Quantis

LIFE CYCLE ASSESSMENT OF PLASTIC ENERGY TECHNOLOGY FOR THE CHEMICAL RECYCLING OF MIXED PLASTIC WASTE

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PLASTIC® ENERGY

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Executive Summary

Context and objectives

Concern is increasing around the environmental and social sustainability of our society's consumption habits. This has put pressure on companies to understand and proactively manage the potential environmental and societal effects of their products and services. Nearly all major product producers now consider environmental and social impacts as part of their business strategy, and sustainability is a recognized point of competition in many industries.

Plastic Energy, a leading company in chemical recycling of mixed plastic, believes that giving a second life to waste plastic is an important factor in tackling the problem of plastics in our natural environment. Due to varying rates of recycling and collection, plastic waste is currently not being recycled to its full potential, and is ending up in landfills and/or as litter in nature. Through the use of a Life Cycle Assessment (LCA), Plastic Energy has engaged in an effort to understand the environmental profile of waste plastic recycling using its chemical recycling process. The environmental performance of the process is evaluated using a waste perspective approach, i.e., comparing it to other waste management practices (landfill and incineration), and on a product perspective approach, i.e., comparing it to other ways of producing plastic, i.e. virgin plastic made from fossil fuels ["fossil"] and mechanically recycled plastic).

This study evaluates the environmental performances related to the chemical recycling process, i.e. chemically recycling mixed plastic waste into new, high quality LDPE, and comparing it to other relevant scenarios. Two approaches are assessed, **waste perspective** and **product perspective**, as described below.

In the waste perspective approach, different end-of-life options are evaluated for treating 1 kilogram (kg) of mixed plastic waste, in order to understand the strengths and weaknesses of each scenario assessed. For the product perspective approach, different ways of producing 1 kg of LDPE plastic are evaluated, using virgin and/or recycled feedstocks.

The evaluated waste perspective scenarios include:

1. Managing mixed plastic waste through the chemical recycling process of Plastic Energy
2. Managing mixed plastic waste through incineration with energy recovery
3. Managing mixed plastic waste in landfill

The evaluated product perspective scenarios include:

1. Chemically recycled LDPE from mixed plastic waste using Plastic Energy technology
2. Virgin (fossil) LDPE
3. Mechanically recycled LDPE

For the waste perspective approach, mechanical recycling is not considered an applicable scenario since chemical recycling is intended to be complementary to it, and rather, substitutes it as the end-of-life scenario.

The specific goals of this study are:

I. To carry out an ISO 14040/14044 compliant LCA of Plastic Energy's chemical recycling process, using primary data.
II. To compare the performance of the chemical recycling process with other waste management schemes (waste perspective approach).
III. To compare the performance of the chemical recycling process with conventional ways to produce plastics (product perspective approach).
IV. To use the results to better understand the environmental profile hotspots of the chemical recycling process.
V. To use the findings of the LCA to potentially support publicly disclosed comparative assertions.

Function and functional unit

Life cycle assessment relies on a "functional unit" (FU) for comparison of alternative products that may substitute each other in fulfilling a certain function for the user or consumer. The FU describes this function in quantitative terms, and serves as an anchor point in the comparison, ensuring that the alternatives do indeed fulfil the same function. As such, it's critical that this parameter is clearly defined and measurable.

In this assessment, the system is analyzed from a waste perspective and product perspective. Since the two perspectives are different, **two functional units** are defined:

Functional unit for waste perspective approach: Waste management of 1 kg of sorted mixed plastic waste in Europe.

Functional unit for product perspective approach: Producing 1 kg LDPE for use in Europe.

The two systems were chosen in order to assess the potential environmental advantages and disadvantages of using Plastic Energy's chemical recycling process as an alternative, from a waste management perspective and a plastic production point of view.

Methodology

This study assesses, on one hand, the management of 1 kg of sorted mixed plastic waste via three alternative pathways, and on the other hand, the production of 1 kg of plastic, based on three possible production streams. For the former, the boundaries exclude the polymer production, not including both the use the end-of-life of the product. (Figure 1)

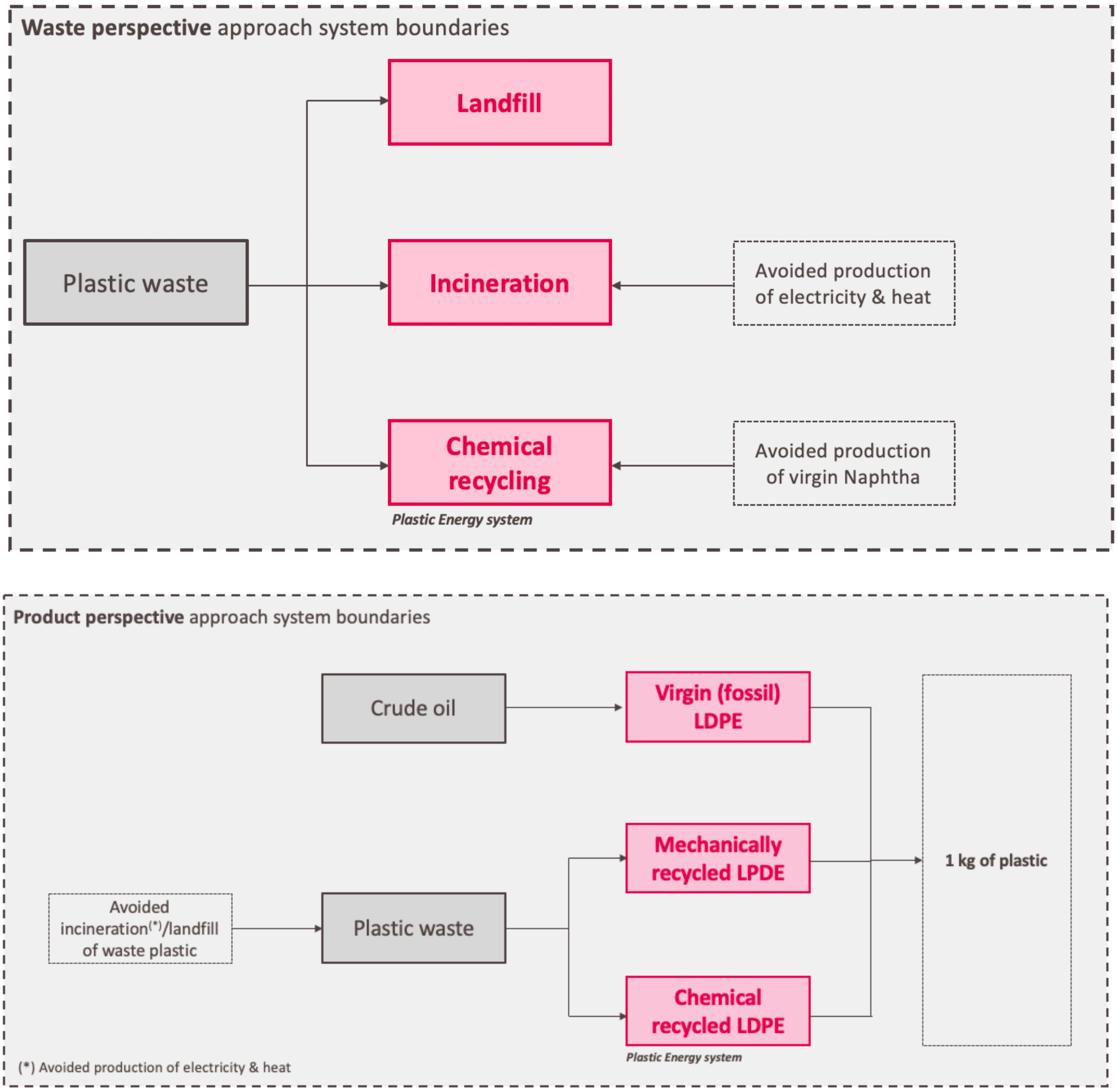

Figure 1 Life cycles of waste and product perspective scenarios evaluated in this study. Red boxes indicate the main system, grey ones the feedstock used.

For this study, given the two functional units, the system boundaries considered in the study are different, depending on the approach (Figure 1).

The method used here to evaluate environmental impacts is the Environmental Footprint (EF) method (JRC-IES 2017). It is the official recommended method used in the Product Environmental Footprint (PEF) context of the Single Market for Green Products (SMGP) initiative (European Commission 2013).

Results

Waste perspective approach

Table 1 presents LCIA results for the chemical recycling, incineration, and landfill waste management systems. Results are reported for the climate change and resources depletion indicators; the two most relevant indicators for the study. Negative values represents environmental benefits.

Table 1: Waste perspective approach—overall LCIA results for 1 kg of treated mixed plastic waste.

	Waste perspective approach		
Indicator (units)	**Chemically recycled LDPE**	**Incineration with energy recovery**	**Landfill**
Climate change (kg CO_2-eq)	0.55	1.60	0.15
Resources use, fossil (MJ)	-31.10	-26.54	0.36

For climate change, landfill shows the lowest impact, followed by chemically recycled LDPE, and incineration. For resource use, fossil chemically recycled LDPE is the most favorable solution, showing environmental credits related to the avoided production of virgin naphtha (Table 1).

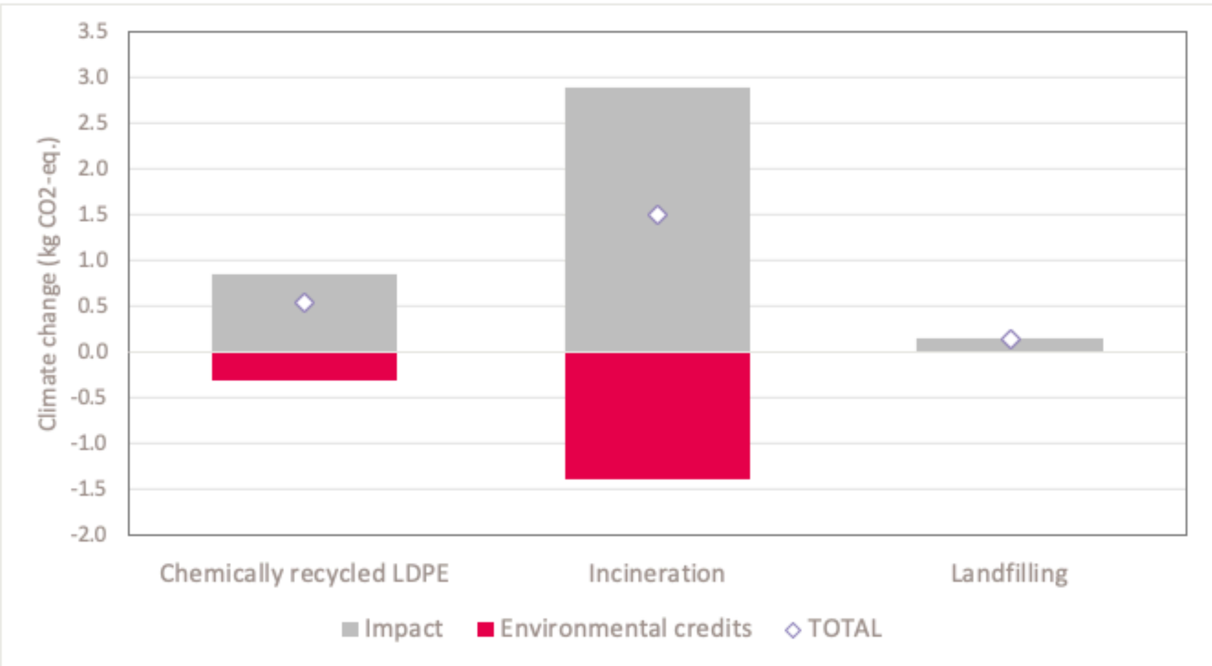

Figure 2: Waste perspective scenarios impacts and benefits, for 1 kg of mixed plastic waste treated, climate change indicator.

Figure 2 shows the results of the three scenarios, dividing between impacts and environmental credits, for climate change. For chemically recycled LDPE, the credits are related to the avoided production of virgin naphtha, while for the incineration, they refer to the avoided production of energy (heat and electricity). An average European mix is considered to be replaced by the electricity production, while natural gas by the heat recovered during the incineration process. The efficiency used in the waste to energy plant are respectively 10.1% for electricity and 31% for heat, as described in section 4.2.3.

To summarize:

- Currently, none of the three scenarios have consistently low or high impacts or scores across all indicators assessed.
- Incineration is the scenario with highest climate change impacts, as GHG emissions from plastic incineration are not fully compensated by the electricity and heat recovered in the process.
- Plastic degrades only partially in a landfill (1%), resulting in relatively low climate change impacts. On the other hand, no environmental credits are generated, as no energy or materials are recovered from the process. Moreover, generally, landfill increases the probability that materials will end up in nature (e.g. plastic leakage into the environment) and should therefore be discouraged. In addition, landfilling is detrimental to circularity, and to fossil resource use, fossil. This aspect would need to be addressed by an indicator which evaluates plastic leakage into the environment, which is out of scope of the current project.
- Overall, considering that disposal of waste in landfills will likely be discouraged more and more in Europe, due to a non-valorization of the waste (as energy, or as recycled materials), and the expectation that the average European energy mix will begin to include more renewable energy options, this will ultimately begin to gap between the economic benefit of incineration (when energy and heat are stored and reused), and chemical recycling, as a viable way to manage plastic waste. As such, **chemical recycling of plastic waste will become in time a more and more favorable solution from a waste management perspective.**

Product perspective approach

Table 2 presents LCIA results related to the production of 1 kg of LDPE with the above-mentioned alternative methods.

Table 2: Product perspective approach—overall LCIA results for 1 kg of LDPE produced.

	Product perspective approach		
Indicator (units)	**Chemically recycled LDPE**	**Virgin (fossil) LDPE**	**Mechanically recycled LDPE**
Climate change (kg CO_2-eq.)	0.86	1.90	-0.45
Resources depletion (MJ)	39.54	80.08	22.14

Both indicators show similar trends for the three systems, with mechanically-recycled LDPE being the most favorable solution, followed by the chemically-recycled LDPE, with virgin (fossil) LDPE as least favorable.

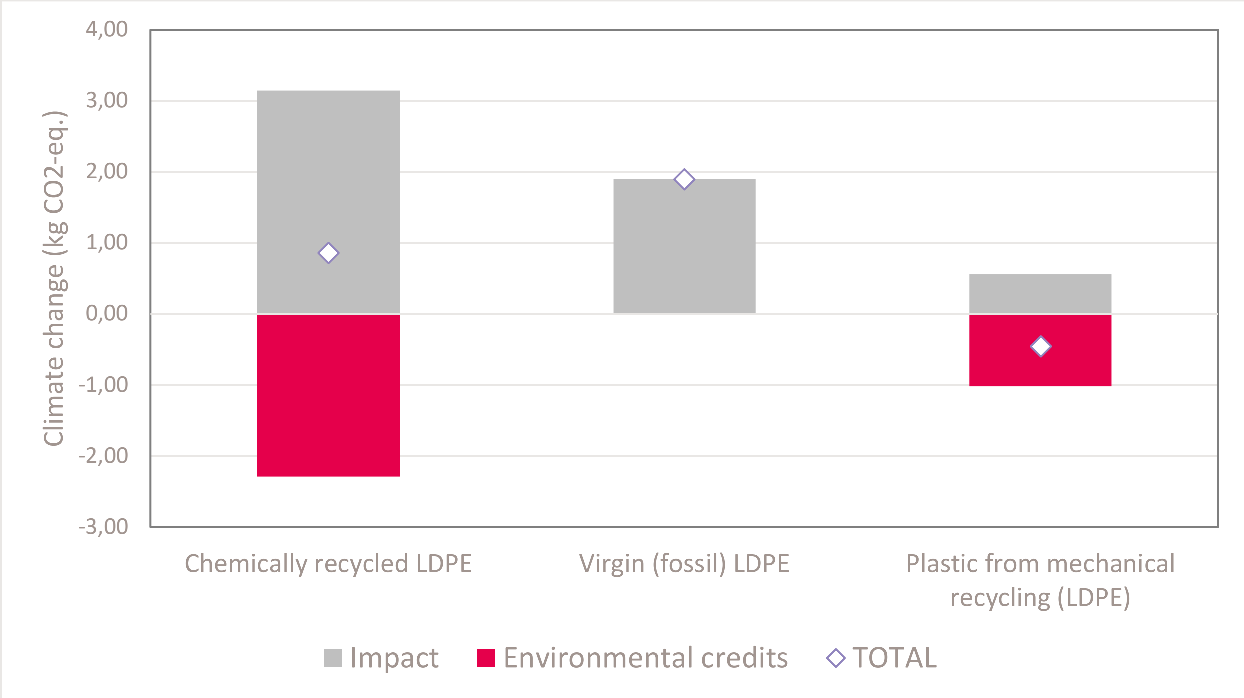

Figure 3: Product perspective scenarios impacts and benefits, for 1 kg of mixed plastic waste treated, climate change indicator.

For both the chemically- and mechanically-recycled LDPE, environmental credits are associated with the avoided impacts related to waste treatment of plastic waste (i.e., 55% avoided with incineration & energy recovery; and 45% avoided due to reduced landfill deposits, according to the average waste management practices in Europe). Chemically-recycled LDPE shows the highest climate change impacts, and also has the highest environmental credits, compared to the other two scenarios. Environmental credits are higher in the chemically recycled LDPE than for the mechanically recycled one because in the former, higher amount of plastic waste is needed for the process, due to a lower efficiency, and therefore diverted from incineration/landfill (Figure 3). To summarize:

- Mechanical recycling shows the best performances for both indicators, compared to the alternative scenarios assessed.
- Compared to virgin (fossil) LDPE, chemically recycled LDPE has lower climate change and resources depletion scores.

Overall, chemically recycled LDPE has favorable results when compared to virgin LDPE, but higher scores than mechanically recycled LDPE.

A series of sensitivity analyses were performed to study the influence of the uncertainty and variability of modelling assumptions, and data on the results and conclusions, thereby evaluating their robustness and reliability. The following parameters and choices were varied to test the sensitivity of the results and conclusions:

- Electricity mix used in the chemical recycling facility, for both the product and waste perspective approaches (i.e., EU mix vs 100% renewable one)
- Assuming, instead, that the entire plastic waste used in the chemical recycling process, alternatively, would have been incinerated (product perspective approach)
- Assuming, instead, that the entire plastic waste used in the chemical recycling process, alternatively, would have been sent to landfill (product perspective approach)
- Different distances travelled by truck (100 km, 500 km, 1000 km) to transport plastic waste to sorting facility for chemical recycling scenario (product and waste perspective approach)
- Electricity utilization for pyrolysis (± 20% compared to the baseline) at the chemical recycling facility
- Different amounts of Naphtha needed to produce 1 kg of LPDE (baseline: 1.6 kg Naphtha / kg LDPE; additional amounts tested include 1.4, 1.2 and 2.0 kg Naphtha / kg LDPE)
- Efficiency of Chemical Recycling process in terms of TACOIL [1]produced/feedstock (baseline: 69.6%; additional efficiencies of 65% and 75% assessed)
- Amount of energy (i.e., electricity and heat) recovered from waste plastic in the incineration process (baseline: average EU energy recovery rate; other scenarios assessed include no energy recovery, and high energy efficiency)
- Mechanical recycling quality ratio (Qs/Qp = 0.9 and 0.75) from the Product Environmental Footprint (PEF) guidance has been tested to integrate the quality of the plastic as a parameter in the study.

Conclusions

From an environmental perspective, **chemical recycling** is an **interesting solution** as it accepts a wide range of plastics types (i.e. PP, LDPE, PS) producing high quality, food grade, recycled plastic. The technology shows promising results in terms of environmental performances, especially when the alternative for the plastic stream would otherwise result in incineration.

In general, **energy consumption and process yield** are more important in chemical recycling than for mechanical recycling. Energy consumption, particularly during the pyrolysis stage, is indeed the main environmental hotspot of chemically recycled LDPE.

Among the scenarios analyzed in the study, the only alternatives which perform consistently better than chemical recycling across most of the indicators is mechanical recycling. However, plastics can be **mechanically recycled only a few times** before their material properties degrade, while chemical recycling breaks the polymer bonds, creating new molecules that can be polymerized again. For this reason, chemically-recycled plastic results in a higher quality product, which can be used for food grade purposes. Ideally, from an environmental perspective,

[1] It is the output of the pyrolysis process, taken from the name of the technology Thermal Anaerobic Conversion (TAC).

mechanical recycling should be firstly applied for a few times and after that, when the polymer is too far degraded, chemical recycling should be performed.

Overall, one can compare end-of-life options with each other and try to answer the question: what is the best route from and environmental standpoint: chemical recycling, mechanical recycling or incineration? Reality is that they all have their assets depending on the quality of plastic waste stream: PET bottles or PE films will automatically go for mechanical recycling (the other options are a No Go), mixed plastic waste stream will likely find good opportunities with chemical recycling, and if the plastic stream is too contaminated then incineration is probably the best choice. So, independent of the outcome of such LCA, there will probably be place for all three end-of-life routes for the current and near future European market.

The results have led to the following recommendations and further improvements of the chemical recycling process:

- **Reduce energy consumption during the process and increase process yield**. Compared to mechanical recycling, chemical recycling is characterized by a **higher number of steps**, **which require high energy consumption.** Increasing the efficiency of the process would reduce the energy consumption and therefore mitigate overall environmental impacts.
- Switching to **100% renewable electricity** sourcing can **significantly decrease the carbon footprint** of the chemical recycling process.