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European alliance for innovation training
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Linking Academy to Industry.

Training program SPECIALIST IN THE CIRCULAR ECONOMY OF PLASTIC PACKAGING: modules

- Eco-design & novel manufacturing processing
- New materials and biomaterials
- Citizen and Consumer Engagement
- **Residue management and valorisation**

Co-funded by the Erasmus+ Programme of the European Union

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Residue management and valorisation

- Logistic and Sorting
- Recycling Systems & novel business models for the second life of residues
- **Economic, environmental and legislative aspects of plastic waste**

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Recycling Systems & novel business models for the second life of residues

- **Economic analysis of plastic waste handling**
- Environmental analysis of plastic waste handling
- European Union's plastic strategy

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Economic impacts

Costs of recovery

Recovery of plastic waste is also greatly influenced by the costs of collection, which include logistics (transport) and sorting (labour and sorting equipment) costs.

Plastic waste with low density transport and automated equipment for sorting are not economical.

Plastic waste recovery costs are very variable and depend on the structure of the recycling programme and the distances between waste handling companies.

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Economic impacts

Costs of recovery

German-based study

	Collection costs	Separation costs
Incineration	300-450 DM/ton	230-300 DM/ton
Gasification/Pyrolysis	900 DM/ton	
Landfill	375 DM/ton	

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Economic impacts

Costs of recovery

EU study for PET-bottles

	Collection		Sorting	TOTAL
	Kerb-side	Bring-schemes		
Recycling	255-305 €/ton	196-242 €/ton	474 €/ton	508-618 €/ton*
Incineration				326-392 €/ton
Landfilling				368-434 €/ton

*includes the revenue from the reprocessed material at 540 €/ton

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Economic impacts
Costs of recovery

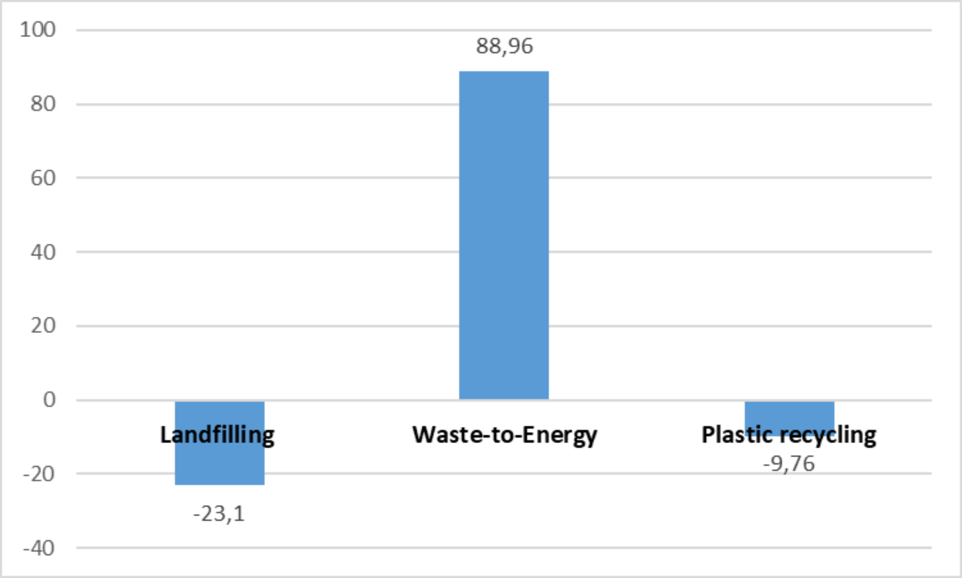

Figure - Profitablility of recycling 1 t of plastic for three different waste handling procedures

- Incineration: Heat and electricity are commercialized. It's the only method with profitability. The numbers depend on the size and yearly capacity of the facilities. The bigger the facility, the lower the costs and the higher the profit.

- Profitability of plastic recycling depends on two factors, which cannot be influenced by the factory: the oil prize and the plastic recycling ratio of consumers.

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Economic impacts

Costs of recovery

To maximize the economic value of the plastic waste recyclate, the plastic waste stream must be sorted by both resin type and colour.

However, manual sorting is not economic and automated sorting has to be used.

Capital costs of automated sorting are high and have to be compensated by high flux of plastic waste treated that can increment also transportation costs.

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Economic impacts

Costs of reprocessing and Market Forces

Major reasons for the lack of adoption of polymer recycling schemes are:

- poor recovery rates,
- unfavourable economics of transportation,
- recycling process cost, including high capital costs
- Volatile markets for recycled polymers

Mechanical recycling is most economic than chemical recycling, specially for thermoplastics.

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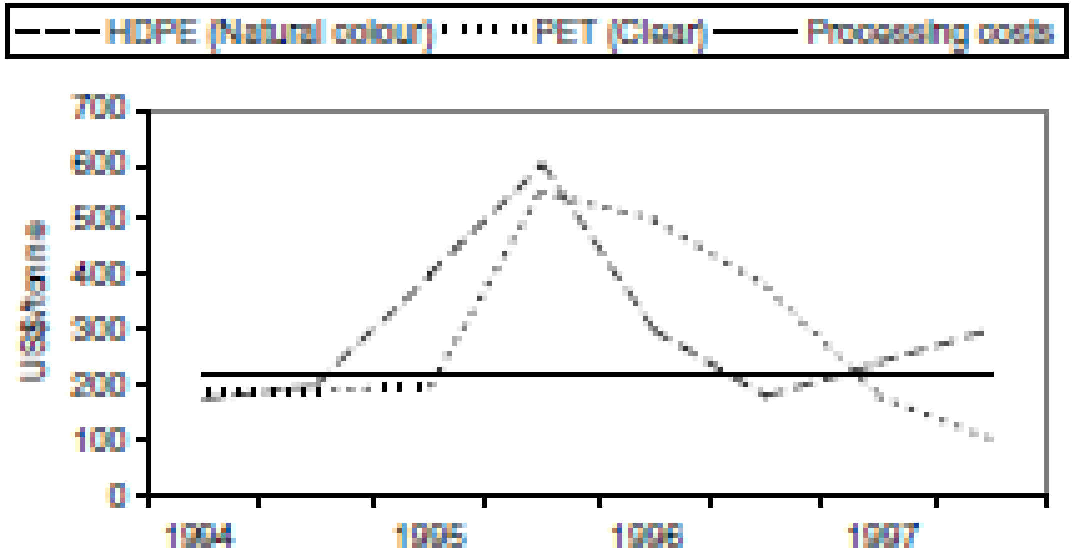
Economic impacts

Costs of reprocessing and Market Forces

USA study for HDPE and PET bottles mechanical recycling



Market prices of the major recycled polymers and mínimum reprocessing costs

Market prices of recycled polymers **depends on oil prizes** and makes the market **extemely volatile** thus discouraging further investment in recycling

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Economic impacts

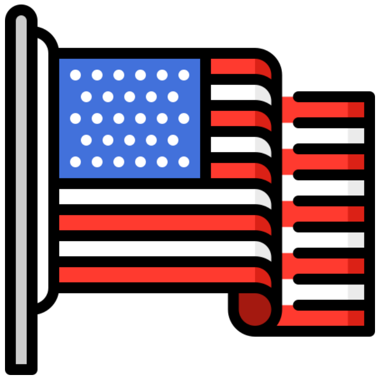
Costs of reprocessing and Market Forces

Both techniques were **not economically viable**

USA study for chemical recycling by pyrolysis and gasification

Activity	Costs ($/tonne)	
	Pyrolysis	Gasification
Collection	140	140
Sorting	200	200
Feed preparartion	160	160
Processing	220	180
Total costs	720	680
Selling price of recyclable	120	300
Loss	(600)	(380)

Economic costs of recycling by pyrolysis and gasification



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Economic impacts

Costs of reprocessing and Market Forces

European study for economic impacts of different options for waste management of plastic packaging

Scenario	**Recycling**		**Incineration**	**Landfilling**
	Mechanical	**Feedstock**		
1	-	-	-	100
2	12	3	15	70
3	15	-	85	-
4	15	10	75	-
5	25	10	65	-
6	35	15	50	-

Percentages of plastic waste treated

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Economic impacts

Costs of reprocessing and Market Forces

European study for economic impacts of different options for waste management of plastic packaging

Scenario	Recycling		Incineration	Landfilling	Plastic waste management costs	TOTAL (Benefits-costs)
	Mechanical	Feedstock				
1	-	-	-	100 %	0.17 €/kg	
2	12 %	3 %	15 %	70 %		
3	15 %	-	85 %	-	0.23 €/kg	**MAXIMUM**
4	15 %	10 %	75 %	-	0.24 €/kg	
5	25 %	10 %	65 %	-		
6	35 %	15 %	50 %	-	0.67 €/kg	

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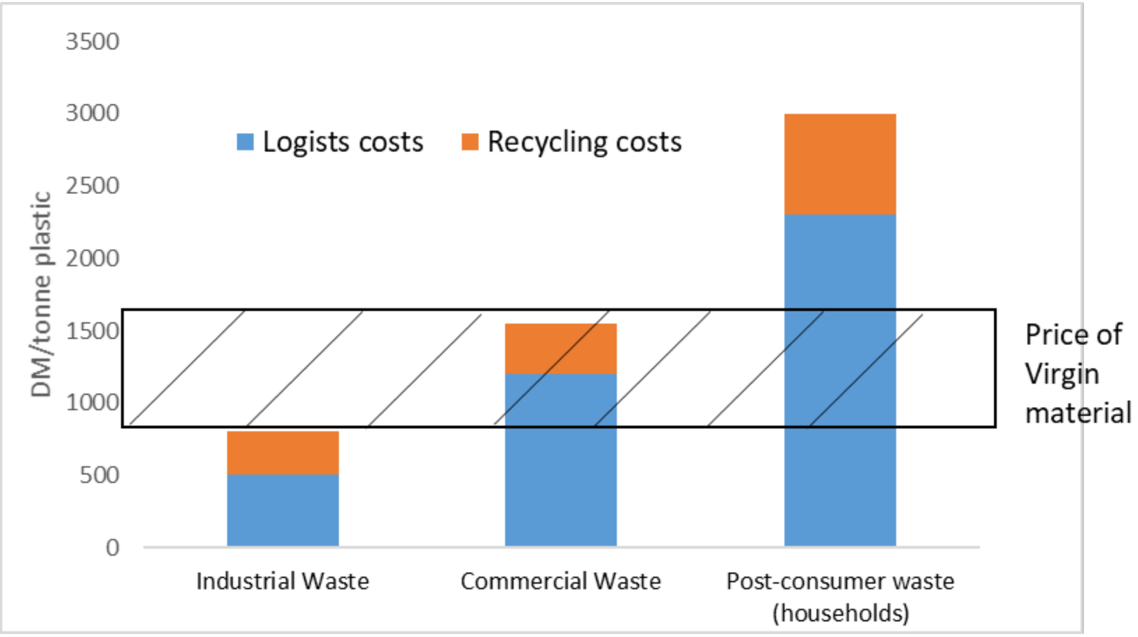
Economic impacts

Costs of reprocessing and Market Forces

German Study about plastic managemet costs depending on the source



Waste management costs depending on the source of waste plastic packaging

<u>Conclussions of this study</u>

- Industrial and comercial wastes recycling are profitable.
- Post-consumer plastic waste recycling is very unprofitable.
- Price of virgin material highly determine benefits or not of plastic waste recycling.

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Economic impacts

CONCLUSIONS

- Recycling can be considered to be economically viable only if the cost of recycling is equal to or lower tan the cost of producing virgin material plus the cost of alternative disposal methods.

- The cheapest economic alternative to recycling is landfilling (30 $/ton), but with the escalation of the disposal costs, recycling polymers may come economically more attractive.

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Economic impacts

CONCLUSIONS

- Incineration is the second cheapest option, followed by mechanical recycling.

- Cost of incineration is around 100 $/ton. In Europe this cost is 400 €/ton. Although incineration has lees environmental impact tan landfill, incineration receives strong opposition from the public.

- If landfilling is still cheaper tan recycling in because it’s underpriced. It only takes into account more visible costs (waste collection, landfill operation and closure cists) but it’s not considered other less tangble costs (loss of valuable resources and environmental protection)

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Linking **Academy** to **Industry**.

- Economic impacts
- **Environmental impacts**

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Environmental impacts

	Advantages	**Disadvantages**
Mechanical Recycling	Simple process	Sorting is labour and energy intensive
Chemical Recycling	Enables to recycle mixed solid waste	High capital costs
Incineration	Cheap	Emissions
Landfill	Cheap	Social end environmental impacts

It´s necessary to quantify environmental impacts besides economic impacts to choose the best option

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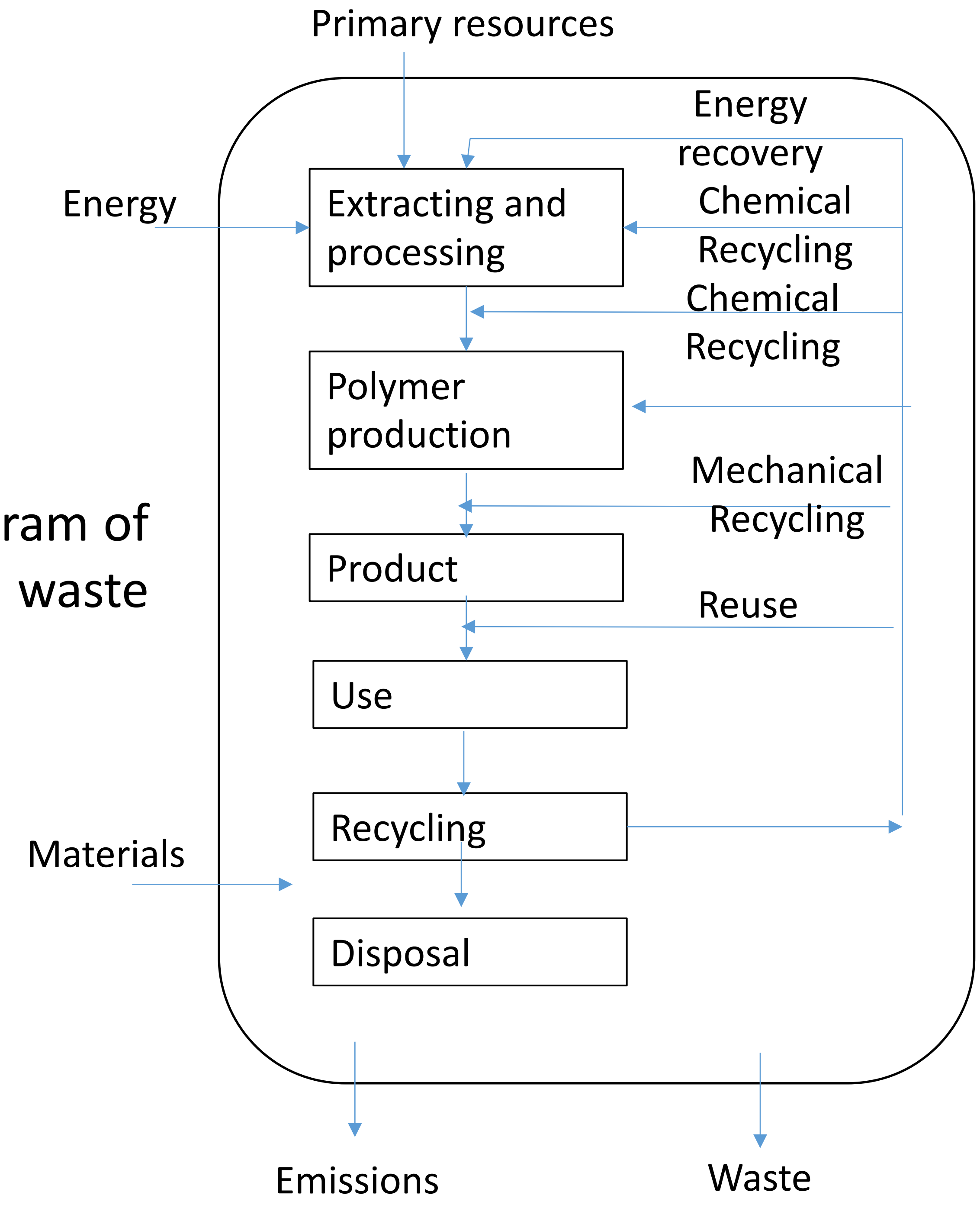
Environmental impacts of recycling: Life cycle considerations

The figue shows the life cycle diagram of the four end-of-life options for waste plastic



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Environmental impacts of recycling: Life cycle considerations

- Re-use: requires collection of waste and some refurbishment or remanufacturing. Each of these activities requires additional energy and materials.

- Mechanical recycling: Sorting is labour or energy intensive depending on if it's manual or automatic. Grinding requires energy (14 % of the total energy used for PET bottles)

- Incineration of most commodity plastics range from 3100 to 3400 kg of CO_2/ton compared with the 1500 -2000 kg of CO_2/ton produced along their life cycles.

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Life Cycle Assessment studies of recycling options and technologies

The environmental impacts of end-of-life options is going to be compared for five different cases.

Environmental impacts are going to be quantified by Life Cycle Assessment tool.

Life cycle assessment transform inputs and outputs of the whole life cycle of the plastics into environmental indicators.

It’s the most useful and scientific tool to quantify environmental impacts.

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Life Cycle Assessment studies of recycling options and technologies

Closed-loop recycling: Plastic Panels

Plastic panels are mounted on various ítems: photocopiers, computers, telephones and fax machines…

It’s important to identify sustainable end-of-life options. Landfill has to be avoided.

In this case, photocopier plastic panels are refurbished, but these panels have limited cycles of refurbishment and have to be disposed (landfill or incineration)

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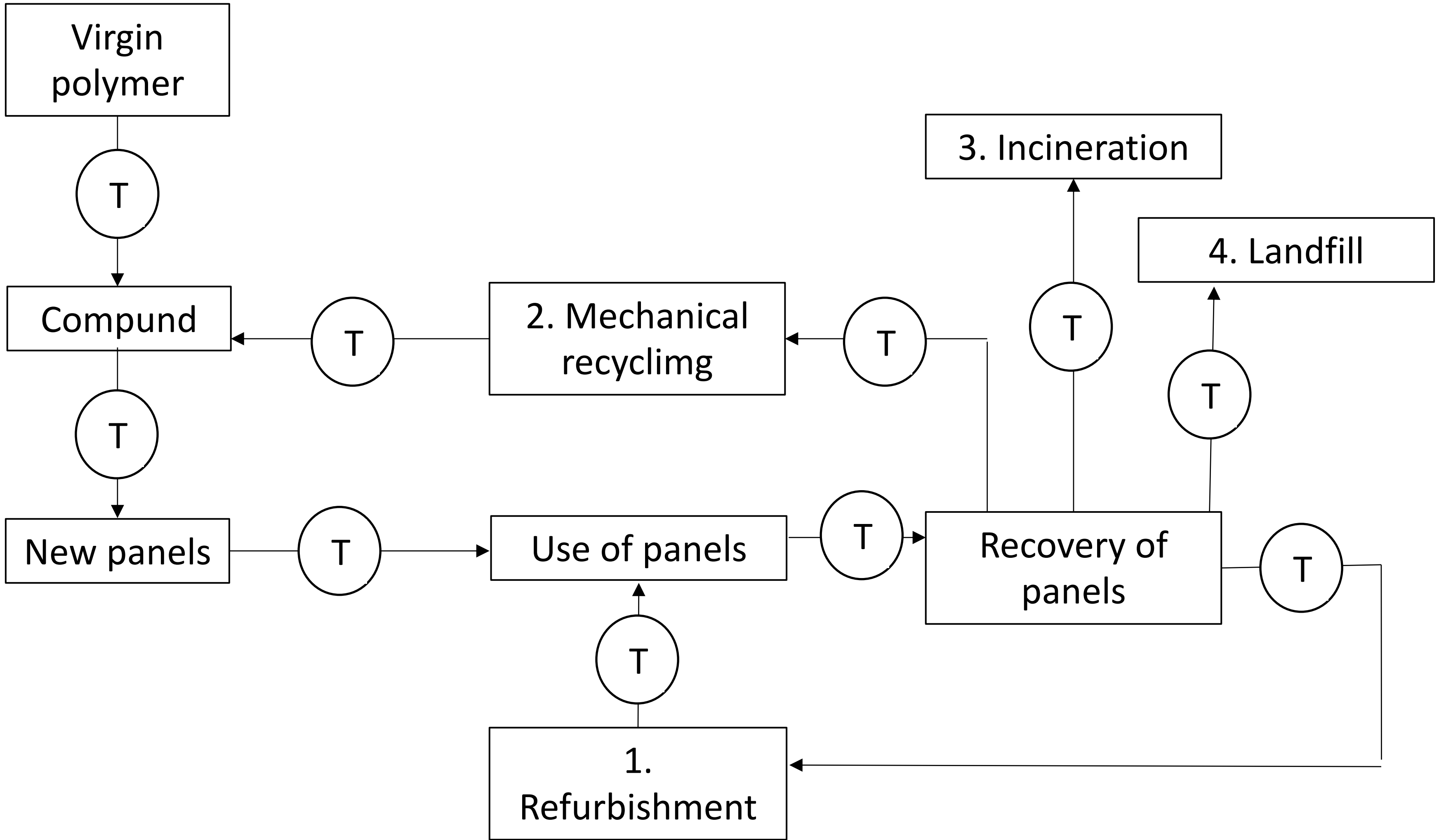
Life Cycle Assessment studies of recycling options and technologies

Closed-loop recycling: Plastic Panels



Life cycle flow diagram illustrating the production, recovery and recycling options for plastic panels

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Life Cycle Assessment studies of recycling options and technologies

Closed-loop recycling: Plastic Panels

The study is for 19000 panels, that is the amount demanded per year in the UK. The virgin polymers are polycarbonate and poly(acrylonitrile-co-butadiene-co-styrene) (ABS).

Plastic panels in this study can only be refurbished once, due to problems associated with unsatisfactory re-painting. Refurbished panels can not be mechanical recycled.

The study considers 5 scenarios.

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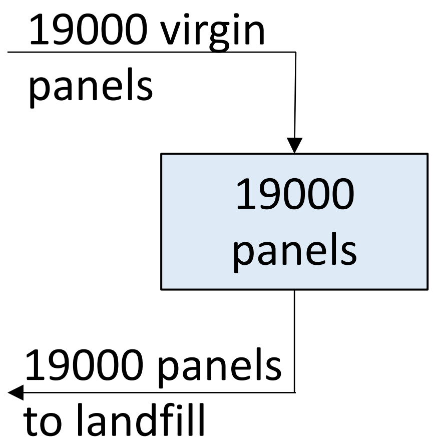
Life Cycle Assessment studies of recycling options and technologies

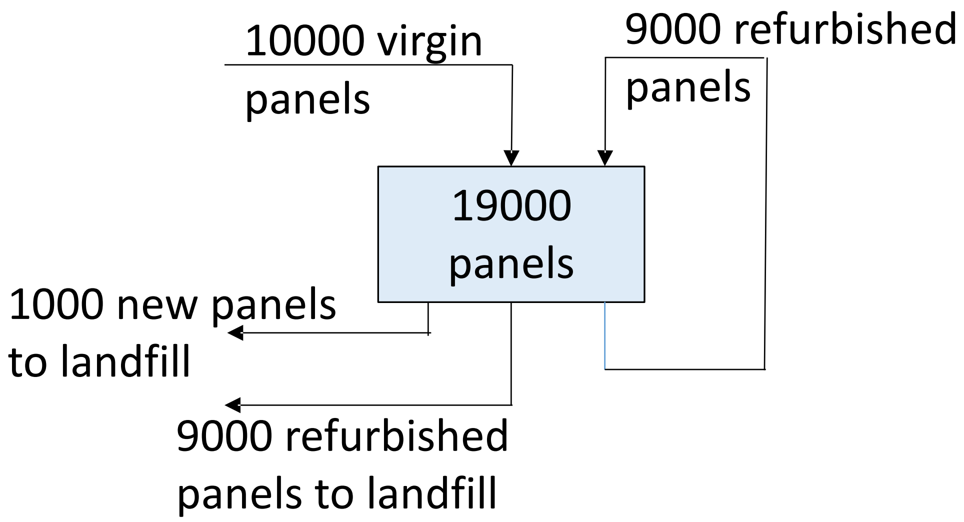
Closed-loop recycling: Plastic Panels

Scenario A



- 19000 panels are made from virgin polymer.
- Panels are assembled, used once and eventually dismantled and sent to landfill.

Scenario B

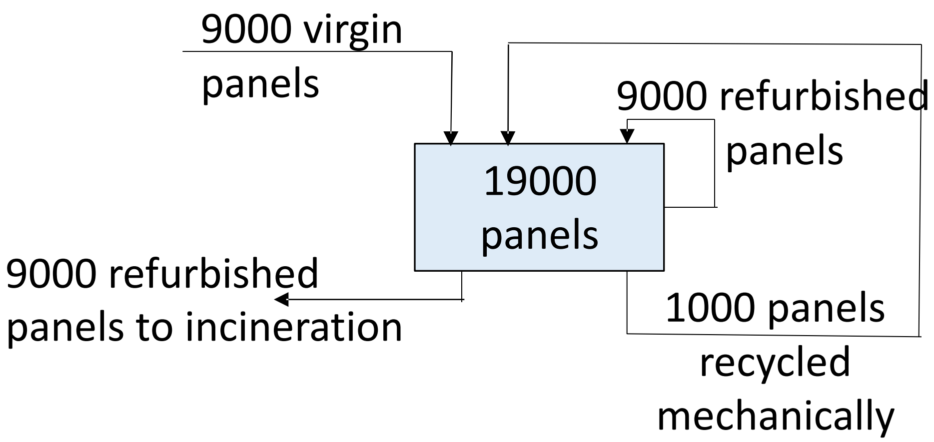


- 10000 panels are made from virgin polymer.
- Together with 9000 refurbished panels, they are assembled into 19000 photocopiers.
- After use, panels are dismantled. 9000 of the 10000 new panels are refurbished, and the 1000 remaining are sent to landfill.
- 9000 refurbished panels are sent to landfill.

Life Cycle Assessment studies of recycling options and technologies

Closed-loop recycling: Plastic Panels

Scenario C

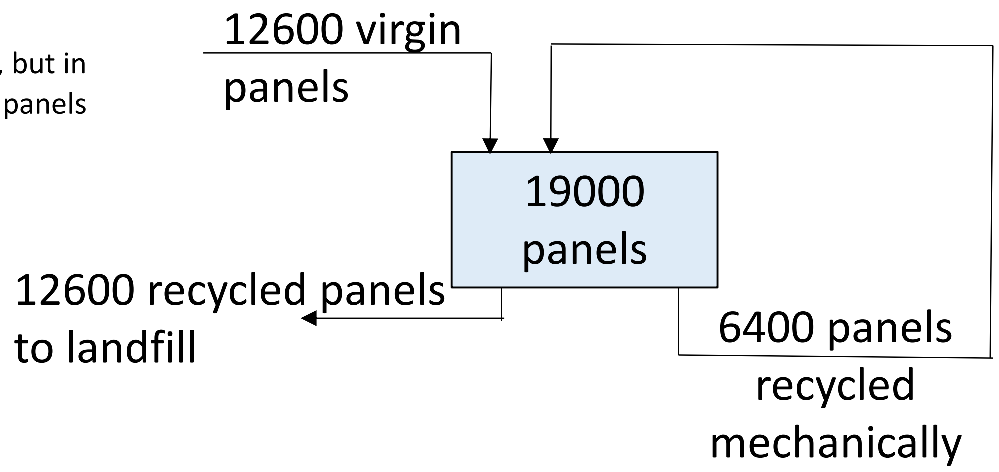


- 9000 panels are made from virgin polymer.
- 9000 panels are refurbished.
- 1000 panels are mechanical recycled panels. They are recycled and mixed with virgin polymers. Owing to quality constraints, only 25 % of recycled material can be mixed with virgin polymers.
- So, 10000 panels are recycled, the remaining 9000 refurbished panels are incinerated.

Scenario D

- It's the same scenario as C, but in this case 9000 refurbished panels are sent to landfill.

Scenario E



- 12600 panels are made with virgin polymer and 6400 from a combination of virgin and recycled polymer.
- 12600 recycled panels are landfilled.

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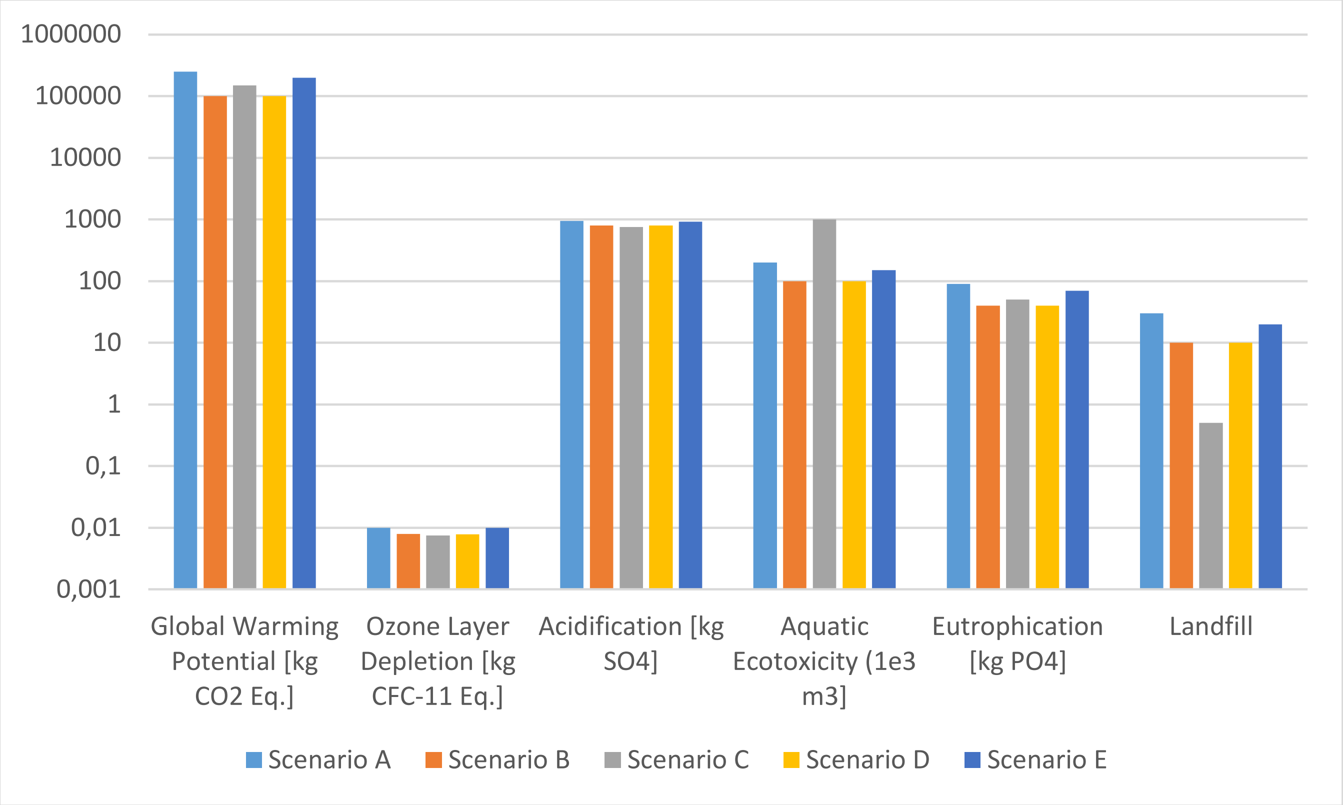
Life Cycle Assessment studies of recycling options and technologies

<u>*Closed-loop recycling: Plastic Panels*</u>

- Option D has the lowest impacts.

- Option C would be the best but it has the higest impacts in aquatic-ecotoxicity . Option C doesn´t recover energy by incineration.

- Option B is has the second lowest impacts. Option B landfilled refurbished panels.



In summary, a combination of close-loop recycling (refurbishment and mechanical) is the best end-of-life option regarding environmental impacts.

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Life Cycle Assessment studies of recycling options and technologies

Cascade Use: Laminated Car Windsceens

This case compares different plastic materials that can be used for laminating car windscreens.

The aim is to identify optimum end-of-life option. Currently, only glass windscreen is recycled. The polymer used by industry is poly(vinyl butyral) (PVB), but it can be used: poly(vinyl chloride) (PVC), poly(ethylene-co.vinyl acetate) (EVA), and polyurethane (PU).

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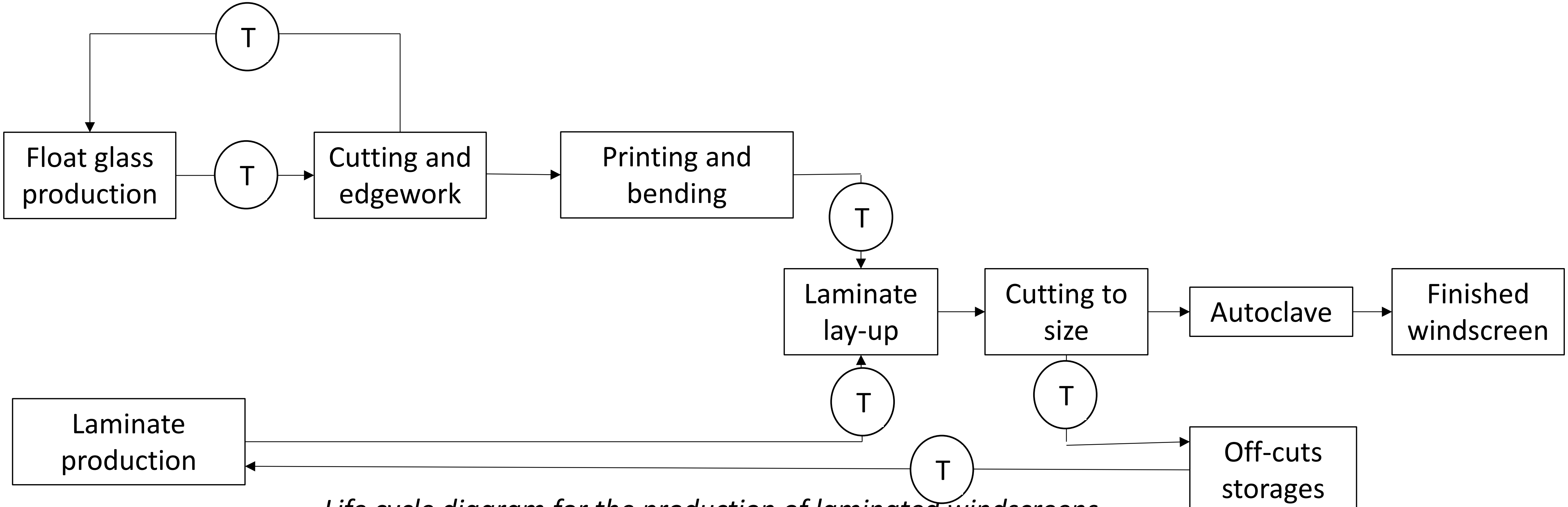
Life Cycle Assessment studies of recycling options and technologies

Cascade Use: Laminated Car Windsceens



Life cycle diagram for the production of laminated windscreens

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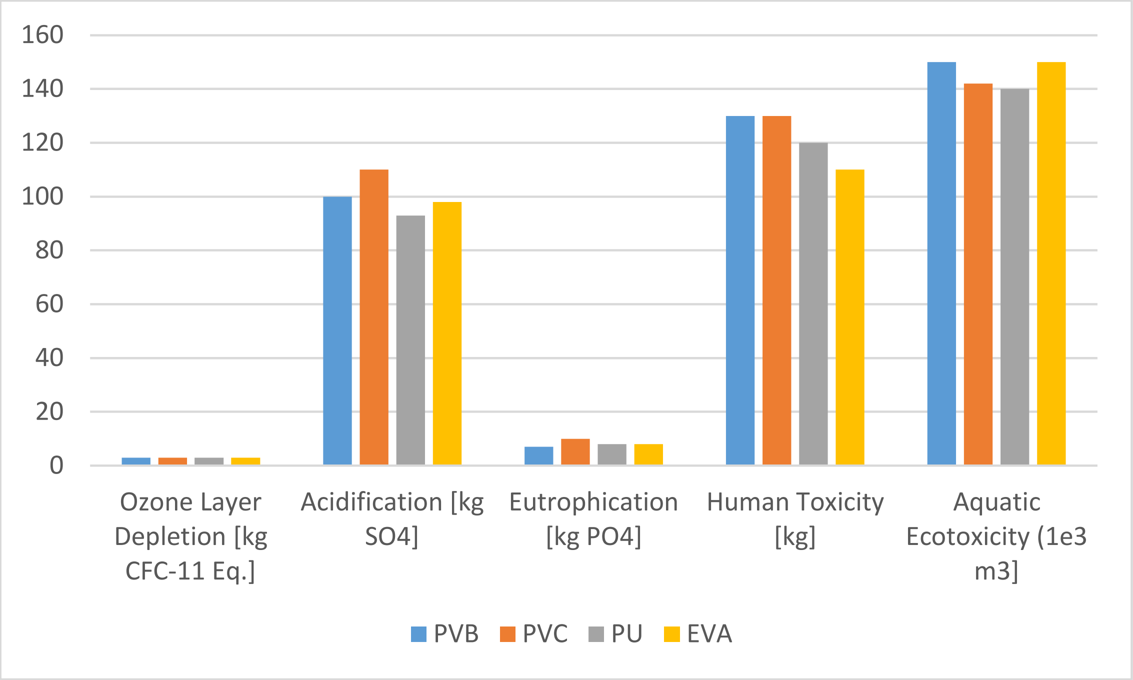
Life Cycle Assessment studies of recycling options and technologies

Cascade Use: Laminated Car Windsceens



The first use of interlayer polymers: comparison of the life cycle environmental impacts. Polymers are landfilled.

	PVB	PVC	PU	EVA
Ozone Layer Depletion [kg CFC-11 Eq.]	2	1	1	1
Acidification [kg SO4]	3	4	1	2
Eutrophication [kg PO4]	1	3	2	2
Human Toxicity [kg]	3	3	2	1
Aquatic Ecotoxicity (1e3 m3]	4	2	1	3

Ranking of interlayers in order of preference regarding their life cycle environmental impacts

The choice of the most environmental sustainable material is not clear.

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Life Cycle Assessment studies of recycling options and technologies

Cascade Use: Laminated Car Windsceens

Using other criterias like economical and technical, PVC and EVA have been selected as the best options.

The second part of the study consider the end-of-life possibilities of selected polymers. Polymers can not be re-used because technical reasons but can be reused in other applications:

- PVC is recyclated for pipe production.
- EVA is recyclated for cable jacket production.

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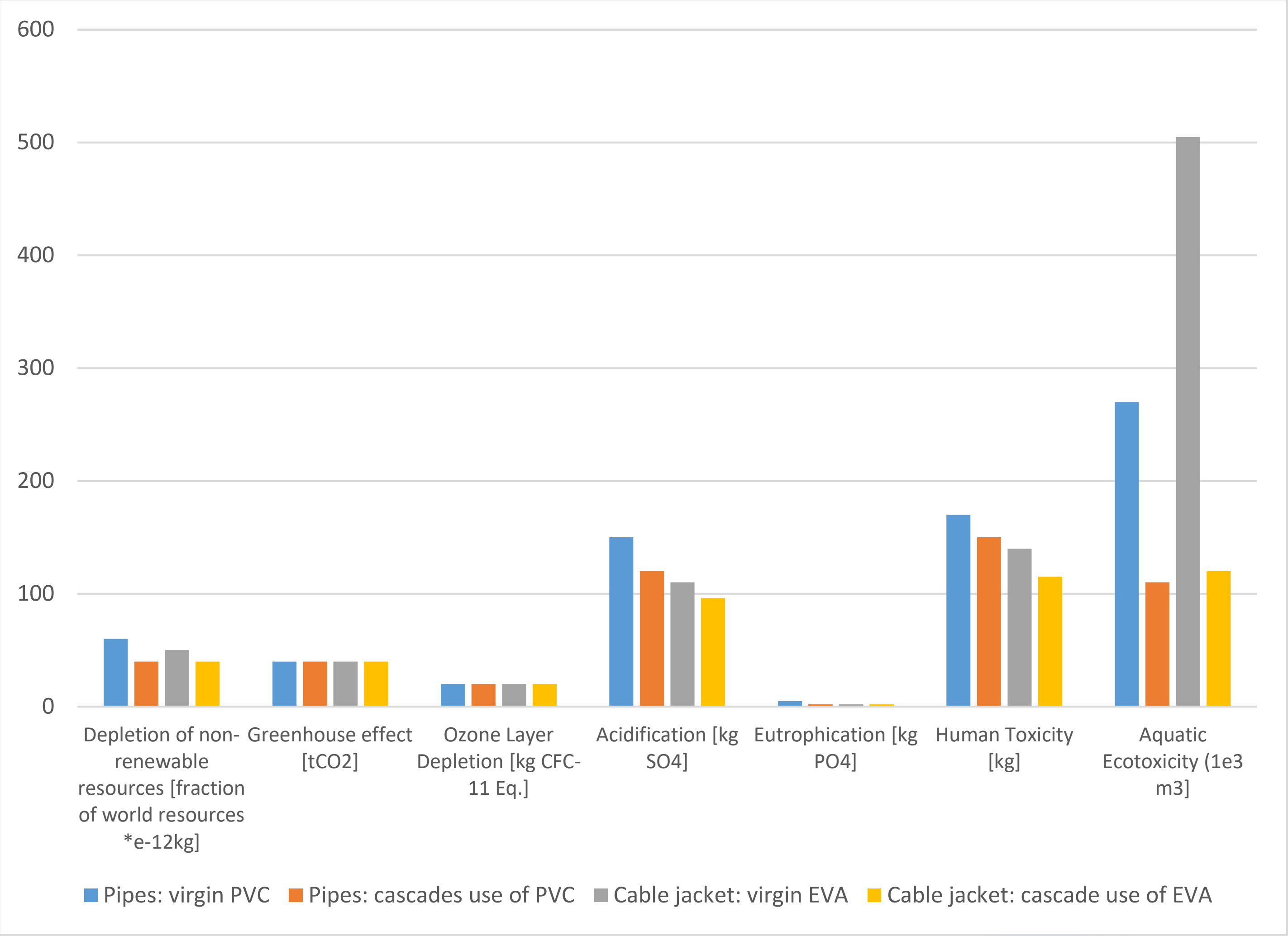
Life Cycle Assessment studies of recycling options and technologies

Cascade Use: Laminated Car Windsceens

- Cascade use results have lower impact for both materials.

- Cascade use of EVA is the best option.

- Conclusion: EVA is the best material and it should be reused to produce cable jackets.



Comparison of life cycle impacts of the virgin and cascade use of PVC and EVA

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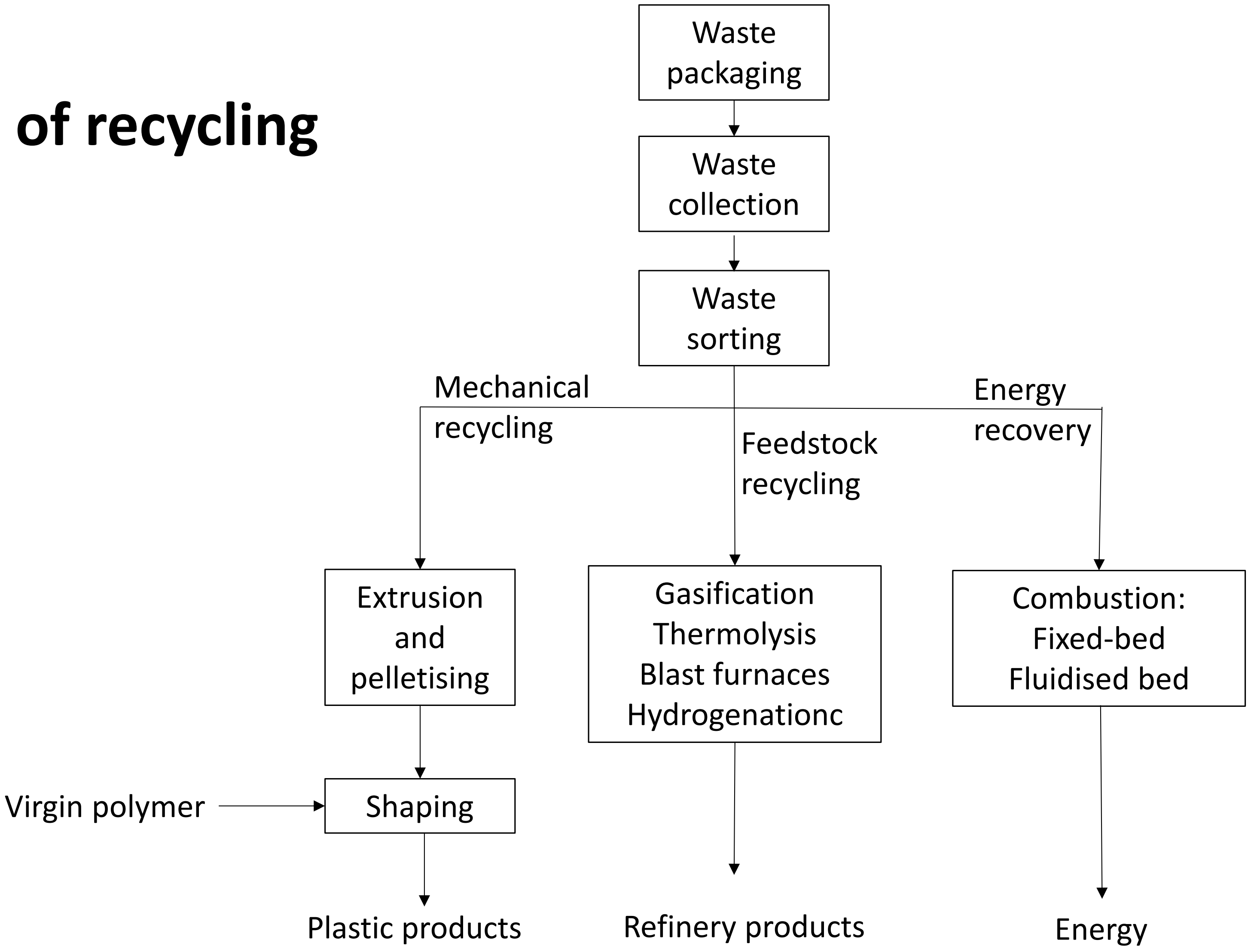
Life Cycle Assessment studies of recycling options and technologies

Integrated Plastic Waste Management: Packaging

A comparison of environmental impacts of mechanical and chemical (feedstock) recycling and energy recovery from waste packaging



Recycling options for waste plastic packaging

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Integrated Plastic Waste Management: Packaging

Mechanical recycling has been considered for waste plastic bottles and film only and comprise the following options:

- recycling granulate from waste bottles back into the bottles;
- recycling packaging film back into the film;
- recycling film into waste sacks;
- recycling film into cable conduit.

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Life Cycle Assessment studies of recycling options and technologies

Integrated Plastic Waste Management: Packaging

The feedstock recycling technologies considered in this case study are:

- fixed-bed gasification with lignite;
- gasification with lignite in a fluidised bed;
- thermolysis of plastics into petrochemical products;
- use of plastics in blast furnaces;
- hydrogenation together with vacuum residue oils.

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Life Cycle Assessment studies of recycling options and technologies

Integrated Plastic Waste Management: Packaging

The environmental impacts of different recycling options are compared in two stages. The first stage examines the feedstock recycling and energy recovery options and the second stage compares these methods with mechanical recycling.

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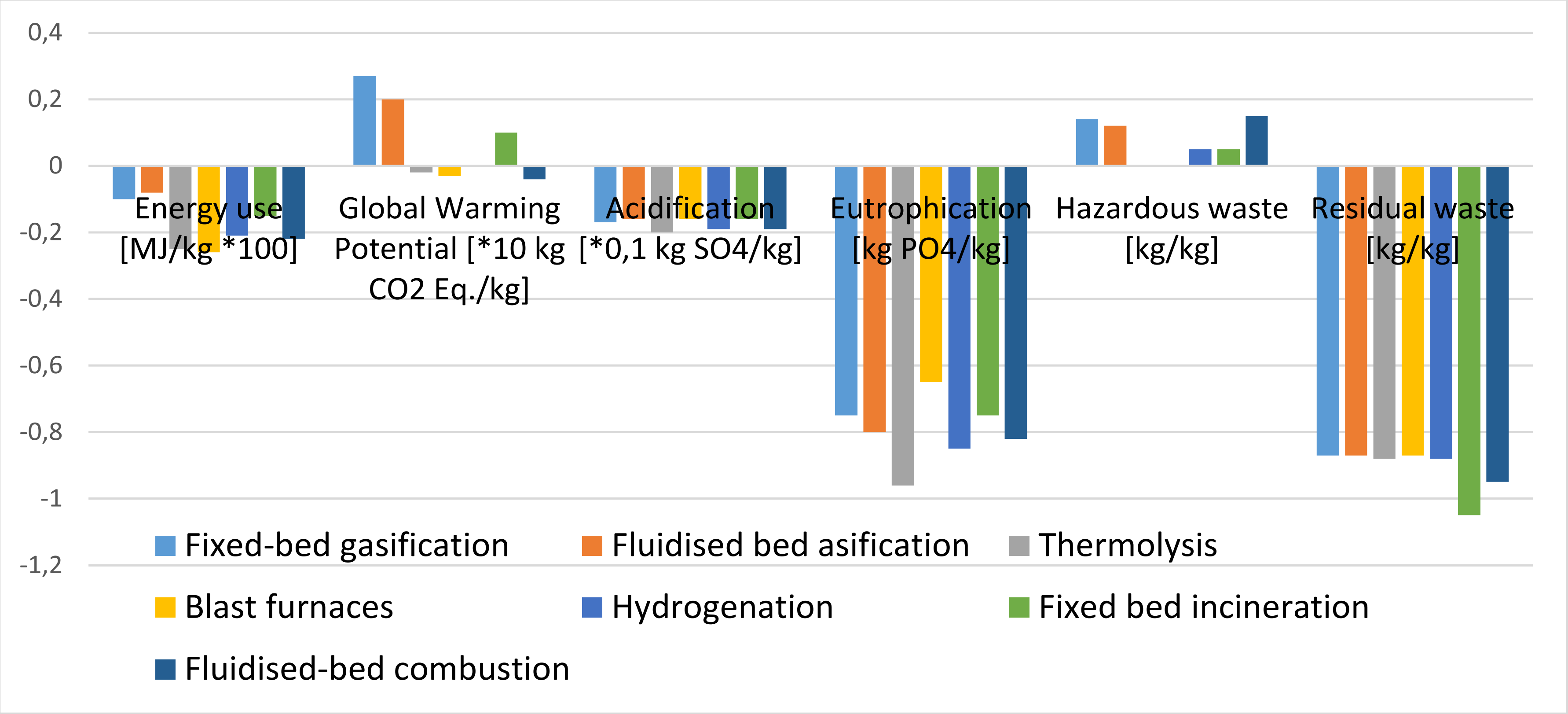
Life Cycle Assessment studies of recycling options and technologies

<u>Integrated Plastic Waste Management: Packaging</u>

First stage: Feedstock recycling and energy recovery comparison

- Landfilling has been chosen as the reference scenario.

- All feedstock and energy recovery options have lower environmental impacts than landfilling.



Comparison of life cycle impacts for feedstock recycling and energy recovery from waste plastic packaging

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Life Cycle Assessment studies of recycling options and technologies

Integrated Plastic Waste Management: Packaging

First stage: Feedstock recycling and energy recovery comparison

	Energy use	Global Warming	Acidification	Eutrophication	Hazardous waste	Residual waste
Fixed-bed gasification	6	6	4	6	6	6
Fluidised bed asification	7	7	5	4	5	5
Thermolysis	2	2	1	1	1	3
Blast furnaces	1	1	6	7	2	6,7
Hydrogenation	4	4	3	2	3	4
Fixed bed incineration	5	5	7	5	4	1
Fluidised-bed combustion	3	3	2	3	7	2

Comparison of life cycle impacts for feedstock recycling and energy recovery from waste plastic packaging

- The feedstock recovery in blast furnaces and thermolysis could be recommended as the most sustainable options

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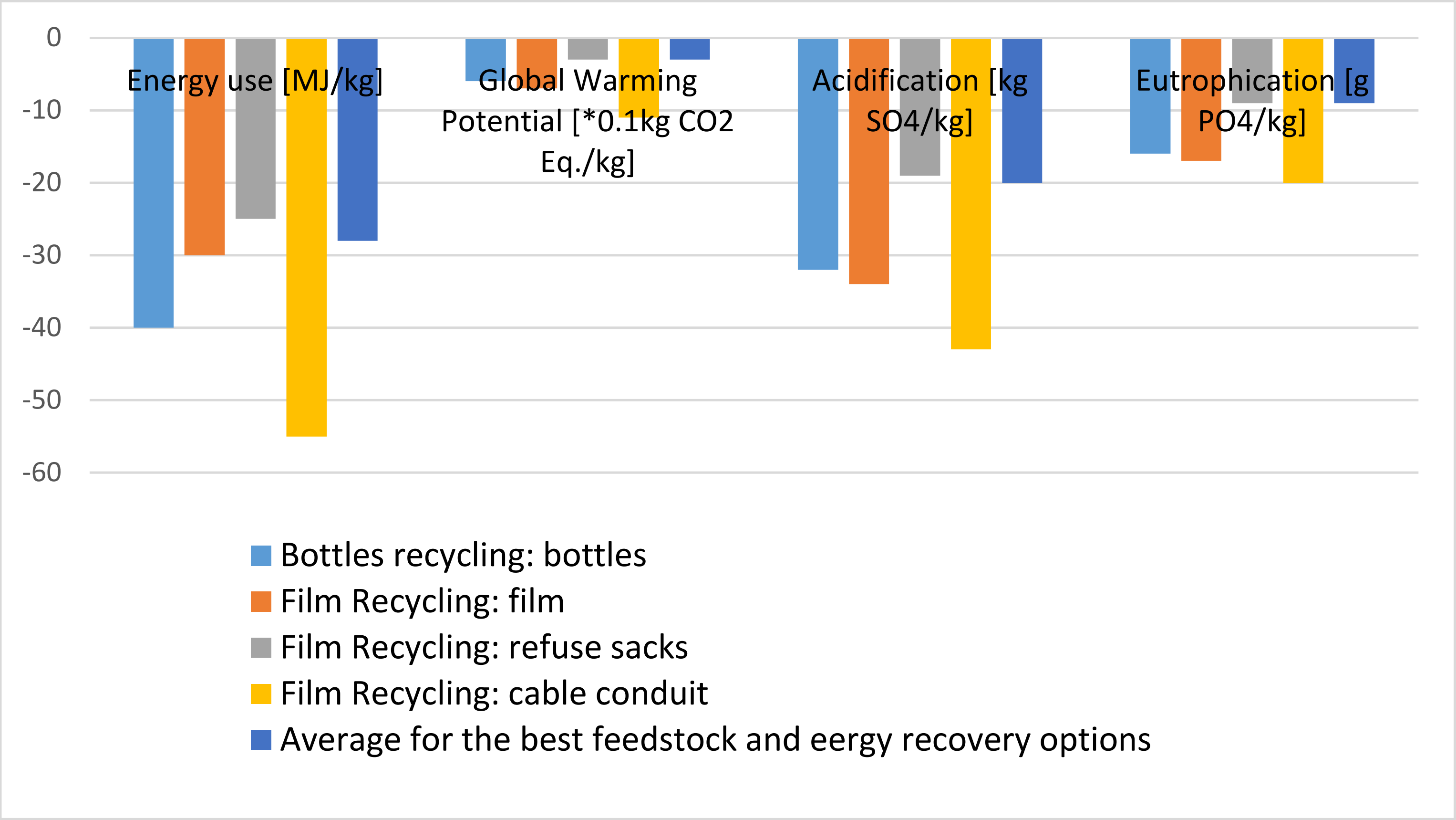
Life Cycle Assessment studies of recycling options and technologies

Integrated Plastic Waste Management: Packaging

Second stage: mechanical recycling comparison

- There is an overall reduction in the impacts for all mechanical recycling options compared to the reference scenario (landfilling).

- The best option for all impacts appears to be film recycling into cable conduit.



Comparison of life cycle impacts from recycling of bottles and film with the best options for feedstock recycling and energy recovery

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Life Cycle Assessment studies of recycling options and technologies

Integrated Plastic Waste Management: Packaging

- In summary, mechanical recycling is environmentally more sustainable than either feedstock or energy recovery.

- However, given the capacity, technological and sorting constraints at present, mechanical recycling is combined with feedstock recycling and energy recovery for the waste that can not be mechanical recycled.

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Life Cycle Assessment studies of recycling options and technologies

Life Cycle Product Design for Chemical Recycling: 'Waterlily' Cushioning

- This case study applies the life cycle design principles to develop a novel, recyclable polyurethane (PU) furniture cushioning material (mattress) called 'Waterlily'.

- The study has aimed to identify the most appropriate end-of-life options for PU foam, which would enable redesign of the existing product for improved recyclability.

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Life Cycle Assessment studies of recycling options and technologies

Life Cycle Product Design for Chemical Recycling: ‘Waterlily’ Cushioning

Several recycling options have been considered:

Rebonding scrap chips into carpet underlay (USA located)
Mechanical recycling to a fine powder, used to produce flexible foam
Incineration
Chemical recycling by split-phase glycolysis that provides pure flexible polyol that is used to replace virgin polyol completely

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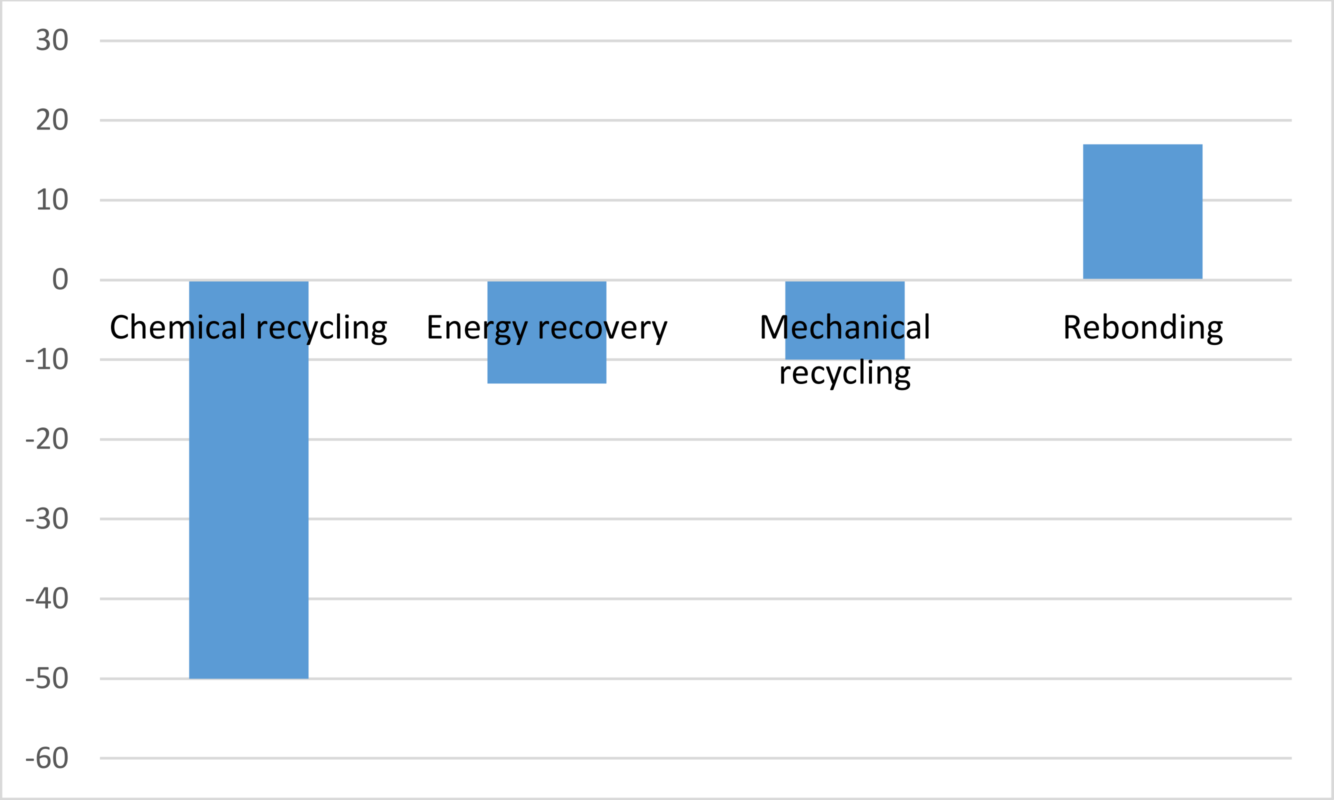
Life Cycle Assessment studies of recycling options and technologies

Life Cycle Product Design for Chemical Recycling: ‘Waterlily’ Cushioning

- Design for chemical recycling in this case appears to be the most sustainable option



Comparison of different recycling options for ‘Waterlily’ mattresses

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Life cycle assessment of paper and plastic packaging waste in landfill, incineration, and gasification-pyrolysis

This study evaluated and compared the environmental performance of the waste treatment of mixed plastic using (1) landfill, (2) incineration and (3) Gasification-Pyrolysis. The functional unit is the treatment of 1 kg of mixed plastic

Demetrious, A., Crossin, E. J Mater Cycles Waste Manag 21, 850–860 (2019). https://doi.org/10.1007/s10163-019-00842-4

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Life cycle assessment of paper and plastic packaging waste in landfill, incineration, and gasification-pyrolysis

Regarding Acidification potential, Eutrophication potential and Photochemical ozone formation, incineration is the best treatment

Regarding Global Warming Potential, landfill is the best treatment

Demetrious, A., Crossin, E. J Mater Cycles Waste Manag 21, 850–860 (2019). https://doi.org/10.1007/s10163-019-00842-4

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