On behalf of
Republic Services

Comparative Carbon Footprint of Recycled and Virgin PET

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On behalf of Sphera Solutions, Inc., and its subsidiaries

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List of Acronyms

CFP	Carbon Footprint of Products
EoL	End-of-Life
EPA	Environmental Protection Agency
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Cycle Data System
IN	India
ISO	International Organization for Standardization
JP	Japan
LCA	Life Cycle Assessment
LCA FE	Life Cycle Assessment for Experts
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LVPC	Las Vegas Polymer Center
MLC	Managed Life Cycle Content
MRF	Materials Recovery Facility
PCF	Product Carbon Footprint
PCR	Product Category Rule
PET	Polyethylene Terephthalate
rPET	Recycled Polyethylene Terephthalate
RS	Republic Services
US	United States

Glossary

Carbon Footprint of Products (CFP)

A life cycle study that only quantifies a single impact category: climate change (ISO, 2019).

Declared Unit

An amount of a product, typically mass-based, that is used as a reference unit for a partial PCF (ISO, 2019).

Partial Product Carbon Footprint

A PCF that does not include all the stages in a product's life cycle. They are most commonly cradle-to-gate assessments (ISO, 2019).

Life Cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life Cycle Interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

Foreground System

"Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study." (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background System

“Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good….” (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

“Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment” (ISO 14044:2006, section 3.45).

Executive Summary

Republic Services, Inc. ("Republic Services") is a leading North American environmental services company based in Phoenix, Arizona, providing comprehensive waste management solutions across North America. Their services include non-hazardous solid waste collection and disposal, waste transfer, recycling, hazardous waste collection and disposal, and energy recovery.

Republic Services commissioned Sphera to conduct a cradle-to-gate comparative product carbon footprint study of their recycled polyethylene terephthalate (rPET) according to ISO 14067 (ISO, 2019) and Product Category Rule (PCR) 2010:16 on Plastics in Primary form (EPD, 2024) . This study allows Republic Services to identify opportunities for improvement as well as for its internal and external stakeholders to understand the relative performance of their own rPET to rPET and virgin PET in the market.

The assessment consists of Republic Services own rPET as produced in Las Vegas Polymer Center (LVPC) which produces bottle grade rPET flake from postconsumer waste and compares it to representative rPET (non-bottle grade) produced in the US and Asia and virgin bottle grade PET produced in the US and India. To support public communication, this report undergoes critical review as per ISO/TS 14071 (ISO, 2024). Note that ISO 14067 (ISO, 2019) studies are solely concerned with a single impact category (i.e., climate change), and thus the results of this study cannot support comparative assertions about the overall environmental superiority or equivalence of one product versus another.

The assessment is based on two declared units where rPET products are compared on the basis of "1 kg of flake at gate in the US" and when virgin PET is assessed, rPET alternatives are compared on the basis of "1 kg of pellet in the US". For the material produced outside of the US, the corresponding transport is included within the system boundaries. The LVPC data is based on a range of yields to represent how efficiencies change with the throughput of rPET – referred to as "Low Capacity" and "High Capacity". Thus, the six types of PET pellets are being compared in this study:

1. Republic Services bottle grade rPET produced in the US – Low Capacity
2. Republic Services bottle grade rPET produced in the US – High Capacity
3. Representative rPET produced in the US
4. Representative rPET produced in Asia
5. Representative virgin PET produced in the US
6. Representative virgin PET produced in India

To summarize results, Figure ES-1 shows that Republic Services rPET, both Low and High Capacity, have a lower carbon footprint than the industry representative rPET for US and Asia and are well below the Virgin counterpart in US and India. On average, Republic Services rPET represents a reduction of 34% relative to rPET US and 49% relative to rPET Asia. When comparing to the virgin PET counterparts, the reductions are far more significant and range between 81% and 84% for US and India respectively.

The pattern of results remains when comparing the carbon footprint on a flake basis (i.e. removing the conversion step). On a flake basis, Republic Services rPET is between 47% and 62% lower relative to rPET US and rPET Asia.

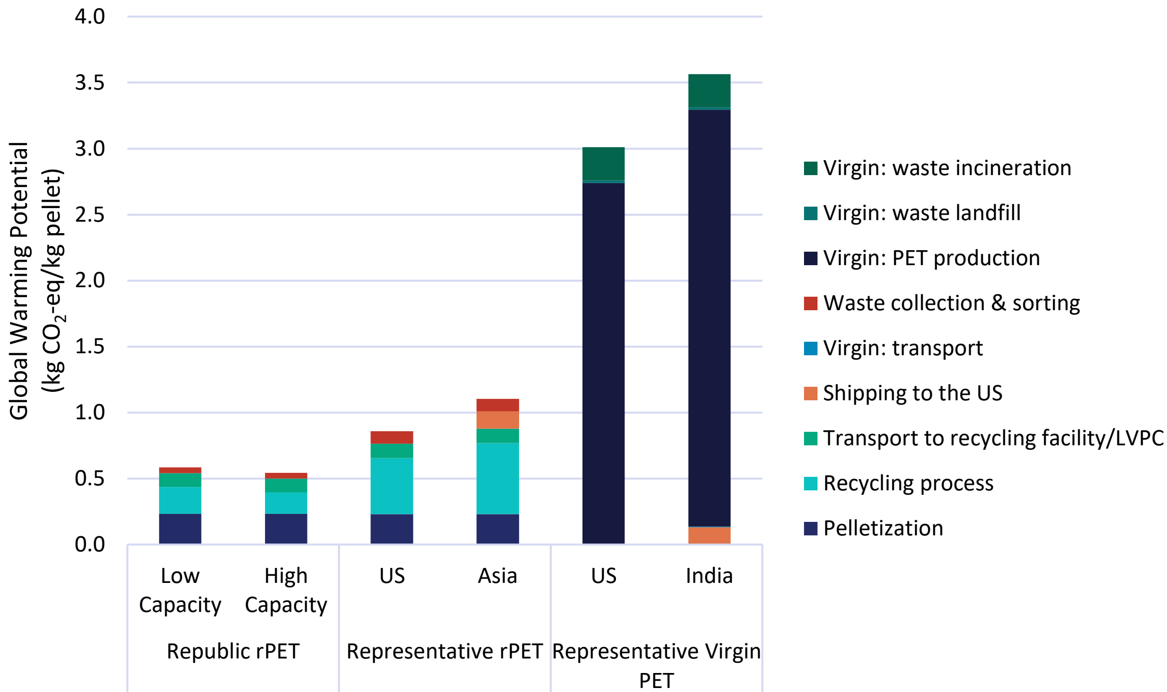

Figure ES- 1: Comparative PCF results for Republic Services and representative recycled PET

Republic Services rPET results in a lower carbon footprint mainly because of lower impacts from the electricity consumption as a result of 1) LVPC being a multi-output facility where various material fractions are recovered and thus sharing some of the electricity load; 2) LVPC being a more efficient facility consuming less electricity and thermal energy per kg of flake and 3) the grid at LVPC having a lower carbon impact than the average US grid and the Asian market's grid mix.

Bottle grade virgin PET's impact is significantly greater than the rPET alternatives due to upstream impacts in the manufacturing (i.e. relying on fossil fuels) and additional shipping to the US (in the case of virgin PET from India). The impacts of baseline waste management also increase this difference.

When taking a closer look within the ISO 14067 (ISO, 2019) carbon footprint indicators, results show over 99.4% of the total GWP comes from fossil greenhouse gas emissions.

In conclusion, Republic Services rPET appears to have a competitive advantage in terms of carbon footprint relative to virgin PET and rPET produced in the US and Asia mainly because of the more energy efficient process. Considering both Low and High Capacity, Republic Services carbon footprint is on average 54% lower than the rPET flake alternatives evaluated and 82% lower, on average, than the virgin PET pellet alternatives. Note that Republic Services rPET offering is unique in that it is both recycled and bottle grade, something which is not the case of the rPET US and Asia depicted in this study. Therefore, to maximize potential reductions, it is important for Republic Services to target the virgin PET market.

In terms of improvement, Republic Services should focus on yields and energy – either improved energy efficiency and/or looking to further decarbonize their energy sources. In terms of maximizing their effort, Republic Services could potentially see some gains from including conversion in their operation.

1. Goal of the Study

Republic Services, Inc. (“Republic Services” or “RS”) is a leading North American environmental services company based in Phoenix, Arizona, providing comprehensive waste management solutions across the United States. Their services include non-hazardous solid waste collection and disposal, waste transfer, recycling, hazardous waste collection and disposal, and energy recovery.

The main goal of this study is to develop a comparative product carbon footprint (PCF) in accordance with ISO 14067 (ISO, 2019) and Product Category Rule (PCR) 2010:16 on Plastics in Primary form (EPD, 2024) to assess their bottle grade recycled polyethylene terephthalate (rPET). This study compares Republic Services rPET with market representative rPET and virgin PET derived from Sphera’s Managed Life Cycle Content (MLC) database on a cradle to gate basis. The study will also inform Republic Services of the main contributors to their carbon footprint to guide improvement efforts. The results of this study are expected to help facilitate the building of a comprehensive case for the use of Republic Services rPET over the representative rPET and virgin counterparts.

The intended audience for this study includes Republic Services internal and external stakeholders. The carbon footprint results are for internal use by RS’s management, engineers, product development and innovation and for marketing as it can aid in differentiating RS’s rPET. The carbon footprint results may, at Republic Services sole discretion, be shared with their value chain partners and other external entities for market claiming and assisting them in advancing their sustainability objectives.

This study is a comparative PCF study which is only concerned with a single impact category. Therefore, the results cannot support comparative assertions about the overall environmental superiority of one product over a competing product.

As the findings are intended to be disclosed to the public, a critical review of this study was carried out according to ISO 14071 (ISO, 2024). The critical review statement can be found in Annex A.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function, declared unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product System

Six types of PET pellets are being compared in this study:

1. Republic Services bottle grade rPET produced in the US – Low Capacity
2. Republic Services bottle grade rPET produced in the US – High Capacity
3. Representative rPET produced in the US
4. Representative rPET produced in Asia
5. Representative virgin PET produced in the US
6. Representative virgin PET produced in India

2.1.1. Republic Services rPET flakes and pellets

Republic Services bottle grade rPET is produced from postconsumer PET. Recyclables separated at curbside are collected, transported and sorted in material recovery facilities (MRFs) before being sent to the Las Vegas Polymer Center (LVPC) to be processed into the final rPET clear flake. Data for the inbound PET bales and PET clear flake production energy is based on primary data of over 7 months (in average 62% of the input PET bale is composed of clear PET flake). The energy data was further split per equipment and considering two plausible flow rates - from 3000 kg/h for the Low Capacity to 4500 kg/h for the High Capacity. These two production scenarios make up a range for the expected performance of Republic Services operation. To make the rPET comparable to bottle grade virgin PET, the rPET flakes are pelletized.

Further details about the processes included in the system boundary of the study are provided in section 2.3.

2.1.2. Representative US and Asia rPET in flake and pellet form

This study considers two prominent rPET alternatives in the US market, either produced in the US or imported from Asia. These representative rPET datasets are not bottle grade and are based on a dataset from Sphera MLC database for the recycled postconsumer PET based on United States National Renewable Energy Laboratory (NREL) inventory with MLC datasets (Sphera, 2025b). While the industry representative rPET is not bottle grade, it represents an important market for Republic Services and therefore is included in this comparison. This product system includes curbside waste collection, transportation, sorting up until the recycling process into PET flakes followed by pelletization.

2.1.3. US and India representative virgin PET pellet

For the assessment of the virgin PET, we used the dataset existing in Sphera MLC database for virgin PET bottle grade. The production process relies on the direct esterification of terephthalic acid with ethylene glycol. The terephthalic acid route is preferred for its higher reaction rate, production of high molecular weight polymer chains, and lower use of ancillary inputs. In this reaction, ethylene glycol and terephthalic acid are combined in the liquid phase with a catalyst, resulting in the esterification of the terephthalic acid. After the separation of unreacted ethylene glycol, the reaction product is vigorously mixed with a catalyst to instigate the polycondensation reaction, resulting in the final polymer product. Further details about the dataset can be found online at https://lcadatabase.sphera.com/.

In addition to the dataset, to ensure a consistent comparison to the rPET product system, the system boundary was expanded to include the impacts from the avoided plastic waste management step. In the US market, the plastic that is not recycled would end up in landfills (83%) or would be incinerated (17%) (EPA, 2024).

2.2. Product Functions and Declared Unit

The declared unit provides a reference for the product being assessed and enables the system inputs and outputs to be quantified and scaled. PET is a common type of plastic used for a variety of food and beverage packaging and in the case of rPET, these product systems also fulfill a waste management function. Given the large range of applications, the study determined a cradle-to-gate system boundary with the following two declared units:

the production of 1 kg of clear PET pellets or flakes in the US market

The declared unit on a per kg pellet basis is to facilitate the comparison with the virgin PET whereas the use of kg flakes is used when comparing among rPET alternatives. When comparing to virgin, the impacts of waste management of plastic are also added via systems expansion to represent the second function of rPET product systems (more information in Section 2.4.2).

This declared unit is consistent with the study’s goals to calculate the environmental impact of Republic Services rPET versus the representative rPET and bottle grade virgin PET. While representative market rPET is not bottle grade, it competes in the same market as Republic Service’s PET market.

The reference flow is the quantified amount of products necessary to fulfill the function described by the declared unit. In this case, the reference flow and the declared unit are the same, assuming both product systems are similar in properties.

2.3. System Boundary

In order to adequately represent the operations of the six systems under comparison, consistent system boundaries were developed and are described in this section. Given the variety of PET applications across industry sectors, the chosen system boundary for PET pellets and flakes is cradle-to-gate.

The system boundaries of Republic Service’s and representative market rPET are depicted in Figure 2-1 and Figure 2-2, respectively. These boundaries include waste collection and sorting that take place in the Materials Recovery Facility, along with the recycling process and all inbound transportation. Pelletization is included whenever the product comparison is at the pellet level. Figure 2-3 depicts the system boundary for the virgin PET, and it covers its life cycle from raw material acquisition through manufacturing. It includes the assessment of all raw material inputs from the extraction and processing of natural resources, raw material supply, transport, and manufacturing up to the point at which the finished products leave the factory gate. To ensure that the recycled and virgin PET product systems are equivalent, waste management impacts are added to the virgin PET production in a system expansion approach (Figure 2-3).

Energy consumption in all manufacturing/recycling stages in the form of electricity, steam, natural gas, or others is considered within the scope of the study.

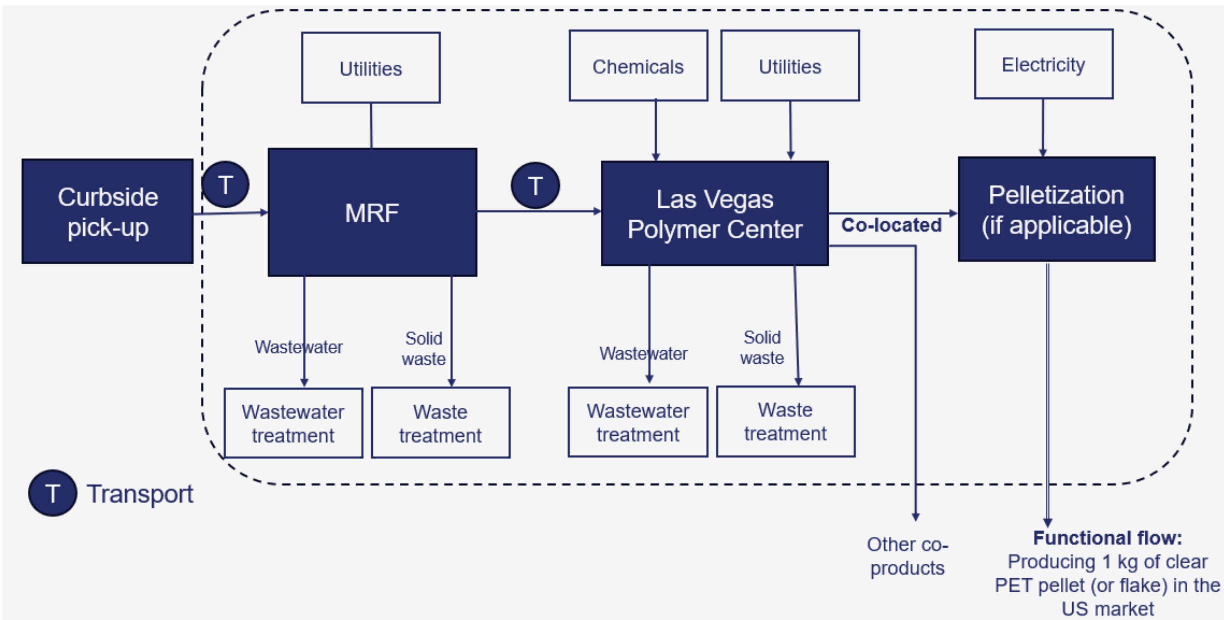

Figure 2-1: Republic Services rPET system boundary

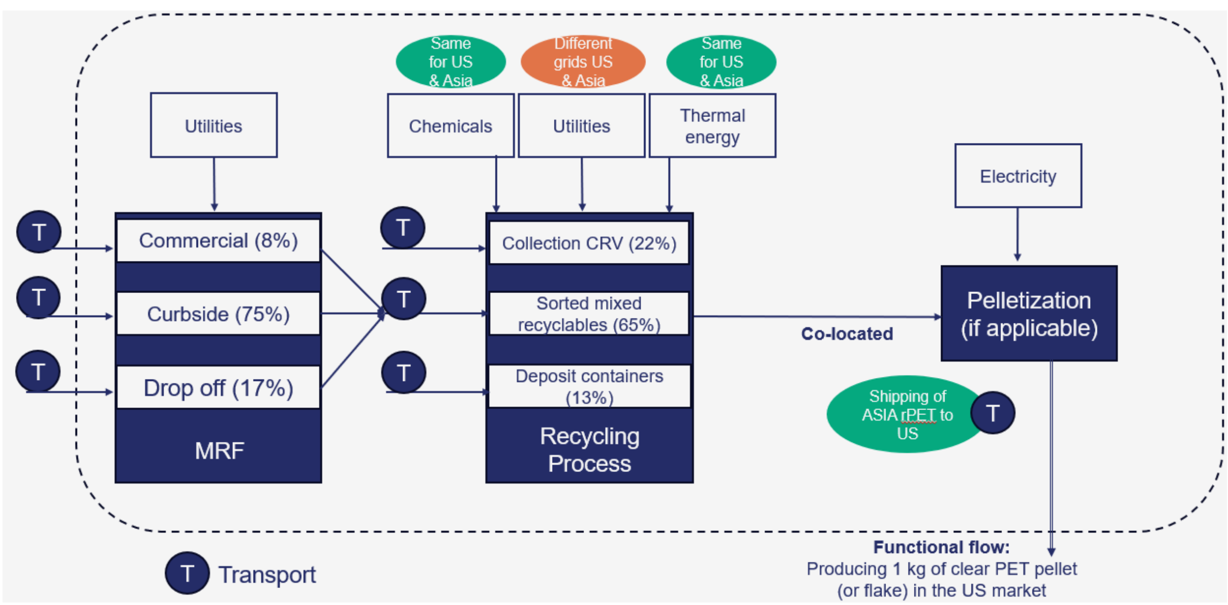

Figure 2-2: Representative market rPET system boundary

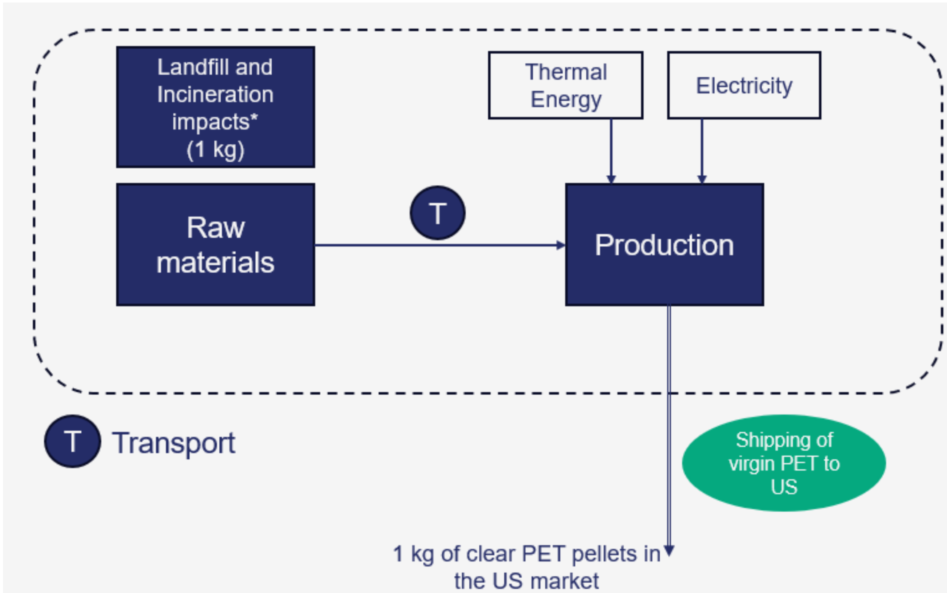

Figure 2-3: Virgin PET system boundary

Table 2-1 lists the main activities included and excluded from the system boundaries of the products assessed. Production and maintenance of plant capital goods (e.g., machinery, buildings) and infrastructure (e.g., power systems, roads) have been excluded from the study. It is expected that these impacts are negligible compared to the impacts associated with running the equipment or using the infrastructure over its operational lifetime.

Table 2-1: System boundaries

Included	Excluded
✓ Curb side waste collection ✓ Product manufacturing ✓ Transport of raw materials from suppliers to manufacturing facility ✓ Generation of energy sources ✓ Waste management (solid waste and wastewater)	× Human labor and employee commute × Capital equipment, construction and maintenance × Outbound packaging

2.3.1. Time Coverage

The intended time reference for this study is 2024. Primary data from Republic Services for the rPET relates to 7 months of operation, from January 1st to the 31st of July in 2024. Republic Services LVPC is new in relation to representative PET and virgin PET manufacturing and as a result, the results are considered concurrent with LVPC's operation. As LVPC continues to scale up and mature, improvements are expected but not a part of this assessment.

Data for the representative rPET and virgin PET in this study is derived from the MLC database version 2025.1. Data is representative of generic industrial practices for recycling, production and precursors.

Given that the virgin PET is a mature industrial process, operating at a much larger scale than Republic Service's LVPC, its operation is more stable overtime.

2.3.2. Technology Coverage

The study aims to represent Republic Services current production system for rPET and the typical industry recycling and production systems of representative rPET and virgin PET respectively. Further details are provided in section 2.1. The results are valid until significant technological changes occur.

2.3.3. Geographical Coverage

The study is intended to represent the impact of rPET and virgin PET in the US market. For this, the study considers production within the US, India and an Asian market mix where these datasets contain primary and secondary data are representative of these countries. The Asian rPET mix is built based on the share of countries that export to the US. Proxy datasets were used as needed for raw material inputs to address lack of data for a specific material or for a specific geographical region.

2.4. Allocation

2.4.1. Multi-output Allocation

Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2 (ISO, 2006). When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Chapter 3.

Multi-output allocation in this study occurs within the LVPC, where multiple streams of material are recycled along with clear PET flake and this process occurs simultaneously so that this allocation cannot be avoided by more granular data. On a mass and economic basis, the clear rPET flake is the most relevant fraction yielding an economic partitioning coefficient of 0.84 and a mass partitioning coefficient of 0.70 (Table 2-2). The baseline analysis for Republic Services PET applies mass allocation to the recycling facility because 1) The LVPC's mission is to recover a variety of material fractions beyond clear PET flake, 2) mass allocation introduces one degree less of uncertainty than economic allocation and 3) system expansion is not applicable as there are no readily available substitutes for each of the fractions recovered. Nonetheless, to understand the implications of this choice in the outcome of results, the study includes a sensitivity analysis including economic allocation.

No allocation was necessary in the foreground system of the other scenarios, and all the scenarios used Sphera's Managed LCA Content 2025.1 databases for background data, which is documented online (Sphera, 2025a).

Table 2-2: Recovered material fractions at LVPC and the corresponding mass and economic partitioning coefficients

Outbound product stream	Output masses*		Volume prices		Allocation	
	Product quantities (short t)	Weight share from input	Price/ Short t	Price/kg	Mass-based (%)	Revenue-based (%)
			REDACTED			

REDACTED

**Values and shares obtained from RS covering the period between 1 January and 31 July 2024*

2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3 (ISO, 2006). Such allocation approaches address the question of how to assign impacts from virgin production processes to material that is recycled and used in future product systems.

There are two instances of end-of-life allocation: upstream burdens of the collected waste and the avoided burdens of rPET alternatives relative to virgin PET. The first instance applies cut-off, where collected postconsumer PET is burden free for all rPET product systems. Then, to compare recycled PET to virgin PET, system expansion is applied so that the burdens of waste management avoided in rPET are added to the virgin PET product systems. For US and IN virgin PET, this consists of 83% landfill and 17% incineration as per EPA statistics (EPA, 2024). The incineration dataset includes thermal and electricity credits.

2.5. Cut-off Criteria

No cut-off criteria are defined for this study. As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analyzed and is discussed in Chapter 5.

2.6. Selection of LCIA Methodology and Impact Categories

The impact assessment categories considered to be of high relevance to the goals of the project and related to the CFP are shown in Table 2-3. It shall be noted that no grouping or further quantitative cross-category weighting has been applied.

Table 2-3: GWP100 impact metrics according to ISO 14067 (ISO, 2018) (kg CO_2 eq.)

Impact Category	Description	Unit	Reference
GWP100, total	A measure of GHG emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. The GWP100 total includes biogenic CO_2.	kg CO_2 equivalent	(IPCC, 2023)
Fossil GHG emissions	GHG emissions and removals arising from fossil car-bon sources and sinks	kg CO_2 equivalent	(ISO, 2018)
Aircraft emissions	GHG emissions resulting from aircraft transportation.	kg CO_2 equivalent	
Biogenic GHG emissions	GHG emissions arising from biogenic carbon sources	kg CO_2 equivalent	
Biogenic GHG removal	GHG removals arising from biogenic carbon sinks	kg CO_2 equivalent	
Emissions from direct land use change (dLUC)*	GHG emissions resulting from change in the human direct land use within the relevant boundary	kg CO_2 equivalent	

* *The calculations for carbon stock changes are based on IPCC rules and PAS2050*

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the declared unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.7. Interpretation to be Used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

2.8. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.9. Type and Format of the Report

In accordance with the ISO 14044 requirements (ISO, 2006) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.10. Software and Database

The LCA model was created using the Life Cycle Assessment for Experts (LCA FE, fka GaBi) Software system version 10.9 for life cycle engineering, developed by Sphera Solutions Inc. Sphera's Managed Life Cycle Content (MLC) LCI database version 2025.1 provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.11. Critical Review

The study has been conducted according to the requirements of ISO 14067 (ISO, 2018) and PCR 2010:16 (EPD, 2024). Since comparative carbon footprint studies are only concerned with a single impact category, they cannot support comparative assertions about the overall environmental superiority of one product over another competing product. A critical review was carried out according to ISO 14071 (ISO, 2024). The goals of a critical review are to ensure that:

- the methods used to carry out the LCA are consistent with ISO 14040 (ISO, 2006) and 14044 (ISO, 2006),
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study
- the study report is transparent and consistent.

The study report is reviewed by Terrie Boguski, from Harmony Environmental, LLC. The Critical Review Statement is attached in Annex A: Critical Review Statement. The Critical Review Report containing the comments and recommendations of the independent expert as well as the practitioner's responses are available upon request from the study commissioner in accordance with ISO 14071 (ISO, 2024).

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

Primary data were collected using customized data collection templates, which were sent out by email to Republic Services. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera engaged with the data provider to resolve any open issues.

3.2. Republic Services rPET

3.2.1. Overview of Product System

Republic Services PET recycling occurs at LVPC with PET collected from postconsumer waste. The first step in the process entails waste collection and sorting occurring at the MRFs. The MRFs then send PET bales to the LVPC facility where PET is separated into the PET and the Olefin line in Stadler frontend area. Within the PET recycling line, the PET bales go through a series of processes where multiple material fractions are recovered. These operations require some utilities and chemicals and generate wastewater, waste, and the final products. All input and output details per process are listed in the sections below.

3.2.2. Waste collection and sorting (MRF)

The first step in the recycling process is postconsumer waste collection. Transportation collection distances assume 31 miles – distance which is conservative considering the weighted average diameter of the metropolitan areas that the recycling centers serve fall below this value (Table C-3, Annex C).

Recycling centers compile the postconsumer waste and gather the initial PET bales. These centers are scattered throughout and have different operators. Due to data accessibility, inventory for the operation is based on recycling centers owned and operated by Republic Services. Utility data for seven recycling centers from January to July 2024, is used to estimate utilities, namely electricity, natural gas, and water. Table 3-1 documents the unit processes for the recycling centers.

Table 3-1: Input and outputs of the waste collection and sorting taking place in recycling centers

Input	Quantity	Unit
Bale inputs	REDACTED	
Curbside collection transport		
Electricity (US average)		
Natural Gas		
Municipal water		

Output	Quantity	Unit
PET bale	REDACTED	
Waste (landfill)		
Wastewater		

3.2.3. Recycling process at LVPC

The Republic Services recycling process of PET bale into PET flakes takes place at the LVPC. At the LVPC, PET bales are opened up and the material is then first sorted into the PET line and the olefin line. The LVPC yields change depending on the composition of the incoming PET bales. To capture this variability, the analysis considers low- and high-capacity operating volumes where the electrical load is consistent as this is based on the material processes, but the amount of clear PET flake recovered changes (Table C-2, Annex C). Table 3-2 shows the unit process for the LVPC and Table 3-3 presents the operating conditions of the LVPC electrical equipment for both operating conditions but for further details about the calculations, refer to Annex D. The low and high-capacity electricity consumption is based on engineering estimates and coincides with the primary data collected for the given time period (0.289 kWh/kg unallocated) which is closer to the high-capacity scenario. The engineering estimates were used as a way to enable more granular information as well as to consider a different operating volume. Note that Stadler frontend area is shared between the PET and olefin line and so the electrical load is shared equally between them. Estimated power and unallocated values are also presented in Table 3-3.

Transportation distances from curbside to waste collection and sorting facility and then to the LVPC were based on metropolitan areas of recycling centers and primary data respectively (Table C-1, Annex C).

Table 3-2 documents unit process for the LVPC. For the electrical equipment, the electricity source used is the AZNM grid, which covers parts of Arizona and New Mexico.

Table 3-2: Input and output quantities of the LVPC (LC: Low Capacity and HC: High Capacity)

Input	Quantity	Unit
REDACTED		
Outputs	Quantity	Unit
REDACTED		

REDACTED		

Table 3-3: LVPC equipment operating conditions allocated and unallocated

LVPC Equipment	Estimated power (kW)	Unallocated		Mass-allocated	
		Low Capacity operation (MJ/kg clear flake)	High Capacity operation (MJ/kg clear flake)	Low Capacity operation (MJ/kg clear flake)	High Capacity operation (MJ/kg clear flake)
		REDACTED			

3.2.4. Pelletization

Republic Services operations at LVPC do not currently include pelletization of the flakes. Therefore, the pelletization process from the "US: Polyethylene terephthalate (PET) granulates secondary" dataset in the MLC 2025.1 database was used to model pelletization (Sphera, 2025c). The pelletization process uses 0.28 kWh/kg clear PET flake of US average grid electricity, and there no losses assumed during this process.

3.3. US and Asia representative rPET

A generic rPET plan was used from Sphera's MLC database for the recycled postconsumer PET flake (Sphera, 2025b). The process includes similar steps to Republic Services operations: waste collection and sorting and recycling process. The main difference between the two geographies lies in the use of region-specific electric grids. As for transportation, additional shipping to the US is included when the recycling takes place in Asia.

3.3.1. Waste collection, sorting and recycling (MRF)

Table 3-4 summarizes the main inputs and outputs for the waste collection, sorting and recycling processes of the Representative rPET. Similar processes are used to model the US and Asian representative rPET, except for the use of regional power grids to more accurately represent the scenario under assessment. The information listed in Table 3-4 is taken from Sphera's MLC database for 1 kg of rPET where several datasets were updated from USLCI to Sphera's latest MLC version.

Table 3-4: Unit processes for the representative rPET

Inputs	Quantity	Unit
PET from collection by California Refund Value (CRV)	0.272	kg
PET from deposit container	0.159	kg
PET from mixed recyclables	0.789	kg
Sodium hydroxide	0.024	kg
Antifoaming agent	0.0022	kg
Surfactant	0.00076	kg
Wetting agent	0.00087	kg
Electricity (for waste collection and sorting)	0.0205	MJ
Electricity (for recycling)	1.66	MJ
Natural Gas	2.96	MJ
Liquified petroleum gas	0.000014	MJ
Water	0.0048	kg
Outputs	Quantity	Unit
PET flake	1	kg
Waste (landfill)	0.22	kg
Wastewater	0.0048	kg

3.3.2. Transportation

Several inbound transportations take place within the system boundary of the representative market rPET. Similar distances are considered for the curbside to waste collection and sorting facility and from the sorting facility to the recycling center for both scenarios considered US and Asia average. For the Asian rPET, an additional shipping step is considered. Table 3-5 documents the distances considered.

Table 3-5: Representative PET bale transport details

Transport steps	Distance (mi)	Data source
Curbside to waste collection & sorting	231	MLC database (weighted average)
Waste collection & sorting to recycling facility	190	MLC database
Shipping rPET flakes from Asia to US	7958	Weighted average shipping port to US distances (Table C-2, Annex C).

3.3.3. Pelletization

Pelletization of the representative rPET flakes was assumed to take place in the US and used the same model as the Republic Services rPET with 0.28 kWh/kg clear PET and no losses.

3.4. US and IN Virgin PET

For the assessment of the virgin PET, we used the dataset existing in Sphera MLC database for virgin PET bottle grade (Sphera, 2025d). The production of the PET granulate is done via purified terephthalic acid (PTA) and ethylene glycol without additives. Further details about the dataset can be found online (Sphera, 2025a).

In order to make the comparison with the rPET consistent, waste management processes were added to the virgin PET systems consisting of 83% landfill and 17% is incineration (EPA, 2024) which is the average form of disposal for plastic in the US market.

Since the assessment is for PET in the US, a shipping step to the US with distance equivalent to 7958 mi was added as well (Table C-2, Annex C).

3.5. Background Data

Documentation for all Sphera's MLC datasets can be found online (Sphera, 2025a).

3.5.1. Fuels and Energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from the Sphera's MLC 2025.1 databases. Table 3-6 shows the most relevant LCI datasets used in modeling the product systems. Electricity consumption was modeled using national and regional grid mixes that account for imports from neighboring countries and regions.

Table 3-6: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Electricity	TW	Electricity grid mix	Sphera	2021	No
Electricity	KR	Electricity grid mix	Sphera	2021	No
Electricity	US	Electricity grid mix	Sphera	2021	No

Electricity	VN	Electricity grid mix	Sphera	2021	No
Electricity	BD	Electricity grid mix	Sphera	2021	No
Electricity	IN	Electricity grid mix	Sphera	2021	No
Electricity	TH	Electricity grid mix	Sphera	2021	No
Electricity	TR	Electricity grid mix	Sphera	2021	No
Electricity	ID	Electricity grid mix	Sphera	2021	No
Electricity	PH	Electricity grid mix	Sphera	2021	No
Electricity	JP	Electricity grid mix	Sphera	2021	No
Electricity	US	Electricity grid mix – AZNM	Sphera	2022	No
Electricity	US	Electricity grid mix – CAMX	Sphera	2022	No
Electricity	US	Electricity grid mix – RFCW	Sphera	2022	No
Electricity	US	Electricity grid mix – SRSO	Sphera	2022	No
Thermal energy	US	Thermal energy from diesel	Sphera	2021	No
Thermal energy	US	Thermal energy from natural gas	Sphera	2022	No
Thermal energy	US	Thermal energy from natural gas	Sphera	2021	No
Thermal energy	US	Thermal energy from propane	Sphera	2021	No

3.5.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the Sphera MLC 2025.1 database. Table 3-7 shows the most relevant LCI datasets used in modelling the product systems.

Table 3-7: Key material and process datasets used in inventory analysis

Material/ process	Location	Dataset	Data Provider	Reference Year	Proxy?*
			Sphera	2024	Geo
	REDACTED		Sphera	2024	Geo
			Sphera	2024	No
			Sphera	2024	Geo
			Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	Geo
			Sphera	2024	Geo

			Sphera	2024	Geo
	REDACTED		Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	No
			Sphera	2024	Geo
			Sphera	2024	Geo

*Geo: geographical proxy

3.5.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities.

Sphera's MLC databases (CUP 2025.1) were used to model transportation. Truck transportation within the United States was modeled using US truck transportation datasets based on data from EPA's SmartWay program (https://www.epa.gov/smartway). SmartWay collects fleet data -- including truck class, fuel consumption, miles driven, etc. -- from various US carriers and aggregates the data to generate average carbon dioxide (CO_2) emissions for each carrier. Emissions for this dataset are then calculated by averaging emissions for all carriers classified under the given SmartWay vehicle category.

Other emissions are calculated based on EPA MOVES data (https://www.epa.gov/moves). An appropriate MOVES truck type is identified and corresponding emission factors in grams per mile obtained from the model. Emission factors are separated for short (less than 200 miles) and long haul (above 200 miles) as the latter accounts for "hoteling", i.e., the hours spend in idle mode during breaks.

Diesel consumption is back-calculated from SmartWay CO_2 emissions while factoring in biodiesel content from the US Energy Information Administration (EIA) Annual Energy Review under the assumption that diesel is the primary fuel consumed by SmartWay carriers. The fraction of biodiesel calculated from EIA data is also used to split SmartWay CO_2 emissions into fossil and biogenic CO_2.

Fuels were modeled using geographically appropriate datasets.

Table 3-8: Transportation and road fuel datasets

Mode / fuels	Geographic Reference	Dataset	Data Provider	Reference Year	Proxy?
Ship	GLO	Container ship, 5,000 to 200,000 dwt payload capacity, deep sea	Sphera	2023	No
Diesel	US	Diesel mix at filling station	Sphera	2021	No
Fuel oil	CN	Heavy fuel oil at refinery (1.0 wt.% S)	Sphera	2021	No
Rail	GLO	Rail transport cargo - Diesel, average train, gross tonne weight 1,000t / 726t payload capacity	Sphera	2023	No
Truck	US	Truck - LTL/dry van (EPA SmartWay)	Sphera	2023	No

3.6. Life Cycle Inventory Analysis Results

ISO 14044 (ISO, 2006) defines the Life Cycle Inventory (LCI) analysis result as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment". As the complete inventory comprises hundreds of flows, the below table only displays a selection of flows based on their relevance to the subsequent impact assessment in order to provide a transparent link between the inventory and impact assessment results.

Table 3-9: LCI results of rPET and Virgin PET (in kg)

Type	Flow	Characterisation factor	RS rPET Low Capacity	RS rPET High Capacity	rPET US	rPET Asia	Pelletization	Virgin US	Virgin IN
Emissions to air	CO_2	1	4.80E-01	4.27E-01	5.81E-01	8.11E-01	2.06E-01	2.51E+00	2.81E+00
	CH_4	29.8	2.15E-03	1.91E-03	1.42E-03	1.73E-03	8.19E-04	1.66E-02	1.63E-02
	N_2O	273	1.56E-05	1.50E-05	6.07E-06	1.64E-05	2.98E-06	1.81E-05	4.56E-05

4. LCIA Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.5. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen declared unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Overall Results

Republic Services cradle-to-gate carbon footprint is lower than all the other alternatives considered for both High and Low Capacity processing and for both PET flakes and pellets. This includes the other representative market rPET and virgin PET. Table 4-1 shows the results for pellet and flake according to the ISO 14067 (ISO, 2019) required categories (flake values are shown in parenthesis). This breakdown also shows that over 99% of the carbon footprint of both rPET and virgin PET is due to fossil GHG emissions.

Table 4-1: Carbon footprint results per ISO 14067 impact category for all products at pellet and (flake).

Impact category kg CO_2 eq./kg of pellet	RS Low Capacity	RS High Capacity	rPET US	rPET Asia	Virgin US	Virgin IN
Aircraft emissions	3.55E-08 (2.06E-08)	2.98E-08 (1.49E-08)	3.485E-08 (1.99E-08)	3.92E-08 (2.43E-08)	3.27E-08	3.82E-08
Biogenic GHG emissions	2.23E-02 (1.17E-02)	2.12E-02 (1.05E-02)	3.04E-02 (1.98E-02)	7.42E-02 (6.35E-02)	2.51E-02	5.61E-02
Biogenic GHG removals	-1.94E-02 (-9.01E-03)	-1.83E-02 (-7.91E-03)	-2.94E-02 (-1.90E-02)	-7.20E-02 (-6.16E-02)	-2.19E-02	-4.65E-02
Emissions from direct land use change	9.78E-04 (5.54E-04)	8.81E-04 (4.58E-04)	1.57E-03 (1.15E-03)	3.89E-03 (3.47E-03)	9.01E-04	3.27E-03
Fossil GHG emissions	5.81E-01 (3.50E-01)	5.39E-01 (3.07E-01)	8.56E-01 (6.25E-01)	1.10E+00 (8.67E-01)	3.01E+00	3.55E+00
GWP100, total	**5.85E-01 (3.53E-01)**	**5.42E-01 (3.10E-01)**	**8.59E-01 (6.27E-01)**	**1.10E+00 (8.73E-01)**	**3.01E+00**	**3.57E+00**

In terms of aircraft emissions of the rPET, these are due to background processes withing the electricity value chain of the recycling process. As for the virgin PET, aircraft emissions result from the raw materials. In all scenarios evaluated, these emissions are due to background processes and represent a negligible amount from the total GWP. Similarly, the direct land use calculations of the product systems evaluated fall in the background datasets and represent a minimal part of the footprint (Table 4-1). As for the biogenic GHG emissions and removals, they originate from the same processes as the aircraft emissions, the electricity (mainly biomass and biogas) for the rPET and the raw materials for the virgin PET.

A closer look into the main contributors to the carbon footprint for each product is provided in the following sections.

4.2. Detailed Results

4.2.1. Production of PET pellets

Looking at the findings in Figure 4-1, the advantage of Republic Services rPET is clear. While the carbon footprint of Republic Services rPET ranges between 0.54 and 0.59 kg CO_2eq/kg pellet, the representative rPET has a carbon footprint equal to 0.86 and 1.1 kg CO_2eq/kg pellet for the US and Asia, respectively. The virgin PET has the highest footprint ranging between 3.0 and 3.5 kg CO_2eq/kg pellet for the PET produced in the US and the PET imported from India. The additional impact for the virgin PET from India mainly results from the additional transport to ship the pellets to the US.

The main contributor to the carbon footprint of all rPET considered (RS and representative) is the recycling step (30 to 49%) followed by the pelletization (21 to 43%). Further details about the rPET are presented in section 4.2.2. As for the virgin PET, the production step is the main contributor (91 to 95% of the total GWP) mainly due to a mix of raw material and fossil fuel needed for the manufacturing of the virgin PET. The detailed LCIA values can be found in Annex E.

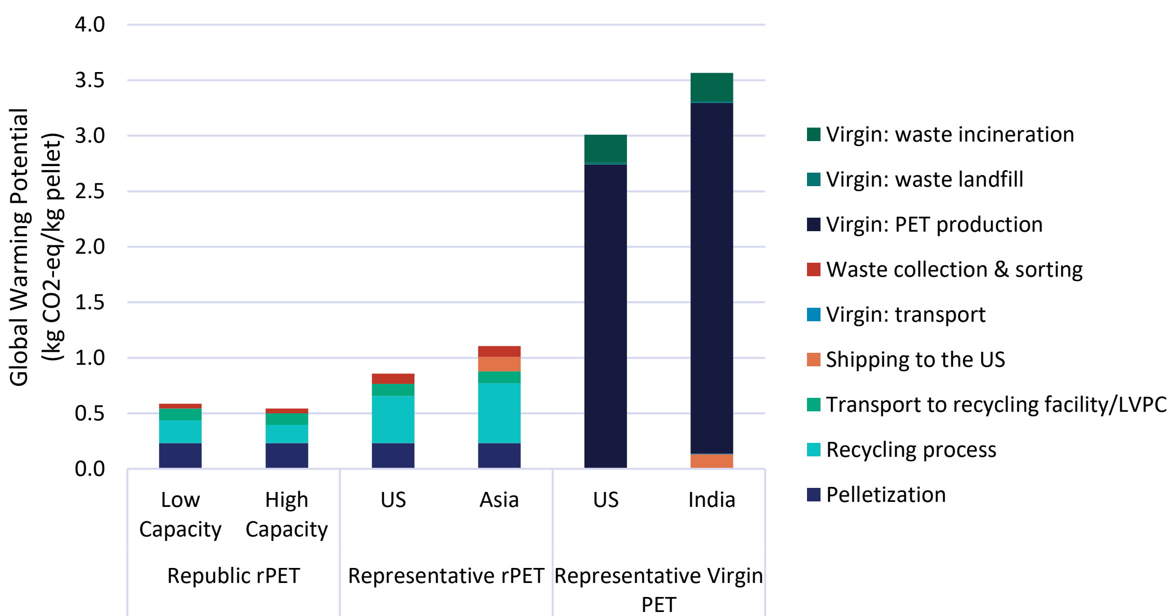

Figure 4-1: Contributions to the PET carbon footprints on a pellet basis

4.2.2. Production of PET Flakes

Figure 4-2 presents a closer look into the contributing processes to the carbon footprint of rPET on a flake basis. Here, the main contributor is considered to be the electricity consumed during the recycling process, reaching up to 39%.

For Republic Services rPET, electricity contributes 25% to 33% to the carbon footprint. The second largest contributor is the transport to the LVPC. Since the recycling center is not in proximity to the waste collection and sorting facilities, the diesel combusted to operate the trucks lead to an approximate impact of 0.105 kg CO_2eq/kg of flake.

For the representative market rPET, the second major contributor is the thermal energy used for the recycling process, and it contributes about 0.171 kg CO_2eq/kg of flake.

The waste and water impacts are negligible from a carbon footprint perspective. The detailed LCIA values can be found in Annex E.

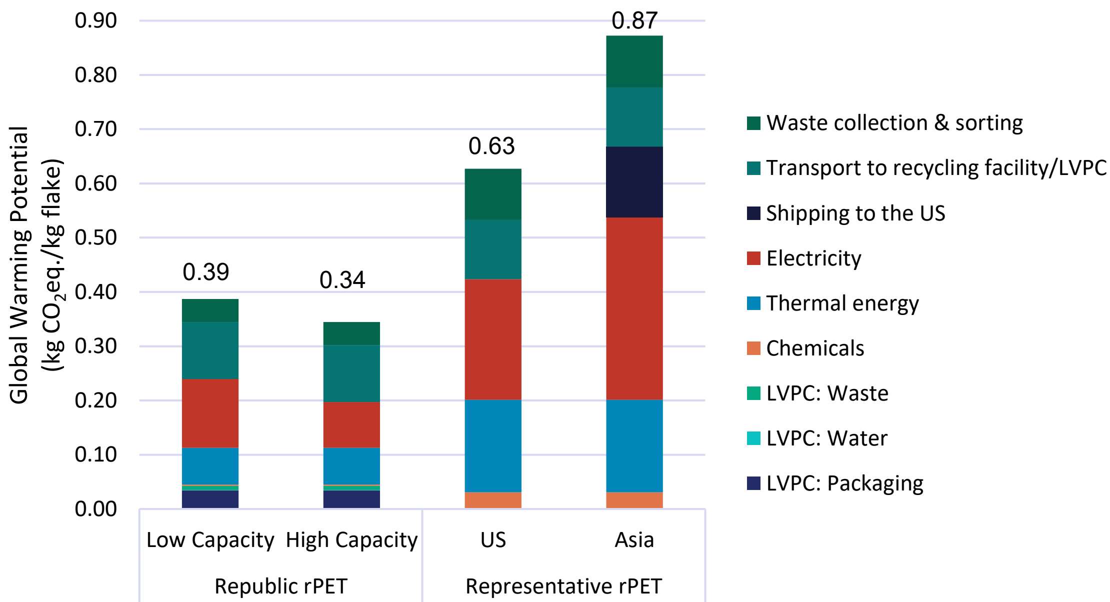

Figure 4-2: Contributions to the rPET carbon footprint on a flake basis

4.2.3. Operation of the LVPC

Since electricity generation is a main contributor to the carbon footprint of Republic Services rPET, a closer look into the LVPC equipment operation is provided in Figure 4-3. Among the various equipment, the contribution from Stadler frontend area is the highest (0.036 and 0.055 kg CO_2eq/kg of flake) depending on the mode of operation (low or High Capacity) while the dosing is the smallest (0.001 kg CO_2eq/kg flake). These findings are aligned with the equipment's estimated power. Therefore, to lower the carbon footprint of the LVPC operation, it would be crucial to look into operating at higher capacity and consider decarbonizing the source of electricity.

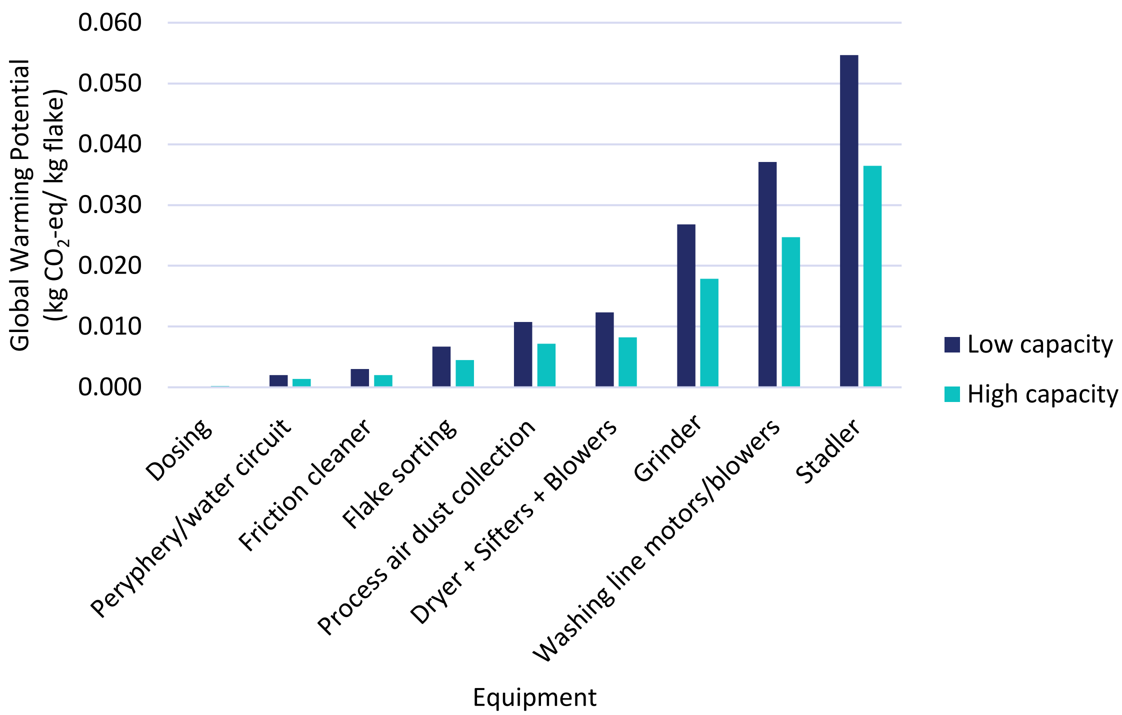

Figure 4-3: Carbon footprint contributions of individual LVPC electrical equipment for low- and high-capacity operations

4.3. Sensitivity Analysis

Sensitivity analyses test the sensitivity of the final result towards variations in parameter values. The results below show the variation in the findings with respect to changes in thermal energy and electric grid selections. Table 4-2 summarizes the analyses performed.

Table 4-2: Summary of the sensitivity analyses

Sensitivity analysis	Alternatives	Description
Multi-output allocation	RS rPET	Applying an economic based approach to allocate the burdens of the LVPC operation between the different products.
Thermal energy variation	rPET US and rPET Asia	Varying thermal energy of the representative rPET by +/- 10%
Specific national energy grid in Asia	rPET Asia	Simulations considering the grid with the highest and lowest carbon intensities (India and Japan respectively) to evaluate a range of performance
Specific electricity grid in US	rPET US	Simulations considering US average grid, SRSO, CAMX, RFCW, AZNM

Residual energy mix for LVPC	RS rPET	Evaluation of maximum residual grid to assess changes in results
Upstream transport	rPET US and rPET Asia	Upstream waste collection transport is highly uncertain. This analysis simulates the same upstream transport in the representative alternatives as with RS rPET

4.3.1 Sensitivity in multi-output allocation approach

Figure 4-4 evaluates the change in results when switching from mass to an economic allocation approach for energy in LVPC. Results of this sensitivity analysis show how the carbon footprint increases slightly in magnitude, but the comparative conclusions remain. Under an economic allocation lens, the carbon footprint of RS rPET is still lower than the representative rPET counterpart. Mass and economic allocation results tend to have a much greater impact, but in the case of LVPC since the clear PET flake is both the largest mass fraction and the most valuable, there is consistency in the results between these two approaches.

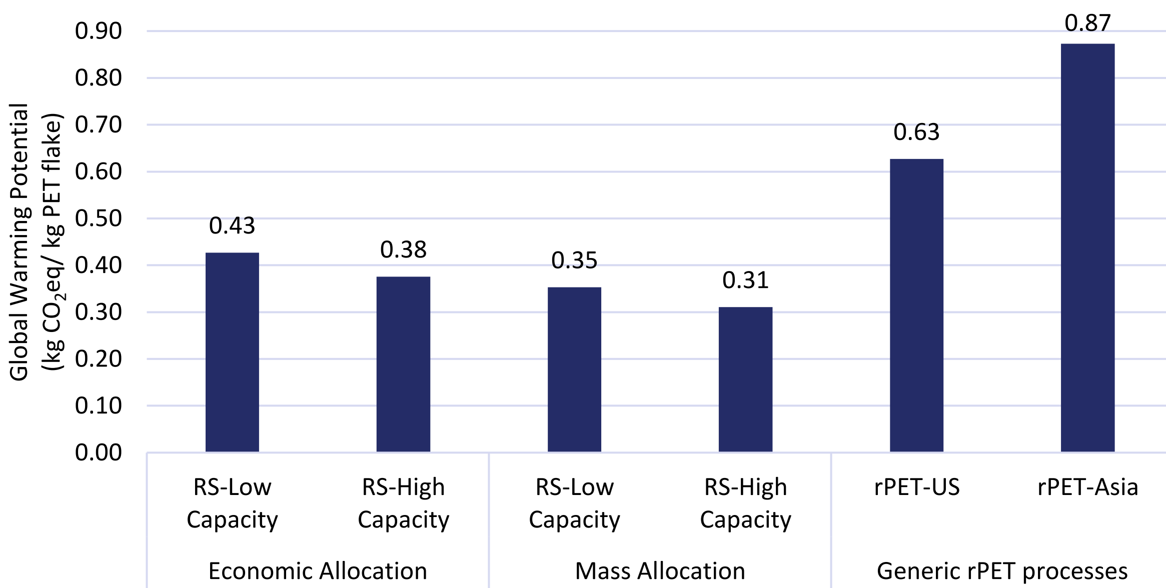

Figure 4-4: GWP results of the variation in allocation approaches

4.3.2 Variations in thermal energy

Thermal energy is one of the main hotspots in the representative rPET alternatives. Provided that this is subject to variation in the market, this sensitivity analysis evaluates a change of +/-10% in thermal energy. The results presented in Figure 4-5 show a very minimal impact on the carbon footprint. The range in impact for Republic Services corresponds to the Low and High Capacity.

Figure 4-5: Sensitivity analysis of thermal energy inputs in representative rPET

4.3.3 Variations in electric grid selections

Since the electricity used for the recycling process is a main contributor to the impacts of the LVPC, a sensitivity analysis was performed testing various power grids for relevant US regions. For the US rPET, four regional grids were considered in addition to the US national average. As for rPET Asia, three grids were considered. The market grid, based on the various grids of the countries shipping rPET to the US, India: the country with the electric grid with the highest GWP and Japan: the grid with the lowest GWP. Further details about the grids considered are provided in Table 4-3 and Table 4-4 below.

Table 4-3: US National and regional electric grids and their primary sources of electricity

EPA eGrid acronym	Geographic coverage	Primary sources of electricity
SRSO	Parts of Alabama, Georgia, and Mississippi	Natural gas (54%) Nuclear (18%)
CAMX	State of California	Natural gas (48%) PV (18%)
RFCW	Parts of the Mid-Atlantic and Midwest U.S., covering portions of Ohio, Michigan, Indiana, Pennsylvania, and West Virginia	Natural gas (33%) Coal (32%)
AZNM	Parts of Arizona and New Mexico	Natural gas (45%) Nuclear (21%)
US	Whole country	Natural gas (40%) Coal (20%)

Table 4-4: Source and share by weight of PET shipped to the US from Asia and the main source of electricity for the respective countries

Source of PET	Share by weight (%)	Primary source of electricity
Thailand	33%	Natural gas (63%) Coal (21%)
Japan	20%	Natural gas (40%) Coal (29%)
Indonesia	18%	Coal (62%) Natural gas (16%)
Taiwan	15%	Natural gas (36%) Coal (34%)
South Korea	3%	Coal (33%) Natural gas (28%)
Philippines	4%	Coal (46%) Natural gas (19%)
Türkiye	2%	Coal (44%) Hydro (26%)

India	3%	Coal (71%) Hydro (10%)
Bangladesh	2%	Natural gas (84%) Fuel cell (12%)
Vietnam	1%	Coal (50%) Hydro (30%)

Figure 4-6 presents the carbon footprint of rPET under varying electricity grid mixes and overall, it shows how the comparative conclusions of Republic Services versus the representative rPET alternatives remain. While the representative rPET carbon footprint changes given the specific energy grid, overall, Republic Services rPET still has a lower carbon footprint regardless of these changes in grid choice.

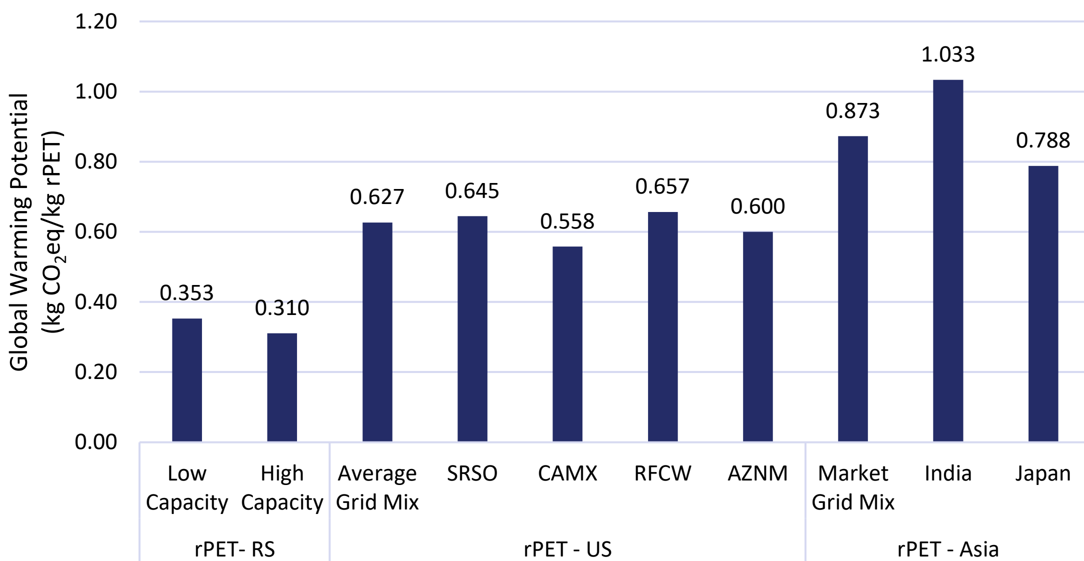

Figure 4-6: Sensitivity analysis of electricity grid mixes for rPET

4.3.4 Consumption based grid mix vs residual grid mix

In the absence of supplier specific grid mix information, ISO 14067 allows the use of a consumption-based grid to model foreground electricity. In this study, it means that Republic Services recycling operation utilizes the AZNM eGrid region to model the impacts of the electricity at the LVPC. ISO 14067 also determines that a consumption-based grid may include some previously claimed attributed electricity.

Therefore, this sensitivity analysis, evaluates the change in the results relative to a conservative estimation of the residual grid (consumption minus possible claimed attributed electricity). The residual grid is estimated by removing the renewable portion (7.38% wind and 6.22% photovoltaic) in the mix. When removing the wind and solar portion, there is an increase 5% and 3% in the carbon footprint of flake and pellet respectively relative to the baseline analysis. Comparative outcomes are not affected by this and the average reduction of Republic Services rPET remains at 45% and 60% relative to representative US and Asia. The reductions relative to virgin PET range between 81% and 84%. Table 4-5: Percent change in the carbon footprint at flake and pellet when a residual grid is considered for RS operationsTable 4-5 contains the summary of results. While the conclusions remain, it is important to consider specific supplier electricity information in future iterations.

Table 4-5: Percent change in the carbon footprint at flake and pellet when a residual grid is considered for RS operations

	Flake		Pellet	
	kg CO_2 eq/ kg	% change	kg CO_2 eq/ kg	% change
Average RS – Residual grid	0.348	n/a	0.579	n/a
Average RS – Baseline	0.332	5%	0.564	3%
Representative rPET - US	0.627	-45%	0.859	-33%
Representative rPET - Asia	0.873	-60%	1.104	-48%
Representative virgin PET- US	n/a	n/a	3.011	-81%
Representative virgin PET - India	n/a	n/a	3.565	-84%

4.3.5 Variations in upstream transport

Datasets for market representative rPET are limited. To enhance the quality of the NREL dataset used in representative rPET modeling, this study switched every single unit process from the disaggregated dataset to MLC datasets. More recent data on rPET operation was found in a Franklin Associates 2018 report (Franklin Associates, 2018) with regards to waste collection distances found to be 120 miles (instead of 230 miles) for curbside to sorting and 182 miles (instead of 190 miles) to the recycling center. These distances are in the ballpark of the baseline, and these are still several years behind the Republic Services product system. Hence, a sensitivity analysis has been added to the representative rPET. The waste collection and sorting step (including the curbside collection, drop off, and commercial waste collection) along with the transport to the recycling facility were set equivalent between the representative rPET and RS rPET. While this change decreased the GWP/kg of flake by 10% for the US representative rPET and 6% for the Asia representative rPET, the impact of both were still higher than RS rPET.

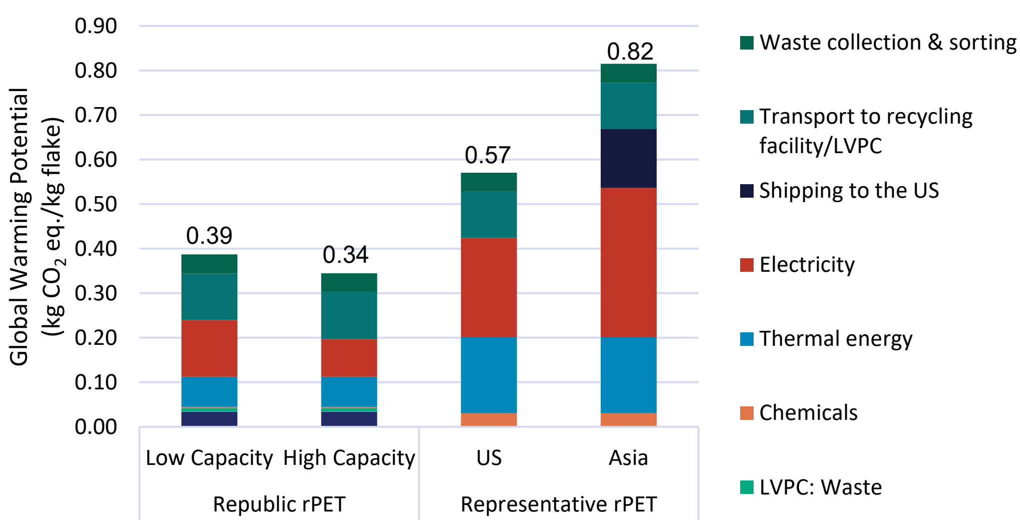

Figure 4-7: Sensitivity analysis of waste collection transport

5. Interpretation

5.1. Identification of Relevant Findings

This study finds that Republic Services bottle grade rPET appears to be a competitive alternative relative to representative rPET in the US market as well as bottle grade virgin PET even while testing for a variety of conditions in the modelling approach, Republic Services yields, regions and energy input. Republic Services competitive advantage is mainly due to a more energy efficient process and the sourcing of lower carbon electricity (as compared to US average and the Asian market mix). To summarize, Table 5-1 contains the average performance and relative reductions and shows how the greatest competitive advantage lies in the bottle-grade PET market.

Table 5-1: Summary of reduction potential of Republic Services rPET compared to representative rPET and virgin PET

	Flake		Pellet	
	kg CO_2 eq/ kg	% reduction	kg CO_2 eq/ kg	% reduction
Average RS	0.332	-	0.564	-
Representative US rPET	0.627	47%	0.859	34%
Representative Asia rPET	0.873	62%	1.104	49%
Virgin PET US	-	-	3.011	81%
Virgin PET India	-	-	3.565	84%

Another key finding is with regards to the conversion step from pelletization which contributes ~40 % of the pellet carbon footprint. This means that additional energy efficiency gains in pellet production could further improve Republic Services competitive advantage.

As a future outlook, opportunities for improvement for Republic Services should focus on process yields, energy efficiency, and renewable energy use.

5.2. Assumptions and Limitations

In order to fill some of the data gaps, several assumptions were made and resulted in limitations.

- For representative rPET and virgin PET, the models assessed are based on MLC datasets which draw representative operations for a regional case. Therefore, conclusions are to be drawn relative to an industry benchmark – not individual competing operations.
- For Republic Services operation, in the case of multi production at LVPC, the study applies a mass allocation approach to assign the energy inputs to the clear rPET flake. While this is justified and a sensitivity analysis showed consistency in the results, this is still an important parameter in the study.

- Another limitation worth highlighting is the temporal coverage of Republic Services data. Data for LVPC is taken in the first 7 months of operation for which operation is not fully optimized thereby possibly overestimating the impacts of Republic Services. The use of data from only part of the year may also miss seasonal differences in waste generation and composition (e.g., packaging waste in December versus the rest of the year).

5.3. Results of Sensitivity Analyses

Sensitivity analyses were performed to test the sensitivity of the results towards changes in parameter values that are based on assumptions or otherwise uncertain. The analysis tested a variation across multiple elements: from the allocation approach and yields in LVPC, the thermal energy input in the representative rPET alternatives, to the electricity grid sources for representative rPET and the consideration of residual grid in RS operations. Sensitivity analysis showed that the conclusions of the study remain, where Republic Services rPET has a lower carbon footprint than the alternatives evaluated.

5.4. Uncertainty Analysis

The contribution, scenario, and sensitivity analyses provide an understanding of the key uncertain parameters across PET product systems and how these may affect the comparative results. The contribution analysis for Republic Services rPET shows that the energy (electricity and thermal) at LVPC is a key driver of impact and also the largest differentiator between Republic Services operation and the representative rPET datasets. For the virgin PET counterparts, majority of the impact is fixed upstream in the fossil fuel value chain. The virgin PET product systems also represent technologies that are further in the maturity scale and therefore uncertainties are considered to be lower and given that the carbon footprint of virgin PET is well above rPET alternatives, these uncertainties are also not expected to change the outcome of results. Within rPET systems, however, electrical and thermal energy was tested in multiple ways. First, the rPET results for Republic Services consider two modes of operation (low and high) to scale the energy inputs accordingly and the comparative results in this study present these separately. Within the Republic Services, the LVPC inventory was also allocated on an economic basis and conclusions remain because there are no substantial differences between the economic and mass allocation. In addition, the representative rPET datasets was also tested in terms of variations in thermal energy and considering alternative grids (within the US and the Asian mix). In both sensitivity analysis, the comparative results are maintained and Republic Services rPET is not only bottle grade but also produced with a lower carbon footprint. Therefore, the results of the analysis appear to be relatively robust in light of the uncertainty in key modeling parameters and assumptions. The differences between the alternatives appear to be outside the range of uncertainty in the model parameters, assumptions, and data.

5.5. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the Sphera MLC 2025.1 database were used. The LCI datasets from the Sphera MLC 2025.1 database are widely distributed and used with the Life Cycle Assessment for Experts (LCA FE) 10.9.1 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.5.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Variations across different manufacturers/suppliers were balanced out by using weighted averages. All background data are sourced from Sphera MLC databases with the documented precision.
- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from Sphera MLC databases with the documented completeness.

5.5.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the Sphera MLC databases. Therefore, consistency is considered to be high.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches. Therefore, reproducibility is considered to be high.

5.5.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2024. All secondary data come from the Sphera MLC 2025.1 databases and are representative of the years 2021-2024. As the study intended to compare the product systems for the reference year 2024, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.6. Model Completeness and Consistency

5.6.1. Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

5.6.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimized by predominantly using LCI data from Sphera MLC 2025.1 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.7. Conclusions, Limitations, and Recommendations

5.7.1. Conclusions

This study highlights the competitive advantage of Republic Services rPET compared to the representative rPET in the US and Asia and to the virgin PET produced in the US and India. The reductions are estimated to range between 47% and 62% if compared to representative rPET in the market and much greater if compared to virgin PET (81% to 84%). The main advantage stems from the efficient recycling process, along with the low carbon electric grid used for the process compared to the other recycling options. As for the main advantage compared to its virgin counterparts is a result of the avoided use and processing of fossil fuels feedstocks.

5.7.2. Limitations

Carbon footprint studies by definition focus on a single environmental metric and thus these comparative results, although favoring Republic Services offering, shall not be interpreted as measurements of overall environmental performance. Within the scope of ISO 14067 (ISO, 2018), a key aspect to consider in the interpretation of results is that the market alternatives are based on industry benchmarks based on life cycle generic libraries (MLC), not a specific operation and thus conclusions here are aimed as a statement on Republic Services competitive advantage relative to a representative case in the market. Finally, a third limitation to highlight is the fact that the upstream stage in waste collection and sorting is a particularly difficult stage to collect data for and varies for each specific case. The product systems in this study are then based on market representation but noting that individual cases may differ. That said, the upstream stage of waste collection and sorting is not a decisive contribution when comparing Republic Services to these benchmarks.

5.7.3. Recommendations

Several recommendations are provided to reduce Republic Services carbon footprint, and they include:

- Position the rPET product in markets where recycling is powered with more carbon intensive grids and/or there is a greater share of plastic incineration to maximize competitive advantage

- Focus on reducing process electricity primarily from Stadler, washing line motors, and blower
- Consider installing renewable energy capacity at LVPC (it targets ~50% of the carbon footprint)
- Identify ways to increase yields (targeted waste collection or improvements from scaling up operations)
- Transport represents ~20% of impacts and so consider utilizing alternative fuels: hybrid, electric, biodiesel or natural gas trucks
- Guide Republic Services customers to perform pelletization in a more energy efficient manner. Reductions may compensate for additional transport if needed
- For improving the study, it is recommended to expand the data collection timeframe for LVPC as it continues to scale as well as gather supplier specific information to model the specific electricity mix.

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Annex A: Critical Review Statement

Harmony Environmental, LLC
Management • Analysis • Communication
Beyond Sustainability, Striving for Harmony

Critical Review Statement

Date: August 13, 2025

LCA Commissioned by: Republic Services

LCA Conducted by: Valentina Prado, Hassana Elzein, James Levis
Sphera Solutions Inc (https://sphera.com/)

Report Title: Comparative Carbon Footprint of Recycled and Virgin PET

Review Conducted by: Terrie K. Boguski, Harmony Environmental, LLC

ISO Referenced Standards: ISO 14067:2018, ISO 14044:2006, ISO 14044+Amd1:2017 +Amd2:2020, EPD International PCR 2010:16, and ISO 14071:2024

Critical Review Process, Scope and Conclusion

In accordance with the international standard, ISO 14044, a Critical Review was conducted for the product carbon footprint (PCF), *Comparative Carbon Footprint of Recycled and Virgin PET*. This is a comparative PCF in accordance with ISO 14067, and it conforms to EPD International's Product Category Rule (PCR) 2010:16 on Plastics in Primary form to the extent needed for a PCF. The purpose of the PCF is to assess Republic Services' bottle grade recycled polyethylene terephthalate (rPET). The PCF compares Republic Services rPET with market representative rPET and virgin PET derived from Sphera's Managed Life Cycle Content (MLC) database on a cradle to gate basis. There is no comparison to any specific competitor's product. Therefore, the comparisions should not be interpreted to apply to any specific product made by another manufacturer.

It is important to note that a carbon footprint is one of many environmental indicators and that it does not reflect overall environmental preferability. Furthermore, communications of footprint results should follow the requirements of ISO 14026 Environmental labels and declarations — Principles, requirements and guidelines for communication of footprint information.

The reviewer received the draft report on June 19, 2025 and attended a video meeting with Sphera and Republic Services staff on June 25, 2025. The reviewer sent initial comments to Sphera on July 14, 2025. The reviewer received the revised report on August 7, 2025. The reviewer and Sphera staff exchanged comments/responses via email. Comments were recorded in an Excel spreadsheet in tabular format based on Annex A of ISO 14071:2024.

All significant comments were addressed, and all open issues were resolved. Review was based on the stipulations in ISO 14067, which are based on principles, requirements and guidelines identified in ISO 14040 and ISO 14044. The review followed guidance in ISO 14071:2024.

The reviewer concludes that the PCP conforms to ISO 14067 and that all required stipulations in ISO 14044:2006 Clause 6.3 were met in the revisions to the report dated August 12, 2025. In particular,

- The methods used to carry out the LCA are consistent with this International Standard,
- The methods used to carry out the LCA are scientifically and technically valid,
- The data used are appropriate and reasonable in relation to the goal of the study,
- The interpretations reflect the limitations identified and the goal of the study, and
- The study report is transparent and consistent.

The reviewer did not have access to LCA calculations, underlying data or LCA models. Therefore, the review is primarily limited to the summary data and model results included in the report.

Completing the critical review does not mean that the reviewer endorses the results of the LCA, nor does it mean the reviewer endorses any of the assessed products.

ISO 14044:2006 requires that this critical review statement, as well as the reviewer's comments and any responses to recommendations made by the reviewer be included in the final report.

Submitted by:

Terrie K. Boguski

Annex B: Confidential Data

Annex C: Inventory details

REDACTED

REDACTED

REDACTED

Annex D: Calculation details

REDACTED

REDACTED

Annex E: LCIA results

The contributions of the various life cycle stages to the PET carbon footprints on a pellet and flake basis can be found in table E-1 and E-2 below.

Table E- 1: Contributions to the PET carbon footprints on a pellet basis per life cycle stage

Scenario	Detail	Pelletiza-tion	Recycling process	Transport to recycling facil-ity/LVPC	Shipping to the US	Virgin: transport	Waste collection & sorting	Virgin: PET production	Virgin: waste landfill	Virgin: waste incineration
Republic rPET	Low Capacity	0.232	0.206	0.105	0	0	0.043	0	0	0
	High Capacity	0.232	0.163	0.105	0	0	0.043	0	0	0
Repre-sentative rPET	US	0.232	0.424	0.109	0	0	0.094	0	0	0
	Asia	0.232	0.538	0.109	0.130	0	0.096	0	0	0
Repre-sentative Virgin PET	US	0.000	0.000	0.000	0	0.005	0.000	2.734	0.018	0.253
	India	0	0	0	0.130	0.005	0	3.159	0.022	0

Table E- 2: Contributions to the PET carbon footprints on a flake basis per life cycle stage

Scenario	Scenario	LVPC: Packaging	LVPC: Water	LVPC: Waste	Chemicals	Thermal energy	Electricity	Shipping to the US	Transport to recycling facility/LVPC	Waste collection & sorting
Republic rPET	Low Capacity	0.034	0	0.008	0.003	0.068	0.127	0	0.105	0.043
	High Capacity	0.034	0	0.008	0.003	0.068	0.085	0	0.105	0.043
Representative rPET	US	0	0	0	0.031	0.171	0.222	0	0.109	0.094
	Asia	0	0	0	0.031	0.171	0.336	0.130	0.109	0.096

The detailed iso 14067 (ISO, 2018) indicators results for Republic Services operation per LCA step for Low Capacity and High Capacity operation are presented in Table E-3 and Table E-4, respectively.

Table E-3: ISO 14067 indicators results for Republic Services low-capacity operation

Impact category	Waste collection & sorting	Recycling process	Transport	Pelletization
Aircraft emissions	2.08E-09	1.83E-08	2.77E-10	1.49E-08
Biogenic GHG emissions	2.05E-03	5.84E-03	3.78E-03	1.07E-02
Biogenic GHG removal	-1.90E-03	-3.87E-03	-3.24E-03	-1.04E-02
Emissions from direct land use change	5.99E-05	4.39E-04	5.50E-05	4.24E-04
Fossil GHG emissions	4.25E-02	2.03E-01	1.04E-01	2.31E-01
GWP100, total	4.27E-02	2.06E-01	1.05E-01	2.32E-01

Table E- 4: ISO 14067 indicators results for Republic Services high-capacity operation

Impact category	Waste collection & sorting	Recycling process	Transport	Pelletization
Aircraft emissions	**2.08E-09**	**1.26E-08**	**2.77E-10**	**1.49E-08**
Biogenic GHG emissions	2.05E-03	4.68E-03	3.78E-03	1.07E-02
Biogenic GHG removal	-1.90E-03	-2.77E-03	-3.24E-03	-1.04E-02
Emissions from direct land use change	5.99E-05	3.43E-04	5.50E-05	4.24E-04
Fossil GHG emissions	4.25E-02	1.61E-01	1.04E-01	2.31E-01
GWP100, total	4.27E-02	1.63E-01	1.05E-01	2.32E-01