200,00 €
Project manager	h	25	70,00 €	1 750,00 €
DEPRECIATIONS				
Computer	h	300	0,50 €	150,00 €
Microsoft Office 365 licence	months	8	7,00 €	56,00 €
OTHER WASTES				
Internet	months	8	35,00 €	280,00 €
Electricity	h	300	0,15 €	45,00 €
Office material	-	-	-	50,00 €
DIRECT COSTS				**14 531,00 €**
Indirect costs	-	-	-	1 453,10 €
TOTAL				**15 984,10 €**

11 CONCLUSIONS

The purpose of this Master Project was to conduct a demonstrative study of the environmental and health impacts of mechanical plastic recycling using the Life Cycle Assessment (LCA) method and a specific database of OpenLCA, Ecoinvent. The study aimed to provide insight into the environmental and health impacts of plastic recycling and to demonstrate the utility of LCA in estimating such impacts.

In order to carry out a meaningful study, we divided our study into several main parts, the first being bibliographical and scientific documentation on the concepts relating to the circular economy and Life Cycle Assessment. This theoretical research was followed by more detailed research into similar studies, and in particular into Life Cycle Assessment studies carried out on plastic production, a study similar to the one carried out in our case. Thanks to this research, we were able to collect the data required for our study and carry out our calculations using OpenLCA software. This software provided us with analytical results that were ready to be used, formatted, and analysed. Our study focused on four different impact categories to give an overall idea of the impact that the mechanical recycling processes studied can have on the environment, soil, oceans, and human health. Finally, we have attempted to highlight the share of energy consumption and the difference between the use of so-called 'clean' energies - renewable energies - and nuclear energy, which is currently used at a rate of almost 70% in France, for example.

The study we have carried out has produced several results. The results we have obtained are respectively from an LCA of the mechanical recycling process of plastics (PET, HDPE and PP) using firstly nuclear energy and secondly renewable energy.

As noted earlier, PET has the highest values for most of the elements and for all impact categories studied. In the case of HTPc, the difference observed is even considerable for the quantities of methane emitted. Furthermore, an important aspect we considered in our study is the impacts of the processes used in mechanical recycling, or rather which type of process has the most impact. We have created 5 different process categories, taking into account the most important ones: energy, chemical production, manufacture of refined petroleum, waste production and the other processes categories. These process types exist in the OpenLCA software, and we were able to retrieve these data from the results calculated by the software. As can be seen in the results exposed earlier, the share of energy in the impacts varies little between the two studies – with nuclear energy or renewable energies - and if it does, it decreases for all impacts except for the case of ODP. For GWP and TAP, it is mainly the manufacture of refined petroleum that is involved, while for MEP and HTPc, it is waste production that takes the largest share. For the ODP, it is generally chemical production that has the greatest impact.

What we can observe is the share that each type of process takes on one of the impacts and that changing the energy consumed by a renewable energy does not seem to be enough to give conclusive results.

Nuclear energy is particularly well known for having low environmental impacts and the results we have obtained show that its impacts on the different categories studied are only slightly higher than those obtained with the use of renewable energy. However, we have to take into account that the renewable energies used in the second case have not been specified, we do not know if they are solar, wind, etc.

If we compare our study to previous studies, we notice that it highlights relatively low impacts in comparison, which could be explained by the choice of energies but also by the fact that we are not dealing with the production of plastic from scratch but rather with a recycling process.

In sum, the recycling process is much less costly in terms of energy, materials and impacts than plastic production. The mechanical recycling process fits well into a circular economy approach.

Despite the limitations imposed by the lack of precise data, the study showed that LCA is a useful method for estimating environmental and human health impacts. The results of the study also suggest that the impact of plastic recycling on the environment and human health can be significant and cannot be ignored. As mentioned in the first part of this project, the importance of limiting these impacts is becoming more and more important in today's world. As a follow-up to this study, it would be interesting to carry out a Life Cycle Assessment using accurate data from a real company-specific process. A possible partnership could be organised to help the said mechanical recycling company to estimate its impacts on the environment or on human health.

However, the study compared the LCA results with information obtained from free and open-source software, indicating that such software can provide an alternative approach to LCA analysis. This project demonstrates that Life Cycle Assessment is an affordable subject for those interested in it and that means are being put in place to facilitate its study.

On another hand, the study also highlights the importance of the circular economy and the role that LCA can play in its implementation. However, it also emphasizes that LCA is just one step in the implementation of the circular economy and that further actions are needed to limit the impact of plastic recycling on the planet.

In conclusion, this Master Project provides valuable insights into the environmental and health impacts of plastic recycling using LCA. The study emphasizes the need for further actions to limit the impact of plastic recycling on the planet. Finally, the limitations of the LCA method for this study are acknowledged, providing opportunities for further research and improvement in LCA methodology.

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13 ANNEXES

In this section will be gathered all the data extracted from OpenLCA.

13.1 Nuclear energy

Name	PET - Impact result	HDPE - Impact result	PP - Impact result	Unit
water use - water consumption potential (WCP)	0,04222	0,02604	0,02479	m3
photochemical oxidant formation: terrestrial ecosystems - photochemical oxidant formation potential: ecosystems (EOFP)	0,00679	0,00572	0,00537	kg NOx-Eq
photochemical oxidant formation: human health - photochemical oxidant formation potential: humans (HOFP)	0,00633	0,00531	0,00501	kg NOx-Eq
particulate matter formation - particulate matter formation potential (PMFP)	0,00334	0,00256	0,00245	kg PM2,5-Eq
ozone depletion - ozone depletion potential (ODPinfinite)	**4,53E-06**	**3,65E-07**	**2,79E-07**	**kg CFC-11-Eq**
material resources: metals/minerals - surplus ore potential (SOP)	0,04282	0,02125	0,02324	kg Cu-Eq
land use - agricultural land occupation (LOP)	0,05245	0,02004	0,019	m2*a crop-Eq
ionising radiation - ionising radiation potential (IRP)	1,53709	1,42018	1,74924	kBq Co-60-Eq
human toxicity: non-carcinogenic - human toxicity potential (HTPnc)	4,23212	1,36006	1,37468	kg 1,4-DCB-Eq
human toxicity: carcinogenic - human toxicity potential (HTPc)	**0,18162**	**0,10804**	**0,09305**	**kg 1,4-DCB-Eq**
eutrophication: marine - marine eutrophication potential (MEP)	**0,00023**	**6,56E-05**	**7,05E-05**	**kg N-Eq**
eutrophication: freshwater - freshwater eutrophication potential (FEP)	0,00075	0,00041	0,0004	kg P-Eq
energy resources: non-renewable, fossil - fossil fuel potential (FFP)	1,45936	1,68284	1,71719	kg oil-Eq
ecotoxicity: terrestrial - terrestrial ecotoxicity potential (TETP)	13,37035	6,14294	5,93817	kg 1,4-DCB-Eq
ecotoxicity: marine - marine ecotoxicity potential (METP)	0,27928	0,07664	0,07612	kg 1,4-DCB-Eq
ecotoxicity: freshwater - freshwater ecotoxicity potential (FETP)	0,21097	0,05732	0,05691	kg 1,4-DCB-Eq
climate change - global warming potential (GWP100)	**3,03563**	**2,42634**	**2,3978**	**kg CO2-Eq**
acidification: terrestrial - terrestrial acidification potential (TAP)	**0,00785**	**0,00646**	**0,00638**	**kg SO2-Eq**

13.1.1 PET

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						3,03563	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,29447	kg	1	kg CO2-Eq/kg	1,29447	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,81647	kg	1	kg CO2-Eq/kg	0,81647	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,28718	kg	1	kg CO2-Eq/kg	0,28718	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,00695	kg	36	kg CO2-Eq/kg	0,25013	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00643	kg	36	kg CO2-Eq/kg	0,23145	kg CO2-Eq
Methane, non-fossil	Emission to air / low population density	0,00351	kg	34	kg CO2-Eq/kg	0,1195	kg CO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00785	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00285	kg	1	kg SO2-Eq/kg	0,00285	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00257	kg	1	kg SO2-Eq/kg	0,00257	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00207	kg	0,36	kg SO2-Eq/kg	0,00075	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00194	kg	0,36	kg SO2-Eq/kg	0,0007	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00155	kg	0,36	kg SO2-Eq/kg	0,00056	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	0,00022	kg	1	kg SO2-Eq/kg	0,00022	kg SO2-Eq
Ammonia	Emission to air / high population density	5,13E-05	kg	1,96	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Ammonia	Emission to air / unspecified	4,25E-05	kg	1,96	kg SO2-Eq/kg	8,34E-05	kg SO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						0,00023	kg N-Eq
Nitrate	Emission to water / ground water, long-term	0,00092	kg	0,0671	kg N-Eq/kg	6,18E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	0,00015	kg	0,297	kg N-Eq/kg	4,32E-05	kg N-Eq
Nitrate	Emission to water / surface water	0,00033	kg	0,0671	kg N-Eq/kg	2,22E-05	kg N-Eq
Ammonium	Emission to water / surface water	9,59E-05	kg	0,23	kg N-Eq/kg	2,21E-05	kg N-Eq
Nitrogen	Emission to water / surface water	7,16E-05	kg	0,297	kg N-Eq/kg	2,13E-05	kg N-Eq
Ammonium	Emission to water / ground water, long-term	8,93E-05	kg	0,23	kg N-Eq/kg	2,05E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water	4,91E-05	kg	0,297	kg N-Eq/kg	1,46E-05	kg N-Eq
Ammonium	Emission to water / ground water	3,05E-05	kg	0,23	kg N-Eq/kg	7,01E-06	kg N-Eq
Nitrate	Emission to water / ground water	0,0001	kg	0,0671	kg N-Eq/kg	6,87E-06	kg N-Eq
Ammonium	Emission to water / ocean	7,75E-06	kg	0,776	kg N-Eq/kg	6,01E-06	kg N-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,18162	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,83E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,13644	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	4,40E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,03277	kg 1,4-DCB-Eq
Nickel II	Emission to water / ground water, long-term	9,96E-05	kg	22,8	kg 1,4-DCB-Eq/kg	0,00227	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	8,49E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00218	kg 1,4-DCB-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						4,53E-06	kg CFC-11-Eq
Methane, bromo-, Halon	Emission to air / unspecified	5,27E-06	kg	0,734	kg CFC-11-Eq/kg	3,87E-06	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,84E-05	kg	0,011	kg CFC-11-Eq/kg	2,02E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,64E-05	kg	0,011	kg CFC-11-Eq/kg	1,81E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	1,45E-05	kg	0,011	kg CFC-11-Eq/kg	1,59E-07	kg CFC-11-Eq
Methane, tetrachloro-, R·	Emission to air / high population density	6,04E-08	kg	0,895	kg CFC-11-Eq/kg	5,41E-08	kg CFC-11-Eq

Name	Category	Impact result	Unit
climate change - global warming potential (GWP100)		3,03563	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,23314	kg CO2-Eq
xylene production | xylene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,21740	kg CO2-Eq
benzene production | benzene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,19483	kg CO2-Eq
heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U - Europe without Switzerland	353:Steam and air conditioning supply	0,11360	kg CO2-Eq
natural gas venting from petroleum/natural gas production | natural gas, vented | Cutoff, U - GLO	061:Extraction of crude petroleum	0,10668	kg CO2-Eq
transport, freight, lorry >32 metric ton, EURO4 | transport, freight, lorry >32 metric ton, EURO4 | Cutoff, U - RER	492:Other land transport	0,07325	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,06730	kg CO2-Eq
hard coal mine operation and hard coal preparation | hard coal | Cutoff, U - CN	051:Mining of hard coal	0,06416	kg CO2-Eq
propylene production | propylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,06279	kg CO2-Eq
treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, U - RoW	382:Waste treatment and disposal	0,05917	kg CO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,05105	kg CO2-Eq
toluene production, liquid | toluene, liquid | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,05016	kg CO2-Eq
xylene production | xylene | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,04833	kg CO2-Eq
butadiene production | butadiene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,04729	kg CO2-Eq
ammonia production, partial oxidation, liquid | ammonia, anhydrous, liquid | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,04180	kg CO2-Eq
electricity production, lignite | electricity, high voltage | Cutoff, U - DE	351:Electric power generation, transmission and distribution	0,03841	kg CO2-Eq
sweet gas, burned in gas turbine | sweet gas, burned in gas turbine | Cutoff, U - GLO	351:Electric power generation, transmission and distribution	0,03437	kg CO2-Eq

Name	Category	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)		0,00785	kg SO2-Eq
benzene production | benzene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00053	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00047	kg SO2-Eq
xylene production | xylene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,00045	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,00032	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - CN	242:Manufacture of basic precious and other non-ferrous metals	0,00019	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - RoW	242:Manufacture of basic precious and other non-ferrous metals	0,00017	kg SO2-Eq
heat production, at coal coke industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,00015	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,00014	kg SO2-Eq
electricity production, hard coal | electricity, high voltage | Cutoff, U - UA	351:Electric power generation, transmission and distribution	0,00014	kg SO2-Eq
propylene production | propylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00013	kg SO2-Eq
electricity production, hard coal, at coal mine power plant | electricity, high voltage, for internal use in coal mining | Cutoff, U - CN	351:Electric power generation, transmission and distribution	0,00013	kg SO2-Eq
heat and power co-generation, hard coal | electricity, high voltage | Cutoff, U - PL	351:Electric power generation, transmission and distribution	0,00012	kg SO2-Eq
butadiene production | butadiene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,00012	kg SO2-Eq
transport, freight, lorry >32 metric ton, EURO4 | transport, freight, lorry >32 metric ton, EURO4 | Cutoff, U - RER	492:Other land transport	0,00012	kg SO2-Eq
electricity production, hard coal, conventional | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	0,00012	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - Europe without Switzerland	353:Steam and air conditioning supply	0,00011	kg SO2-Eq
transport, freight, sea, container ship | transport, freight, sea, container ship | Cutoff, U - GLO	501:Sea and coastal water transport	0,00011	kg SO2-Eq
electricity production, lignite | electricity, high voltage | Cutoff, U - RS	351:Electric power generation, transmission and distribution	0,00011	kg SO2-Eq
transport, freight, sea, bulk carrier for dry goods | transport, freight, sea, bulk carrier for dry goods | Cutoff, U - GLO	501:Sea and coastal water transport	0,00011	kg SO2-Eq
synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | ethylene | Cutoff, U - ZA	192:Manufacture of refined petroleum products	0,00010	kg SO2-Eq
diesel, burned in building machine | diesel, burned in building machine | Cutoff, U - GLO	431:Demolition and site preparation	0,00010	kg SO2-Eq
xylene production | xylene | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,00010	kg SO2-Eq
toluene production, liquid | toluene, liquid | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,00009	kg SO2-Eq
blasting | blasting | Cutoff, U - RoW	431:Demolition and site preparation	0,00009	kg SO2-Eq
transport, freight, sea, tanker for petroleum | transport, freight, sea, tanker for petroleum | Cutoff, U - GLO	501:Sea and coastal water transport	0,00009	kg SO2-Eq

Name	Category	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)		0,00023	kg N-Eq
treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, U - RoW	382:Waste treatment and disposal	6,57E-05	kg N-Eq
uranium production, in yellowcake, in-situ leaching | uranium, in yellowcake | Cutoff, U - GLO	072:Mining of non-ferrous metal ores	2,49E-05	kg N-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	2,14E-05	kg N-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	1,68E-05	kg N-Eq
treatment of municipal solid waste, unsanitary landfill, dry infiltration class (100mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	1,57E-05	kg N-Eq
treatment of municipal solid waste, unsanitary landfill, moist infiltration class (300mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	1,17E-05	kg N-Eq
treatment of municipal solid waste, open dump, dry infiltration class (100mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	1,06E-05	kg N-Eq
market for wastewater, average | wastewater, average | Cutoff, U - RoW	370:Sewerage	7,36E-06	kg N-Eq
treatment of water discharge from petroleum extraction, offshore | water discharge from petroleum extraction, offshore | Cutoff, U - GLO	061:Extraction of crude petroleum	6,01E-06	kg N-Eq
urea production | urea | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	5,84E-06	kg N-Eq
urea production | urea | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	4,98E-06	kg N-Eq
treatment of water discharge from petroleum/natural gas extraction, onshore | water discharge from petroleum/natural gas extraction, onshore | Cutoff, U - GLO	062:Extraction of natural gas	3,42E-06	kg N-Eq
treatment of municipal solid waste, unsanitary landfill, wet infiltration class (500mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	3,28E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - RoW	370:Sewerage	2,94E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - Europe without Switzerland	370:Sewerage	2,52E-06	kg N-Eq

Name	Category	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)		0,18162	kg 1,4-DCB-Eq
treatment of electric arc furnace slag, residual material landfill | electric arc furnace slag | Cutoff, U - RoW	382:Waste treatment and disposal	0,08834	kg 1,4-DCB-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,01507	kg 1,4-DCB-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,01408	kg 1,4-DCB-Eq
treatment of basic oxygen furnace slag, residual material landfill | basic oxygen furnace slag | Cutoff, U - GLO	382:Waste treatment and disposal	0,00989	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - RoW	382:Waste treatment and disposal	0,00863	kg 1,4-DCB-Eq
treatment of hard coal ash, residual material landfill | hard coal ash | Cutoff, U - RoW	382:Waste treatment and disposal	0,0062	kg 1,4-DCB-Eq
treatment of sludge from steel rolling, residual material landfill | sludge from steel rolling | Cutoff, U - RoW	382:Waste treatment and disposal	0,00561	kg 1,4-DCB-Eq
treatment of redmud from bauxite digestion, residual material landfill | redmud from bauxite digestion | Cutoff, U - RoW	382:Waste treatment and disposal	0,00308	kg 1,4-DCB-Eq
treatment of uranium tailing, non-radioactive emission | uranium tailing, non-radioactive emission | Cutoff, U - GLO	382:Waste treatment and disposal	0,00233	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - CH	382:Waste treatment and disposal	0,00232	kg 1,4-DCB-Eq
treatment of coal slurry, impoundment | coal slurry | Cutoff, U - GLO	382:Waste treatment and disposal	0,0021	kg 1,4-DCB-Eq

Name	Category	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)		4,53E-06	kg CFC-11-Eq
purified terephthalic acid production | purified terephthalic acid | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	3,13E-06	kg CFC-11-Eq
purified terephthalic acid production | purified terephthalic acid | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	7,38E-07	kg CFC-11-Eq

13.1.2 HDPE

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						2,42634	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,29199	kg	1	kg CO2-Eq/kg	1,29199	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,51299	kg	1	kg CO2-Eq/kg	0,51299	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01063	kg	36	kg CO2-Eq/kg	0,38262	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,12895	kg	1	kg CO2-Eq/kg	0,12895	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00254	kg	36	kg CO2-Eq/kg	0,09159	kg CO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00646	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,0027	kg	1	kg SO2-Eq/kg	0,0027	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,0019	kg	1	kg SO2-Eq/kg	0,0019	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	0,0001	kg	1	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00252	kg	0,36	kg SO2-Eq/kg	0,00091	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00142	kg	0,36	kg SO2-Eq/kg	0,00051	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00069	kg	0,36	kg SO2-Eq/kg	0,00025	kg SO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						6,56E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	6,56E-06	kg	0,297	kg N-Eq/kg	1,95E-06	kg N-Eq
Nitrogen	Emission to water / surface water	1,84E-05	kg	0,297	kg N-Eq/kg	5,45E-06	kg N-Eq
Nitrate	Emission to water / ground water, long-term	0,00061	kg	0,0671	kg N-Eq/kg	4,06E-05	kg N-Eq
Nitrate	Emission to water / ground water	8,50E-05	kg	0,0671	kg N-Eq/kg	5,70E-06	kg N-Eq
Nitrate	Emission to water / surface water	4,46E-05	kg	0,0671	kg N-Eq/kg	2,99E-06	kg N-Eq
Ammonium	Emission to water / surface water	1,36E-05	kg	0,23	kg N-Eq/kg	3,14E-06	kg N-Eq
Ammonium	Emission to water / ocean	2,86E-06	kg	0,776	kg N-Eq/kg	2,22E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	4,17E-06	kg	0,23	kg N-Eq/kg	9,59E-07	kg N-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,10804	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,10E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,08167	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	2,74E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,02036	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	5,00E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00129	kg 1,4-DCB-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						3,65E-07	kg CFC-11-Eq
Methane, tetrachloro-, R·	Emission to air / high population density	4,20E-09	kg	0,895	kg CFC-11-Eq/kg	3,76E-09	kg CFC-11-Eq
Methane, bromotrifluoro·	Emission to air / low population density	4,26E-10	kg	14,1	kg CFC-11-Eq/kg	6,00E-09	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,47E-05	kg	0,011	kg CFC-11-Eq/kg	1,62E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,01E-05	kg	0,011	kg CFC-11-Eq/kg	1,11E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	7,17E-06	kg	0,011	kg CFC-11-Eq/kg	7,89E-08	kg CFC-11-Eq

Name	Category	Impact result	Unit
climate change - global warming potential (GWP100)		2,42634	kg CO2-Eq
synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | ethylene | Cutoff, U - ZA	192:Manufacture of refined petroleum products	0,12893	kg CO2-Eq
polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,03	kg CO2-Eq
natural gas venting from petroleum/natural gas production | natural gas, vented | Cutoff, U - GLO	061:Extraction of crude petroleum	0,0327	kg CO2-Eq
heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,03518	kg CO2-Eq
heat production, light fuel oil, at industrial furnace 1MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,02786	kg CO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,03684	kg CO2-Eq
hard coal mine operation and hard coal preparation | hard coal | Cutoff, U - CN	051:Mining of hard coal	0,03808	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	1,20685	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,28937	kg CO2-Eq

Name	Category	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)		0,00646	kg SO2-Eq
transport, freight, sea, container ship | transport, freight, sea, container ship | Cutoff, U - GLO	501:Sea and coastal water transport / 5012:Sea and coastal freight water transport	0,00011	kg SO2-Eq
synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | ethylene | Cutoff, U - ZA	192:Manufacture of refined petroleum products / 1920:Manufacture of refined petroleum products	0,00054	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - RoW	242:Manufacture of basic precious and other non-ferrous metals / 2420:Manufacture of basic precious and other non-ferrous metals	9,17E-05	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - CN	242:Manufacture of basic precious and other non-ferrous metals / 2420:Manufacture of basic precious and other non-ferrous metals	0,0001	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply / 3530:Steam and air conditioning supply	0,00023	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products / 1920:Manufacture of refined petroleum products	0,00245	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products / 1920:Manufacture of refined petroleum products	0,00059	kg SO2-Eq
electricity production, hard coal, conventional | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution / 3510:Electric power generation, transmission and distribution	0,00022	kg SO2-Eq
electricity production, hard coal, at coal mine power plant | electricity, high voltage, for internal use in coal mining | Cutoff, U - CN	351:Electric power generation, transmission and distribution / 3510:Electric power generation, transmission and distribution	7,47E-05	kg SO2-Eq
blasting | blasting | Cutoff, U - RoW	431:Demolition and site preparation / 4312:Site preparation	6,50E-05	kg SO2-Eq

Name	Category	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)		6,56E-05	kg N-Eq
uranium production, in yellowcake, in-situ leaching | uranium, in yellowcake | Cutoff, U - GLO	072:Mining of non-ferrous metal ores	2,31E-05	kg N-Eq
treatment of water discharge from petroleum/natural gas extraction, onshore | water discharge from petroleum/natural gas extraction, onshore | Cutoff, U - GLO	062:Extraction of natural gas	1,46E-06	kg N-Eq
treatment of water discharge from petroleum extraction, offshore | water discharge from petroleum extraction, offshore | Cutoff, U - GLO	061:Extraction of crude petroleum	2,22E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - RoW	370:Sewerage	1,47E-06	kg N-Eq
treatment of waste plastic, mixture, unsanitary landfill, wet infiltration class (500mm) | waste plastic, mixture | Cutoff, U - GLO	382:Waste treatment and disposal	6,75E-07	kg N-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	6,86E-06	kg N-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	1,39E-05	kg N-Eq
treatment of decarbonising waste, residual material landfill | decarbonising waste | Cutoff, U - RoW	382:Waste treatment and disposal	1,36E-06	kg N-Eq
market for wastewater, average | wastewater, average | Cutoff, U - RoW	370:Sewerage	3,67E-06	kg N-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	8,47E-07	kg N-Eq

Name	Category	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)		0,10804	kg 1,4-DCB-Eq
treatment of uranium tailing, non-radioactive emission | uranium tailing, non-radioactive emission | Cutoff, U - GLO	382:Waste treatment and disposal	0,00216	kg 1,4-DCB-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,00483	kg 1,4-DCB-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,01161	kg 1,4-DCB-Eq
treatment of sludge from steel rolling, residual material landfill | sludge from steel rolling | Cutoff, U - RoW	382:Waste treatment and disposal	0,00129	kg 1,4-DCB-Eq
treatment of residue from Na-dichromate production, residual material landfill | residue from Na-dichromate production | Cutoff, U - RoW	382:Waste treatment and disposal	0,02017	kg 1,4-DCB-Eq
treatment of redmud from bauxite digestion, residual material landfill | redmud from bauxite digestion | Cutoff, U - RoW	382:Waste treatment and disposal	0,00196	kg 1,4-DCB-Eq
treatment of hard coal ash, residual material landfill | hard coal ash | Cutoff, U - RoW	382:Waste treatment and disposal	0,00811	kg 1,4-DCB-Eq
treatment of electric arc furnace slag, residual material landfill | electric arc furnace slag | Cutoff, U - RoW	382:Waste treatment and disposal	0,02974	kg 1,4-DCB-Eq
treatment of basic oxygen furnace slag, residual material landfill | basic oxygen furnace slag | Cutoff, U - GLO	382:Waste treatment and disposal	0,00303	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - RoW	382:Waste treatment and disposal	0,01263	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - CH	382:Waste treatment and disposal	0,00302	kg 1,4-DCB-Eq

Name	Category	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)		3,65E-07	kg CFC-11-Eq
polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	6,27E-08	kg CFC-11-Eq
polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,48E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - UN-SEASIA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	5,11E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - SAS	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	4,66E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,16E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RNA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	2,21E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RLA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,02E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RAF	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	4,09E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	2,03E-08	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	1,38E-08	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - MX	351:Electric power generation, transmission and distribution	3,85E-09	kg CFC-11-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	4,40E-09	kg CFC-11-Eq

13.1.3 PP

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						2,3978	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,28758	kg	1	kg CO2-Eq/kg	1,28758	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,47035	kg	1	kg CO2-Eq/kg	0,47035	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01164	kg	36	kg CO2-Eq/kg	0,41907	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,13062	kg	1	kg CO2-Eq/kg	0,13062	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00209	kg	36	kg CO2-Eq/kg	0,07514	kg CO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00638	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00277	kg	1	kg SO2-Eq/kg	0,00277	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00184	kg	1	kg SO2-Eq/kg	0,00184	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00242	kg	0,36	kg SO2-Eq/kg	0,00087	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00134	kg	0,36	kg SO2-Eq/kg	0,00048	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00068	kg	0,36	kg SO2-Eq/kg	0,00025	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	9,41E-05	kg	1	kg SO2-Eq/kg	9,41E-05	kg SO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						7,05E-05	kg N-Eq
Nitrate	Emission to water / ground water, long-term	0,00066	kg	0,0671	kg N-Eq/kg	4,42E-05	kg N-Eq
Nitrate	Emission to water / ground water	9,95E-05	kg	0,0671	kg N-Eq/kg	6,68E-06	kg N-Eq
Nitrogen	Emission to water / surface water	1,74E-05	kg	0,297	kg N-Eq/kg	5,16E-06	kg N-Eq
Nitrate	Emission to water / surface water	4,50E-05	kg	0,0671	kg N-Eq/kg	3,02E-06	kg N-Eq
Ammonium	Emission to water / surface water	1,28E-05	kg	0,23	kg N-Eq/kg	2,95E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	8,09E-06	kg	0,297	kg N-Eq/kg	2,40E-06	kg N-Eq
Ammonium	Emission to water / ocean	2,16E-06	kg	0,776	kg N-Eq/kg	1,67E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	5,10E-06	kg	0,23	kg N-Eq/kg	1,17E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / unspecified	3,14E-06	kg	0,297	kg N-Eq/kg	9,31E-07	kg N-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,09305	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	9,42E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,07011	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	2,27E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,01689	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	5,02E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00129	kg 1,4-DCB-Eq
Arsenic ion	Emission to water / ground water, long-term	2,78E-06	kg	345	kg 1,4-DCB-Eq/kg	0,00096	kg 1,4-DCB-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						2,79E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,07E-05	kg	0,011	kg CFC-11-Eq/kg	1,18E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	7,67E-06	kg	0,011	kg CFC-11-Eq/kg	8,43E-08	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	6,00E-06	kg	0,011	kg CFC-11-Eq/kg	6,60E-08	kg CFC-11-Eq
Methane, tetrachloro-, R·	Emission to air / high population density	5,55E-09	kg	0,895	kg CFC-11-Eq/kg	4,97E-09	kg CFC-11-Eq
Methane, bromotrifluoro·	Emission to air / low population density	3,22E-10	kg	14,1	kg CFC-11-Eq/kg	4,53E-09	kg CFC-11-Eq

<table>
<tr><th>Name</th><th>Category</th><th>Impact result</th><th>Unit</th></tr>
<tr><td>climate change - global warming potential (GWP100)</td><td></td><td>2,3978</td><td>kg CO2-Eq</td></tr>
<tr><td>propylene production | propylene | Cutoff, U - RoW</td><td>192:Manufacture of refined petroleum products</td><td>1,21818</td><td>kg CO2-Eq</td></tr>
<tr><td>propylene production | propylene | Cutoff, U - RER</td><td>192:Manufacture of refined petroleum products</td><td>0,29251</td><td>kg CO2-Eq</td></tr>
<tr><td>synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | propylene | Cutoff, U - ZA</td><td>192:Manufacture of refined petroleum products</td><td>0,15066</td><td>kg CO2-Eq</td></tr>
<tr><td>ethylene production, average | ethylene | Cutoff, U - RoW</td><td>192:Manufacture of refined petroleum products</td><td>0,06767</td><td>kg CO2-Eq</td></tr>
<tr><td>polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RoW</td><td>201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics</td><td>0,03395</td><td>kg CO2-Eq</td></tr>
<tr><td>hard coal mine operation and hard coal preparation | hard coal | Cutoff, U - CN</td><td>051:Mining of hard coal</td><td>0,03006</td><td>kg CO2-Eq</td></tr>
<tr><td>heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW</td><td>353:Steam and air conditioning supply</td><td>0,02603</td><td>kg CO2-Eq</td></tr>
<tr><td>electricity production, hard coal, conventional | electricity, high voltage | Cutoff, U - ZA</td><td>351:Electric power generation, transmission and distribution</td><td>0,0253</td><td>kg CO2-Eq</td></tr>
<tr><td>natural gas venting from petroleum/natural gas production | natural gas, vented | Cutoff, U - GLO</td><td>061:Extraction of crude petroleum</td><td>0,02458</td><td>kg CO2-Eq</td></tr>
</table>

Name	Category	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)		0,00638	kg SO2-Eq
propylene production | propylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00248	kg SO2-Eq
synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | propylene | Cutoff, U - ZA	192:Manufacture of refined petroleum products	0,00063	kg SO2-Eq
propylene production | propylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,0006	kg SO2-Eq
electricity production, hard coal, conventional | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	0,00025	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,00016	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00014	kg SO2-Eq
transport, freight, sea, container ship | transport, freight, sea, container ship | Cutoff, U - GLO	501:Sea and coastal water transport	0,0001	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - CN	242:Manufacture of basic precious and other non-ferrous metals	0,0001	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - RoW	242:Manufacture of basic precious and other non-ferrous metals	8,96E-05	kg SO2-Eq
blasting | blasting | Cutoff, U - RoW	431:Demolition and site preparation	6,72E-05	kg SO2-Eq

Name	Category	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)		7,05E-05	kg N-Eq
uranium production, in yellowcake, in-situ leaching | uranium, in yellowcake | Cutoff, U - GLO	072:Mining of non-ferrous metal ores	2,85E-05	kg N-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	1,42E-05	kg N-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	5,51E-06	kg N-Eq
market for wastewater, average | wastewater, average | Cutoff, U - RoW	370:Sewerage	3,62E-06	kg N-Eq
treatment of water discharge from petroleum extraction, offshore | water discharge from petroleum extraction, offshore | Cutoff, U - GLO	061:Extraction of crude petroleum	1,67E-06	kg N-Eq
treatment of decarbonising waste, residual material landfill | decarbonising waste | Cutoff, U - RoW	382:Waste treatment and disposal	1,60E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - RoW	370:Sewerage	1,45E-06	kg N-Eq
treatment of water discharge from petroleum/natural gas extraction, onshore | water discharge from petroleum/natural gas extraction, onshore | Cutoff, U - GLO	062:Extraction of natural gas	1,10E-06	kg N-Eq
treatment of waste plastic, mixture, unsanitary landfill, wet infiltration class (500mm) | waste plastic, mixture | Cutoff, U - GLO	382:Waste treatment and disposal	9,30E-07	kg N-Eq
polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	8,98E-07	kg N-Eq
propylene production | propylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	8,49E-07	kg N-Eq

Name	Category	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)		0,09305	kg 1,4-DCB-Eq
treatment of electric arc furnace slag, residual material landfill | electric arc furnace slag | Cutoff, U - RoW	382:Waste treatment and disposal	0,0289	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - RoW	382:Waste treatment and disposal	0,01395	kg 1,4-DCB-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,01191	kg 1,4-DCB-Eq
treatment of hard coal ash, residual material landfill | hard coal ash | Cutoff, U - RoW	382:Waste treatment and disposal	0,00844	kg 1,4-DCB-Eq
treatment of basic oxygen furnace slag, residual material landfill | basic oxygen furnace slag | Cutoff, U - GLO	382:Waste treatment and disposal	0,00709	kg 1,4-DCB-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,00388	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - CH	382:Waste treatment and disposal	0,00334	kg 1,4-DCB-Eq
treatment of uranium tailing, non-radioactive emission | uranium tailing, non-radioactive emission | Cutoff, U - GLO	382:Waste treatment and disposal	0,00266	kg 1,4-DCB-Eq
treatment of redmud from bauxite digestion, residual material landfill | redmud from bauxite digestion | Cutoff, U - RoW	382:Waste treatment and disposal	0,00194	kg 1,4-DCB-Eq
treatment of sludge from steel rolling, residual material landfill | sludge from steel rolling | Cutoff, U - RoW	382:Waste treatment and disposal	0,00118	kg 1,4-DCB-Eq

Name	Category	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)		2,79E-07	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RNA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	2,51E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	2,31E-08	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	1,54E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,32E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RLA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,16E-08	kg CFC-11-Eq
polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	7,37E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - UN-SEASIA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	5,83E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - SAS	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	5,32E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RAF	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	4,66E-09	kg CFC-11-Eq
electricity production, hard coal, conventional | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	3,65E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RER w/o RU	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	3,53E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - UN-OCEANIA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	3,47E-09	kg CFC-11-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	3,11E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - MX	351:Electric power generation, transmission and distribution	3,06E-09	kg CFC-11-Eq

13.2 Renewable energies

Name	PET - Impact result	HDPE - Impact result	PP - Impact result	Unit
water use - water consumption potential (WCP)	0,0367	0,02022	0,01697	m3
photochemical oxidant formation: terrestrial ecosystems - photochemical oxidant formation potential: ecosystems (EOFP)	0,00673	0,00565	0,00365	kg NOx-Eq
photochemical oxidant formation: human health - photochemical oxidant formation potential: humans (HOFP)	0,00626	0,00524	0,00334	kg NOx-Eq
particulate matter formation - particulate matter formation potential (PMFP)	0,00329	0,00251	0,00155	kg PM2,5-Eq
ozone depletion - ozone depletion potential (ODPinfinite)	**4,52E-06**	**3,57E-07**	**1,17E-07**	**kg CFC-11-Eq**
material resources: metals/minerals - surplus ore potential (SOP)	0,04075	0,01906	0,00761	kg Cu-Eq
land use - agricultural land occupation (LOP)	0,05197	0,01954	0,01115	m2*a crop-Eq
ionising radiation - ionising radiation potential (IRP)	0,24547	0,05846	0,09279	kBq Co-60-Eq
human toxicity: non-carcinogenic - human toxicity potential (HTPnc)	4,06301	1,18178	0,77962	kg 1,4-DCB-Eq
human toxicity: carcinogenic - human toxicity potential (HTPc)	**0,17605**	**0,10216**	**0,06084**	**kg 1,4-DCB-Eq**
eutrophication: marine - marine eutrophication potential (MEP)	**0,0002**	**4,03E-05**	**2,30E-05**	**kg N-Eq**
eutrophication: freshwater - freshwater eutrophication potential (FEP)	0,00074	0,0004	0,00021	kg P-Eq
energy resources: non-renewable, fossil - fossil fuel potential (FFP)	1,82171	1,67963	1,60574	kg oil-Eq
ecotoxicity: terrestrial - terrestrial ecotoxicity potential (TETP)	12,75679	5,49608	3,2182	kg 1,4-DCB-Eq
ecotoxicity: marine - marine ecotoxicity potential (METP)	0,27622	0,07341	0,05821	kg 1,4-DCB-Eq
ecotoxicity: freshwater - freshwater ecotoxicity potential (FETP)	0,20883	0,05506	0,04451	kg 1,4-DCB-Eq
climate change - global warming potential (GWP100)	**3,02416**	**2,41425**	**1,96238**	**kg CO2-Eq**
acidification: terrestrial - terrestrial acidification potential (TAP)	**0,00779**	**0,00639**	**0,00447**	**kg SO2-Eq**

13.2.1 PET

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						3,02416	kg CO2-Eq
Methane, non-fossil	Emission to air / low population density	0,00351	kg	34	kg CO2-Eq/kg	0,11945	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,00695	kg	36	kg CO2-Eq/kg	0,2501	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,0064	kg	36	kg CO2-Eq/kg	0,23025	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,2925	kg	1	kg CO2-Eq/kg	1,2925	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,81024	kg	1	kg CO2-Eq/kg	0,81024	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,28545	kg	1	kg CO2-Eq/kg	0,28545	kg CO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00779	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00283	kg	1	kg SO2-Eq/kg	0,00283	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00256	kg	1	kg SO2-Eq/kg	0,00256	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	0,00021	kg	1	kg SO2-Eq/kg	0,00021	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00207	kg	0,36	kg SO2-Eq/kg	0,00074	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,0019	kg	0,36	kg SO2-Eq/kg	0,00068	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00154	kg	0,36	kg SO2-Eq/kg	0,00055	kg SO2-Eq
Ammonia	Emission to air / high population density	5,11E-05	kg	1,96	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Ammonia	Emission to air / unspecified	4,18E-05	kg	1,96	kg SO2-Eq/kg	8,19E-05	kg SO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						0,0002	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	0,00015	kg	0,297	kg N-Eq/kg	4,32E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water	4,91E-05	kg	0,297	kg N-Eq/kg	1,46E-05	kg N-Eq
Nitrogen	Emission to water / surface water	7,11E-05	kg	0,297	kg N-Eq/kg	2,11E-05	kg N-Eq
Nitrate	Emission to water / ground water, long-term	6,50E-04	kg	0,0671	kg N-Eq/kg	4,37E-05	kg N-Eq
Nitrate	Emission to water / surface water	3,30E-04	kg	0,0671	kg N-Eq/kg	2,19E-05	kg N-Eq
Nitrate	Emission to water / ground water	4,15E-05	kg	0,0671	kg N-Eq/kg	2,79E-06	kg N-Eq
Ammonium	Emission to water / surface water	9,24E-05	kg	0,23	kg N-Eq/kg	2,13E-05	kg N-Eq
Ammonium	Emission to water / ground water, long-term	8,92E-05	kg	0,23	kg N-Eq/kg	2,05E-05	kg N-Eq
Ammonium	Emission to water / ground water	3,05E-05	kg	0,23	kg N-Eq/kg	7,01E-06	kg N-Eq
Ammonium	Emission to water / ocean	7,69E-06	kg	0,776	kg N-Eq/kg	5,97E-06	kg N-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,17605	kg 1,4-DCB-Eq
Nickel II	Emission to water / ground water, long-term	9,81E-05	kg	22,8	kg 1,4-DCB-Eq/kg	0,00224	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,78E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,13279	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	4,30E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,03199	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	7,87E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00202	kg 1,4-DCB-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						4,52E-06	kg CFC-11-Eq
Methane, tetrachloro-, R-10	Emission to air / high population density	6,03E-08	kg	0,895	kg CFC-11-Eq/kg	5,39E-08	kg CFC-11-Eq
Methane, bromo-, Halon 1001	Emission to air / unspecified	5,27E-06	kg	0,734	kg CFC-11-Eq/kg	3,87E-06	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	1,81E-05	kg	0,011	kg CFC-11-Eq/kg	1,99E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,63E-05	kg	0,011	kg CFC-11-Eq/kg	1,79E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	1,42E-05	kg	0,011	kg CFC-11-Eq/kg	1,56E-07	kg CFC-11-Eq

Name	Category	Impact result	Unit
climate change - global warming potential (GWP100)		3,02416	kg CO2-Eq
xylene production | xylene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,2174	kg CO2-Eq
xylene production | xylene | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,04833	kg CO2-Eq
treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, U - RoW	382:Waste treatment and disposal	0,05916	kg CO2-Eq
transport, freight, lorry >32 metric ton, EURO4 | transport, freight, lorry >32 metric ton, EURO4 | Cutoff, U - RER	492:Other land transport	0,07325	kg CO2-Eq
toluene production, liquid | toluene, liquid | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,05016	kg CO2-Eq
sweet gas, burned in gas turbine | sweet gas, burned in gas turbine | Cutoff, U - GLO	351:Electric power generation, transmission and distribution	0,03419	kg CO2-Eq
propylene production | propylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,06279	kg CO2-Eq
natural gas venting from petroleum/natural gas production | natural gas, vented | Cutoff, U - GLO	061:Extraction of crude petroleum	0,10609	kg CO2-Eq
heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U - Europe without Switzerland	353:Steam and air conditioning supply	0,11339	kg CO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,0503	kg CO2-Eq
hard coal mine operation and hard coal preparation | hard coal | Cutoff, U - CN	051:Mining of hard coal	0,06379	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,23313	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,06729	kg CO2-Eq
electricity production, lignite | electricity, high voltage | Cutoff, U - DE	351:Electric power generation, transmission and distribution	0,03834	kg CO2-Eq
butadiene production | butadiene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,04728	kg CO2-Eq
benzene production | benzene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,19482	kg CO2-Eq
ammonia production, partial oxidation, liquid | ammonia, anhydrous, liquid | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,04178	kg CO2-Eq

Name	Category	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)		0,00779	kg SO2-Eq
xylene production | xylene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,00045	kg SO2-Eq
xylene production | xylene | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	9,90E-05	kg SO2-Eq
transport, freight, sea, tanker for petroleum | transport, freight, sea, tanker for petroleum | Cutoff, U - GLO	501:Sea and coastal water transport	8,48E-05	kg SO2-Eq
transport, freight, sea, container ship | transport, freight, sea, container ship | Cutoff, U - GLO	501:Sea and coastal water transport	0,00011	kg SO2-Eq
transport, freight, sea, bulk carrier for dry goods | transport, freight, sea, bulk carrier for dry goods | Cutoff, U - GLO	501:Sea and coastal water transport	0,0001	kg SO2-Eq
transport, freight, lorry >32 metric ton, EURO4 | transport, freight, lorry >32 metric ton, EURO4 | Cutoff, U - RER	492:Other land transport	0,00012	kg SO2-Eq
toluene production, liquid | toluene, liquid | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	9,31E-05	kg SO2-Eq
synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | ethylene | Cutoff, U - ZA	192:Manufacture of refined petroleum products	0,0001	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - RoW	242:Manufacture of basic precious and other non-ferrous metals	0,00017	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - CN	242:Manufacture of basic precious and other non-ferrous metals	0,00019	kg SO2-Eq
propylene production | propylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00013	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,00031	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - Europe without Switzerland	353:Steam and air conditioning supply	0,00011	kg SO2-Eq
heat production, at coal coke industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,00015	kg SO2-Eq
heat and power co-generation, hard coal | electricity, high voltage | Cutoff, U - PL	351:Electric power generation, transmission and distribution	0,00012	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00047	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,00014	kg SO2-Eq
electricity production, lignite | electricity, high voltage | Cutoff, U - RS	351:Electric power generation, transmission and distribution	0,00011	kg SO2-Eq
electricity production, hard coal, conventional | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	0,00011	kg SO2-Eq
electricity production, hard coal, at coal mine power plant | electricity, high voltage, for internal use in coal mining | Cutoff, U - CN	351:Electric power generation, transmission and distribution	0,00013	kg SO2-Eq
electricity production, hard coal | electricity, high voltage | Cutoff, U - UA	351:Electric power generation, transmission and distribution	0,00014	kg SO2-Eq
diesel, burned in building machine | diesel, burned in building machine | Cutoff, U - GLO	431:Demolition and site preparation	0,0001	kg SO2-Eq
butadiene production | butadiene | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,00012	kg SO2-Eq
blasting | blasting | Cutoff, U - RoW	431:Demolition and site preparation	8,43E-05	kg SO2-Eq
benzene production | benzene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00053	kg SO2-Eq

Name	Category	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)		0,0002	kg N-Eq
urea production | urea | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	5,84E-06	kg N-Eq
urea production | urea | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	4,98E-06	kg N-Eq
uranium production, in yellowcake, in-situ leaching | uranium, in yellowcake | Cutoff, U - GLO	072:Mining of non-ferrous metal ores	3,91E-06	kg N-Eq
treatment of water discharge from petroleum/natural gas extraction, onshore | water discharge from petroleum/natural gas extraction, onshore | Cutoff, U - GLO	062:Extraction of natural gas	3,39E-06	kg N-Eq
treatment of water discharge from petroleum extraction, offshore | water discharge from petroleum extraction, offshore | Cutoff, U - GLO	061:Extraction of crude petroleum	5,97E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - RoW	370:Sewerage	2,93E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - Europe without Switzerland	370:Sewerage	2,52E-06	kg N-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	2,13E-05	kg N-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	1,67E-05	kg N-Eq
treatment of municipal solid waste, unsanitary landfill, wet infiltration class (500mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	3,27E-06	kg N-Eq
treatment of municipal solid waste, unsanitary landfill, moist infiltration class (300mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	1,17E-05	kg N-Eq
treatment of municipal solid waste, unsanitary landfill, dry infiltration class (100mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	1,57E-05	kg N-Eq
treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, U - RoW	382:Waste treatment and disposal	6,57E-05	kg N-Eq
treatment of municipal solid waste, open dump, dry infiltration class (100mm) | municipal solid waste | Cutoff, U - GLO	382:Waste treatment and disposal	1,06E-05	kg N-Eq
market for wastewater, average | wastewater, average | Cutoff, U - RoW	370:Sewerage	7,33E-06	kg N-Eq

Name	Category	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)		0,17605	kg 1,4-DCB-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,01502	kg 1,4-DCB-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,01401	kg 1,4-DCB-Eq
treatment of sludge from steel rolling, residual material landfill | sludge from steel rolling | Cutoff, U - RoW	382:Waste treatment and disposal	0,00553	kg 1,4-DCB-Eq
treatment of redmud from bauxite digestion, residual material landfill | redmud from bauxite digestion | Cutoff, U - RoW	382:Waste treatment and disposal	0,00304	kg 1,4-DCB-Eq
treatment of hard coal ash, residual material landfill | hard coal ash | Cutoff, U - RoW	382:Waste treatment and disposal	0,00617	kg 1,4-DCB-Eq
treatment of electric arc furnace slag, residual material landfill | electric arc furnace slag | Cutoff, U - RoW	382:Waste treatment and disposal	0,0859	kg 1,4-DCB-Eq
treatment of coal slurry, impoundment | coal slurry | Cutoff, U - GLO	382:Waste treatment and disposal	0,00209	kg 1,4-DCB-Eq
treatment of basic oxygen furnace slag, residual material landfill | basic oxygen furnace slag | Cutoff, U - GLO	382:Waste treatment and disposal	0,00973	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - RoW	382:Waste treatment and disposal	0,0086	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - CH	382:Waste treatment and disposal	0,00232	kg 1,4-DCB-Eq

Name	Category	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)		4,52E-06	kg CFC-11-Eq
purified terephthalic acid production | purified terephthalic acid | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	3,13E-06	kg CFC-11-Eq
purified terephthalic acid production | purified terephthalic acid | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	7,38E-07	kg CFC-11-Eq

13.2.2 HDPE

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						2,41425	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01063	kg	36	kg CO2-Eq/kg	0,38258	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00251	kg	36	kg CO2-Eq/kg	0,09032	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,28992	kg	1	kg CO2-Eq/kg	1,28992	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,50642	kg	1	kg CO2-Eq/kg	0,50642	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,12713	kg	1	kg CO2-Eq/kg	0,12713	kg CO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00639	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00269	kg	1	kg SO2-Eq/kg	0,00269	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00188	kg	1	kg SO2-Eq/kg	0,00188	kg SO2-Eq
Sulfur dioxide	Emission to air / unspecified	9,71E-05	kg	1	kg SO2-Eq/kg	9,71E-05	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00251	kg	0,36	kg SO2-Eq/kg	0,0009	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00138	kg	0,36	kg SO2-Eq/kg	0,0005	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00068	kg	0,36	kg SO2-Eq/kg	0,00025	kg SO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						4,03E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	6,52E-06	kg	0,297	kg N-Eq/kg	1,94E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / unspecified	2,16E-06	kg	0,297	kg N-Eq/kg	6,42E-07	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water	1,44E-06	kg	0,297	kg N-Eq/kg	4,28E-07	kg N-Eq
Nitrogen	Emission to water / surface water	1,78E-05	kg	0,297	kg N-Eq/kg	5,29E-06	kg N-Eq
Nitrate	Emission to water / ground water, long-term	3,20E-04	kg	0,0671	kg N-Eq/kg	2,15E-05	kg N-Eq
Nitrate	Emission to water / surface water	4,00E-05	kg	0,0671	kg N-Eq/kg	2,68E-06	kg N-Eq
Nitrate	Emission to water / ground water	2,08E-05	kg	0,0671	kg N-Eq/kg	1,40E-06	kg N-Eq
Ammonium	Emission to water / surface water	9,96E-06	kg	0,23	kg N-Eq/kg	2,29E-06	kg N-Eq
Ammonium	Emission to water / ocean	2,80E-06	kg	0,776	kg N-Eq/kg	2,17E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	4,14E-06	kg	0,23	kg N-Eq/kg	9,52E-07	kg N-Eq
Ammonium	Emission to water / unspecified	1,82E-06	kg	0,23	kg N-Eq/kg	4,18E-07	kg N-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,10216	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	1,05E-05	kg	7440	kg 1,4-DCB-Eq/kg	0,07782	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	2,63E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,01954	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	4,35E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,00112	kg 1,4-DCB-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						3,57E-07	kg CFC-11-Eq
Methane, tetrachloro-, R	Emission to air / high population density	4,04E-09	kg	0,895	kg CFC-11-Eq/kg	3,62E-09	kg CFC-11-Eq
Methane, bromotrifluoro	Emission to air / low population density	4,18E-10	kg	14,1	kg CFC-11-Eq/kg	5,89E-09	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	1,46E-05	kg	0,011	kg CFC-11-Eq/kg	1,60E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	9,84E-06	kg	0,011	kg CFC-11-Eq/kg	1,08E-07	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	6,89E-06	kg	0,011	kg CFC-11-Eq/kg	7,58E-08	kg CFC-11-Eq

Name	Category	Impact result	Unit
climate change - global warming potential (GWP100)		2,41425	kg CO2-Eq
synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | ethylene | Cutoff, U - ZA	192:Manufacture of refined petroleum products	0,12893	kg CO2-Eq
polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,03	kg CO2-Eq
natural gas venting from petroleum/natural gas production | natural gas, vented | Cutoff, U - GLO	061:Extraction of crude petroleum	0,03208	kg CO2-Eq
heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,03516	kg CO2-Eq
heat production, light fuel oil, at industrial furnace 1MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,02786	kg CO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,03606	kg CO2-Eq
hard coal mine operation and hard coal preparation | hard coal | Cutoff, U - CN	051:Mining of hard coal	0,0377	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	1,20683	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,28936	kg CO2-Eq

Name	Category	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)		0,00639	kg SO2-Eq
transport, freight, sea, container ship | transport, freight, sea, container ship | Cutoff, U - GLO	501:Sea and coastal water transport	0,0001	kg SO2-Eq
synthetic fuel production, from coal, high temperature Fisher-Tropsch operations | ethylene | Cutoff, U - ZA	192:Manufacture of refined petroleum products	0,00054	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - RoW	242:Manufacture of basic precious and other non-ferrous metals	8,96E-05	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - CN	242:Manufacture of basic precious and other non-ferrous metals	0,0001	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	0,00022	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	0,00245	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,00059	kg SO2-Eq
electricity production, hard coal, conventional | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	0,00022	kg SO2-Eq
electricity production, hard coal, at coal mine power plant | electricity, high voltage, for internal use in coal mining | Cutoff, U - CN	351:Electric power generation, transmission and distribution	7,39E-05	kg SO2-Eq

Name	Category	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)		4,03E-05	kg N-Eq
uranium production, in yellowcake, in-situ leaching | uranium, in yellowcake | Cutoff, U - GLO	072:Mining of non-ferrous metal ores	9,22E-07	kg N-Eq
treatment of water discharge from petroleum/natural gas extraction, onshore | water discharge from petroleum/natural gas extraction, onshore | Cutoff, U - GLO	062:Extraction of natural gas	1,43E-06	kg N-Eq
treatment of water discharge from petroleum extraction, offshore | water discharge from petroleum extraction, offshore | Cutoff, U - GLO	061:Extraction of crude petroleum	2,17E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - RoW	370:Sewerage	1,46E-06	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - Europe without Switzerland	370:Sewerage	6,40E-07	kg N-Eq
treatment of waste plastic, mixture, unsanitary landfill, wet infiltration class (500mm) | waste plastic, mixture | Cutoff, U - GLO	382:Waste treatment and disposal	6,74E-07	kg N-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	6,78E-06	kg N-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	1,38E-05	kg N-Eq
polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	5,79E-07	kg N-Eq
market for wastewater, average | wastewater, average | Cutoff, U - RoW	370:Sewerage	3,64E-06	kg N-Eq
ethylene production, average | ethylene | Cutoff, U - RoW	192:Manufacture of refined petroleum products	8,47E-07	kg N-Eq

Name	Category	Inventory result	Unit
human toxicity: non-carcinogenic - human toxicity potential (HTPnc)		1,18178	kg 1,4-DCB-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,23467	kg 1,4-DCB-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,09654	kg 1,4-DCB-Eq
treatment of hard coal ash, residual material landfill | hard coal ash | Cutoff, U - RoW	382:Waste treatment and disposal	0,09587	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - CL	382:Waste treatment and disposal	0,07665	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - RoW	382:Waste treatment and disposal	0,05613	kg 1,4-DCB-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - CN	242:Manufacture of basic precious and other non-ferrous metals	0,04622	kg 1,4-DCB-Eq
treatment of copper slag, residual material landfill | copper slag | Cutoff, U - GLO	382:Waste treatment and disposal	0,0456	kg 1,4-DCB-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - RoW	242:Manufacture of basic precious and other non-ferrous metals	0,04545	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - RoW	382:Waste treatment and disposal	0,03134	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - PE	382:Waste treatment and disposal	0,02991	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - CN	382:Waste treatment and disposal	0,02545	kg 1,4-DCB-Eq
treatment of zinc in car shredder residue, municipal incineration | zinc in car shredder residue | Cutoff, U - RoW	382:Waste treatment and disposal	0,02354	kg 1,4-DCB-Eq
treatment of coal slurry, impoundment | coal slurry | Cutoff, U - GLO	382:Waste treatment and disposal	0,02075	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - CA	382:Waste treatment and disposal	0,01906	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - US	382:Waste treatment and disposal	0,01828	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - AU	382:Waste treatment and disposal	0,01715	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from gold mine operation, tailings impoundment | sulfidic tailings, from gold mine operation | Cutoff, U - AU	382:Waste treatment and disposal	0,01375	kg 1,4-DCB-Eq
treatment of sulfidic tailings, from copper mine operation, tailings impoundment | sulfidic tailings, from copper mine operation | Cutoff, U - RU	382:Waste treatment and disposal	0,01269	kg 1,4-DCB-Eq

Name	Category	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)		3,57E-07	kg CFC-11-Eq
polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	6,27E-08	kg CFC-11-Eq
polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,48E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - UN-SEASIA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	4,96E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - SAS	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	4,52E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,12E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RNA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	2,17E-08	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RLA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	9,86E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RAF	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	3,96E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,99E-08	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - ZA	351:Electric power generation, transmission and distribution	1,38E-08	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - MX	351:Electric power generation, transmission and distribution	3,82E-09	kg CFC-11-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	4,30E-09	kg CFC-11-Eq

13.2.3 PP

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
climate change - global warming potential (GWP100)						1,96238	kg CO2-Eq
Methane, fossil	Emission to air / high population density	0,01181	kg	36	kg CO2-Eq/kg	0,4252	kg CO2-Eq
Methane, fossil	Emission to air / low population density	0,00075	kg	36	kg CO2-Eq/kg	0,02716	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / high population density	1,28166	kg	1	kg CO2-Eq/kg	1,28166	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / low population density	0,15687	kg	1	kg CO2-Eq/kg	0,15687	kg CO2-Eq
Carbon dioxide, fossil	Emission to air / unspecified	0,06297	kg	1	kg CO2-Eq/kg	0,06297	kg CO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)						0,00447	kg SO2-Eq
Sulfur dioxide	Emission to air / high population density	0,00265	kg	1	kg SO2-Eq/kg	0,00265	kg SO2-Eq
Sulfur dioxide	Emission to air / low population density	0,00073	kg	1	kg SO2-Eq/kg	0,00073	kg SO2-Eq
Nitrogen oxides	Emission to air / high population density	0,00239	kg	0,36	kg SO2-Eq/kg	0,00086	kg SO2-Eq
Nitrogen oxides	Emission to air / low population density	0,00028	kg	0,36	kg SO2-Eq/kg	0,0001	kg SO2-Eq
Nitrogen oxides	Emission to air / unspecified	0,00015	kg	0,36	kg SO2-Eq/kg	5,50E-05	kg SO2-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)						2,30E-05	kg N-Eq
Nitrogen, organic bound	Emission to water / ground water, long-term	5,08E-06	kg	0,297	kg N-Eq/kg	1,51E-06	kg N-Eq
Nitrogen, organic bound	Emission to water / unspecified	3,13E-06	kg	0,297	kg N-Eq/kg	9,31E-07	kg N-Eq
Nitrogen	Emission to water / surface water	6,45E-06	kg	0,297	kg N-Eq/kg	1,92E-06	kg N-Eq
Nitrate	Emission to water / ground water, long-term	1,70E-04	kg	0,0671	kg N-Eq/kg	1,11E-05	kg N-Eq
Nitrate	Emission to water / surface water	5,66E-05	kg	0,0671	kg N-Eq/kg	3,80E-06	kg N-Eq
Nitrate	Emission to water / ground water	8,51E-06	kg	0,0671	kg N-Eq/kg	5,71E-07	kg N-Eq
Ammonium	Emission to water / surface water	4,99E-06	kg	0,23	kg N-Eq/kg	1,15E-06	kg N-Eq
Ammonium	Emission to water / ground water, long-term	3,24E-06	kg	0,23	kg N-Eq/kg	7,46E-07	kg N-Eq
Ammonium	Emission to water / ocean	7,79E-07	kg	0,776	kg N-Eq/kg	6,05E-07	kg N-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)						0,06084	kg 1,4-DCB-Eq
Chromium VI	Emission to water / ground water, long-term	6,10E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,04541	kg 1,4-DCB-Eq
Chromium VI	Emission to water / surface water	1,63E-06	kg	7440	kg 1,4-DCB-Eq/kg	0,01209	kg 1,4-DCB-Eq
Chromium VI	Emission to air / low population density	3,91E-08	kg	2,57E+04	kg 1,4-DCB-Eq/kg	0,001	kg 1,4-DCB-Eq

Name	Category	Inventory result	Unit	Impact factor	Unit	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)						1,17E-07	kg CFC-11-Eq
Methane, tetrachloro-, R-	Emission to air / high population density	3,86E-09	kg	0,895	kg CFC-11-Eq/kg	3,46E-09	kg CFC-11-Eq
Methane, bromotrifluoro-	Emission to air / low population density	2,61E-10	kg	14,1	kg CFC-11-Eq/kg	3,68E-09	kg CFC-11-Eq
Methane, bromochlorodi	Emission to air / low population density	1,66E-10	kg	8,78	kg CFC-11-Eq/kg	1,45E-09	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / unspecified	4,15E-06	kg	0,011	kg CFC-11-Eq/kg	4,57E-08	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / low population density	3,08E-06	kg	0,011	kg CFC-11-Eq/kg	3,39E-08	kg CFC-11-Eq
Dinitrogen monoxide	Emission to air / high population density	2,53E-06	kg	0,011	kg CFC-11-Eq/kg	2,78E-08	kg CFC-11-Eq

Name	Category	Impact result	Unit
climate change - global warming potential (GWP100)		1,96238	kg CO2-Eq
propylene production | propylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	1,53328	kg CO2-Eq
polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	0,04195	kg CO2-Eq
heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U - Europe without Switzerland	353:Steam and air conditioning supply	0,02699	kg CO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,08272	kg CO2-Eq

Name	Category	Impact result	Unit
acidification: terrestrial - terrestrial acidification potential (TAP)		0,00447	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - RoW	242:Manufacture of basic precious and other non-ferrous metals	8,34E-05	kg SO2-Eq
smelting of copper concentrate, sulfide ore | copper, anode | Cutoff, U - CN	242:Manufacture of basic precious and other non-ferrous metals	9,33E-05	kg SO2-Eq
propylene production | propylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,00312	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - RoW	353:Steam and air conditioning supply	4,67E-05	kg SO2-Eq
heat production, at hard coal industrial furnace 1-10MW | heat, district or industrial, other than natural gas | Cutoff, U - Europe without Switzerland	353:Steam and air conditioning supply	5,43E-05	kg SO2-Eq
heat and power co-generation, hard coal | electricity, high voltage | Cutoff, U - PL	351:Electric power generation, transmission and distribution	5,17E-05	kg SO2-Eq
ethylene production, average | ethylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	0,00017	kg SO2-Eq
electricity production, lignite | electricity, high voltage | Cutoff, U - RS	351:Electric power generation, transmission and distribution	4,60E-05	kg SO2-Eq
electricity production, hard coal | electricity, high voltage | Cutoff, U - UA	351:Electric power generation, transmission and distribution	5,71E-05	kg SO2-Eq

Name	Category	Impact result	Unit
eutrophication: marine - marine eutrophication potential (MEP)		2,30E-05	kg N-Eq
uranium production, in yellowcake, in-situ leaching | uranium, in yellowcake | Cutoff, U - GLO	072:Mining of non-ferrous metal ores	1,48E-06	kg N-Eq
treatment of water discharge from petroleum/natural gas extraction, onshore | water discharge from petroleum/natural gas extraction, onshore | Cutoff, U - GLO	062:Extraction of natural gas	3,15E-07	kg N-Eq
treatment of water discharge from petroleum extraction, offshore | water discharge from petroleum extraction, offshore | Cutoff, U - GLO	061:Extraction of crude petroleum	6,04E-07	kg N-Eq
treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - Europe without Switzerland	370:Sewerage	2,97E-06	kg N-Eq
treatment of waste plastic, mixture, sanitary landfill | waste plastic, mixture | Cutoff, U - RoW	382:Waste treatment and disposal	9,12E-07	kg N-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	7,16E-06	kg N-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	2,41E-06	kg N-Eq
treatment of municipal solid waste, sanitary landfill | municipal solid waste | Cutoff, U - RoW	382:Waste treatment and disposal	4,64E-07	kg N-Eq
propylene production | propylene | Cutoff, U - RER	192:Manufacture of refined petroleum products	1,07E-06	kg N-Eq
polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,11E-06	kg N-Eq
market for wastewater, average | wastewater, average | Cutoff, U - RoW	370:Sewerage	3,89E-07	kg N-Eq
market for wastewater, average | wastewater, average | Cutoff, U - Europe without Switzerland	370:Sewerage	7,79E-07	kg N-Eq

Name	Category	Impact result	Unit
human toxicity: carcinogenic - human toxicity potential (HTPc)		0,06084	kg 1,4-DCB-Eq
treatment of spoil from lignite mining, in surface landfill | spoil from lignite mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,00504	kg 1,4-DCB-Eq
treatment of spoil from hard coal mining, in surface landfill | spoil from hard coal mining | Cutoff, U - GLO	382:Waste treatment and disposal	0,00201	kg 1,4-DCB-Eq
treatment of sludge from steel rolling, residual material landfill | sludge from steel rolling | Cutoff, U - RoW	382:Waste treatment and disposal	0,00075	kg 1,4-DCB-Eq
treatment of redmud from bauxite digestion, residual material landfill | redmud from bauxite digestion | Cutoff, U - RoW	382:Waste treatment and disposal	0,00151	kg 1,4-DCB-Eq
treatment of hard coal ash, residual material landfill | hard coal ash | Cutoff, U - RoW	382:Waste treatment and disposal	0,00065	kg 1,4-DCB-Eq
treatment of electric arc furnace slag, residual material landfill | electric arc furnace slag | Cutoff, U - RoW	382:Waste treatment and disposal	0,02044	kg 1,4-DCB-Eq
treatment of basic oxygen furnace slag, residual material landfill | basic oxygen furnace slag | Cutoff, U - GLO	382:Waste treatment and disposal	0,00598	kg 1,4-DCB-Eq
treatment of average incineration residue, residual material landfill | average incineration residue | Cutoff, U - CH	382:Waste treatment and disposal	0,01744	kg 1,4-DCB-Eq
ferrochromium production, high-carbon, 68% Cr | ferrochromium, high-carbon, 68% Cr | Cutoff, U - RoW	241:Manufacture of basic iron and steel	0,00074	kg 1,4-DCB-Eq

Name	Category	Impact result	Unit
ozone depletion - ozone depletion potential (ODPinfinite)		1,17E-07	kg CFC-11-Eq
polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RER	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	9,10E-09	kg CFC-11-Eq
petroleum and gas production, offshore | natural gas, high pressure | Cutoff, U - NO	B:Mining and quarrying	1,20E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,37E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RNA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	2,83E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - RLA	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,20E-09	kg CFC-11-Eq
nitric acid production, product in 50% solution state | nitric acid, without water, in 50% solution state | Cutoff, U - CN	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	2,51E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - SE	351:Electric power generation, transmission and distribution	1,30E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - RU	351:Electric power generation, transmission and distribution	2,16E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - PL	351:Electric power generation, transmission and distribution	1,22E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - IT	351:Electric power generation, transmission and distribution	2,19E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - GB	351:Electric power generation, transmission and distribution	2,16E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - FR	351:Electric power generation, transmission and distribution	4,14E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - ES	351:Electric power generation, transmission and distribution	1,89E-09	kg CFC-11-Eq
market for electricity, high voltage | electricity, high voltage | Cutoff, U - DE	351:Electric power generation, transmission and distribution	3,99E-09	kg CFC-11-Eq
electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U - GB	351:Electric power generation, transmission and distribution	1,45E-09	kg CFC-11-Eq
electricity production, lignite | electricity, high voltage | Cutoff, U - DE	351:Electric power generation, transmission and distribution	4,40E-09	kg CFC-11-Eq
electricity production, hard coal | electricity, high voltage | Cutoff, U - DE	351:Electric power generation, transmission and distribution	2,50E-09	kg CFC-11-Eq
chlor-alkali electrolysis, membrane cell | sodium hydroxide, without water, in 50% solution state | Cutoff, U - RoW	201:Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics	1,58E-09	kg CFC-11-Eq
anaerobic digestion of manure | biogas | Cutoff, U - RoW	382:Waste treatment and disposal	3,26E-09	kg CFC-11-Eq