A circular multilayer plastic approach for value retention of end-of life multilayers films

D6.5: CIMPA's circular-driven business models for multilayer packaging solutions

WP6: Circular economy – Economic & impact assessment

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Abbreviations

BM:	Business Model
CAPEX:	Capital expenditure
CBM:	Circular-driven Business Model.
CE:	Circular Economy
DF:	Discounting Factor
DP:	Depreciation Period
DR:	Discount Rate
EoL:	End of Life
EPR:	Extended Producer Responsibility
IFR:	Inflation Rate
IRR:	Internal Rate of Return
LCA:	Life-Cycle Assessment
LCC:	Life Cycle Costing
ML:	Multi-Layer
NPV:	Net Present Value
OPEX:	Operational expenditure
P&L:	Profit and Loss
PA:	Polyamide
PE:	Polyethylene
PET:	Polyethylene terephthalate
RV:	Residual Value
TCO:	Total Cost of Ownership

Executive summary

The document presents CIMPA's circular business models aimed at maximizing the value of end-of-life multilayer plastic films by integrating innovative technologies into the value chain. The primary objective is to identify relevant business practices to ensure full circularity of CIMPA products. This involves an in-depth analysis of the multilayer packaging value chain, considering current legislation, industrial practices, and financial flows associated with each stage of production and recycling.

The document proposes several circular business models:

- Transformer model: focused on internal recycling of plastic waste to secure a reliable supply of recycled raw materials.
- Converter model: centered on the purification of plastic materials to produce food-grade quality materials.
- Compounder model: aimed at processing waste to produce high-quality plastic pellets.

Each of these models was evaluated for economic viability at an industrial scale (TRL9), considering operational expenditures (OPEX), capital expenditures (CAPEX), and economic externalities such as eco-contributions and plastic taxes. Financial indicators, including Net Present Value (NPV) and Internal Rate of Return (IRR), were used to assess the profitability of different scenarios.

The results show that while some models offer promising profit margins, most require additional financial support to break even within three years. The document recommends exploring public and private funding options and considering pilot projects at intermediate scales to facilitate the deployment of technologies.

In conclusion, the study highlights the challenges and opportunities associated with integrating circular business models for multilayer packaging, emphasizing the importance of innovation and financial support in successfully transitioning to a circular economy.

1 Definition of the goal and methodology

The objective of Task 6.5 is to identify the most relevant business practices to enable a full circularity to the CIMPA end-products (plastic multi-layers packaging). In other words, the complexity of the CIMPA value chain, in terms of number of steps and technologies, will cover an important part of the current packaging value chain. It will be then possible to design several business models according to the end-products and clients targeted. Hence, the methodology to construct the different circular business models will included the following items:

- Review of the literature
    - Identify main circular business model
    - Identify the current industrial business practices
    - Identify main legislative and regulatory levers

- Construction of the complete circular value chain:
    - Identification of actors
    - Integrating current EPR national schemes
    - Identification of the main financial flows and externalities
    - Integrate the legislation items that will reshape the future business model
    - Integrated the linear and current value chain (fossil based) for comparison purposes

- Circular cost structure definition:
    - Construction of economics baseline based on fossil based product
    - Complete the data collection with the information that were missing and/or incomplete in the screening (see other project Deliverable D6.3).
    - Propose models to obtain a cost projection of the different technologies at TRL9.

- Revenue streams:
    - Set up of the Profit & Loss (P&L) analysis to measure the gross margin of the product foreseen by the project. Extract the revenue table from the P&L.
    - Replicate the P&L analysis according to the different products.
    - Extract the NPV and IRR from the different P&L

- Financial analysis of the different business models profitability
    - Replicate the P&L analysis according to different business model and/or products.
    - Extract the NPV and IRR from the different P&L

The business models will be studied for the French market to simplify the hypothesis on the value chain and also the market prices chosen.

2 Description of potential business models

2.1 Review of the literature on current circular business model

As defined by Florian Lüdeke-Freund[1] a Circular Economy business model (CE) may be defined as system in which resource input and waste, emission, and energy are minimised. This endeavour could be achieved by different business models such as long-lasting design, repair or reuse and recycling, among other models.

Hence, the ultimate gaol of sustainable and circular model is to achieve greater resource efficiency and effectiveness.

The main actions leading towards a CE have first been identified as the **3R principles of reduce, reuse, and recycle.**

Valtteri Ranta *et al.*[2] described feasible CE business models combining the 3R principles based on the following propositions:

- the cost-efficiency of circular operations is the key proponent to successful CE business,
- take-back services enable the acquisition of particular wastes as resources, but they need to be incentivized through **reductions in customers' total waste management costs**,
- circular business models require the focal firm to separately **manage multiple positions in the value chain,**
- the take-back system for gaining value through CE can be implemented successfully in multiple ways, and
- **recycling is easier** to implement than reducing or reusing due to a smaller impact on the business.

Based on Valtteri Ranta *et al.* studies, the "recycle" principle is more dominant in economic value creation in CE when compared with the "reduce" and especially "reuse" principles.

Adding two more R principles – Refuse and Repair can add more solutions to making plastics a strong and sustainable alternative. Hence, **the 5R principles focuses on Refuse, Reduce, Reuse, Repair, and then Recycle.**

Circular business models based on **remanufacturing and reuse** promise significant cost savings as well as radical reductions in environmental impact. Variants of such business models have been suggested for decades, and there are

[1] *Florian Lüdeke-Freund, Stefan Gold, Nancy M. P. Bocken - A Review and Typology of Circular Economy Business Model Patterns - Volume23, Issue1, February 2019, Pages 36-61*

[2] *Valtteri Ranta, Leena Aarikka-Stenroos, Saku J. Mäkinen, Creating value in the circular economy: A structured multiple-case analysis of business models, Journal of Cleaner Production, Volume 201, 10 November 2018, Pages 988-1000*

notable success stories such as the Xerox product–service offering based on photocopiers that are remanufactured. Still, we are not seeing widespread adoption in industry.
Described by M. Linder and M. Williander[3], circular business models based on remanufacturing and reuse lead to significant cost savings as well as radical reductions in environmental impact. Nonetheless, the author noticed a lack of widespread adoption in industry.
Slow consumption (Refuse) CE business models are less widespread. Bocken and Short[4] described 'sufficiency' as a driver of business model innovation for sustainability. Sufficiency-driven business models seek to moderate overall resource consumption by curbing demand through education and consumer engagement, making products that last longer and avoiding built-in obsolescence, focusing on satisfying 'needs' rather than promoting 'wants' and fast-fashion, conscious sales and marketing techniques, new revenue models, or innovative technology solutions.

2.2 Review of legislation

The decree of application of the Anti-Waste law for a Circular Economy (AGEC), the decree known as "3R" for Reduction, Reuse and Recycling has been published[5]. If this decree is non-binding and does not set any prohibition, it defines objectives for the period 2021-2025, to tend towards the end of the marketing of single-use plastic packaging by 2040. About packaging, the focus is set to:

- 20% reduction in single-use plastic packaging by the end of 2025
- 100% reduction in "unnecessary" single-use plastic packaging by 2025
- An operational recycling channel for all single-use plastic packaging by January 1, 2025

In order to fight waste, the AGEC law also provides actions aimed at extending the life of our everyday apparatus, in particular by facilitating their repair. This law will **act against planned obsolescence.**

This law will have a strong impact on the 3R/5R principles and ultimately novel circular business that had difficulties to emerge.

In 2023, the European Commission's **proposal for a Packaging and Packaging Waste Regulation (PPWR)** officially entered the co-decision process, with the Parliament and Council now discussing the details of the text under an ambitious timeline. Regarding article 6 on recycling, the text stated:

[3] *M. Linder and M. Williander, Circular Business Model Innovation: Inherent Uncertainties Bus. Strat. Env. (2015)*

[4] *N.M.P. Bocken , S.W. Short, Towards a sufficiency-driven business model: Experiences and opportunities, Environmental Innovation and Societal Transitions, Volume 18, March 2016, Pages 41-61*

[5] https://www.citeo.com/le-mag/decret-3r-quels-objectifs-de-reduction-reemploi-recyclage-dici-2025

- All packaging shall be recyclable.
- Packaging shall be considered recyclable where it complies with the following:
    - it is designed for recycling;
    - it is effectively and efficiently separately collected;
    - it is sorted into defined waste streams without affecting the recyclability of other waste streams;
    - it can be recycled so that the resulting secondary raw materials are of sufficient quality to substitute the primary raw materials;
    - it can be recycled at scale from 1 January 2035.

During the European legislative procedures, the evolution of Article 7 of the PPWR related to the minimum recycled content in plastic packaging shows that the amount of recycled material in food contact packaging other than PET (excluding bottles) **range from 0% to 10%.**

In a nutshell:

- Different circular business models are proposed today according to the 3R or 5R principals
- The recent legislation will strengthen mainly business models based on recycling and reuse/repair.
- We choose a **reincorporation rate of 10% of recycled material** in flexible food contact packaging.

2.3 Industrial business practices

2.3.1 Converter full circular business model

In the project, this business model is **embodied by the Barbier Group**. This model focuses on sourcing waste and treating it internally through mechanical recycling. Its purpose is then to have access to different waste sources to secure its procurement.

As described in Figure 1, Barbier group already integrates several steps for the preparation of flexible film waste in a commercial product except for the $scCO_2$ cleaning. Indeed, sorting, pre-treatment (grinding, washing, compounding) are part of their daily business. The input of this value chain is a sorted stream that will then be sorted again to ensure stable quality.

Inspired by this model, the CIMPA circular business model includes also scCO2 decontamination and digital watermark, upgrading and innovative reprocessing, which are key in this study.

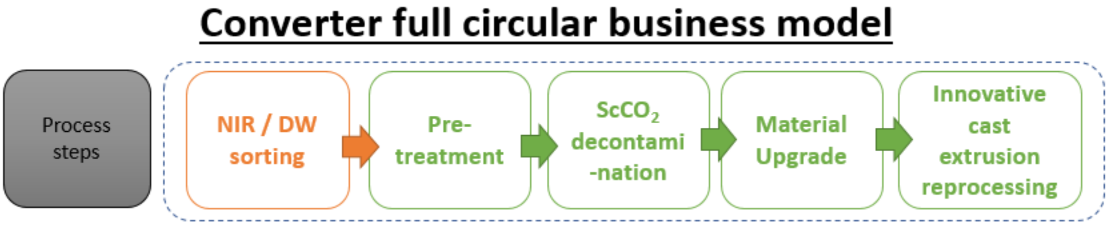

Figure 1: Description of each step of the converter full circular business model

2.3.2 Converter circular business model

This model focuses on sourcing mechanically treated and sorted recycled compounds. Its purpose is then to have access to different recycled plastics sources of different quality or purity level and then secure its procurement. This model could be integrated by every plastic converter eager to source sorted plastic waste and then purified it.

This business model is innovative because of advanced purification steps (i.e. scCO2); the plastic converters may access the food grade quality recycled material and then propose products at a much higher price (upcycling).

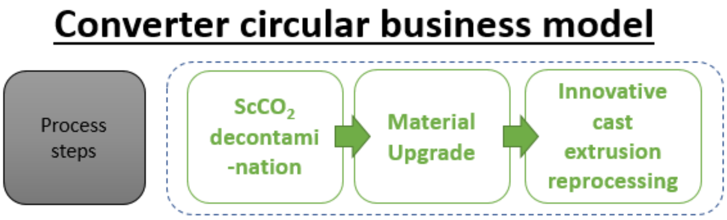

Figure 2: Description of each step of the converter circular business model

2.3.3 Compounder circular business model

This model focuses on sourcing waste and treat it internally through mechanical recycling. Its purpose is then to have access to different waste sources to secure its procurement and ultimately produces purified sorted plastics pellets. This model could be integrated in every recycler company, **such as PAPREC**, eager to source unsorted plastic waste and then purified it.

The innovation in this business model is mainly due to the scCO2 purification step. Indeed, the produced pellets could be sold at a much higher price given that its quality will meet food contact grade. Moreover, DW sorting is also essential to meet the food grade requirement (food/non food sorting)

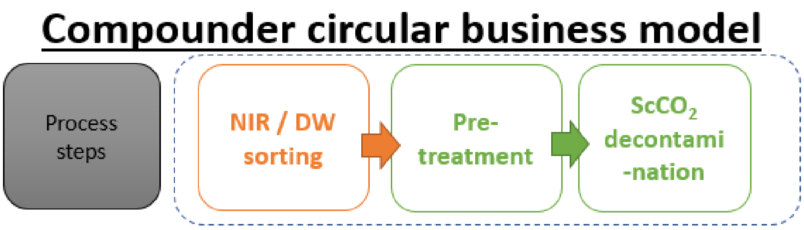

Figure 3: Description of each step of the compounder circular business model

2.4 Stakeholder feedback

The stakeholder engagement activities conducted within WP1 contributes to the project's output to ensure a comprehensive valuable circular economy model. This CIMPA *Value Chain workshop* held on September 8th 2022 was the first one in the series of value chain workshops targeting multilayer plastics value chain actors. All information regarding those activities is summarized in the deliverable D1.7: "*First report on Stakeholder Engagement*".
Business modelling for CIMPA solution was the focus of this *Value Chain workshop* and has for objectives to gather experts' inputs and approaches to business modelling at various levels of multilayer plastics value chain and to discuss how these could be applied to CIMPA.

During the breakout sessions of the workshop, participants were asked to identify main gaps of actors and elements of the value chain. **The idea was to make sure that all elements of the value chain were taken into account for further business modelling** works. Below, we present a list of the main points that were relevant to the present work.

Missing actors and elements in the value chain:

- **Extended Producer Responsibility (EPR)** (policy) should be in middle of the value chain (from brand owner to regulator)
- Point of attention: **municipalities** and different standards across Europe
- Equipment suppliers
- Reuse systems
- Mixed waste

Who influences and interacts strongly with whom that could impact the CIMPA objectives:

- **EPR** will have a huge impact on different aspects connected to the value chain: what is put on the market, the future of multilayers, how to engage sorting operators, how to create sorting streams, and the economics behind it, also the quality of sorting
- **Brand owners** influence a lot the actors, they need to be willing to use recycled material to close the loop.

To conclude, the representation of the value chain described in Figure 4 were updated with the elements described above and were used as a starting point for the work described in the paragraph 3.1.

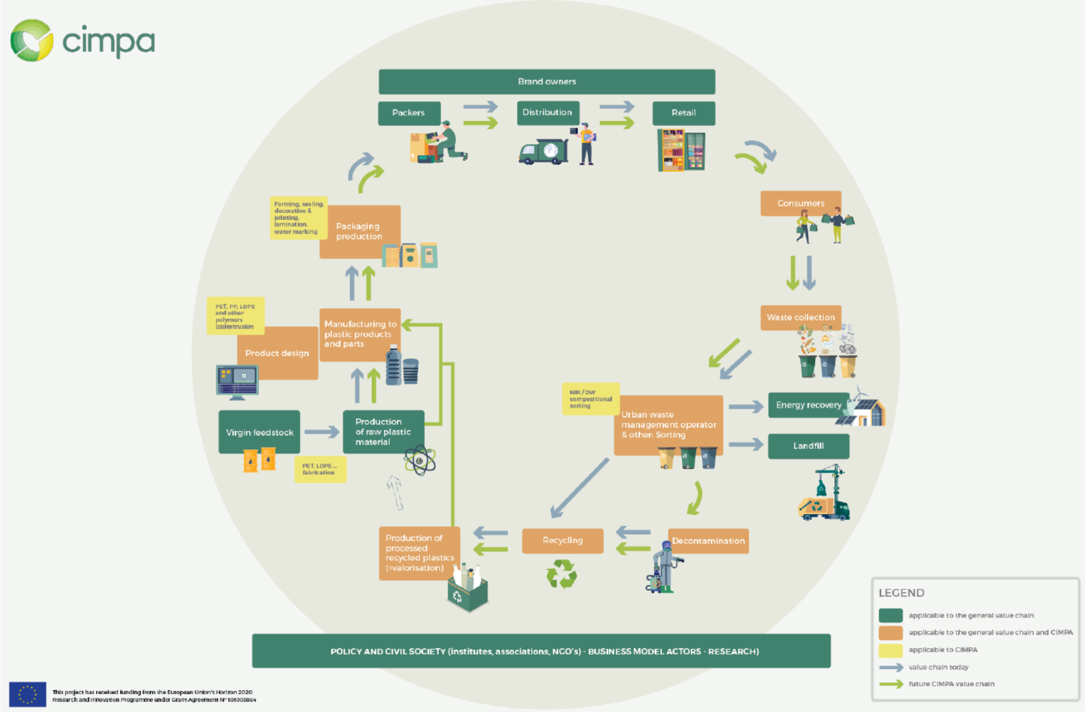

Figure 4: First description of the value chain presented during the stakeholder workshop organized by PROSPEX in WP1.

3 Overview of the circular value chain

The objective of this paragraph is to define all stakeholders involved in the production and recycling of multilayer packaging. This value chain needs to include the following:

- The EPR has a central position in the value chain and in the definition of the Circular-driven Business Model (CBM)
- Inclusion of the eco-modulation and eco-contribution in the CBM
- Inclusion of the gate fee and all end-of-life taxes into the Business Model (BM)
- Inclusion of the CIMPA technologies (i.e. watermarking and recycling value chains)

The CIMPA value chain includes most of the technical stakeholders involved in the ML packaging production, use and recycling. The Figure 5 represents this value chain as a circular chart flow centred on the EPR eco-organism.

3.1 Main representation of the circular value chain

EPR schemes were set up in order to organize the waste prevention and management. Each product types lead to a specific EPR (for example, there are EPR for packaging, toys, sport goods…). The objective of the EPR system is to act on the entire life cycle of products: eco-design, waste prevention, lifetime extension and end of life management. Its involvement on the financial management of each element of the value chain make it central. However, EPR does not cover the upper part of the value chain (i.e. the production of semi product and ML film packaging). This is an important point that will be discussed later.

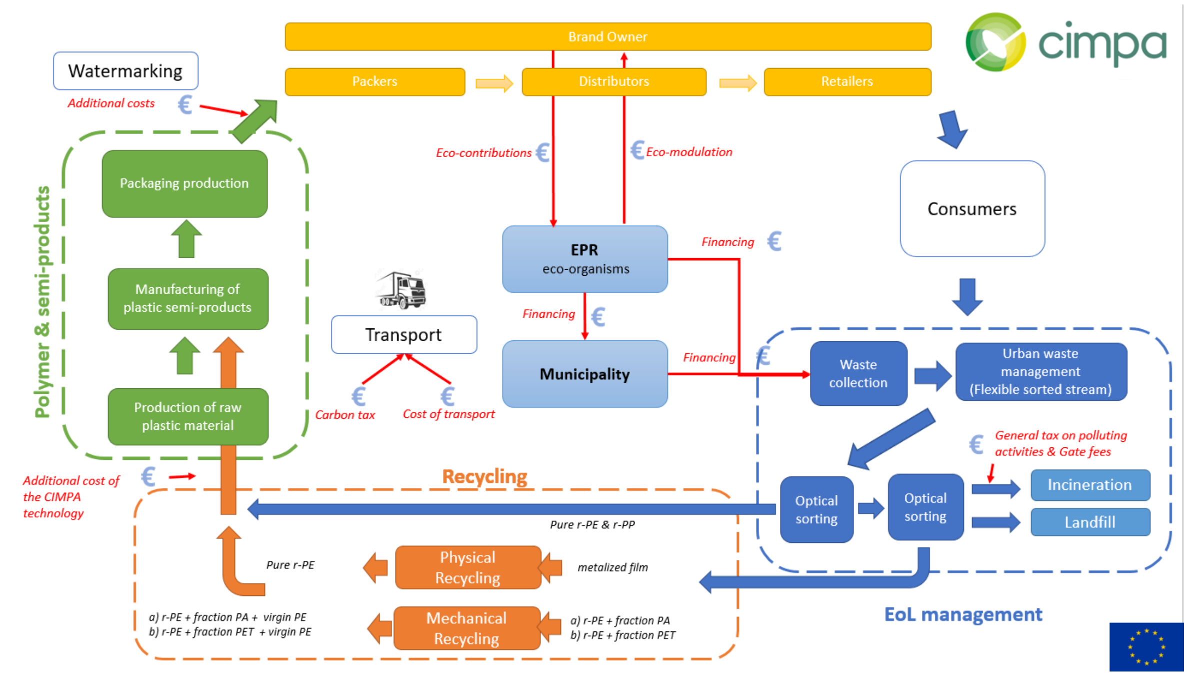

Figure 5: Description of the circular value chain

EPR is based on the "polluter pays" principle: companies, **i.e. the people responsible for bringing products on the market**, are responsible for the entire life cycle of these products, from their design to their end of life (EoL). **EPR transfers all or part of the waste management costs to the producers**.

To fulfil their obligations, producers have the choice of setting up collective non-profit structures, **called eco-organizations**, or forming their own individual system.

For each product placed on the market, **the producer pays an eco-contribution** to the relevant eco-organization. Its amount is directly linked to the product type placed on the market and the end-of-life waste management cost. Eco-contributions thus make it possible to fund all the producers' obligations (prevention, reuse, collection, sorting, recycling of waste, awareness, etc.). If they fulfil a stated environmental criterion, in particular related to the eco-design of products, **the contributions can be modulated (eco-modulation).** The producers' best interest is therefore to limit their waste production and facilitate its recovery.

There are two standard models for financing waste prevention and management operations in EPR sectors:

- <u>Contributory or financial model.</u> Eco-organizations collect eco-contributions from producers and **redistribute them to local authorities** or other operators who collect and sort this waste.

- Operating model. The eco-organization collects eco-contributions from producers and uses these funds **to pay itself the service providers** who collect and process waste.

In a nutshell:

- The companies responsible for bringing a product on the market pay eco-contributions to the eco-organism
- The contributions can be modulated (eco-modulation).
- Collected eco-contributions are distributed to local authorities or directly used by the eco-organism to manage the waste

3.2 Description of the different financial flows and externalities

3.2.1 Eco-contribution and eco-modulation

Standard eco-contribution in France

The financial contribution that companies pay to the eco-organisms or any EPR bodies enables to finance the packaging collection and sorting in order to recycle it, to support them in eco-design approaches and in the development of new modes of consumption such as reuse.

It is interesting to see that in France[6], the household packaging end-of-life cost increase is partially due to the simplification of sorting, which is progressing everywhere in France. **This increased recycling performance results in an increase of operating costs and therefore of the eco-contribution**. It is by taking these parameters into account, and being aware of the uncertain economic context, that the EPR bodies has calculated the evolution of its prices as accurately as possible. Plastic packaging eco-contributions have been put in place to reflect the recycling sectors development and allow to better measure the packaging recyclability level.

In an EPR scheme, the modulation of the eco-contribution is called eco-modulation. This modulation is an economic incentive for producers to favour more repairable and recyclable products, which contain fewer hazardous substances, and which incorporate more recycled material in a circular economy logic.

A first contribution is made according to the typology of material put on the market according to its weight. In our case study (ML film packaging), in France, the material of interest is a **complex packaging taxed up to 0.5528€/kg**[8].

Of course, there is no indicative cost for putting on the market recyclable MLs as they do not exist today. **We make the hypothesis** that the cost for putting recyclable PE or PP flexible ML will be aligned with PE flexible packaging cost. Hence, **the eco-contribution of PE/PP flexible ML is 0.4221€/kg**[8].

[6] *https://www.citeo.com/le-mag/la-contribution-2021-pour-le-recyclage-des-emballages-menagers*

Finally, putting a recyclable ML on the market instead of the non-recyclable one **will save 0.1307€/kg of eco-contribution.**

Bonus (eco-modulation) for the integration of post-consumer materials from recycling[7, 8]

A bonus or eco-modulation is given to plastic packaging that incorporates **at least 10wt% of recycled plastic materials,** coming from household, industrial or commercial packaging. The use of internal production scraps (adjustment waste, non-compliant products, shrinkages...) to produce packaging is not eligible for these bonuses or additional bonuses.

The bonuses amount is determined according to the recycled material mass incorporated. The incorporation of material from household packaging recycling can lead to an additional bonus according to the recycled material mass coming from recycling of specific household packaging categories.

Integration of recycled PET (Polyethylene terephthalate) (rPET) in the PET packaging:

- A bonus of €0.05/kg is granted if the rPET comes from household, industrial or commercial recycling.

Additional bonus for rigid PET packaging only such as "jars and trays" excluding bottles and flasks:

- An additional premium of €0.35/kg is granted for rigid PET packaging excluding bottles and flasks, in particular for the jar or tray type.

Integration of recycled PE (Polyethylene) (rPE) in flexible PE packaging (mainly Low Density Polyethylene - LDPE):

- A premium of €0.40/kg is granted if the rPE comes from household, industrial or commercial recycling.
- An additional bonus of 0.15 €/kg is granted if the rPE comes exclusively from household packaging recycling.

Integration of recycled PE (Polyethylene) (rPE) in rigid PE packaging (mainly High Density Polyethylene - HDPE):

- A bonus of 0.45 €/kg is granted if the rPE comes from household, industrial or commercial recycling.

Integration of recycled PP (Polypropylene) (rPP) in PP packaging:

- A bonus of €0.45/kg is granted if the rPP comes from household, industrial or commercial recycling.

[7] *https://bo.citeo.com/sites/default/files/2021-02/20210201_Citeo_Outil%20interactif_2021.pdf*
[8] *https://bo-citeo.dev-dropteam.com/sites/default/files/2023-02/220930_Citeo_Guide_Tarifs_2023_FR_1.pdf*

Type of recycled polymers	Bonuses based on the recycled material mass	Additional Bonuses based on the recycled material mass
PET	0.05 €/kg	0.35 €/kg
LDPE	0.4 €/kg	0.15 €/kg
HDPE	0.45 €/kg	-
PP	0.45 €/kg	-
PS	0.55 €/kg	-

Table 1: Summary of the bonuses granted by CITEO, the French packaging EPR, based on the recycled material mass

In a nutshell:

- The companies responsible for bringing a product on the market pays an eco-contribution to the eco-organism
- The **eco-contribution for a ML packaging is 0.55€/kg** of packaging put on the market by the brand owner (in France).
- We assume that the eco-contribution of flexible ML recyclable will be 0.42€/kg, i.e. a saving of 0.13€/kg of eco-contribution.
- Bonuses we will be granted if mono-material recyclates are incorporated in virgin material in a concentration higher than 10wt%, such as:
  - Bonuses up to 0.55€/kg for r-PE in PE
  - Bonuses up to 0.45€/kg for r-PP in PP

3.2.2 European plastic tax

The "plastic tax", payable by the Member States, was calculated according to the **volume of non-recycled plastic packaging waste produced in twelve months**, on the basis of **800€/ton**. It concerns both household and non-household plastic waste. France gathered them at around 1.5 million tonnes in 2021[9].

Started 1st January 2021, the contributions will be calculated based on Eurostat data which Member States already collect and provide under existing reporting obligations (specifically the Packaging and packaging waste Directive and its Implementing Decision (Decision (EU) 2019/665).

Hence, France paid 1.2 billion euros in "plastic tax" to the European Union (EU) last year, according to data published by INSEE.

[9] https://www.lesechos.fr/politique-societe/societe/la-france-a-paye-12-milliard-deuros-de-taxe-plastique-a-bruxelles-en-2021-1397364

For other EU countries, the tax is partially **transferred to the plastic packaging producers** and ultimately the consumers[10], for instance **0.45€/kg for Spain and Italy.**

In a nutshell:

- The EU plastic tax amount for 0.8€/kg according to the volume of non-recycled plastic packaging waste produced in twelve months
- The tax will be paid by each members states
- Depending on the EU country, the **tax is partially transferred** to the plastic packaging producers (**0.45€/kg for Spain and Italy.)**

3.2.3 Transport

Road transport is modelled taking into account the distance travelled, the vehicle size, the vehicle consumption at full load (depending on the vehicle size), the ratio between the load actually transported and the payload (depending on the vehicle size) and the distance travelled by the empty vehicle[11].

The truck used for the model is a 40t long distance one, carrying a payload of 25t with a consumption of 53.43L/100km. At an average diesel fuel price of 1.66€/L[12], **this leads to the price per kilometres of 88.69€/100km.** The truckers' salaries, charges included, add up to 20.68€/h[13] with 1.13 trucker per vehicles, leading to an average of 39,726k€/y. When divided by 130 542km/y, we end up with **38.36€/100km for the salaries**.

The 40t motor vehicle life span is 6.2 years with an average of 103 542 km/y[13] travelled. The total fixed vehicle costs per operating day is 173.36€/day[13] (including assurance, taxes and ownership cost / CAPEX) on a 237days/y basis, leading to 41,086k€/y. When divided by 130 542km/y, we end up with **39.68€/100km for the CAPEX**.

Transport costs are also described in the JRC technical report[14]. A cost of 0.077€/t/km is proposed that leads to 308€/100km for a 40t truck. This value is higher but coherent.

[10] https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/tax/tax-pdfs/ey-plastics-and-packaging-taxes-webcast-summary.pdf
[11] *Cadre de référence - ACV* comparatives entre différentes *solutions d'emballages, ADEME, 2022*
[12] *https://www.europe-camions.com/news/oil-price*
[13] https://www.cnr.fr/prix-revient/9
[14] *JRC technical report: Environmental and economic assessment of plastic waste recycling. comparison of mechanical, physical, chemical recycling and energy recovery of plastic waste Garcia-Gutierrez, et al., 2023*

In a nutshell:

- The modelled 40t long distance truck used possesses a price per kilometres of **88.69€/100km**.This represents the direct cost of the OPEX (fuel, load / payload ratio – French Road tolls of 0,053 €/km[13] excluded)
- The indirect cost of the OPEX linked to the truck driver salaries leads to **38,36€/100km.**
- The indirect cost of the CAPEX linked to the truck ownership leads to **39,68€/100km.**
- All cost included the exploitation of a 40t truck cost 166,73€/100km[15]

3.2.4 Taxes and gate fees for landfilling

Disclaimer: for consistency, EoL costs have been updated from D6.3 and use now on 2022 figures.

A gate fee (or tipping fee) is the charge collected for a waste quantity received at a waste processing facility. In a landfill case, it is generally levied to fund the site opening, maintenance and eventually closure. **It may also include any landfill tax which is applicable in the region**. The gate fee differs from the waste removal fee which is in place for areas where waste collection is not covered by local taxes such as Ireland.

In other waste treatment facilities case, such as incinerators, mechanical biological treatment facilities or composting plants, the fee compensates the facility operation, maintenance, labour costs, capital costs,

The fee can be charged per load, per ton, or per item depending on the waste source and type. Table 2 shows figures for the landfill gate fee in EU.

Country	Landfill gate fee in €/t	Landfill tax excl. VAT in €/t	total
Austria	70	87	157
Belgium (Wallonia)	40	65	105
Bulgaria		7 to 15	7 to 15
Czech republic	16	20	36
Denmark	44	63	107
Estonia	40	12	52
Finland	59	50	109
France	60	9 to 30	69 to 90
Ireland	70	75	145
Italy	90	7 to 30	97 to 120
Latvia	16	22	38
Netherlands	25	107	132
Poland	70	27	97
Portugal	11	4	15
Slovenia	105	19	124
Spain(Catalonia)	41	12.4	53.4
Sweden	106	47	153
United Kingdom	27	100	127

Table 2: Landfill fees and taxes in different European countries (Horizon, 2020).[16]

In general, this polluting activity tax is paid by:

[15] To be compared the reference [5] that shows 157,29€/100km. The assumption on fuel cost were lower

[16] Elrabaya, Daker & Marchenko, Valentina. (2021). Identifying the full cost to landfill municipal solid waste by incorporating emissions impact and land development lost opportunity: Case study, Sharjah-UAE. International Journal of Engineering Sciences.

- Any person receiving waste, whether it is hazardous or non-hazardous, and operating a classified facility, subjected to a permit allowing the waste storage or thermal treatment.
- Any person who transfers or causes to waste transfer to another State in application of the regulation (CE) n° 1013/2006 of 14 June 2006 on waste shipments.
- In France, local authorities often play these roles, especially the first one, and are therefore often in charge of paying the tax (TGAP[17]).

In addition, data were collected internally by the project partners. Several waste management centres were questioned about their costs. We end up with values around 180€/t for landfilling management.

In a nutshell:

- Gate fees generally **levied to the cost** of opening and maintenance, and may also include any **landfill tax** which is applicable in the region
- In France, gate fee for landfilling non-dangerous material reaches **0.060€/kg**
- In France, tax fees (TGAP) for landfilling non-dangerous material reaches **0.058 €/kg**
- Internal survey shows a cost of **0.180€/kg for landfilling**.
- EoL cost for landfilling ranges from 0.118 to 0.180€/kg
- For the rest of the study, we choose a cost of 0.150€/kg for the landfilling cost

3.2.5 Taxes and gate fees for incineration

Very few data are publicly available on the money collected for the waste incineration. Hence only recent and coherent data on UK use case were to be found about Energy from Waste (EfW) facilities[18].

In 2019-2020, the reported median gate fee for incineration with EfW is £93/ton compared to £89/ton last year. For pre-2000 EfW facilities, the median gate fee is £62/ton, compared to £65/ton last year. For post-2000 facilities, the median gate fee is £95/ton compared to £93/ton last year.

The tax related to incineration is publicly available in France[17]. For 2022, the amount of 0.022€/kg for the French tax component related to the thermal treatment of non-hazardous waste.

In addition, data were collected internally by the project partners. Several waste management centres were questioned about their costs. We end up with values around 180€/t for incineration management.

[17] *BOI-BAREME-000039 - BAREME - TCA - Taxe générale sur les activités polluantes | bofip.impots.gouv.fr*

[18] *WRAP, Gate Fees 2018/19 Report, Comparing the costs of alternative waste treatment options*

This value is coherent with other references found[19].

In a nutshell:

- Gate fee costs for incineration with energy recovery reach **0.107€/kg in the UK**
- In France, in 2022, the incineration tax is 0.022€/kg of waste
- We considered that the total incineration EoL cost in France **ranges from 0.129 to 0.180€/kg**
- For the rest of the study, we choose a cost of 0.150€/kg for the incineration cost

3.2.6 Carbon tax

The carbon tax is an environmental tax on carbon dioxide emissions, the greenhouse gas that contributes the most to global warming. The carbon tax is one of the two main tools intended to put a price on carbon dioxide, the other being the tradable emission quotas (via a carbon exchange – ETS: Emissions Trading Schemes).

The tax fixes the price of carbon dioxide without controlling the quantities of CO_2 emitted, while the quotas fix the quantities emitted without controlling the price of carbon dioxide on the markets. The two systems can coexist, the tax allowing to involve the small emitters, which are difficult to take into account with the quota system.

The carbon tax is a tax based on the "polluter pays" principle, which gives a price to the carbon dioxide of fossil fuels, added to the selling price, and charges all or part of their negative externalities. Externalities are the damage caused hidden costs, now and even more in the long term, by anthropogenic global warming.

The **carbon tax in France has been found in three of the four domestic consumption taxes (TIC) since 2014**: the domestic consumption tax on energy products (TICPE), which contributes 57% of the price of petrol, the domestic tax on consumption of natural gas (TICGN), and the internal tax on coal consumption (TICC). It is calculated from a price per ton of carbon dioxide, set by the government.

In 2018, the tax rates observed in countries that have introduced a carbon tax range from >$1/t CO2 (for Poland) to $138/t CO2 (for Sweden)[20]. In 2019, the IMF estimates that a carbon tax reaching $75/t CO_2[21] (76€/t CO_2) (i.e. a level higher than the average price per ton of carbon in the world, of around $2) by 2030 in all G20 countries would reduce emissions enough to limit global warming to 2°C by 2100.

For this study the carbon tax is set at an average price of 50€/t CO_2.

19 *https://www.zerowastefrance.org/lincineration-des-dechets/#:~:text=L'incin%C3%A9ration%2C%20dont%20le%20co%C3%BBt,le%20compostage%20%C3%A0%20court%20terme.*

20 *https://openknowledge.worldbank.org/bitstream/handle/10986/35620/9781464817281%20Executive%20Summary.pdf?sequence=3&isAllowed=y*

21 *https://www.latribune.fr/entreprises-finance/transitions-ecologiques/face-au-rechauffement-climatique-le-fmi-milite-pour-un-taxe-carbone-internationale-830583.html*

In a nutshell:

- In France, the tax only has an **impact on the price of energy products** (natural gas, coal, gas and oil).
- In France, the carbon tax is set at an average price of **50€/t CO_2**.
- The carbon tax impacts the price of decentralized processes and petro-sourced energy consumers (depending on the energy mix)

3.2.7 Price of electricity

A process electrical consumption on a LCA point of view include a electricity transformation step from medium to low voltage. In the processes studied in CIMPA, we believed that this conversion needs to be applied and ultimately included in financial analysis.

Hence, from the data gathered in SIMAPRO, we obtained a consumption of 1.031kWh of medium voltage for 1kWh consumed in low voltage.

In addition, we choose an average price for the purchasing of electricity on French market of 0.1847 €/kWh.

In a nutshell:

- 1kWh of electricity consumed in low voltage account for 1.031kWh of medium voltage at a market price of 0.1847 €/kWh.

3.2.8 Workforce cost

The average salary of the **French plastic industry** value chain is described in the table below. Those labour prices will be used is the LCC analysis.

Type of workforce	**Average monthly gross wages per type**	**Average monthly gross wages per type including all taxes (30%)** [22]	**Average hourly gross wages per type including all taxes**[23]
Worker	1800€	2340€	17.5€/h
Technician	2500€	3250€	24.2€/h
Engineer	4500 - 9000€	5850 – 11 700€	40.6 – 81.2€/h

Figure 6: average salary of the French plastic industry value chain

[22] The employer's contributions are calculated on the basis of the worker's gross monthly salary. These charges correspond to an amount between 25 and 45% of the gross salary.
[23] 1728h per year for engineer with 215 day of work and 1608h per year for technician and worker this will lead 144h/month and 134h/month for technician / worker

4 Economic analysis of CIMPA technology at TRL9

4.1 Sales baseline prices

The baseline prices aim to compare prices of the film structures developed in CIMPA compared to the prices of the ones available on the market.

Market available multilayers cost prices

Based on the LCC screening described in D6.3 and taking into account 2023 market prices (LDPE: 1.55€/kg, PET: 1.25€/kg)[24], **a calculated price of 2.18€/kg** was found for the LDPE/PET multilayer film structure. The figure below details the cost used and collected during this previous work.

A quick estimation that will take into account the CAPEX depreciated over a period of 8 years will give us a **cost price[25] of 2.23/kg**.

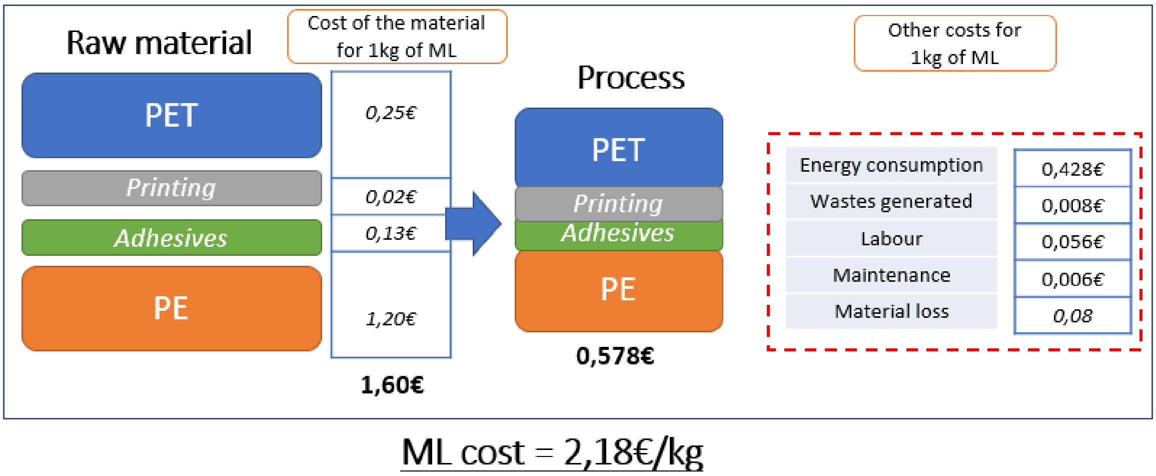

Figure 7 : LDPE/PET multilayer film cost structure with detailed costs used and collected during the LCC screening

CIMPA multilayers material model, a 10% Blend of r-PE in virgin PE

For the two streams of waste labelled a) for r-PE/PA and b) for r-PE/PET (cf. Figure 5: a), the recycled material will be incorporated in the virgin material at a 10wt% rate. This is consistent with the objectives of MPR integration from the PPWR legislation.

[24] *RECYCLAGE RÉCUPÉRATION Magazine – 124 Avril 2023, https://www.recyclage-recuperation.fr/les-cours/*

[25] *see section 4.4*

Hypothesis: - Blend of 10% of r-(PE / PA) or r-(PE / PET) in virgin PE

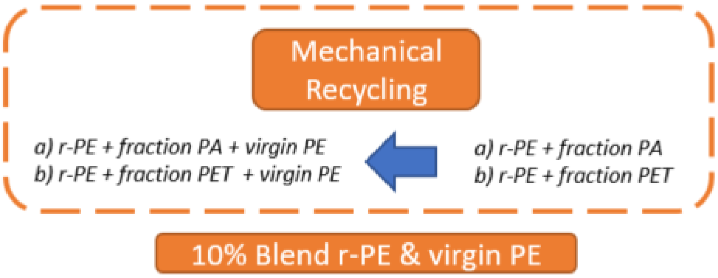

Figure 8: material stream in the mechanical recycling steps

In addition, the prices described below were found on the market in December 2022, but they are volatile, and will probably vary a lot during the project period.

- Classic PE sealant (PE/PET): 2.4€/kg (example above and baseline of the study)
- Classic PE sealant with EVOH Barrier: 3.5€/kg
- PE/PA classic type applications under vacuum: 4€/kg (targeted by the project)
- OPE for replacement of PET for recyclable structures: 4€/kg
- Low temperature PE sealant for recyclable structures: 3€/kg
- Low temperature PE sealant for recyclable structures with EVOH Barrier: 4€/kg
- Complex BoPP +mBoPP (40µ thick): Price: 5,30 €/kg (targeted by the project)

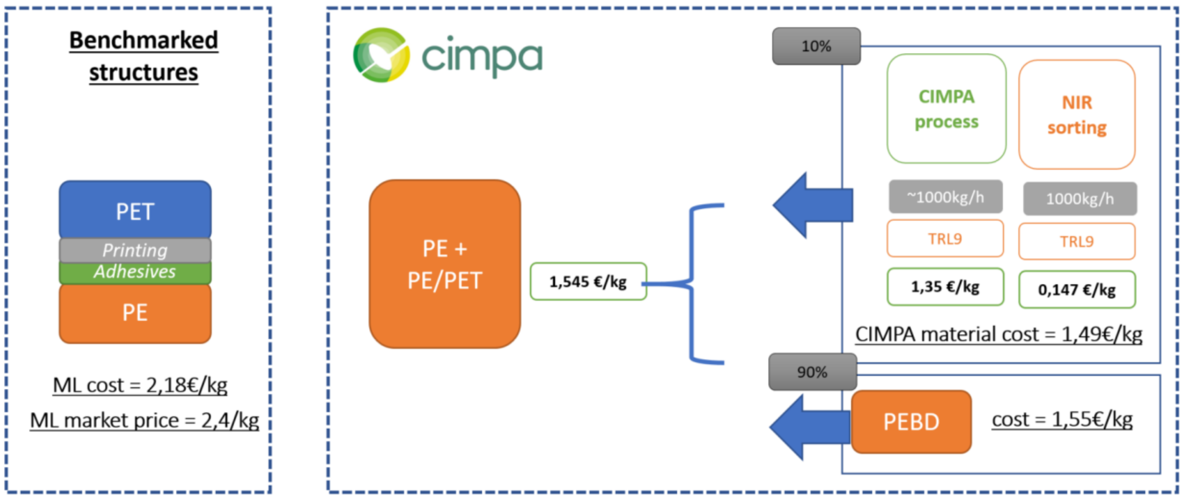

Figure 9: Description of the cost structure of the PE/PET structure in METEOR compare to its commercial counterpart.

In a nutshell:

- Based on our calculation the **PE/PET ML costs 2.18€/kg** to be produced
- Based on our calculation the **CIMPA PE+ PE/PET structure costs 1.54€/kg** to be produced
- The value created by CIMPA innovative recycling is evaluated to be 0.64€/kg

This value will be assess to understand if this is sufficient to motivate future investments.

4.2 CAPEX dimensioning baseline

In order to choose the size of the system at TRL9, the total throughput of the production system must be estimated, either its total annual production capacity or its hourly throughput.

For the CIMPA recycling value chain modelling, a production capacity of 1000kg/hour was chosen to dimension the last process step. Hence, the annual production capacity reaches 8000 tons /year based on a 10days working shift plans (8000h/year)[26].

However, the $scCO_2$ decontamination step exhibits a smaller throughput of 6400t/y. This will lead to the global dimensioning of the value chain at 6400t/y with a yield of 800kg/h for decontamination and every other step yield at 1000kg/h.

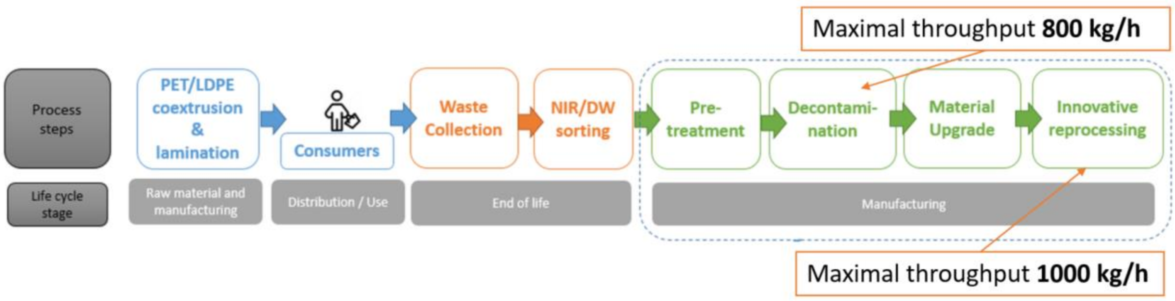

Figure 10: Dimensioning of the system CAPEX by defining the nominal throughput of one of the process steps

[26] *https://en.wikipedia.org/wiki/Shift_plan*

4.3 Externalities integration

4.3.1 Externalities modelling

As part of the LCC methodology, the external costs (or externalities) could be accounted in the total cost structure of the product. Indeed, those costs impact eventually the product life cycle cost and shall be modelled to measure their impacts. In the frame of CIMPA value chain, the externalities were identified and described in the paragraph 3.2. They are summarized in the table below.

Externalities	Amount	Payer	Modelling
Eco -contribution for a recyclable multilayer packaging	0.13€/kg	Brand owner	Still have to be paid. Existing cost in every scenario
Eco -contribution Bonuses[27]	0.55€/kg for r-PE in PE 0.45€/kg for r-PP in PP	**Given** to brand owner	Do not exist in the mechanical recycling value chain **Exist** in the **physical recycling value chain**. Bonuses integrated in the direct cost structure
EU plastic tax	0.8€/kg (or 0.45€/kg)	Each member states (or the packaging manufacturer)	Assumption that the ML is considered as recyclable according to the legislation. Assumption that the tax is paid by the **plastic packaging manufacturer**. The tax become a bonus existing in both value chains as it is not paid anymore
Transport cost	166,73€/ 100km	Any transporter in the value chain. *In fine*, paid by the end client as included in the cost of goods	Not included

[27] *Granted if mono-material recyclates are incorporated in virgin material in a concentration higher than 10%*

Total gate fees for landfilling	0.150€/kg (chosen)	Waste Owner	**Exist** in both value chain. The cost is transferred as negative costs integrated in the direct cost structure with the sorted ML prices
Total gate fees for incineration	0.129 to 0.180€/kg	Waste Owner	
Carbon tax	50€/t CO_2	Energy products retailer	Not included

Table 3: externalities identified in the CIMPA value chain

4.3.2 Externalities integration in the value chain

Based on the hypothesis that the DW allows the full sorting of the ML, that the recycling value chain is at scale and ultimately the ML is recycled, the CIMPA ML can be considered recyclable according the French and European legislation. Hence, the EPR together that the French government will considered a reduction of the eco-contribution and the exemption of the EU tax payment. This will lead to a cost of **-0.33/kg (savings) for the mechanical recycling value chain.**

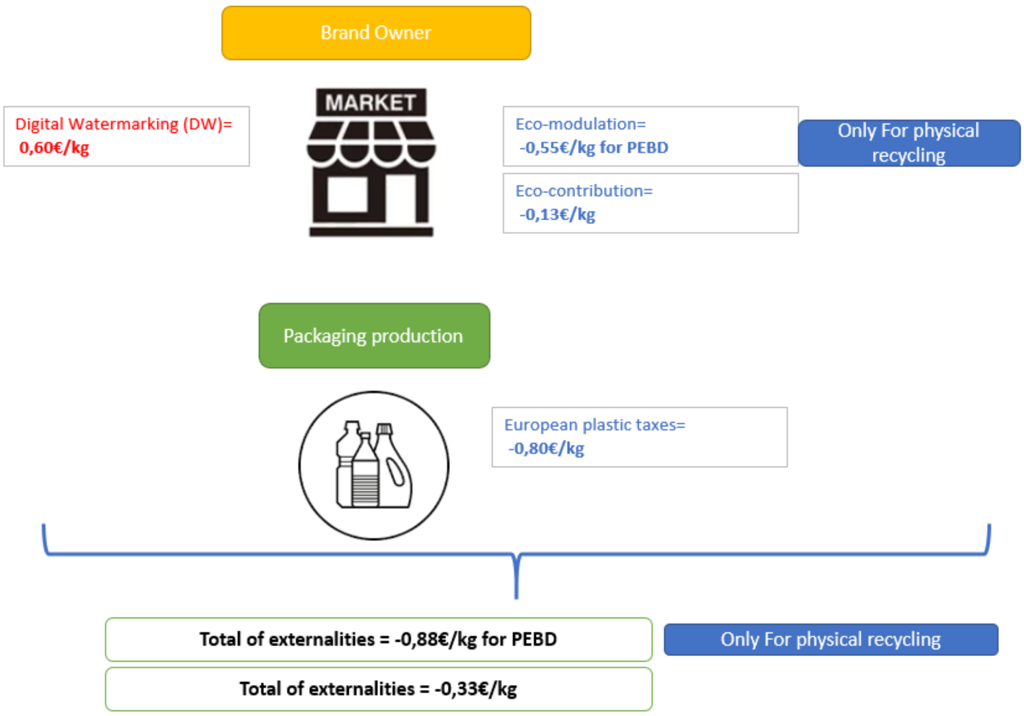

Figure 11: Integration of externalities according to brand owner and packaging manufacturer

In a nutshell:

- All externalities lead to a cost of **-0.33/kg (savings) for the mechanical recycling** value chain.
- All externalities lead to a cost of -**0.88/kg (savings) for the physical recycling** value chain.
- The sum of all externalities in CIMPA novel value chain is negative meaning **that value is created** that will allow to fund its establishment

4.4 Projection of the cost structure of the different value chain elements at higher TRL

Methodology: Both value chain costs are described in France, meaning that the workforce, the cost of energy, water, etc. are based on 2022 French prices.

The calculation of the cost price takes into account the OPEX and CAPEX values. This cost represents the price at which the product needs to be sold to "pay back the investment". It is then calculated over the depreciation period assuming the investment is repaid at the end of this period. For the sake of comparison, **a depreciation period of eight years is chosen**. The cost price is calculated using the following formula:

$$Product\ cost\ price\ = OPEX + \frac{CAPEX}{Depreciation\ period\ \times\ annual\ production}$$

4.4.1 NIR and DW sorting

The NIR sorting are based on a MISTRAL+[28], an equipment working at a throughput of 1000kg/h and of nominal power of 15kW. To understand the cost structure of such a step, the waste flows handled by the equipment need to be understood (see Figure 12). Indeed, the CIMPA concept will focus on the sorting of the rejected stream from the flexible PP and PE sorted streams. This second sorting step will sort the ML that would have been incinerated otherwise.

Hence, negative value could be accounted for the material input, which is removed from the incineration stream, resulting in a cost saving that would have been paid for the EoL management. Likewise, in every scenario, positive waste costs, resulting from the wastes that are still refused, are accounted as output but on a smaller amount explaining why this step could show negative costs at the end.

[28] *https://www.pellencst.com/wp-content/uploads/2021/07/MistralCONNECT-2021-WEB-UK_1.1.pdf*

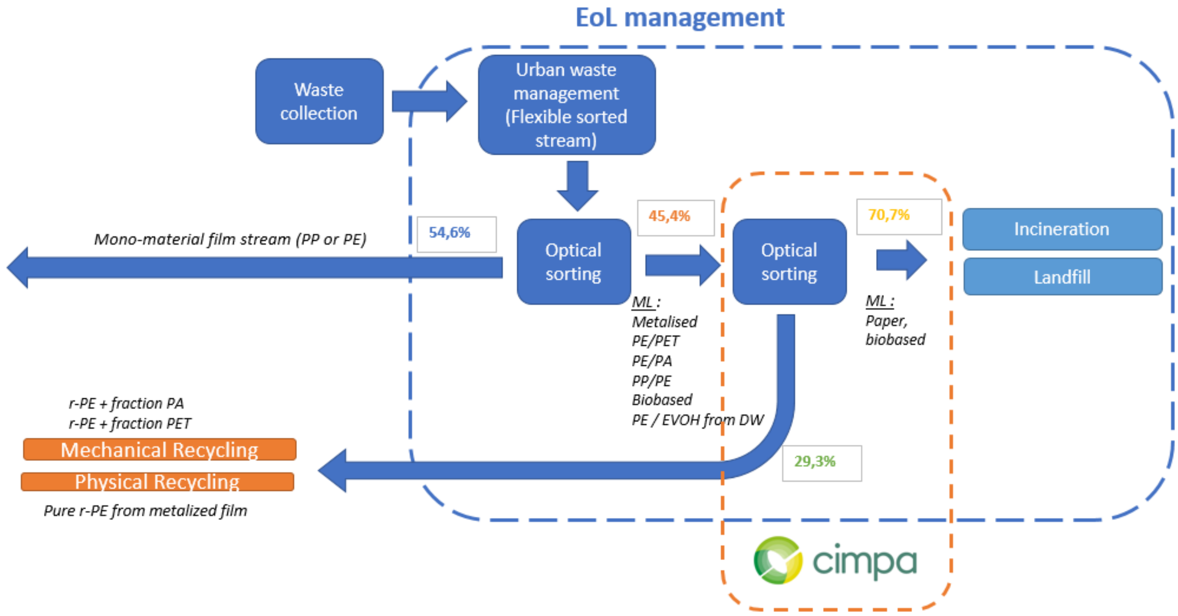

Figure 12: Flow chart of the waste stream focusing on flexible packaging EoL management

The different cost structures of the TRL9 equipment taking into account the cost in the waste input is described in the Figure 13.

Hypothesis to be modelled in the business plan.

The ML waste used in CIMPA came from sorting refusal stream, originally planned for incineration or landfilling. Hence, its value is negative and correspond to EoL gate fees plus taxes. On a competitive market, it is reasonable to consider that this ML stream will ultimately have value. Hence, the waste will gain more and more value with the increase of demand. Its value will then come from -**0.15€/kg** *(cost of landfilling/incineration)* to a value that needs to be modelled.

If we considered that a plastic waste bale costs 0.035€/kg[29], we make the hypothesis that waste collector wants to sell it at this minimum price. We end up with a cost of 0.147€/kg for the OPEX in scenario c) that corresponds to the OPEX of scenario a) plus the cost of baling.

Considering the CAPEX of the optical sorter, we choose a single channel machine with the input and output conveyers. In this configuration, the machine will be able to sort only one material from the mainstream. **The machine will then cost 300k€.** In our case, we need to sort two materials from the mainstream, an addition 50k€ will be needed.

Fair to assume:

- The increase of incineration/landfilling costs, especially through taxes, will keep the cost of the ML waste down.

[29] *RECYCLAGE RÉCUPÉRATION Magazine – 124 Avril 2023 https://www.recyclage-recuperation.fr/les-cours/*

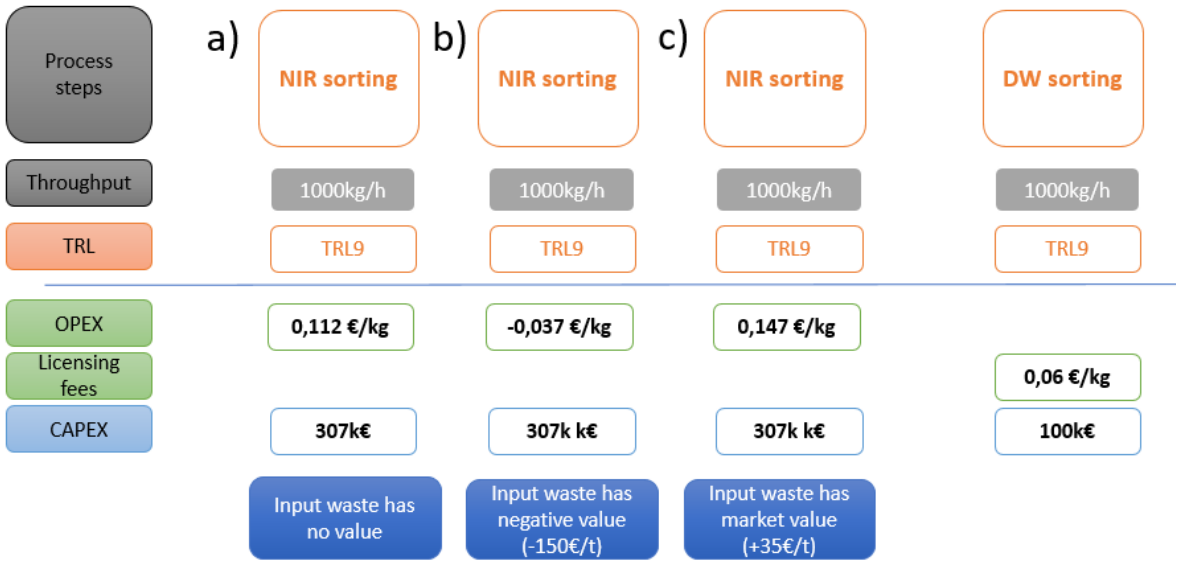

Figure 13: costs description of the sorting step with a sorting waste refusal with (a) no value (b) a negative value that correspond to EoL costs savings and c) a market value of 0.035€/kg. In this model, the cost of incineration and landfilling were fixed at 0.15€/kg.

Regarding the DW developed in the project and provided to the packaging supply chain; only brand-owners are **charged a licensing fee**. For the purpose of LCC, we assumed that brand-owners **will pay 60€ for each ton of multilayer packaging material that is equipped with the digital watermark**. ***The 60€ per ton is used for modelling purposes.*** FiliGrade offers different business and pricing models. Specific pricing and contract terms depends on specific circumstances and are not available in the public domain.

Manufacturers of waste sorting equipment have access to the technology without paying a licence fee but need to **purchase the proper equipment (100k€)**.

Waste volume available in France

Following the call for tenders launched by Citeo, the French ERP, in March 2022[30] for the plastic household packaging recycling, Citeo announces the volumes of waste available per typology of resins. At least 50,000 tonnes of recycled PE, PP flexibles films per year will be provided under Citeo contracts. CIMPA work has made it possible to estimate the proportion of complex films in this source, as detailed below. Indeed, in the deliverable D2.1, the waste stream composition was estimated by the partners making it possible to calculate their volume per material with, as outcome, the PE/PP flexibles targeted by CITEO.

30 *https://bo.citeo.com/sites/default/files/2023-03/Citeo_CP_Appel%20d%27offres%20recyclage%202eme%20tour_10022023%20%281%29.pdf*

Input flexible films - 91575 t/an				
			Waste fraction	Accessible volume (tons)
Refusal stream			30,0%	27473
Films	PE		33,3%	50000
	PP		21,4%	
	ML	Metalised	5,6%	5128
		PE/PET	3,2%	2885
		PE/PA	3,2%	2885
		PP/PE	0,7%	641
		other ML	0,7%	641
	Other non ML	Bio	1,8%	1603
		Other ML	0,4%	321
		Total	100,0%	91575

Figure 14: Description of the different waste faction according to their nature and volume[31]. The waste stream of interest in CIMPA is described in blue.

In a nutshell:

- The cost of the sorting step strongly depends on:
    - The waste fraction removed from the sorting refusal stream.
    - The EoL cost (gate fee and taxes –TGAP)
- The sorting step costs are:
    - **0.112€/kg of ML sorted** if the unsorted waste is considered having no monetary value
    - **-0.037€/kg of ML sorted** if the unsorted waste is considered having a negative value of –0.15€/kg (incineration cost)
    - **0.147€/kg of ML sorted** if the unsorted waste is considered at a positive price of 0.035€/kg
- The **cost of DW is 0.06€/kg** and will be paid by the brand owner.
- The **CAPEX** of an optical sorter equipped with DW is about **407k€**
- The available waste in France for the PA/PE and PE/PET fraction is about 5770t/y

4.4.2 Mechanical value chain cost structure

As a reminder from previous LCC screening work, the mechanical recycling value chain is described in Figure 15.

[31] From D2.1: Characterisation of ML in incoming waste flows

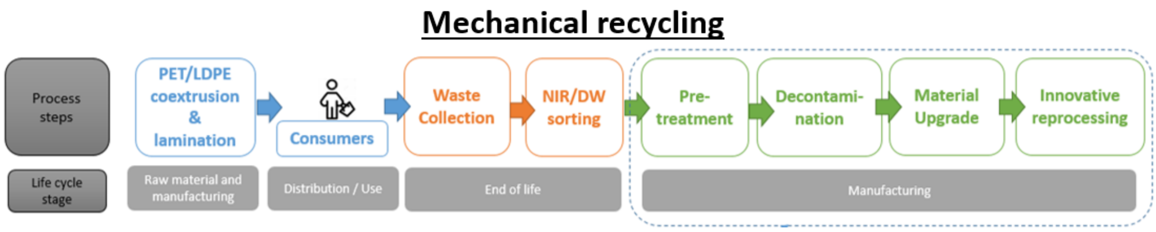

Figure 15: Description of the mechanical recycling value chain as described in D6.3

The following paragraph will describe the models used to obtain the different steps cost structures at TRL9.

4.4.2.1 Mechanical pre-treatment step

The pre-treatment step is composed of a recycling line together with a cleaning line with a throughput of 1000kg/h leading to annual productivity of maximum 8000t/year. The pre-treatment line consists of a shredder in line with a washing and drying unit and an extruder.

The primary cost items for the OPEX remains the energy consumption while the maintenance account for the secondary cost items.

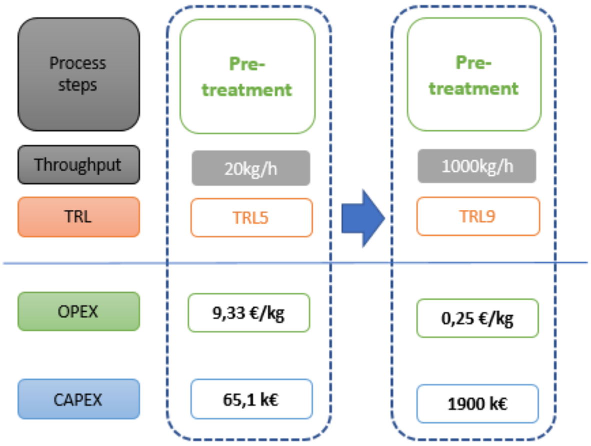

Figure 16: Description of the pre-treatment lines OPEX and CAPEX depending on their TRL

4.4.2.2 $scCO_2$ decontamination step

To model the $scCO_2$ decontamination step, it was decided to use $scCO_2$ technology in batch instead of the reactive extrusion CO_2 technology described in the project and during the screening. Indeed, the batch technology is commonly used at TRL9 and data are available for outputs that match our value chain throughout.

The unit used for the model is a 5000 to 6250 ton/year step managed by a staff of 10 technicians.

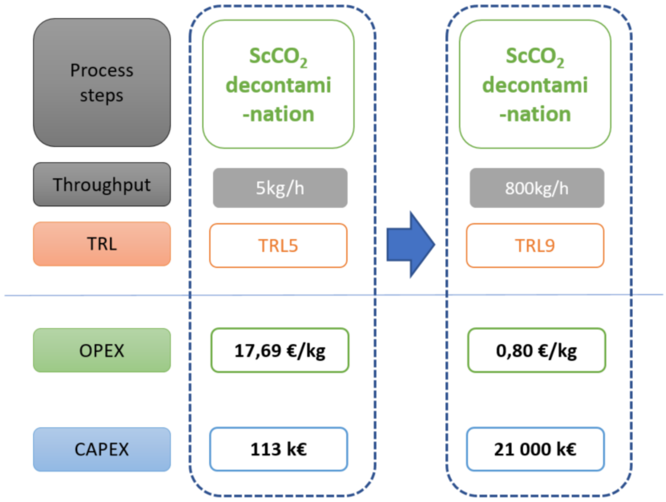

Figure 17: Description of the scCO₂ decontamination step OPEX and CAPEX depending on their TRL [32]

4.4.2.3 Material upgrade / in line rheological optimisation

The in-line rheometer and gravimetric feeders required for the VAREX upgrading are fully compatible with industrial scale equipment. In an industrial scale value chain, the VAREX upgrading step could be integrated either into the extrusion-based sc-CO_2 decontamination step or into the last film conversion step during the standard film extrusion step. The base requirement for integrating the VAREX upgrading scheme is to invest on the in-line rheometer, gravimetric feeders and control software. The cost for the in-line rheometer and feeders will **approximately 150-200 k€.**

Hence, this step will be included in the model within the conversion step at TRL9 where extruders are already set up. Additional CAPEX will be added but OPEX will only integrate additives (0.03€/kg) as the other inputs will be neglected (no personnel cost or energy cost) compared to the OPEX of a simple extrusion step.

[32] Cost structure description of a **batch** $scCO_2$ purification setup at 5000ton/year (625kg/h). Courtesy of Institut Fluid Supercritique and IPC from the SUPERPE research project.

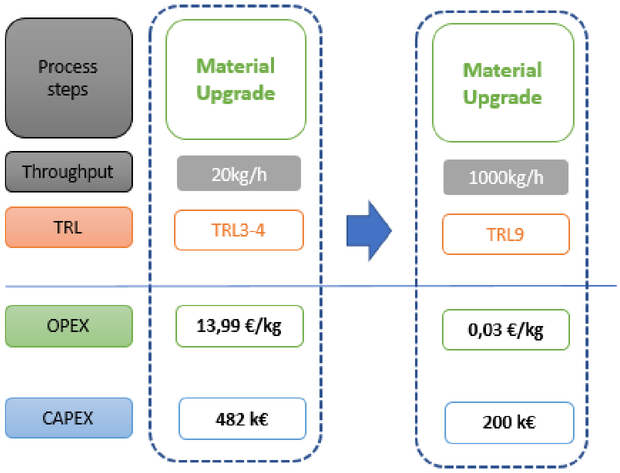

Figure 18: Description of the material upgrade equipment OPEX and CAPEX depending on its TRL

4.4.2.4 METEOR recycling / reprocessing

The METEOR® value chain is modelled based on two industrial extrusion lines (2x500kg/h) to reach the nominal throughput of 1000kg/h. We considered that additional costs of the tailor-made elongational flow mixer block have to be added to the total equipment CAPEX together with additional electrical cost of +25% compared to the industrial extruder.

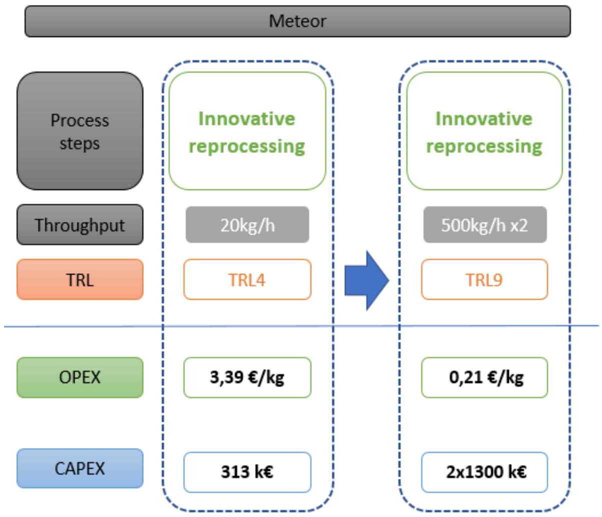

Figure 19: Description of the METEOR® equipment OPEX and CAPEX depending on its TRL

4.4.2.5 MNL recycling / reprocessing

The MNL value chain is modelled based on two industrial lines (2x500kg/h) that will produce the innovative film. The relative energy consumption is likely to be reduced from TRL6 to TRL9. We propose then a conservative energy cost at TRL9 using TRL6 values.

At TRL6, the MNL block is at industrial scale. Therefore, le CAPEX and OPEX of the multiplying elements, the coextrusion block, the die and the mono-axial stretcher will not change.

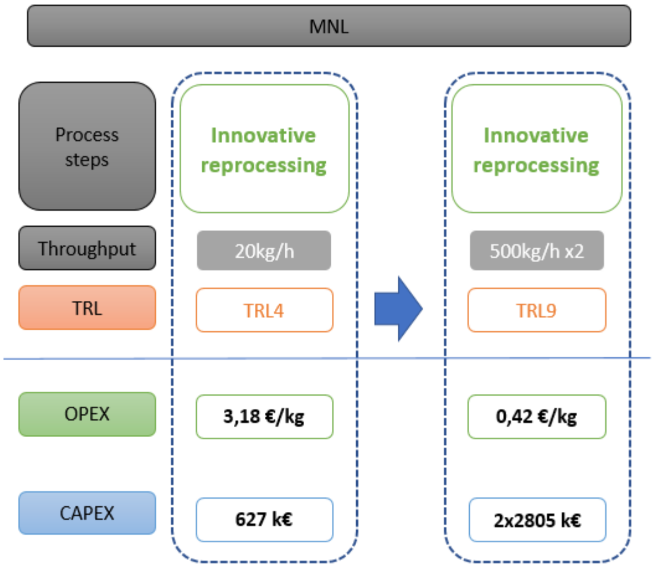

Figure 20: Description of the MNL equipment OPEX and CAPEX depending on its TRL

4.4.2.6 Complete mechanical value chain cost structure

The Figure 21 summarises all costs incurred by the mechanical recycling value chain. All the elements of this value chained were modelled at TRL9 with a throughput of 800-1000kg/h.

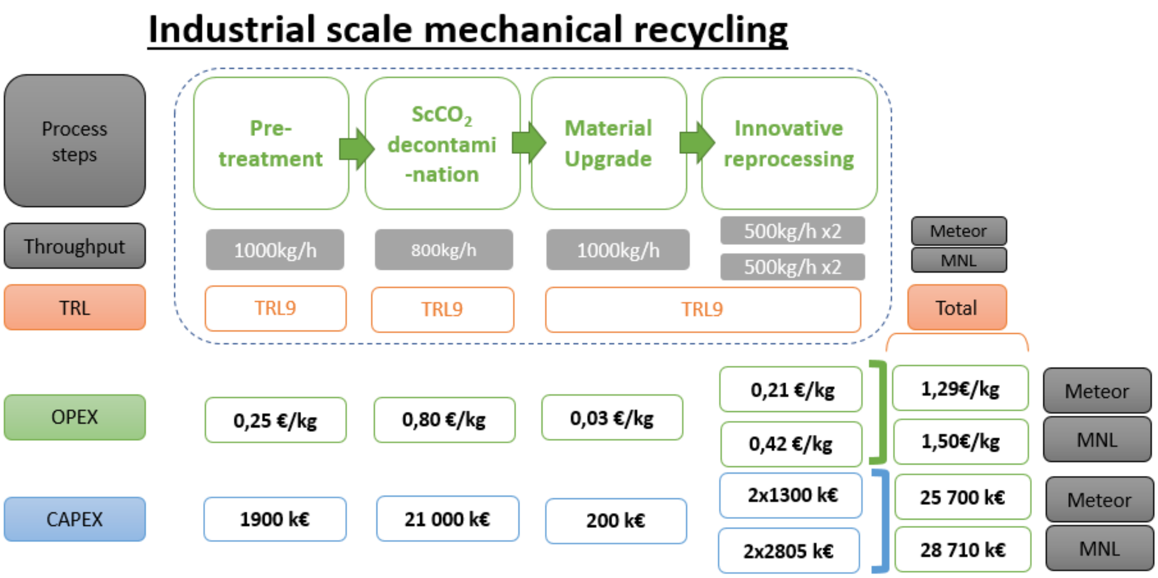

Figure 21: Summary of the cost incurred by each step of the mechanical recycling value chain at industrial scale

4.4.3 Physical value chain cost structure

As a reminder from previous LCC screening work, the physical recycling value chain is described in Figure 22.

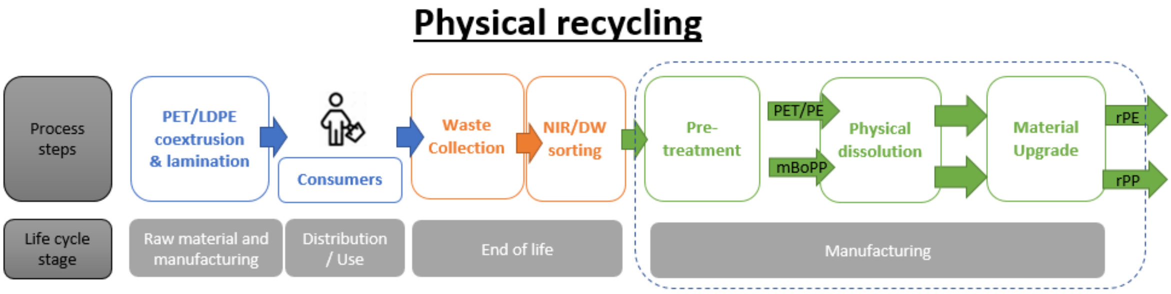

Figure 22: Description of the physical recycling value chain as described in D6.3

The following paragraph will describe the models used to obtain the different steps cost structures at TRL9.

4.4.3.1 Physical dissolution

The modelling of the physical dissolution step is based on the results obtained on the process designed at TRL5. For TRL9, the plant is based on a dissolution process with a 10kta foil annual processing capacity. The throughput of this sept was estimated to be around 1200kg/h.

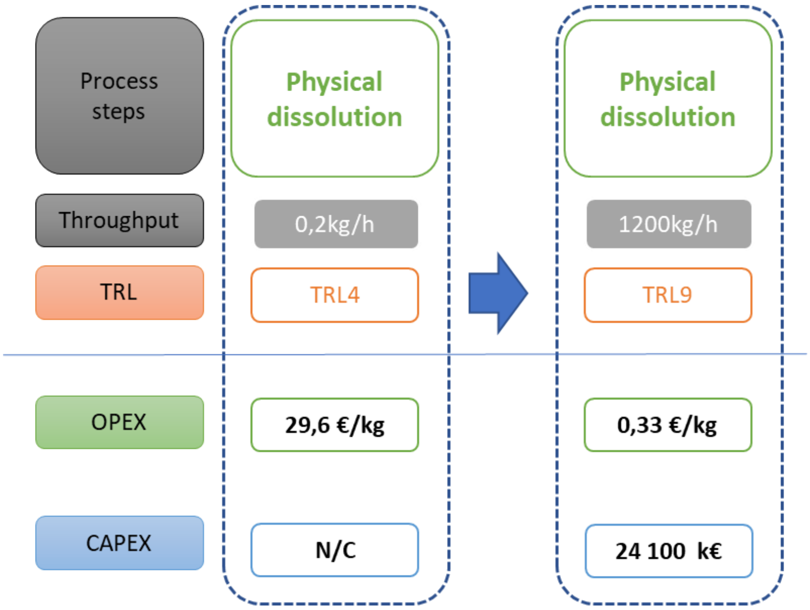

Figure 23: Description of the physical dissolution step OPEX and CAPEX depending on its TRL

The cost structure described here include the ultimate PET waste treatment cost that occurred in the processing of PE/PET. This ultimate waste is neglected in the case of the mBoPP processing.

4.4.3.2 Material upgrade / inline rheological optimisation

In comparison with the step that was described in the mechanical recycling value chain, here, the VAREX upgrading scheme will need to be implemented in an industrial scale compounder. We then integrate the OPEX and the CAPEX of a 1t/h compounder, i.e. 0.152€/kg at a 1200k€ for initial investment.

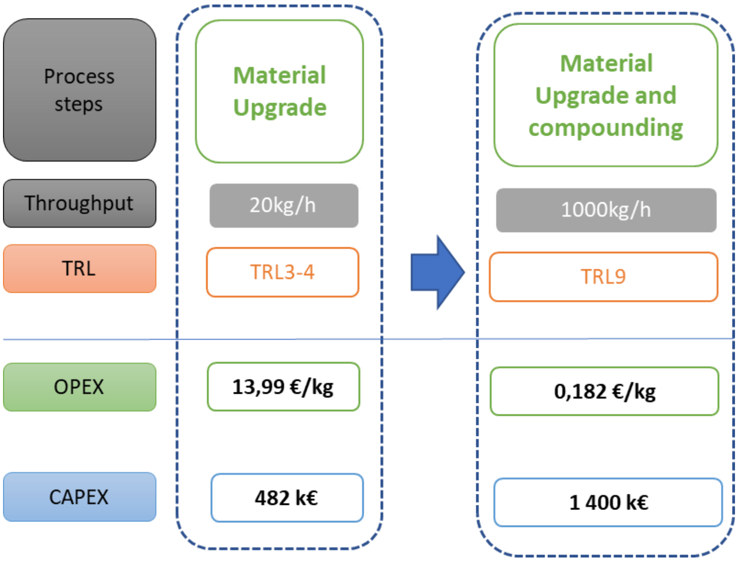

Figure 23: Description of the material upgrade and compounding step OPEX and CAPEX depending on its TRL within the physical dissolution step

4.4.3.3 Complete physical value chain cost structure

The Figure 24 summarises all costs incurred by the physical recycling value chain. All the elements of this value chained were modelled at TRL9 with a minimum throughput of 1000kg/h.

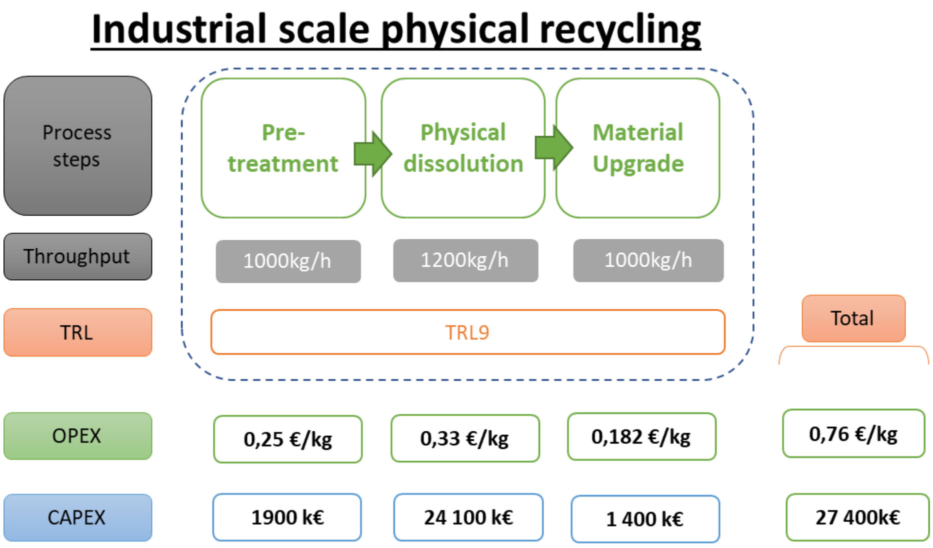

Figure 24: Summary of the cost incurred by each steps of the physical recycling value chain at industrial scale

4.5 Business plans

4.5.1 Hypothesis of the economics studies and financial indicators

As described above, the complete value chain output is set to be 1000kg/h at the maximum. Nonetheless, one step in the mechanical recycling value chain shows a smaller throughput due to the batch nature of the technology. Indeed, the $scCO_2$ decontamination step will exhibit a throughput of 800kg/h maximum.

- Hence, an output of 800kg/h for the whole system during 8000h/a will reach **6400t/y for mechanical value chain**.
- The annual capacity of the **physical dissolution reaches 8000t/y**
- **35€/t for the waste stream** as the input (including the sorting cost, see section 4.4.1)
- All CAPEXs are depreciated over 8 years
- The model is based on the use of **METEOR/MNL technologies** as the reprocessing step
- **A ramp up** is proposed for the first two years to take into account the market uptake
- **No inflation rate nor discount rate** is proposed to take into account the price modification over time. This is not the purpose of the modelling.

In addition, several financial indicators were used to describe the financial performances of the systems described.

Hence, **the Net Present Value (NPV)** is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyse the profitability of a projected investment or project.

$$NPV = \frac{cash\ flow}{(1+i)^n} - initial\ investment$$

i=Required return or discount rate

n=Number of time periods

The IRR is also presented in the table below. The Internal Rate of Return (IRR) is a metric used in financial analysis to estimate the profitability of potential investments. IRR is a discount rate that makes the NPV of all cash flows equal to zero in a discounted cash flow analysis.

$$NPV = \sum_{t=1}^{T} \frac{Ct}{(1+IRR)} - C_0 = 0$$

C_t=Net cash inflow during the period t

C_0=Total initial investment costs

t=the number of time periods

T= the maximum number of periods

Finally, with the help of the industrial partners, we proposed a couple of conditions to identify where a project could be considered as suitable for investment. Those criteria are described in Table 4.

Financial KPI	Objective to make the project suitable for investment
NPV >0	Before 3 years
IRR >10%	Before 3 year
Discount rate	10%

Table 4: Financial indicators for investment decision making. The data were collected from the industrial partners.

4.5.2 Economics of the complete mechanical recycling value chain

The first business plan will model the full CIMPA value chain and will highlight its profitability. All steps of the mechanical recycling value chain are included in this model and will be assessed according to different products (PA/PE and PE/PET). In this description, we did not use a discount rate to better appreciate the value creation. The discount rate will be used at a later stage.

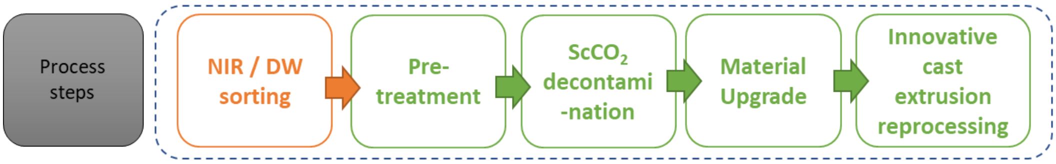

Figure 25: Description of each step of the converter full circular business model

4.5.2.1 Economics of the PE/PET structure

The first economic analysis focuses on the PE/PET product substituted by the PE + rPE/PET CIMPA mono-material architecture. The targeted selling price is the market price of the PE/PET commercially available (2.4€/kg). Both innovative steps (METEOR and MNL) were modelled. Figure 26 summarises the sales strategy for the PE/PET product.

From paragraph 4.4.1, we understood that the **amount of waste available on the French market is 1575t/a** (for r-PA/PE and r-PE/PET respectively). Hence, the revenue model will have to integrate this maximal threshold on the available waste, otherwise European sourcing needs to be taken into account.

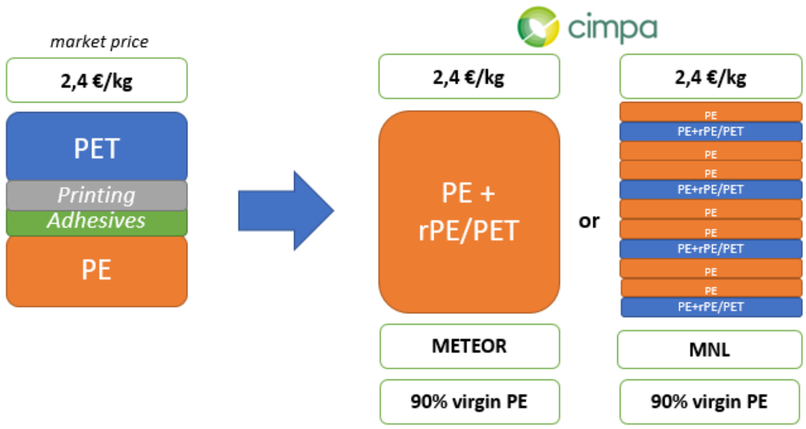

Figure 26: Targeted price of the PE/PET structure made in CIMPA. The structure is diluted at 10% of recycled material in virgin material for the METEOR and the MNL use case.

Business case using METEOR technology as innovative process

	Phase	Ramp-up	Ramp-up	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	
	Revenue	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**Cummulated**
Sales	ML (unit price, €/tons)	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	
	ML (Quantity, tons)	2 000	4 000	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	70 000
	ML (Turnover)	4 800 000 €	9 600 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	168 000 000 €
	Total volume (tons)	**2 000**	**4 000**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**70 000**
	Total of Turnover	**4 800 000 €**	**9 600 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**168 000 000 €**
Costs	**Waste as input (tons) -**	200	400	640	640	640	640	640	640	640	640	640	640	**7 000**
	Step - Sorting (0,147€/kg)	29 400 €	58 800 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	**1 029 000 €**
	Waste as input for processing (tonne)	*200*	*400*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	
	Step - Pretreatment (0,25€/kg)	50 000	100 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	1 750 000
	Step- Decontamination (0,8€/kg)	160 000	320 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	5 600 000 €
	Step - Material upgarde (0,03€/kg)	6 000	12 000	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	210 000
	Step - METEOR (0,21€/kg)	420 000	840 000	1 344 000	1 344 000	1 344 000	1 344 000	1 344 000	1 344 000	1 344 000	1 344 000	1 344 000	1 344 000	14 700 000 €
	Step - Blending material (PEBD-1,55€/kg) - 90% PEBD	2 790 000 €	5 580 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	97 650 000 €
	Virgin as input (tonne)	*1 800*	*3 600*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*63 000*
	Total direct cost	**3 455 400 €**	**6 910 800 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**11 057 280 €**	**14 910 000 €**
	Gross margin	**1 344 600 €**	**2 689 200 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**4 302 720 €**	**47 061 000 €**
	Gross margin Ratio	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	28%	

Figure 27: revenue of the business plan using METEOR for a PE/PET structure.

			2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
NPV	Discount rate	0%	-24 892 935	-22 334 270	-18 162 085	-13 989 900	-9 817 715	-5 881 045	-1 944 375	1 992 295	5 928 965	9 058 104
IRR			-	-89,72%	-53,60%	-30,67%	-16,61%	-8,03%	-2,20%	1,90%	4,85%	6,63%

Figure 28: NPV description of the business plan using METEOR for a PE/PET structure. No discount rate was applied.

Business case using MNL technology as innovative process

	Phase	Ramp-up	Ramp-up	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	
	Revenue	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**Cummulated**
Sales	ML (unit price, €/tons)	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	2 400	
	ML (Quantity, tons)	2 000	4 000	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	70 000
	ML (Turnover)	4 800 000 €	9 600 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	15 360 000 €	168 000 000 €
	Total volume (tons)	**2 000**	**4 000**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**70 000**
	Total of Turnover	**4 800 000 €**	**9 600 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**15 360 000 €**	**168 000 000 €**
Costs	**Waste as input (tons) - 10%**	200	400	640	640	640	640	640	640	640	640	640	640	**7 000**
	Step - Sorting (0,147€/kg)	29 400 €	58 800 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	**1 029 000 €**
	Waste as input for processing (tons)	*200*	*400*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	
	Step - Pretreatment (0,25€/kg)	50 000	100 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	1 750 000 €
	Step- Decontamination (0,8€/kg)	160 000	320 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	5 600 000 €
	Step - Material upgarde (0,03€/kg)	6 000	12 000	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	210 000 €
	Step - MNL (0,42€/kg)	840 000	1 680 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	29 400 000 €
	Coextrusion material (PEBD-1,55€/kg) - 90% PEBD	2 790 000 €	5 580 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	97 650 000 €
	Virgin as input (tonne)	*1 800*	*3 600*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*63 000*
	Total direct cost	**3 875 400 €**	**7 750 800 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**29 610 000 €**
	Gross margin	**924 600 €**	**1 849 200 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**2 958 720 €**	**32 361 000 €**
	Gross margin Ratio	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	

Figure 29: revenue of the business plan using MNL for a PE/PET structure.

			2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
NPV	Discount rate	0%	-28 337 985	-26 634 370	-23 821 235	-21 008 100	-18 194 965	-15 381 830	-12 568 695	-9 755 560	-6 942 425	-4 129 290
IRR		0%	-	-93,99%	-65,34%	-44,25%	-30,20%	-20,69%	-14,04%	-9,23%	-5,66%	-2,94%

Figure 30: NPV description of the business plan using MNL for a PE/PET structure. No discount rate was applied.

In a nutshell:

Considering PE/PET product substituted by the PE+rPE/PET CIMPA architecture, we see that:

- For METEOR strategy:
  - Gross margin of 28%
  - The break-even point is reached between 7-8 year
  - The sourcing of waste could be limited to France (640t/y)
- For MNL strategy:
  - Gross margin of 19%
  - The break-even point is reached between >10 year
  - The sourcing of waste could be limited to France (640t/y)

4.5.2.2 Economics of the PE/PA structure

The second economic analysis focuses on the PE/PA product substituted by the PE+rPE/PA CIMPA architecture. The targeted selling price is the PE/PA commercially available market price (4€/kg). Both innovative steps (METEOR and MNL) were modelled. Figure 31 summarises the sales strategy for the PE/PA product.

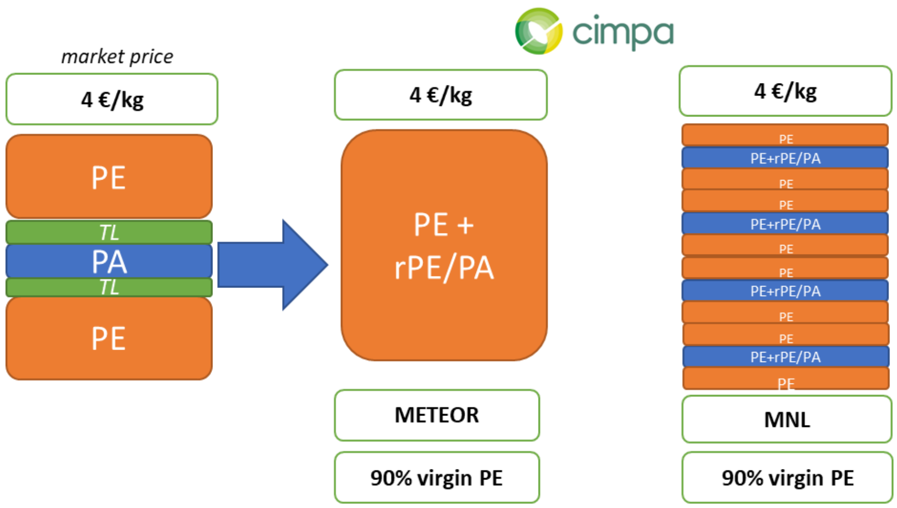

Figure 31: Targeted price of the PE/PA structure made in CIMPA. The structure is diluted at 10% of recycled material in virgin material for the METEOR and the MNL use case.

Business case using METEOR technology as innovative process

	Phase	Ramp-up	Ramp-up	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	
Sales	**Revenue**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**Cummulated**
	ML (unit price, €/tons)	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	
	ML (Quantity, tons)	2 000	4 000	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	70 000
	ML (Turnover)	8 000 000 €	16 000 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	280 000 000 €
	Total volume (tons)	**2 000**	**4 000**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**70 000**
	Total of Turnover	**8 000 000 €**	**16 000 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**280 000 000 €**
Costs	**Waste as input (tons) - 10% in mass**	200	400	640	640	640	640	640	640	640	640	640	640	**7 000**
	Step - Sorting (0,147€/kg)	29 400 €	58 800 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	**1 029 000 €**
	Waste as input for processing (tons)-	*200*	*400*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	
	Step - Pretreatment (0,25€/kg)	50 000	100 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	1 750 000
	Step- Decontamination (0,8€/kg)	160 000	320 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	5 600 000 €
	Step - Material upgarde (0,03€/kg) - additives	6 000	12 000	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	210 000
	Step - METEOR (0,21€/kg)	42 000	84 000	134 400	134 400	134 400	134 400	134 400	134 400	134 400	134 400	134 400	134 400	1 470 000 €
	Step - Blending material (PEBD-1,55€/kg) - 90% PEBD	2 790 000 €	5 580 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	97 650 000 €
	Virgin as input (tonne)	*1 800*	*3 600*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*5 760*	*63 000*
	Total direct cost	**3 077 400 €**	**6 154 800 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**9 847 680 €**	**1 680 000 €**
	Gross margin	**4 922 600 €**	**9 845 200 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**15 752 320 €**	**172 291 000 €**
	Gross margin Ratio	62%	62%	62%	62%	62%	62%	62%	62%	62%	62%	62%	62%	

Figure 32: revenue of the business plan using METEOR for a PA/PE structure.

			2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
NPV	Discount rate	0%	-21 314 935	-11 982 443	2 026 520	14 558 703	27 090 885	39 623 068	52 155 250	64 687 433	77 219 615	88 935 954
IRR			-	-56,22%	5,87%	29,55%	40,97%	46,92%	50,20%	52,09%	53,22%	53,86%

Figure 33: NPV description of the business plan using METEOR for a PA/PE structure. No discount rate was applied.

Business case using MNL technology as innovative process

	Phase	Ramp-up	Ramp-up	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	
	Revenue	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**Cummulated**
Sales	ML (unit price, €/tons)	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	
Sales	ML (Quantity, tons)	2 000	4 000	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	6 400	70 000
Sales	ML (Turnover)	8 000 000 €	16 000 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	25 600 000 €	280 000 000 €
Sales	**Total volume (tons)**	**2 000**	**4 000**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**6 400**	**70 000**
Sales	**Total of Turnover**	**8 000 000 €**	**16 000 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**25 600 000 €**	**280 000 000 €**
Costs	**Waste as input (tons) - 10% in mass**	200	400	640	640	640	640	640	640	640	640	640	640	**7 000**
Costs	**Step - Sorting (0,147€/kg)**	29 400 €	58 800 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	94 080 €	**1 029 000 €**
Costs	***Waste as input for processing (tons)***	*200*	*400*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	*640*	
Costs	**Step - Pretreatment (0,25€/kg)**	50 000	100 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	160 000	1 750 000
Costs	**Step- Decontamination (0,8€/kg)**	160 000	320 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	512 000	5 600 000 €
Costs	**Step - Material upgarde (0,03€/kg) - additives**	6 000	12 000	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	19 200	210 000
Costs	**Step - MNL (0,42€/kg)**	840 000	1 680 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	2 688 000	29 400 000 €
Costs	**Coextrusion material** (PEBD-1,55€/kg) - 90% PEBD	2 790 000 €	5 580 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	8 928 000 €	97 650 000 €
Costs	***Virgin as input (tonne)***	*1 000*	*2 000*	*3 200*	*3 200*	*3 200*	*3 200*	*3 200*	*3 200*	*3 200*	*3 200*	*3 200*	*3 200*	*35 000*
Costs	**Total direct cost**	**3 875 400 €**	**7 750 800 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**12 401 280 €**	**29 610 000 €**
	Gross margin	**4 124 600 €**	**8 249 200 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**13 198 720 €**	**144 361 000 €**
	Gross margin Ratio	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	

Figure 34: revenue of the business plan using MNL for a PA/PE structure.

			2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
NPV	Discount rate	0%	-25 137 985	-17 119 218	-5 182 080	5 517 678	16 217 435	26 917 193	37 616 950	48 316 708	59 016 465	68 806 316
IRR			-	-68,10%	-13,32%	10,12%	22,36%	29,19%	33,21%	35,69%	37,26%	38,21%

Figure 35: NPV description of the business plan using MNL for a PA/PE structure. No discount rate was applied.

In a nutshell:

Considering PE/PA product substituted by the PE+rPE/PA CIMPA architecture, we see that:

- For METEOR strategy:
  - Gross margin of 62%
  - The break-even point is reached between 2 and 3 year
  - The sourcing of waste could be limited to France (640t/y)
- For MNL strategy:
  - Gross margin of 52%
  - The break-even point is reached between 3 and 4 year
  - The sourcing of waste could be limited to France (640t/y)

4.5.3 Economics of the complete physical recycling value chain

4.5.3.1 Economics of the PE/PET and mBoPP structure

The study of the physical dissolution value chain focuses on the production of recycled and pure compound made of rPE or rPP that will come from the PE/PET and mBoPP waste stream respectively. The studies are very different because they will consider the sale of materials rather than transformed films.

Additional hypothesis:

- Purified rPE= 2.5€/kg (virgin PE: 1.6€/kg[35])

	Phase	Ramp-up	Ramp-up	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	Prod	
	Revenue	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**Cummulated**
Sales	ML (unit price, €/tons)	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	
	ML (Quantity, tons)	2 000	4 000	6 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	84 000
	ML (Turnover)	5 000 000 €	10 000 000 €	15 000 000 €	20 000 000 €	20 000 000 €	20 000 000 €	20 000 000 €	20 000 000 €	20 000 000 €	20 000 000 €	20 000 000 €	20 000 000 €	210 000 000 €
	Total volume (tons)	**2 000**	**4 000**	**6 000**	**8 000**	**8 000**	**8 000**	**8 000**	**8 000**	**8 000**	**8 000**	**8 000**	**8 000**	**84 000**
	Total of Turnover	**5 000 000 €**	**10 000 000 €**	**15 000 000 €**	**20 000 000 €**	**20 000 000 €**	**20 000 000 €**	**20 000 000 €**	**20 000 000 €**	**20 000 000 €**	**20 000 000 €**	**20 000 000 €**	**20 000 000 €**	**210 000 000 €**
Costs	**Waste as input (tons)**	2 000	4 000	6 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	8 000	**84 000**
	Step - Sorting (0,147€/kg)	294 000 €	588 000 €	882 000 €	1 176 000 €	1 176 000 €	1 176 000 €	1 176 000 €	1 176 000 €	1 176 000 €	1 176 000 €	1 176 000 €	1 176 000 €	**12 348 000 €**
	Waste as input for processing (tonne) - yield 100%	*2 000*	*4 000*	*6 000*	*8 000*	*8 000*	*8 000*	*8 000*	*8 000*	*8 000*	*8 000*	*8 000*	*8 000*	
	Step - Pretreatment (0,25€/kg)	500 000	1 000 000	1 500 000	2 000 000	2 000 000	2 000 000	2 000 000	2 000 000	2 000 000	2 000 000	2 000 000	2 000 000	21 000 000
	Step- Dissolution (0,33€/kg)	660 000	1 320 000	1 980 000	2 640 000	2 640 000	2 640 000	2 640 000	2 640 000	2 640 000	2 640 000	2 640 000	2 640 000	27 720 000 €
	Step - Material upgarde (0,182€/kg)	364 000	728 000	1 092 000	1 456 000	1 456 000	1 456 000	1 456 000	1 456 000	1 456 000	1 456 000	1 456 000	1 456 000	15 288 000
	Total direct cost	**1 818 000 €**	**3 636 000 €**	**5 454 000 €**	**7 272 000 €**	**7 272 000 €**	**7 272 000 €**	**7 272 000 €**	**7 272 000 €**	**7 272 000 €**	**7 272 000 €**	**7 272 000 €**	**7 272 000 €**	**15 288 000 €**
	Gross margin	**3 182 000 €**	**6 364 000 €**	**9 546 000 €**	**12 728 000 €**	**12 728 000 €**	**12 728 000 €**	**12 728 000 €**	**12 728 000 €**	**12 728 000 €**	**12 728 000 €**	**12 728 000 €**	**12 728 000 €**	**133 644 000 €**
	Gross margin Ratio	64%	64%	64%	64%	64%	64%	64%	64%	64%	64%	64%	64%	

Figure 36: revenue of the business plan using the physical dissolution on PET/PE structures

			2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
NPV	Discount rate	0%	-24 764 035	-18 539 070	-9 835 003	1 255 565	11 550 633	21 845 700	32 140 768	42 435 835	52 730 903	62 172 626
IRR			-	-74,86%	-26,83%	2,29%	15,74%	23,29%	27,79%	30,59%	32,41%	33,52%

Figure 37: NPV description of the business plan using the physical dissolution on PET/PE structures. No discount rate was applied

In a nutshell:

Considering PE/PET waste treating with the physical dissolution value chain, we see:

- A gross margin of 62%
- The break-even point is reached between 3 and 4 year
- The sourcing of waste could not be limited to France (8000t/y for a maximum 2885kg/y of PE/PET)

4.5.4 Comparison of the different business model economics

4.5.4.1 Economics of the converter full circular business model

The first business model, the converter full circular business model, focuses on the purchasing of sorted wastes of various quality to ultimately purified them and produced added-value films (as decribed in Figure 38). The business plan will follow the same hypothesis as previously described.

Additional hypothesis:

- Waste sourcing: rPET=1.7€/t[33], r-PE/PA=0.7€/kg[34] as it is still a refusal stream with limited commercial outcomes
- Products' price: 4€/kg (PE/PA film)
- Innovative reprocessing technology: MNL for a PE/PA structure.
- Maximum annual production 6400t/y (waste sourcing: Europe)

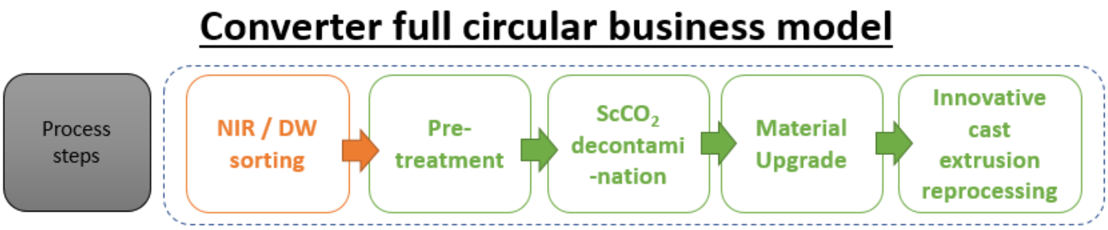

Figure 38: Description of each step of the converter full circular business model

			2023	2024	2025	2026	2027
NPV	Discount rate	10%	-22 852 714	-16 225 633	-7 257 085	50 993	6 694 701
IRR			-	-68,10%	-13,32%	10,12%	22,36%

Figure 39: NPV description of the converter full circular business plan based on a MNL technology.

4.5.4.2 Economics of the compounder's circular business model

The second business model studied was the compounder's BM. This model only takes into account the first steps of the CIMPA technology (as described in Figure 40). The business plan will follow the same hypothesis as previously described.

[33] IPC reference, from internal procurement

[34] We took the minimum price of commercial waste as an upper limit for a waste that is not valorised today. https://www.recyclage-recuperation.fr

Additional hypothesis:

- Waste sourcing include both rPA/PE and rPE/PET streams
- Purified rPE/PET = 2.5€/kg (virgin PET: 1.25€/kg[35])
- Purified rPA/PE = 1.6€/kg (virgin PA: 0.83€/kg[36])
- Purified rPE= 2.5€/kg (virgin PE: 1.6€/kg[35])
- Discount rate: 10%[37]
- Maximum annual production 6400t/y for the mechanical recycling and 8000t/y for the physical dissolution (waste sourcing: Europe)

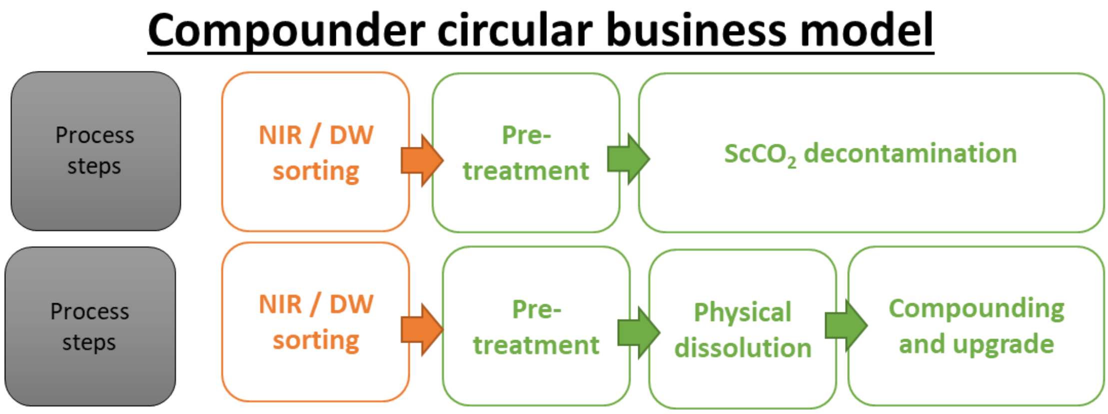

Figure 40: Description of each step of the compounder's circular business model

Business case using only sorting, pre-treatment and CO_2 decontamination technologies

			2023	2024	2025	2026	2027	2028	2029
NPV	Discount rate	10,0%	-19 379 577	-15 994 895	-11 241 220	-7 351 224	-3 814 864	-599 992	2 322 619
IRR			-	-80,79%	-35,07%	-12,26%	0,89%	8,82%	13,86%

Business case using only sorting, pre-treatment, physical dissolution and compounding

			2023	2024	2025	2026	2027
NPV	Discount rate	10%	-22 512 759	-17 368 160	-10 828 665	-3 253 658	3 138 769
IRR			-	-74,86%	-26,83%	2,29%	15,74%

Figure 41: NPV description of the compounder's business plan with different scenario (mechanical or physical recycling).

4.5.4.3 Economics of the converter circular business model

The third business model, the converter buisess model, focuses on the purchasing of sorted wastes of various quality to ultimately purified them and produced added-value films (as decribed in Figure 42).

[35] *RECYCLAGE RÉCUPÉRATION Magazine – 124 Avril 2023, https://www.recyclage-recuperation.fr/les-cours/*
[36] *https://www.chemanalyst.com/Pricing-data/polyamide-57*
[37] *Chosen according to the industrial partners WACC*

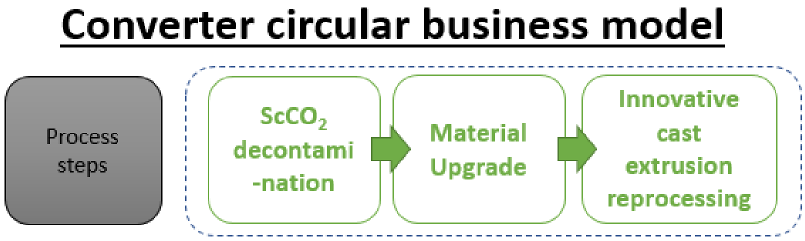

Figure 42: Description of each steps of the converter's circular business model

Additional hypothesis:

- Waste sourcing: r-PE/PA=0.7€/kg[38] as it is still a refusal stream with limited commercial outcomes
- Products price: 4€/kg (PE/PA)
- Innovative reprocessing technology: MNL for a PE/PA structure *(best case scenario).*
- Maximum annual production 6400t/y (waste sourcing: Europe)

Business case using only CO_2 decontamination, material upgrade and MNL technologies

			2023	2024	2025	2026	2027
NPV	Discount rate	10%	-22 893 259	-16 330 683	-7 452 608	-217 639	6 359 605
IRR			-	-68,47%	-13,94%	9,48%	21,75%

Figure 43: NPV description of the converter's business plan

In a nutshell:

- From the previous description of profitability (NPV and IRR), none of the business model based on PET/PE could make the mechanical recycling economically works. Selling prices will not allow a short break-even point.
- The METEOR mechanical recycling BM is more profitable than the MNL one, as the CAPEX of METEOR is less important as well as is electrical consumption (METEOR function with fewer extruders)
- When considering the investment criteria stated above, none of the business models are suitable for investment. Several levers have to be pulled to reduce the break-even point **but** in each scenario, we are very close to complete the objectives.

[38] *We took the minimum price of commercial waste as an upper limit for a waste that is not valorized today. https://www.recyclage-recuperation.fr*

5 Conclusion

The CIMPA project has highlighted the importance of circular economic models for the treatment of multilayer packaging, particularly in the context of new legislative and environmental requirements. The models studied, based on mechanical and physical recycling technologies, demonstrate varying profit margins and different payback periods depending on the technologies used (METEOR, MNL and physical recycling). Despite certain economic limitations, the analyses show that these innovations offer significant potential for cost reduction and material sustainability improvement.

However, to ensure the viability and industrial adoption of these technologies, it is recommended to continue fundraising efforts and seek public subsidies. Additionally, implementing pilot projects at intermediate scales (TRL7 and TRL9) could better assess the transition to larger-scale systems.

The search for solutions to support the adoption of these business models by industrial companies has led to several areas which worth further exploration. These ideas aim to reduce the operational costs necessary for implementing the studied processes or to encourage industries to source recycled materials.

➢ Replication of Technologies in Other Domains:

- Sorting and Digital Marking: Expanding these technologies to new sectors such as:
  - Medical
  - Sport equipment
- Decontamination and Food Contact Approval: Applicable to various industries such as:
  - Toys
  - Automotive
  - Hazardous decontamination
- Recycling (Mechanical/Physical) & Upcycling: Relevant for sectors such as:
  - Waste Electrical and Electronic Equipment (WEEE)
  - Automotive
  - Packaging Industry

The replication of this process can increase the volume of input material and reduce implementation cost, which is one of the main obstacles to the adoption of these technologies

➢ Design for Recycling:

- Testing Compatibility: Ensuring that products are designed with recycling in mind by testing their compatibility with recycling processes.
- Standardised the technologies and materials used

By reducing the types of input materials, certain process steps could be simplified, thereby optimising costs.

- Economic Incentives to Encourage the Use of Recycled Materials:

  - EPR (Extended Producer Responsibility) Fee Modulation for R&D: Adjusting fees to support research and development efforts.
  - Local Incentives: Encouraging the use of recycled materials through localized financial support.
  - EPR Harmonization in the EU: Standardizing EPR regulations across the European Union to facilitate broader adoption.

These actions would target stakeholders in need of resources to overcome existing technological constraints by investing in R&D. Economic incentives would also play a significant role in influencing industrial choices and help rebalance the current gap between virgin and recycled materials.

In summary, the CIMPA project underscores the critical role of circular economic models in addressing multilayer packaging challenges amid evolving legislative and environmental demands. While mechanical and physical recycling technologies present opportunities for cost reduction and material sustainability, ongoing fundraising and pilot projects are essential for successful industrial adoption. Expanding these technologies into new sectors and emphasizing design for recycling can streamline processes and reduce operational costs. Additionally, implementing economic incentives, such as EPR fee modulation and local support, will encourage industries to transition towards recycled materials. Overall, these strategies are vital for fostering a sustainable future in packaging and beyond.