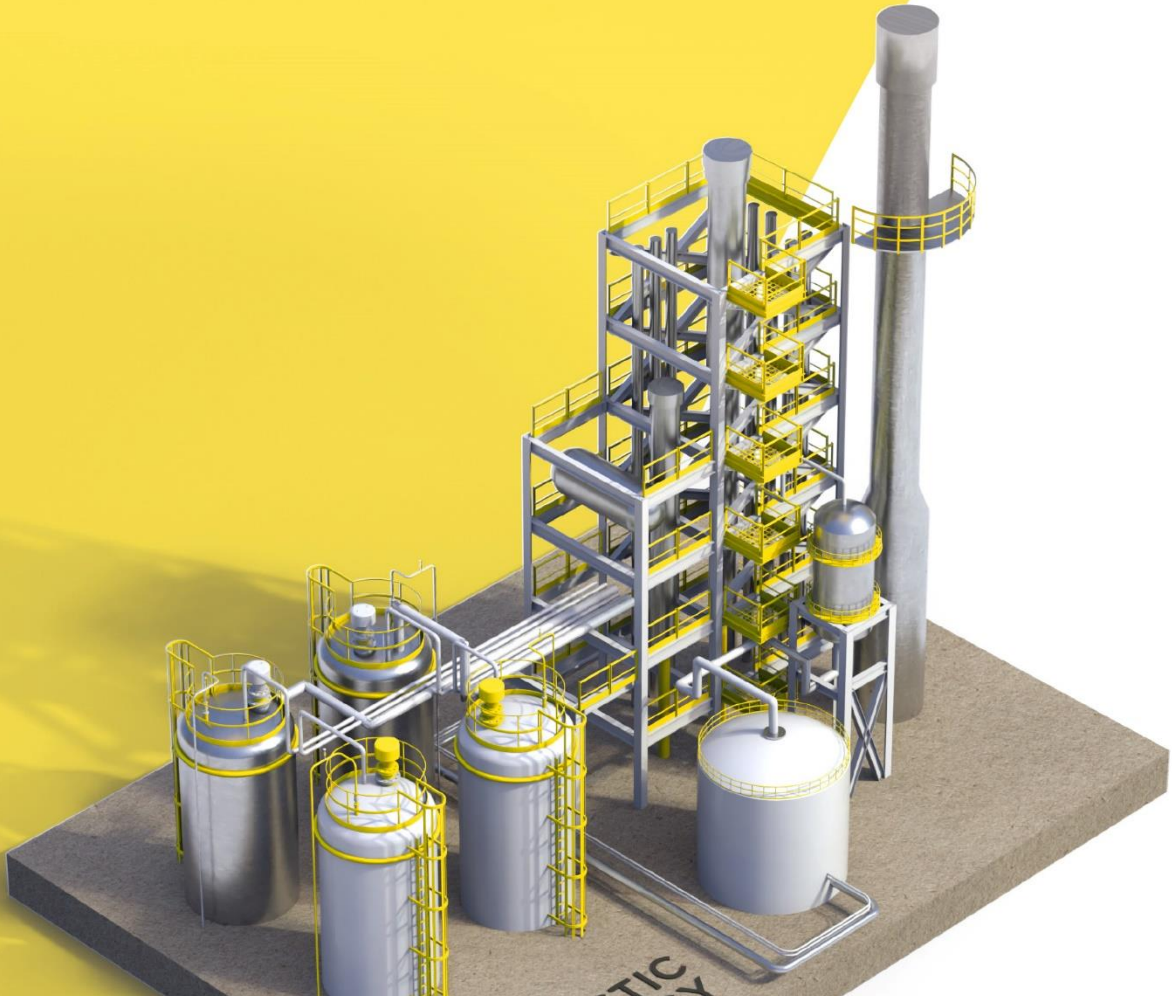
PLASTIC ENERGY

PLASTIC ENERGY LCA EXECUTIVE SUMMARY



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INTRODUCTION

Plastic Energy is an industry-leading chemical recycling technology provider, transforming mixed post-consumer plastic waste into a valuable alternative feedstock.

Our patented TAC™ recycling process converts end-of-life plastic into a recycled oil called TACOIL™, which replaces fossil oils in the production of new plastics, while diverting plastic waste from landfill and incineration.

Since 2016, TACOIL™, produced from our two operational chemical recycling plants in Spain, has been used to increase the amount of recycled content in plastic packaging products, contributing to a circular economy of plastics.

In 2020, we published our first chemical recycling Life Cycle Assessment (LCA) to help us demonstrate the impact of our technology (Quantis, 2020).

Since then, our TAC™ process has developed significantly, with higher efficiencies in throughput and energy usage, along with changes to the methodology for conducting LCAs.

These combined developments led to Sphera being commissioned in 2023 to conduct this LCA study of our updated TAC™ technology data. The LCA study was reviewed by a panel of independent LCA experts.

January 2025

EXECUTIVE SUMMARY

Headline results

1. Base case CO_2 eq. savings: Managing 1 tonne of mixed plastic waste via our TAC™ process has up to 78% CO_2 eq. savings compared to incineration with energy recovery (currently a status quo method of plastic waste disposal across Europe).

2. Further savings as the grid decarbonises: When using 100% renewable electricity, the CO_2 eq. savings of managing 1 tonne of mixed plastic waste, compared to incineration with energy recovery, increase from 78% to 89%.

3. Improvements from increased valorisation of by-products: Valorising syngas and char by-products from our TAC™ process into valuable by-products can lead to additional overall CO_2 eq. savings. We are conducting extensive R&D to maximise the output from our process.

LCA study scope

Chemical recycling through pyrolysis of mixed plastic waste (MPW) has two functions; it is both a waste treatment process, and a secondary material production process. To understand the impact of chemical recycling in both functions, previous studies have taken the approach of evaluating the system from a "waste perspective" and a "product perspective" (Quantis, 2020; Sphera Solutions GmbH, 2022; Sphera Solutions GmbH, 2020). This study also follows the two perspectives approach, by comparing chemical recycling to a status quo scenario that serves either a waste management, or a material production function.

- Waste perspective: Treatment of 1 tonne of MPW.

- Product perspective: Production of 1 tonne of virgin-quality low density polyethylene (LDPE) granulate, and treatment of 1.46 tonnes of MPW (the calculated quantity of pre-sorted MPW required to produce 1 tonne of LDPE).

The reference year for the study is 2023 and the geographical scope is Europe. The system boundary covers the waste-to-gate value chain with the additional waste-to-energy boundary for the status quo.

A selection of the Environmental Footprint (EF) 3.1 impact category indicator results were calculated for all product systems. For the purpose of this executive summary, Global Warming Potential (GWP) was identified as the most relevant impact category for further analysis.

In the waste perspective, the chemical recycling system includes the waste collection, sorting, extra sorting, pyrolysis (TAC™ process), and hydrotreatment of the TACOIL™ (pyrolysis oil). A credit for recovered naphtha is also assigned to the hydrotreated TACOIL™ output. The status quo includes waste collection, sorting, and incineration with energy recovery of MPW.

In the product perspective, the TACOIL™ is further processed with steam cracking and polymerisation to yield 1 tonne of LDPE granulate. In the status quo, the production of 1 tonne of fossil-based LDPE granulate is included, expanding the system by the additional functional unit of managing 1.46 t of MPW via municipal solid waste incineration (MSWI) with energy recovery.

Background data taken from the Sphera Managed LCA Content version 2024.1 is documented online (Sphera Solutions GmbH, 2024). Material datasets have a reference year of 2023 and energy datasets of 2020.

About Plastic Energy's TAC™ process

Within our patented TAC™ process, plastics are heated in the absence of oxygen to form hydrocarbon vapours. These vapours are then condensed into a recycled oil, called TACOIL™. The process consists of:

1. Hot Melt Pump – The plastic is heated until it becomes a plastic melt. It is then pumped to the reactors.
2. Reactor – The plastic melt is further heated (in the absence of oxygen) and changes from liquid to vapour. A small portion of solids are extracted as char.
3. Contactor – The vaporised molecular chains are selected and act as a filter.
4. Condensation – Condensed vapours are refined through a series of separators and filtration steps, creating a synthetic oil which is a feedstock for new plastics. The synthetic gas is used to heat the reactors.
5. Recycled oils: TACOIL™ – The synthetic output, called TACOIL™, is stored for sale to our petrochemical partners.

We strive to continually improve our TAC™ process to make it more efficient in terms of resource and energy usage. This LCA uses design data for a second-generation plant of the TAC™ process technology. Design data refers to second-generation design data that has not been measured at an actual operational process, but which is derived from a first-generation operational plant data, with adjustments made to account for differences in capacity, yield, efficiencies, utilisation of waste streams, and by-products. As such, this data represents estimated values rather than measured ones.

LCA product systems

In this assessment, our TAC™ process is compared to the status quo of waste management and virgin LDPE production in Europe, evaluating a case study from both a waste and product perspective.

Waste perspective

In the waste perspective, the system boundary starts from the collection of waste and ends at the production of TACOIL™ from 1 tonne of sorted MPW (functional unit). This is compared against the status quo where MPW is incinerated with energy recovery, rather than recycled.

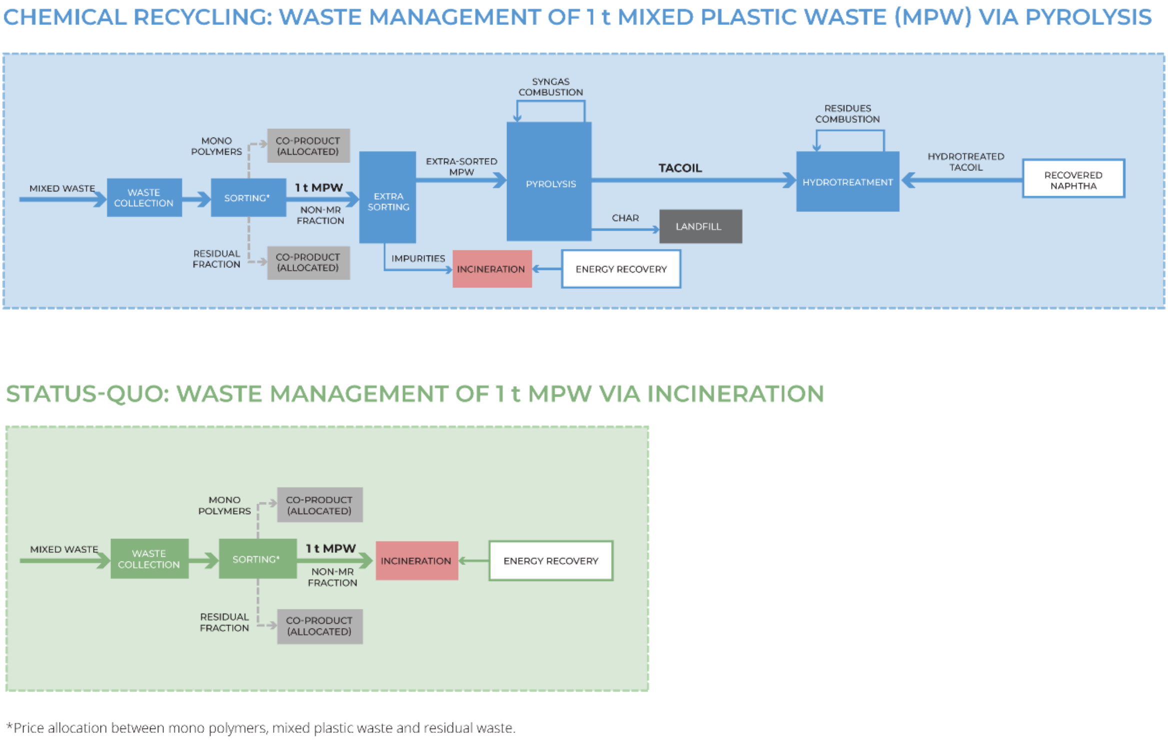


Figure 1: Waste perspective system boundaries: chemical recycling and status quo

Chemical recycling system (waste perspective).

1. Mixed waste is collected from households and sorted into mono polymer streams that are sent to mechanical recycling, MPW, and residual fractions.
2. MPW is sorted further to separate a high-calorific value waste from residual fractions. This is necessary to meet the feedstock requirements of the TAC™ process.
3. The sorted MPW undergoes our chemical recycling process (pyrolysis) and is turned into TACOIL™.

4. The TAC™ process produces two other products. Syngas is recirculated to heat the reactors, and the char is landfilled.

5. Resulting TACOIL™ undergoes a hydrotreatment step and the purified TACOIL™ is used as feedstock in the chemical industry.

Status quo (waste perspective).

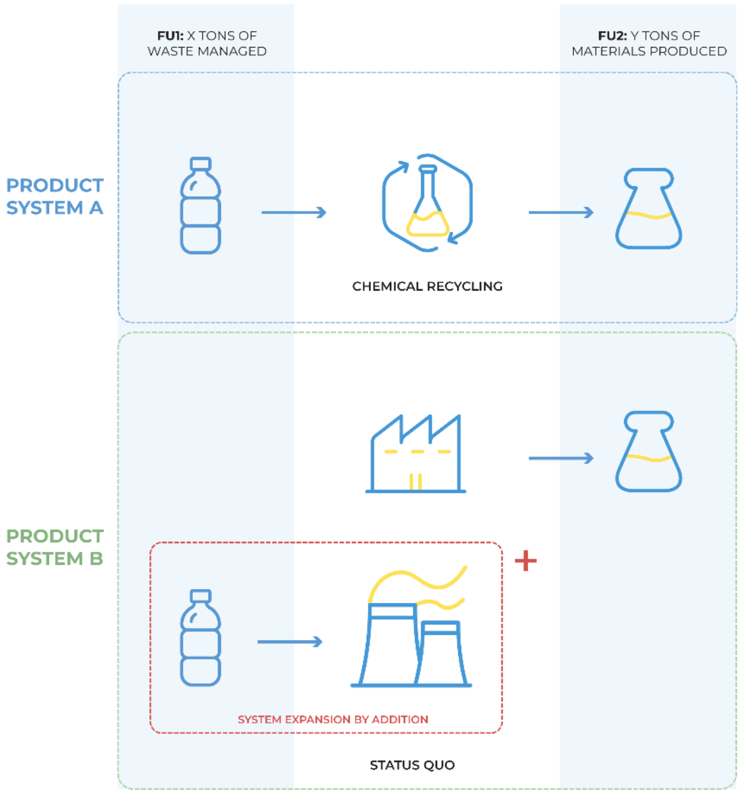
1. Mixed waste is collected from households and sorted into mono polymer streams that are sent to mechanical recycling, MPW, and residual fractions.

2. MPW is transported and treated in a MSWI plant. The resulting energy (a mix of thermal energy and electricity) is recovered and substitutes thermal energy and electricity on the European market.

Product perspective

In the product perspective, the system boundary begins with the collection of waste and ends with the production of 1 tonne of LDPE (functional unit). This is compared against two status quo systems where MPW is incinerated with energy recovery, and where 1 tonne of LDPE is produced from virgin fossil instead.

Since the pyrolysis process serves two functions, the product perspective deals with multi-functionality in the system. This is addressed by implementing a system expansion through an addition to the status quo (comparative system), as is described by Koffler, et al. (2021).



The assumption is that MPW feedstock to pyrolysis is diverted from MSWI with energy recovery. Therefore, the burden of this waste treatment process is included as part of the status quo, together with the production of the virgin LDPE granulate.

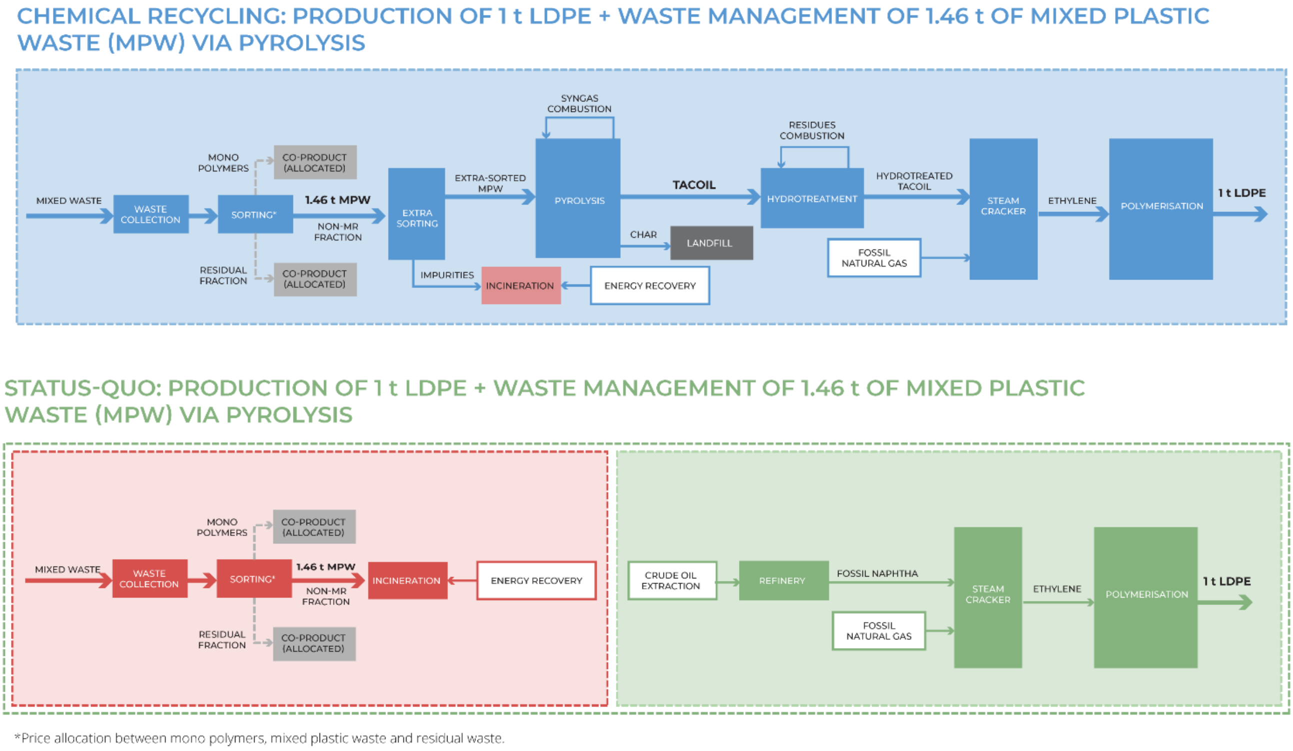


Figure 2: Product perspective system boundaries: chemical recycling and status quo

Chemical recycling system (product perspective).

1. Mixed waste is collected from households and sorted into mono polymer streams that are sent to mechanical recycling, MPW, and residual fractions.

2. MPW is sorted further to separate a high-calorific value waste from residual fractions. This is necessary to meet the feedstock requirements of the TAC™ process.

3. This sorted MPW undergoes our TAC™ process and is turned into TACOIL™.

4. The TAC™ process produces two other products. Syngas is recirculated to heat the reactors, and the char is landfilled.

5. Resulting TACOIL™ undergoes a hydrotreatment step and the purified TACOIL™ is used as feedstock in the chemical industry, substituting naphtha from conventional (fossil-based) production.

6. Purified TACOIL™ is treated in a steam cracker yielding ethylene, which is further processed into low density polyethylene (LDPE).

Status quo (product perspective).

1. Mixed waste is collected from households and sorted into mono polymer streams that are sent to mechanical recycling, MPW, and residual fractions.

2. MPW is transported and treated in a MSWI plant. The resulting energy (a mix of thermal energy and electricity) is recovered and substitutes thermal energy and electricity on the European market.

3. Fossil naphtha (from crude oil) is treated in a steam cracker yielding ethylene, which is further processed into LDPE.

Collection, sorting, and extra sorting of MPW, as well as the TACOIL™ hydrotreatment process, were based on primary and secondary data taken from the published study "Life Cycle Assessment of Chemical Recycling for Food Grade Film" provided by Sphera and commissioned by the Consumer Goods Forum in 2022 (Sphera Solutions GmbH, 2022).

Limitations of the system boundaries

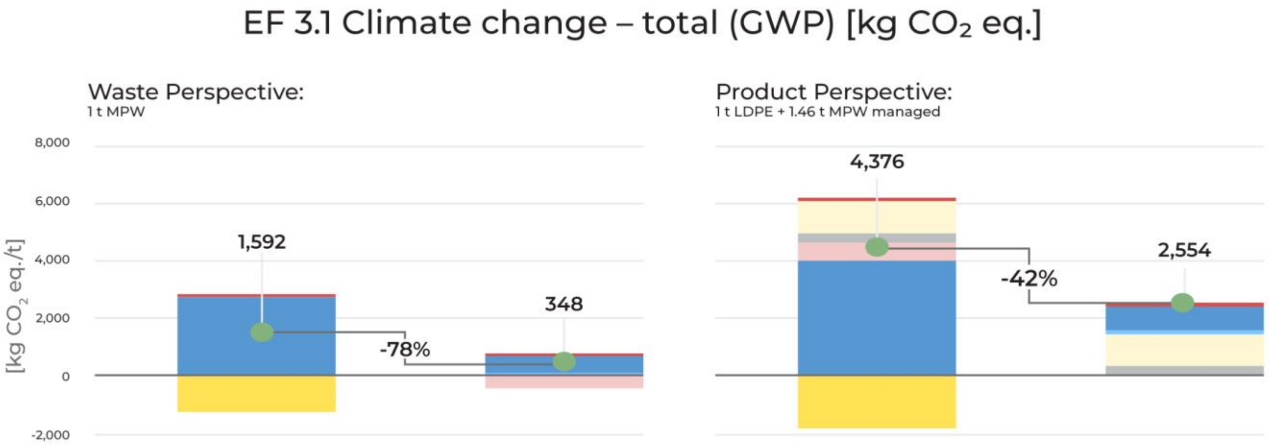
The system boundaries include the production of all raw materials, auxiliaries, utilities and energy needed to fulfil the function of the system. The manufacturing processes from the LDPE granulate to final application, use phase, and end-of-life of the plastic product are not included in the study. The reason for not including them is based on assumptions that would be equal for both the status quo and the chemical recycling systems.

Collection of mixed waste from households and transport of sorted MPW to the chemical recycling plant or to the MSWI plant (status quo) are included in the study, as well as the transport of residues from extra sorting and pyrolysis to MSWI. Transport of other raw materials to their respective processes were excluded as it was assumed that transport happens within the site via pipeline. The impact of excluded transport is either equal or likely to be similar for the assessed systems

Life cycle impacts of production equipment and infrastructure are excluded from the system boundaries. For large-scale processes, the impact of equipment and infrastructure production is normally in orders of magnitude lower than the impact of material and energy supply. Also, these impacts are likely to be similar for both assessed systems.

Results

Compared to the status quo, chemical recycling has the potential to reduce the GWP result by 78% in the waste perspective and 42% in the product perspective.



	Waste Perspective: STATUS QUO	Waste Perspective: CHEMICAL RECYCLING	Product Perspective: STATUS QUO	Product Perspective: CHEMICAL RECYCLING
Coll. & sorting	79	87	116	127
Pyrolysis	0	577	0	845
Hydrotreatment	0	103	0	150
Cracker	0	0	1,115	1,115
Polymerization	0	0	317	317
Naphtha	0	-418	612	0
EoL MPW	2,742	0	4,017	0
Energy recovery	-1,230	0	-1,802	0
Total	1,592	348	4,376	2,554

Figure 3 - EF 3.1 Climate Change – absolute contributions

The results of this study demonstrate the potential of our TAC™ process as a well-established chemical recycling technology producing a valuable alternative feedstock for the chemical industry and a novel waste management pathway for MPW treatment.

Considering the limited availability of non-renewable resources and increasing global temperatures, the implementation of plastic recycling technologies is encouraged to deal with the current and future global environmental challenges. To reach higher recycling rates, it is important that more packaging fractions are designed for recycling, while encouraging the development of chemical recycling technologies at industrial scale.

Future improvements and efficiencies

Carbon savings can increase by 10% with a 100% green electricity grid, compared to the base case

In the following future electricity grid mix scenario, all electricity use in the foreground system was exchanged from a current grid mix (base case) to a 2030, 2050, and green electricity grid mix. The share of renewable energy in the mix increases from ca. 40% in the base case to 55% in 2030, 85% in 2050, and 100% in the green electricity mix scenario. The green mix scenario includes electricity from 62% photovoltaics, 32% wind, 5% hydropower and others. Thermal energy use, including thermal energy recovery from MSWI, remained unchanged throughout the system.

In the green (100% renewable) electricity mix scenario, CO_2 eq. savings have an overall increase from 78% (base case) to 89% in the waste perspective, and from 42% (base case) to 55% in the product perspective.

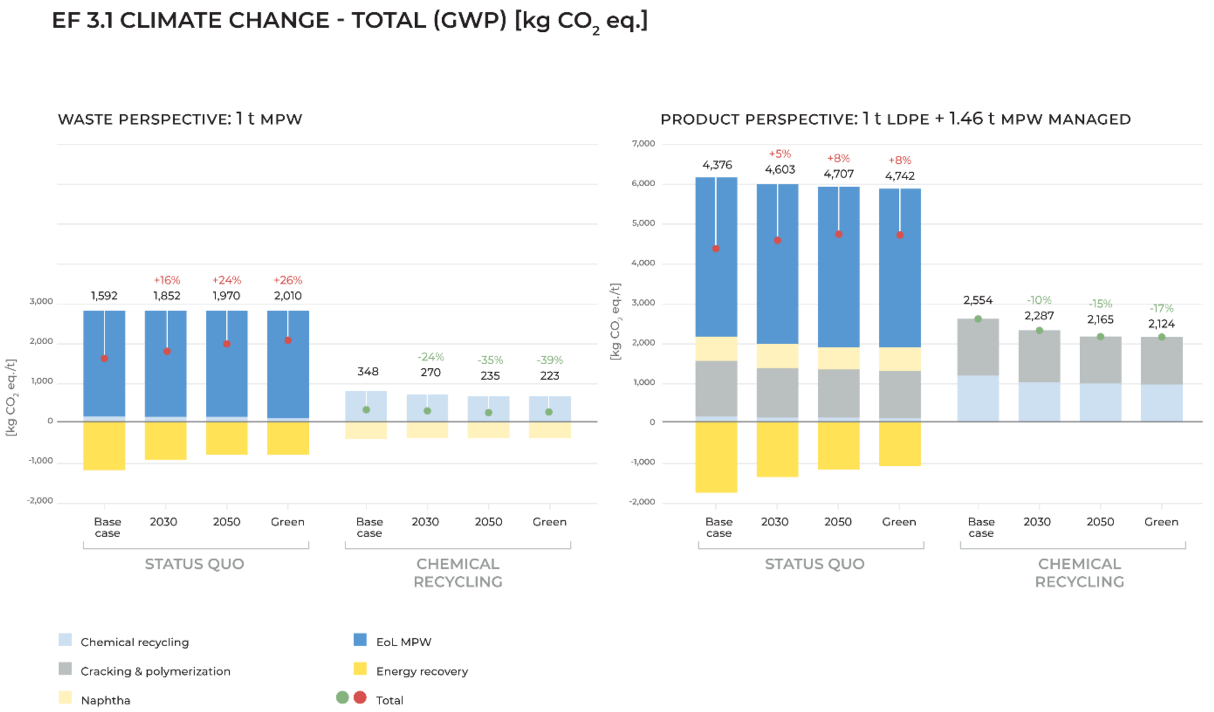


Figure 4 - electricity grid mix – contribution analysis for EF 3.1 Climate Change

A lower-carbon circular economy of plastics is closer than we think

Our LCAs have consistently demonstrated that the chemical recycling of MPW has lower carbon emissions compared to the current status quo in Europe. In addition, a circular economy of plastics minimises plastic leakage into the environment and allows necessary contact-sensitive applications of plastic to be made more sustainably. This LCA has enabled us to see more clearly where in our process the largest carbon emissions are, and to focus on reducing these pain points.

We are conducting extensive R&D into valorising syngas and char into valuable by-products to maximise the output from our process. This would translate into additional carbon savings, thus further reducing the overall carbon footprint.

We are not alone in our commitment to reduce the environmental impact from our process. Across the plastics value chain, there have been numerous strides in progress towards decarbonisation.

The electrification of steam crackers has the potential to reduce current fossil-fuel cracker emissions by 90%, which will have an immensely positive impact on the recycled plastics value chain. In April 2024, BASF, SABIC, and Linde began operations of an electric steam cracker demonstration plant in Germany. Other industry players such as Shell and Dow have also begun investing resources into developing electric steam cracker processes (Sustainable Plastics, 2024).

From industry electrification, to more ambitious policy targets and legislation, to plastic packaging designed for recyclability, a sustainable decarbonised plastics value chain is closer than we think.

PLASTIC® ENERGY

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