REDUCING PLASTIC POLLUTION: A COMPREHENSIVE, EVIDENCE-BASED STRATEGY FOR SOUTH AFRICA

Technical report

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EXECUTIVE SUMMARY

The mismanagement of plastic waste, and resulting plastic pollution of the environment, has become an issue of global concern. The Pew Charitable Trusts' 2020 report "**Breaking the Plastic Wave**" provided the first global, comprehensive assessment of pathways towards stopping ocean plastic pollution. South Africa, like most countries, is faced with growing plastic consumption and disposal, and with it, leakage of plastic into the terrestrial and aquatic environment. The Breaking the Plastic Wave **Pathways Tool ("Pathways")** which evolved from the Pew report, is a modelling framework and software tool developed by Prof. Richard M Bailey (University of Oxford) in partnership with The Pew Charitable Trusts.

This South African pilot study applied the Pathways tool to provide an evidence-based approach to improve plastics management and reduce plastic pollution of the environment. The Pathways tool enables the analysis of current and projected plastic material flows, and models the effects of policies and strategies to reduce plastic pollution. In addition, the Pathways tool extends the global '*Breaking the Plastic Wave*' analysis by providing an opportunity for multi-objective optimisation. This enables an optimal model for sustainability to be developed which fulfils the need to protect the environment and reduce plastic pollution, while also considering the socio-economic imperatives of employment creation and economic development, which are often constrained by high capital costs.

This project aimed to answer the following two research questions:

- **Can the Pathways tool be successfully applied to a local scale, and to a developing country context such as South Africa?**
- **Based on the application of the Pathways tool, what should South Africa's response be to addressing plastic pollution?**

The three major outputs of the project are:

- **A localised plastics system map appropriate to South Africa, and possibly other developing countries with similar approaches to waste management**
- **An assessment of future scenarios with opportunities to reduce plastic pollution**
- **An evidence-based strategy to reduce plastic pollution in South Africa**

The system map for South Africa provides the basis for modelling the plastic flows – from production and consumption, to collection and sorting, recycling, disposal, and the (mis-)management of waste. Plastic products are produced from virgin and recycled polymers to meet the market demand. Plastic waste that is recycled can replace virgin plastic required for the manufacture of new plastic products. Plastic waste that is mis-managed because of either being uncollected and disposed to open-dumps, or collected and disposed to unsanitary landfill, leaks into the environment resulting in plastic pollution. In contrast, managed plastic waste that is collected and disposed to sanitary landfills prevents plastic pollution.

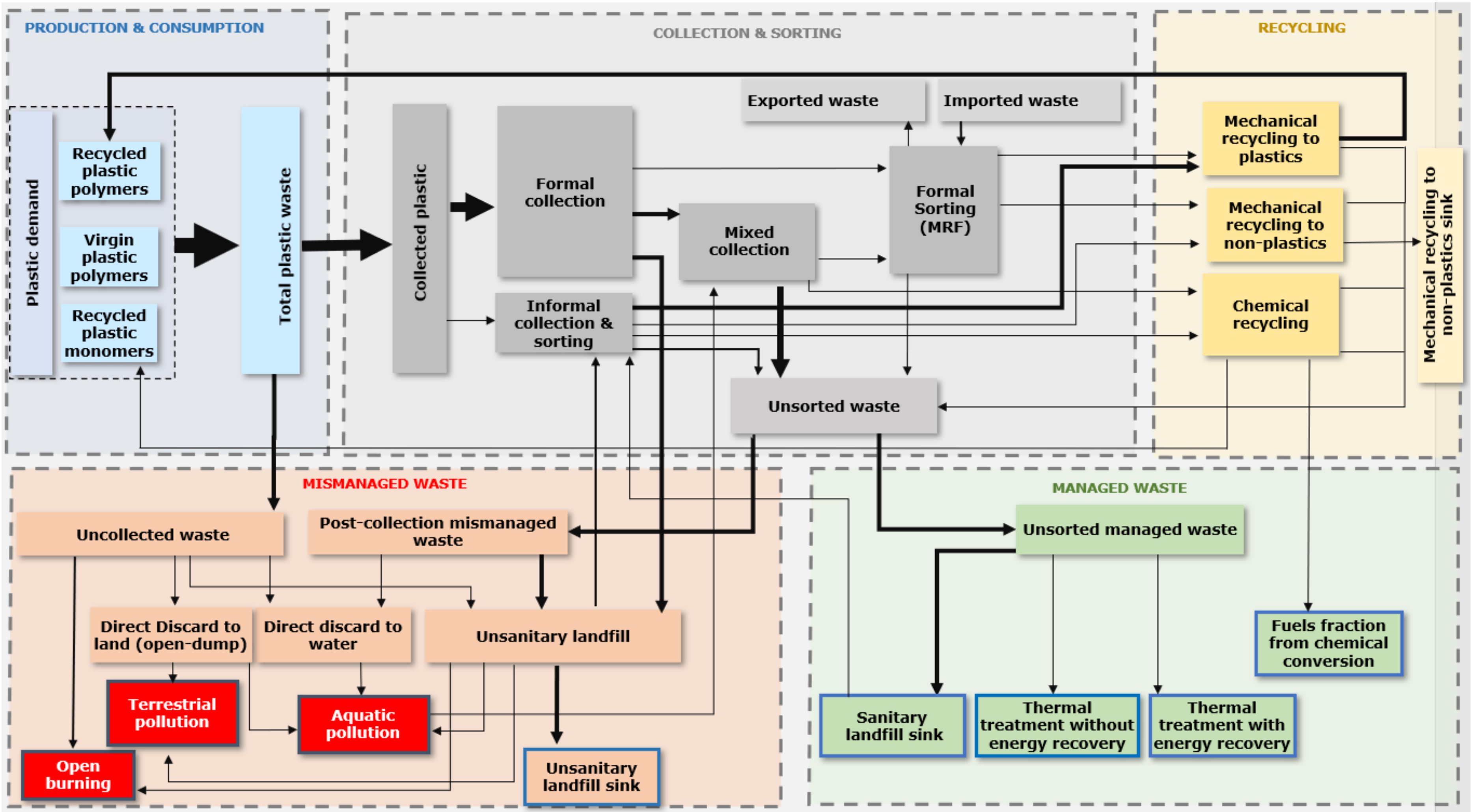


Figure E1: System map for South Africa showing plastic flows in 2020. The arrow width indicates the plastic mass flow (Sankey diagram).

The Pathways tool was used to model three distinct scenarios –

Business-As-Usual (BAU), which is based on current practices without Extended Producer Responsibility and with no policies or measures put in place in relation to plastic production, consumption, disposal or waste management. The BAU scenario also assumes no future changes in the carbon-intensity of South Africa's electricity mix, plastic polymer production or the future ability of Sasol to maintain its market share in the local plastic polymer market.

Extended Producer Responsibility (EPR) incorporates the collection and recycling targets for paper and packaging according to the EPR regulations and notices gazetted by Government (R1187 of 5 November 2020). The implementation of the five-year EPR recycling targets is set to 2023-2027.

Optimal System Change, which balances or "trades-off" South Africa's sustainable development objectives of reducing plastic pollution and greenhouse gas (GHG) emissions, while minimising capital costs and maximising employment. The Optimal System Change scenario combines the strategies of reducing plastics demand, increasing the collection and recycling of plastics, and ensuring the safe disposal of plastic waste.

Currently, approximately 37% of households in South Africa do not have weekly waste collection services, leaving 29% of all household waste uncollected, which is often disposed of improperly. Furthermore, the waste that is collected is sent to landfill, but many municipal landfill sites do not function effectively in terms of waste treatment and containment (non-compliant landfills).

Mismanagement of plastic waste (i.e., plastic waste that is either uncollected, or that is collected and subsequently improperly disposed at non-compliant landfills) results in plastic pollution of the environment; impacting air quality, water and land resources. South Africa's waste management practices and the percentage of the population living in proximity (< 1 km) to a water body, was used to model plastic leakage and the fate of the plastic pollution in the receiving environment. The total current annual plastic waste generated (2020 data)[1] is 1546 kt; of which 1350 kt is collected and 196 kt uncollected. Most of the plastic waste collected is in the form of mixed municipal solid waste, with relatively little separation at source (8% of formally collected plastics). Only 301 kt per annum of plastic is recycled – this represents a recycling rate of 19% of the total plastic waste generated, or 22% of the total plastic waste collected. Due to the mismanagement of plastic waste, 488 kt per annum of plastic pollutes the environment; where it contributes to air pollution through open burning (275 kt), land pollution (145 kt), or aquatic (freshwater and marine) pollution (68 kt). To date, much of the global attention on plastic pollution has focused on marine plastic pollution. The findings of this study reveal that plastic pollution in South Africa is dominated by the open burning of waste, as well as terrestrial pollution, with aquatic (freshwater and marine) pollution being a relatively small component of South Africa's pollution problem.

[1] The year 2020 is the most current date with primary data. Note: 1kt=1kilo-tonne=1000 metric tonnes=1 megagram (Mg)

The informal waste sector is responsible for collecting and sorting the majority (76%) of waste plastic that enters recycling (mostly mechanical recycling) in South Africa. These informal waste collectors operate at both household kerbside and at landfill, but most of the plastic waste recovered for recycling is collected from landfill sites. This indicates that there is ample opportunity to divert waste away from disposal, by improving waste collection and separation in order to increase the recycling rate and move towards a more circular plastics economy.

Under a scenario of **Business-As-Usual** (BAU), there is a projected growth in plastic consumption of 1.33% per annum, due to the rising population and increased consumption. **Without EPR regulations and with no new plastics-related policies and measures in place, plastic pollution is set to almost double – from 491 kt in 2020 to 865 kt in 2040.** Assuming no changes in the carbon-intensity of South Africa's plastic polymer production or in the future ability of Sasol to maintain its market share in local plastic polymer consumption, the plastics-related greenhouse gas (GHG) emissions under the Business-As-Usual scenario will increase 63% by 2040. The GHG footprint of South African polymer and plastic products is significantly greater than the global average due to the carbon intensity of the Sasol coal-to-liquids process for plastic polymer production, as well as South Africa's energy generation mix, which is dominated by coal power. Therefore, GHG emission reductions could be achieved through reducing the demand for plastics and the substitution of locally produced plastic polymers with alternatives; namely – imported plastic polymers or bio-based materials (local or imported). Although it is critical that these alternatives provide equal functionality and offer reduced environmental impacts across the whole product life cycle, this finding indicates that a policy to localise the entire plastics value chain to achieve socio-economic benefits should be considered with caution. The plastics disposal stage accounts for only 8% of plastics related GHG emissions, from the open burning of plastics that occurs in uncollected waste dumps and municipal unsanitary landfills. Although a relatively small component of the total plastic GHG emissions, these emissions are greater than any formal waste management system and have significant local environmental and health impacts in terms of air pollution. Due to the inefficiency of open burning practices and the notable local air pollution impacts from partial combustion of plastics and associated mixed waste, there is a strong recommedation to reduce these practices through policy and enforcement.

The **Extended Producer Responsibility (EPR)** scenario, which involves a strategy of increasing **collection and recycling,** with five-year targets as set out in the current regulations[2], **can avoid 33% of total plastic pollution** over the period 2023-2040, compared to BAU (aquatic pollution will be reduced by 25% over this period, plastic pollution to land will decrease by 33%, and plastic pollution to air from open burning by 35%). The EPR scenario can also avoid 14% of projected GHG emissions between 2023-2040, compared to the BAU scenario, as a result of recycled plastics partially replacing the need for virgin plastic production.

While increased collection and recycling can significantly avoid plastic pollution from the dumping and open burning of waste, other strategies are required to achieve greater reductions in plastic pollution.

[2] Regulation 1187, Government Gazette 43882 of 5 November 2020.
Available at: https://www.gov.za/sites/default/files/gcis_document/202011/43882gon1187.pdf

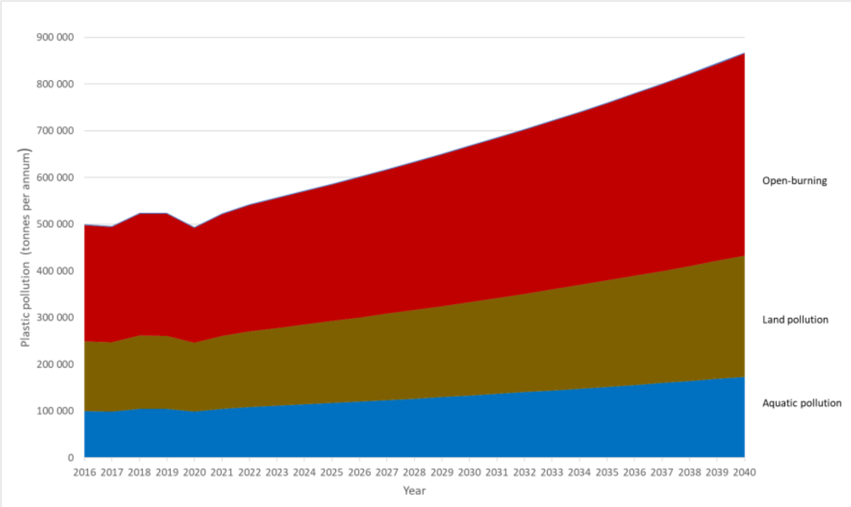
The **Optimal System Change** scenario combines the strategies of increasing plastic waste collection, recycling, and improved disposal to sanitary landfill, as well as reducing the demand for plastics. The Optimal System Change scenario **can avoid 63% total plastic pollution** over the period 2023-2040, compared to the BAU (aquatic pollution will be reduced by 56%, plastic pollution to land will decrease by 66%, and plastic pollution to air from open burning by 63%). In addition, the Optimal System Change scenario also avoids 37% of projected GHG emissions; reduces required investment by 67% as a result of avoided capital costs for plastic production, conversion, and disposal; and leads to a 3% increase in employment opportunities; compared to BAU. The Optimal System Change scenario has a marginal effect on employment in the plastics value chain; since employment losses are associated with reducing plastic demand, while employment gains are associated with increased collection and recycling. However, it is notable that combining strategies of reducing plastics demand coupled with increasing waste collection and disposal to sanitary landfill may result in net employment gains, and not employment losses as is often believed.

The Optimal System Change scenario requires a combination of strategies – reducing plastic demand, increasing collection, and recycling, and increasing the safe disposal of plastics to sanitary landfill.

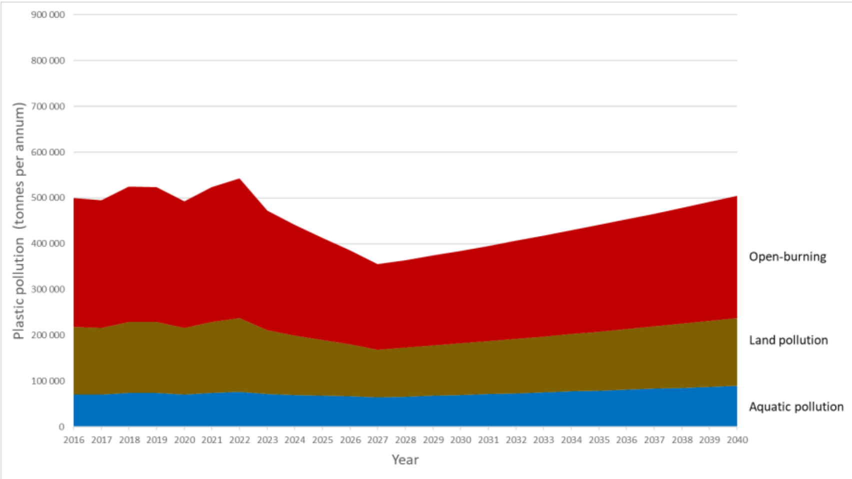
Under the Optimal System Change scenario:

- **Plastic demand** decreases by 2.57% per annum (includes plastics reuse, elimination, and alternative delivery models; as well as the substitution of plastics with alternatives such as paper, coated paper, and compostable bioplastics);
- **Collection** increases by 4.85% per annum
- **Recycling** increases by 4.87% per annum
- **Disposal to sanitary landfill,** where containment of plastics *in situ* is assured, increases by 3.36% per annum.

A. Business-as-usual (BAU)



B. Extended Producer Responsibility



C. Optimal System Change

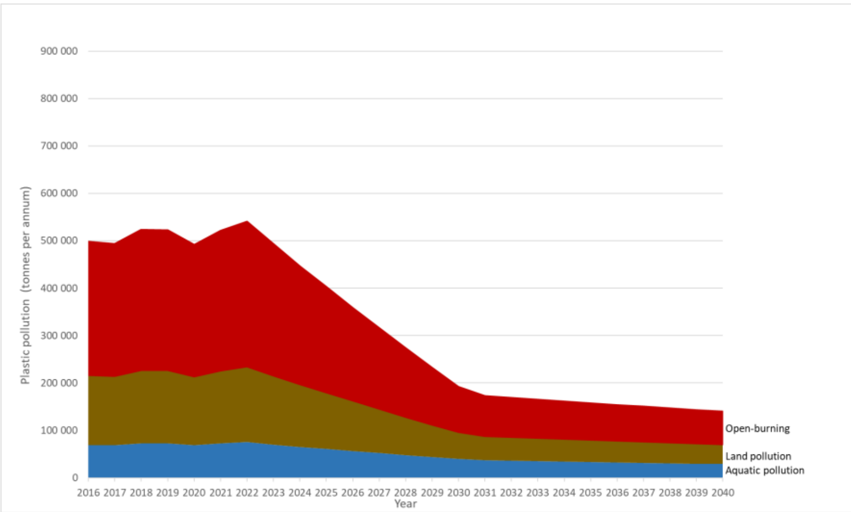


Figure E2 Plastic pollution (consisting of air pollution from open-burning, land pollution and aquatic pollution) under: ***(A) Business-As-Usual,*** *with no policies or measures;* ***(B) Extended Producer responsibility,*** *with five-year recycling targets as per the recent EPR legislation; and* ***(C) Optimal System Change,*** *which combines the strategies of reducing demand, increasing collection and recycling and increasing safe disposal to sanitary landfill*

The **Optimal System Change** scenario thereby improves the management of plastics at end-of-life by avoiding and reducing the risks of plastic pollution. The improved management of plastics at end-of-life through reduction and substitution, recycling, and disposal to sanitary landfill provides an effective set of combined strategies to substantially reduce plastic pollution.

Since recycling processes favour plastics that are rigid mono-materials and, to a lesser extent, flexible mono-materials; there is a depletion of these materials from the waste-stream in the System Change scenario; so that the composition of plastics disposed to waste has a greater proportion of multi-materials. Therefore, the implementation of the Optimal System Change scenario could be enhanced further through the targeted reduction of multi-materials that are deemed unnecessary and problematic.

Achieving the full benefits of this Optimal System Change scenario will require a collaborative approach between all stakeholders, and a commitment to support the necessary changes across the plastics value chain.

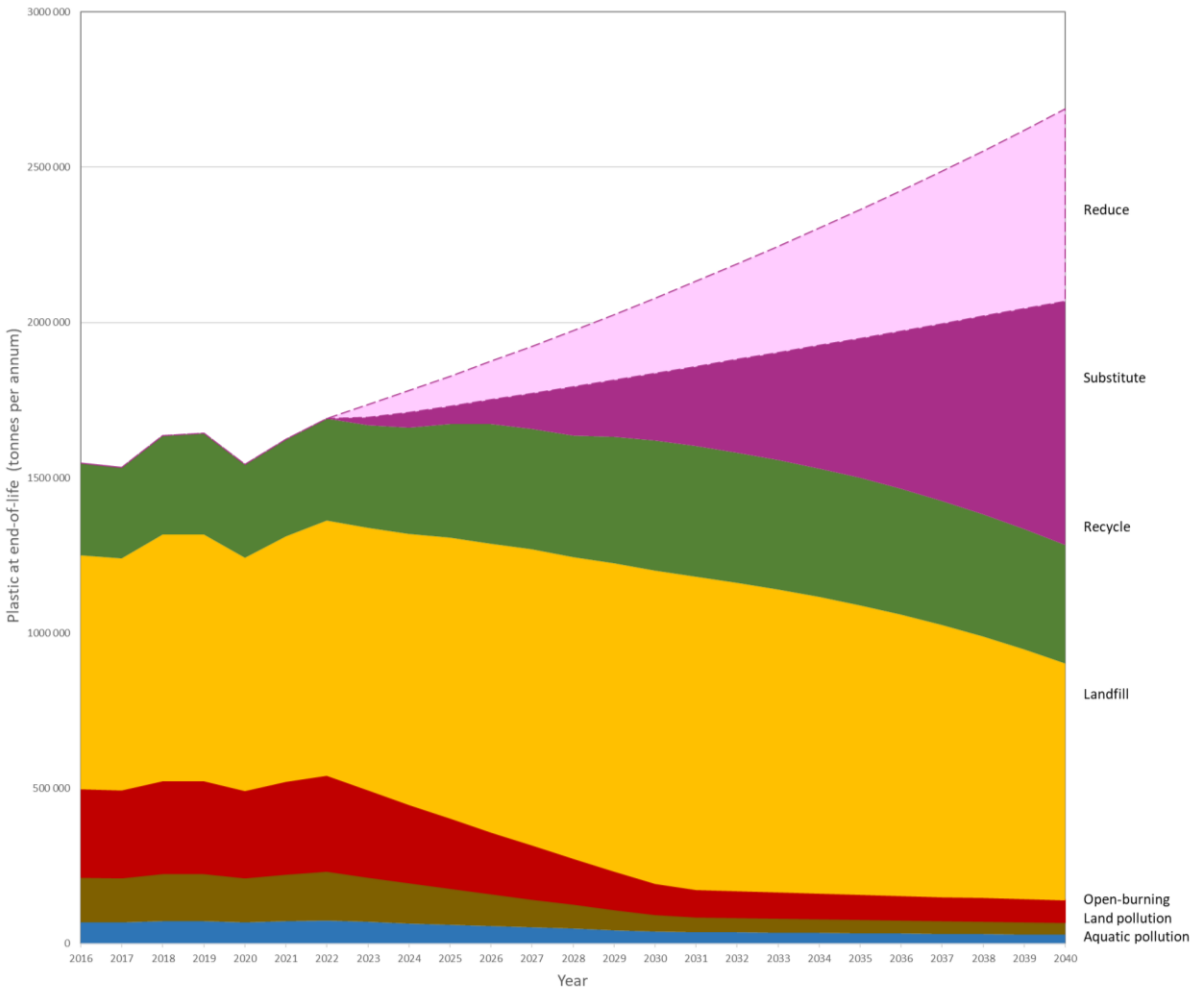


Figure E3: The avoided plastic pollution (tonnes/annum) of the Optimal System Change scenario compared to the Business-As-Usual plastics end-of-life. Plastic pollution (air pollution from open burning, land pollution, and aquatic pollution) is substantially reduced in the Optimal System Change scenario by avoiding plastics reaching end-of-life through reducing and substituting; delaying the plastics end-of-life through recycling; and disposing of residual plastic waste to sanitary landfill where containment can be assured.

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LIST OF ABBREVIATIONS

BAU	Business-As-Usual
Pathways tool	Breaking the Plastic Wave Pathways tool, previously Plastics to Oceans (P20)
CAPEX	Capital Expenditure
CARG	Compound annual rate of growth
Chem conv	Chemical Conversion
CL	Closed-loop recycling
CSIR	Council for Scientific and Industrial Research, South Africa
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and the Environment
DSI	Department of Science and Innovation
EPR	Extended Producer Responsibility
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GHG	Greenhouse gas
HDPE	High-density Polyethylene
IWMP	Integrated Waste Management Plan
kt	Kilo-tonne
MRF	Material recycling facility
MR	Mechanical Recycling
MSW	Municipal solid waste
ODE	Ordinary differential equation
OL	Open-loop recycling
OPEX	Operational Expenditure
OS	Operating System
p.a.	Per annum
P2F	Plastic to fuel conversion
P2P	Plastic to Plastic conversion
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PET	Polyethylene terephthalate
Pew	The Pew Charitable Trusts
PHB	Polyhydroxybutyrate
PLA	Polylactide
PP	Polypropylene
PS	Polystyrene
RDI	Research, Development and Innovation
REQ	Required
SARS	South African Revenue Service
SAWIS	South African Waste Information System
StatsSA	Statistics South Africa
TAG	Technical Advisory Group
UMI	Upper middle income
Yr.	Year

1 Introduction

The mismanagement of plastic waste, and associated plastic pollution of the environment, has become an issue of global concern. Currently, leakage of plastic waste to the marine environment is estimated at 12.7 million tonnes per annum (Boucher et al., 2020), while accumulated marine plastic debris since the 1950s is estimated to be in the order of 75 to 199 million tonnes (UNEP, 2021). Approximately 80% of marine plastic debris is thought to originate from land-based sources; and without intervention, this plastic pollution is predicted to nearly triple by 2040 (Li *et al*., 2016 and Lau *et al*., 2020).

An early study estimated that South Africa was a major contributor to marine plastic pollution, ranking 11th out of 192 coastal countries in terms of mismanaged plastic waste, and generating an estimated 90 to 250 kilo-tonnes per annum of plastic polluting the oceans (Jambeck *et al.,* 2015). Subsequent estimates of South Africa's contribution to marine plastic debris are somewhat lower, ranging between 15 to 40 kilo-tonnes (Verster and Bouwman, 2020) and 79 kilo-tonnes (Sorrentino, 2022 and IUCN-EA-QUANTIS, 2020).

The global 'Breaking the Plastic Wave' study, published by The Pew Charitable Trust and SYSTEMIQ in 2020, produced an analysis of the global plastics system, in order to provide evidence of both the extent and nature of the plastic waste and pollution problem, and to understand the strategies needed to reduce plastic pollution. The modelling and analysis used in the 'Breaking the Plastic Wave' study has been developed as a software application; hereinafter referred to as the *Pathways tool*. To test and ensure applicability at the country-scale and to inform the development of strategies to reduce plastic pollution in developing countries, the CSIR collaborated with the Pew Charitable Trusts (USA) and Oxford University (UK) to apply the Pathways tool to South Africa.

This report outlines the process of using the Pathways tool in the South African context. It provides an overview of the modelling framework and its adaptation to the local context, and describes the scenarios modelled (Chapter 2). The data requirements and the collection of local data, together with challenges experienced during data collection, are described in Chapter 3. The results of the modelling and findings from three different scenarios are then described (Chapter 4). Lastly, strategies to reduce plastic pollution in South Africa are developed, and recommendations and conclusions drawn (Chapters 5 and 6).

With the learning gained from the application of the Pathways tool in South Africa and the benefits of adopting a strong evidence-based approach to addressing plastic pollution, it is hoped that other African countries will move to undertaking similar studies.

2 Modelling South Africa's approach to reduce plastic pollution

This section outlines the tool, approach, and system map that supported the modelling undertaken in this study.

2.1 Pathways tool

The Pathways tool is a data-driven coupled ordinary differential equation (ODE) model, that models the flows of plastics through a system. An ODE modelling framework was chosen because the output of such a model takes the form of flows (derivatives) and stocks (integrals), while also ensuring mass balance of the system. The model is dynamic – it estimates the stocks and flows over time, accounts for quantitative changes in these stocks and flows, and captures feedbacks and flow constraints in the system. The Pathways tool also estimates the mitigation potential and system-level effects of different strategies aimed at minimising plastic pollution, and offers the ability to optimise based on a 'trade-off' of objectives (Lau *et al*., 2020a, Lau *et al*., 2020b[3]). Following the publication of the global study, the model has been expanded and further developed by Oxford University in partnership with The Pew Charitable Trusts, to include new functionality in terms of optimisation, and the development of a software graphic user interface (GUI). The Pathways tool (previously termed Plastics-to-Oceans, P2O) is under active development, and the beta version (v 1.9.7.8) was used for the modelling carried out for this report (Bailey, 2020).

2.2 A systems approach – levers and wedges to reduce plastic pollution

There are four main strategies or 'levers' to address plastic pollution; namely –

- **Reduce Demand** by reducing plastic consumption and substituting plastics with alternatives. A reduction in plastic consumption involves design for re-use, the elimination of problematic and unnecessary plastics, and the introduction of new delivery models that avoid or reduce the need for packaging (examples include refill services, shifting products to services, e-commerce, and dispensers). Substituting plastics with alternatives involves switching from plastics to alternatives such as paper, coated paper, and compostable bio-based materials; but with careful consideration to maintain functionality requirements and to ensure that these alternatives do not incur additional environmental impacts.
- **Increase Collection** through improvements in waste collection services. Currently, not all South African households have weekly waste collection services, and a large proportion of waste is disposed to open-dumps, which are frequently burnt (an informal waste management practice aimed at reducing waste volume). Improving waste collection can make plastics more readily available and amenable for recycling, while reducing the potential for plastic pollution.
- **Increase Recycling** of plastic by diverting plastic waste away from disposal to recycling. Recycling plastic reduces the need for virgin polymers in the production of new plastic products. An increase in the collection and sorting of plastics will be required to make plastic

[3] Lau et al 2020b Appendix of for modelling details
https://www.science.org/doi/suppl/10.1126/science.aba9475/suppl_file/aba9475-lau-sm-rev.1.pdf

material available for recycling, and five-year collection and recycling targets have been mandated by the recent Extended Producer Responsibility (EPR) regulations (R1187 of 5 November 2020[4]).

- **Improve Disposal** by improving waste management infrastructure and practices. Currently, landfill is the predominant waste management solution in South Africa, and there is negligible dedicated waste thermal treatment (without energy recovery). However, not all municipal landfills are properly managed or compliant with legislation, and many do not effectively contain plastics waste *in situ*. Improved safe disposal to sanitary landfills that ensure containment will be needed to reduce plastics leaking to the environment

This study considers the impact that each strategy or 'lever' can have on reducing plastic leakage to the environment. It also considers the interaction between the various strategies, as well as a possible optimum combination, or systems approach, that can substantially reduce plastic pollution in South Africa.

The impact of each lever or strategy that will help to avoid or reduce plastic pollution is presented graphically as a 'wedge'- the area under the graph's curve used to allow comparison of different scenarios with unique trendlines, to the Business-As-Usual (BAU) scenario.

2.3 System map

The Pathways tool adopts a systems approach, by which plastic flows are modelled through a waste management system, considered representative of the local context in question. The first step in applying the Pathways tool to South Africa was to review the system map adopted in the global study and evaluate its appropriateness for the South African environment. The system map indicates the flows of macro-plastics throughout the value chain from production to end-of-life treatment. Following review, and consultation with stakeholders, the system map was adjusted to accommodate specific features unique to the South African waste and plastics context (Figure 1). The South African specific additions to the global systems map (highlighted in red in Figure 1) include the following:

Features added:

Box 26: Thermal treatment without energy recovery
Box 28: Unsanitary landfill sink
Flow 46: Uncollected waste to surface storage (AA)
Flow 47: Unsanitary landfill to engineered landfill
Flow 48: Unsorted managed waste to Thermal treatment without energy recovery
Flow 49: Formal collection to surface storage (AA)
Flow 50: Unsanitary landfill to Unsanitary sink

Features removed:

No sinks or flows were removed from the global system map

[4] Regulation 1187, Government Gazette 43882 of 5 November 2020.
Available at: *https://www.gov.za/sites/default/files/gcis_document/202011/43882gon1187.pdf*

2.3.1 System boundaries

The study considers only the macro-plastic component of municipal solid waste (MSW), which consists mainly of packaging plastics, but may also contain other plastic consumer products that enter the municipal waste stream. Waste synthetic textiles, clothing and footwear, automotive, and agricultural plastics are not included in the study. Primary microplastics, such as those generated from tyre abrasion and the washing of synthetic textiles, are also not considered, despite the fact that they can make a significant contribution to microplastic pollution of the ocean. As such, the results presented here should be considered partial and a conservative estimate in terms of plastic leakage and pollution of the environment.

2.3.2 Terminology

In addition to new flows, certain terms in the system map were modified to reflect the general South African understanding, and to provide clarification for the reader.

It is important to note that South Africa has two distinctly different waste management systems that operate in parallel – a formal waste management system responsible for the regular collection and disposal of municipal solid waste, and an informal waste management system, which targets high-value recyclable materials from waste bins at kerbside or from landfill sites and sells them into the recycling value chain.

Within the formal waste management system, there are varying levels of service delivery. In typically middle- and high- income urban areas, which have adequate road infrastructure and accessible waste points, a fairly well managed municipal waste management system operates. In this system, households typically receive weekly waste collection from kerbside or from communal collection points. The waste is disposed of at facilities that range from "*Unsanitary landfills*", to engineered "*Sanitary landfills*". In addition to design, the management and operations of these facilities also varies considerably, resulting in varying levels of containment of the waste once disposed. This terminology is reflected in Boxes N and V in the system map (Figure 1).

In informal settlements and rural villages, often with poor access and weak road infrastructure to accommodate waste collection vehicles, little to no formal waste collection is provided by the municipality. The households in these areas must manage their own waste through on-site disposal, or take their waste to earmarked communal dumps which are not engineered and often not well managed. In many cases these open-dumps are regularly burnt to reduce the volume of waste, control wind-blown litter, reduce odours and pests, and reduce the risk of disease (Levis *et al*., 2017). The lack of formal waste collection systems also typically results in a high prevalence of illegal dumping and littering, which may be removed by authorities on an *ad hoc* basis and taken to the nearest landfill. In South Africa, approximately 29% of all domestic waste generated is not collected or treated via formal waste management systems (Rodseth *et al*., 2020), and many municipal landfill sites do not function effectively in terms of waste treatment and containment, and fail to comply with the National Norms and Standards for Disposal of Waste to Landfill[5] (Pienaar and Palm, 2018).

[5] Regulation 636, Government Gazette 36784 of 23 August 2013

As such, in South Africa, waste is either "*Mismanaged*" or "*Managed*". The "*Mismanaged waste*" consists of "*Uncollected waste*" from households that do not have regular waste collection services, as well as "*Post-collection Mismanaged waste*", which refers to waste that has been collected but subsequently mismanaged at a landfill site that does not effectively contain the plastic waste. This terminology is reflected in Box Q "*Uncollected waste*" and Box R "*Post-collection mismanaged waste*", both of which directly contribute to plastic pollution. It is only "*Managed waste*" (Box M), which is the proportion of plastic waste that is disposed properly to sanitary landfills to effectively contain it *in situ*, which completely prevents plastic pollution (i.e. it is assumed that there is zero leakage of plastic to the environment from *Managed Waste*).

Concerning waste collection, we distinguish between "*formal collection*" and "*informal collection*". Specifically, "*formal collection"* refers to formally collected plastic waste for disposal and recycling by municipalities and private companies as part of the formal waste management system. "*Informal collection'* refers to plastic waste collected by the informal waste sector which operates at kerbside (street waste pickers), sorting through waste bins ahead of the formal waste collection vehicles; or at landfills/open-dumps (landfill waste pickers) sorting through disposed waste. The job opportunities reported include both formal and informal jobs and are adjusted to full time equivalents.

Recycling can be carried out by mechanical or chemical means, with mechanical recycling the dominant form of plastic recycling in South Africa. Mechanical recycling of plastics can be carried out by substituting plastic or non-plastic products. Within "*Mechanical recycling to plastics*" there can be both "*closed loop*" recycling, involving no loss of material quality in the recycling process, e.g., bottle-to-bottle; or "*open-loop recycling*", which does involve a loss of material quality, e.g., bottle-to-textiles. In South Africa, most of the mechanical recycling is for plastics-to-plastics and involves open-loop recycling (95%), with PET bottle-to-bottle recycling being the only significant closed loop recycling carried out to date.

These changes in terminology from the 'Breaking the Plastics Wave' global study are shown on the final System map for South Africa in Figure 1 and in Annexure 1 that shows how the South African map (Figure 42) was developed from the original system map (Figure 41) of the global study.

2.4 Scenarios modelled

Given the range of possible strategies that can reduce plastic pollution, this study modelled three main scenarios:

1. **Business-As-Usual**
   Assumes no policies or measures are in place in relation to plastic production, consumption, disposal or waste management The BAU scenario also assumes no future changes in the carbon-intensity of South Africa's electricity mix or plastic polymer production, or in the future ability of Sasol to maintain its market share in the local plastic polymer market.

2. **Extended Producer Responsibility**
   Assumes that the Extended Producer Responsibility (EPR) collection and recycling targets gazetted by Government through the EPR regulations and notices for paper and packaging (R1187 of 5 November 2020) is implemented in 2023 for a five-years

3. **Optimal System Change**
   Seeks to identify an optimal solution that balances or "trades-off" South Africa's sustainable development objectives of reducing plastic pollution and greenhouse gas (GHG) emissions, while minimising capital costs and maximising employment. The Optimal System Change scenario combines the strategies of reducing plastic demand, increasing the collection and recycling of plastics, and ensuring the safe disposal of plastic waste.

Each scenario has been modelled for the period 2016-2040, using available historical data. The future projections consider the implementation of the afore-mentioned policies and measures in the year 2023.

2.5 Key assumptions and limitations

- The Business-As-Usual scenario assumes and that Extended Producer Responsibility is not yet implemented and there are no future changes in waste management practices or the carbon-intensity of South Africa's electricity mix or plastic polymer production, and assumes that Sasol can maintain its share in the local plastic polymer market.

- A reduction in plastic consumption involves design for re-use, the elimination of problematic and unnecessary plastics, and the introduction of new delivery models that avoid or reduce the need for packaging (examples include refill services, shifting products to services, e-commerce, and dispensers). Substituting plastics with alternatives involves switching from plastics to paper, coated paper, and bio-based materials. Other materials such as glass and metal have not been considered as substitutions in this study since they are not readily biodegradable or compostable and therefore not considered suitable substitutes, since these materials may also pollute the environment. The additional or avoided costs for plastics production, manufacturing, collection, recycling and disposal have been considered together with costs of substitution to alternatives, the costs of plastics reduction by means of re-use, alternative delivery models and elimination have not been included, due to lack of data.

- The model is unconstrained in that it allows plastic production and waste infrastructure to grow in accordance with what is required to process the respective plastic flows.

For additional key assumptions on data and data sources, please refer to Annexure 2.

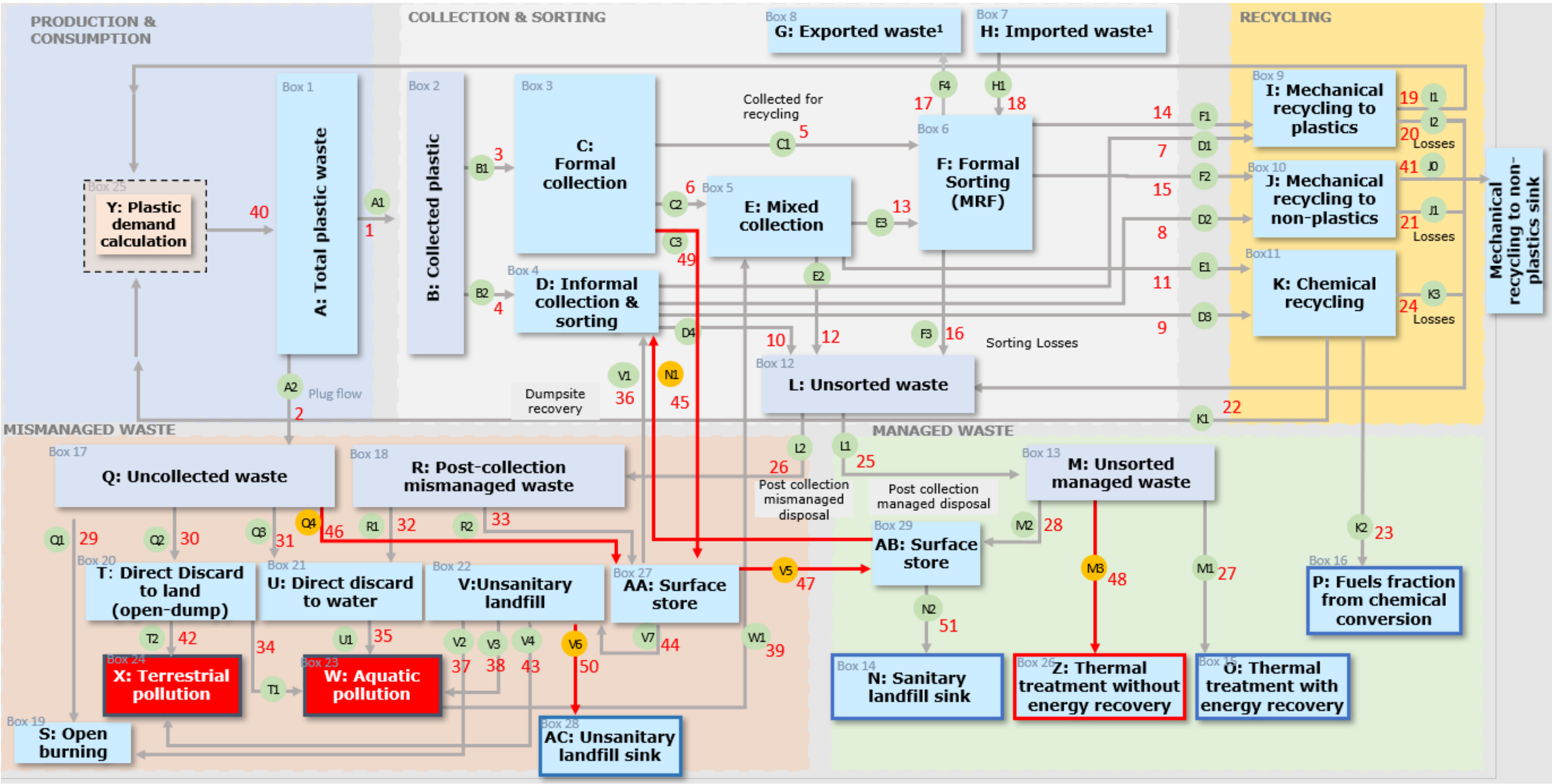


Figure 1: System map of South African plastics production, consumption and disposal used in this study.

3 Data

The Pathways tool is data intensive. This is both a benefit, in that it provides a uniquely tailored and strongly evidence-based approach to understanding plastic pollution in the local context. However, it can also be a challenge; particularly for countries that have poor and incomplete data sets for plastic flows and waste management.

Having developed the system map for South Africa, data collection was focused on populating all system flows (arrows between boxes), as well as any stocks or mass of plastic accumulating in the boxes, for each plastic category (rigid mono-material, flexible mono-material, as well as multi-materials or multi-layers), and for each of the three modelled scenarios (see Annexure 4 for details).

3.1 Data requirements

The Pathways tool requires plastic-specific data, including total plastic, total plastic waste, waste generation per capita, projected annual growth in waste generation, and the proportion split between the three plastic categories; namely rigid, flexible, and multi (i.e., multi-material or multi-layered) in the waste stream.

Projected growth in demand for plastic is calculated using country level population statistics and the per capita estimate of the macro-plastic component of municipal solid waste (MSW), as defined by the system boundary. The leakage potential for plastic is calculated based on the waste management processes implemented (such as collection, processing, recycling, and recovery rates). The population is differentiated by their distance to a water body (<1km or >1km) to estimate the relative flows of plastic pollution to terrestrial or aquatic (freshwater and marine) systems. Plastics are also differentiated into the three material categories described above (rigid, flexible, and multi), to account for different waste management pathways and flows into the environment in each case.

Costs are provided in constant 2018 US dollars, and specifically refer to the capital costs (required investment at a given point in time) and the operational costs (OPEX) and capital expenditure (CAPEX) that are amortised over the asset lifetimes. Costs are calculated as a function of modelled plastic flows, with changes in costs due to production scale and technological advancement accounted for through learning curves and returns to scale (Lau *et al*., 2020b). In alignment with Lau *et al*. (2020b), data on revenue-generating activities were available only for recycling and incineration with energy recovery.

3.2 Data time period

Each scenario was run for the period 2016-2040. Existing data was used for the period 2016-2020 (last year for which we have historical data for South Africa), after which trends were projected into the future. The EPR and system change interventions were implemented in 2023, and comparisons between scenarios made over the period 2023-2040.

3.3 Data sources

Plastic-specific data is collected and reported on by the South African plastics industry. Data were therefore sourced from Plastics SA, the industry association representing plastics in South Africa, as well as the various plastics Producer Responsibility Organisations (PROs). The Plastics Recycling Survey, published annually by Plastics SA, was a useful source of data for this study. Industry data was also benchmarked, where possible, against independent sources such as von Blottnitz *et al*. (2017) and Rodseth *et al*. (2020).

Data on municipal waste management is collected by various spheres of government in accordance with the National Environmental Management: Waste Act, 2008 (Act No 59 of 2008) (as amended) and the National Waste Information Regulations (R625 of 2012); and submitted into the South African Waste Information System (SAWIS). However, information uploaded to the SAWIS, and the verification of this data, is largely incomplete, with many local municipalities not reporting, and some uncertainty with regards to the data accuracy (DEA, 2018). The primary source of municipal waste data used in this study was therefore the latest official government statistics as published in the State of Waste Report (DEA, 2018). Population data were obtained from the General Household Survey (Stats SA, 2020). This information was supplemented by scientific publications estimating the informal disposal of waste (Rodseth *et al*., 2020), various municipal waste characterisation studies, and municipal Integrated Waste Management Plans (IWMPs).

3.4 Data gaps

The types of waste and plastics data, and the format of the data required by the Pathways tool, was not always readily available for South Africa. The project team therefore relied heavily on the members of the Technical Advisory Group (TAG) and representatives from the plastics industry to assist with data collection and interpretation.

The global 'Breaking the Plastics Wave' study developed eight geographic archetypes according to the World Bank income categories and the United Nations urban-rural classifications (Lau *et al*., 2020). Where data gaps could not be filled for South Africa, archetype data from the global model (developing country, upper middle-income archetype) was critically assessed and, where appropriate, used to fill these data gaps. These gaps were flagged as 'high uncertainty' (discussed in the following section), with the tool factoring this uncertainty into the calculations. This approach allowed the application of the Pathways tool to the South African context, despite some data gaps.

These country-specific data gaps have been noted, and the recommendation is made to institute action to close these data gaps, so that the model can be rerun in the future, using the same or different scenarios, with reduced data uncertainty.

3.5 Filling data gaps

Data gaps were also filled by sourcing expert opinions from the South African plastics sector and waste management consultants with relevant experience, to help identify the correct degree of uncertainty in the available data. All assumptions were transparently made and presented to the TAG for discussion. The data sources and rationale for the key assumptions are outlined in Annexure 2: Key assumptions and data sources). Uncertainty of the data used in the analyses were addressed by using the pedigree scoring framework developed by Lau *et al*. (2020).

The challenges in data collection are listed in Annexure 3 for future reference and to inform future data collection strategies for modelling purposes.

3.6 Uncertainty

Applying uncertainty levels to the data used by the Pathways tool was a critical part of the modelling exercise. For each input variable, all data sources were scored across four features: sample size, uncertainty, accuracy and reliability, and date of publication; in order to determine the data pedigree score (Table 1). The sum of the scores across all four attributes for each data point was used to determine the data pedigree level (Table 2). For example, if sample size and uncertainty each scored 2, and accuracy and reliability and date of publication each scored 3, the total score would be 10 (2+2+3+3), for a pedigree level of 3 (high to medium uncertainty).

Table 1: Data Pedigree Scoring (Lau *et al*., 2020)

Data pedigree level	1	2	3	4
Sample size	Representative	Representative under certain conditions and/or in some scenarios	Limited representation: only representative under a specific condition or in one scenario	Unknown
Uncertainty measurement	Uncertainty is measured and reported (e.g., standard deviation, confidence interval, interquartile range, mean, error bars)	Uncertainty is not measured nor reported, but all assumptions are stated and the impacts of assumptions on results are discussed.	Assumptions are stated, but no reference is made to the impact of assumptions on results.	Uncertainty and assumptions are neither measured nor discussed
Accuracy and reliability	Verified based on empirical measurements and/or direct-to-source interviews (e.g., cost data quoted directly from a recycling facility will be graded as 1 in this category).	Verified data based on empirical measurements and or direct-to-source interviews with some assumptions and/or estimates to fill data gaps.	Non-verified data based on estimates and/or assumptions including qualified estimates (e.g., expert opinion).	Non-verified and/or non-qualified data.
Date of publication	<5 years ago	<10 years ago	<15 years ago	>15 years ago and/or unknown

Table 2: Data Uncertainty Score (Lau et al., 2020)

Data Pedigree Level	Data Pedigree score	Uncertainty Level	Uncertainty Percentages
1	4-5	Low	± 10%
2	6-8	Low-Medium	± 20%
3	9-12	High-Medium	± 35%
4	13-16	High	± 50%

The pedigree scoring for the South African data as outlined in Table 2 was assigned to each flow in the model for all plastic categories, as follows:

- Scores of 1 were assigned to historical data as well as trends sourced from reputable sources (Plastics SA data and documented expert knowledge on current practices).
- Scores of 2 were assigned to data inferred/calculated from historical data (e.g. projections).
- Scores of 3 were assigned to data inferred/calculated from reputable sources which provided estimates, and from expert opinion and personal communications).
- Scores of 4 were assigned to best estimates, based either on opinion, calculated estimates or the use of data sources that were deemed not fully reliable (e.g., SARS Trade Stats which does not account for the plastic packaging associated with import of packaged goods).

When using data from the Pew global model to fill gaps, the same uncertainty as assigned in the global study was maintained.

The uncertainty is propagated through the model outputs using a Monte Carlo simulation. In compiling the results, the model was set to run with a very high number of Monte Carlo simulations (300) to ensure the result would reach a steady trend. Uncertainty ranges are not shown in the main results.

4 Results and discussion

4.1 Business-As-Usual Scenario

The Business-As-Usual (BAU) scenario provides a future projection without EPR and any other policies or measures put in place regarding South Africa's plastic production, consumption or subsequent plastic pollution. Figure 2 to Figure 9 present the trends in pollution, waste management, recycling, GHG emissions, employment, and associated capital costs between 2016 and 2040. Under the BAU scenario, plastic pollution would almost double (approximately 75% increase of 2020 levels- from 491 kt in 2020 to 865 kt in 2040.

4.1.1 Pollution flows

Figure 2 presents the pollution flows over the twenty-five year (2016-2040) time period investigated. The total plastic waste (Box A) trend is comprised of historical data (2016-2020) and projections (2021-2040), which were calculated on the basis of projected trends in population and plastic waste generation per capita. The latter was based on the South Africa GDP growth rate used for projections for years 2021 to 2026 (data from STATISTA[6]); thereafter the same growth rate for 2026 was applied until 2040. Although plastic consumption was observed to be relatively constant from 2016 to 2020, this relative lack of growth was likely attributable to the Covid-19 pandemic, and the general trend is that of an increasing population as well as an increase in per capita plastics consumption, resulting in a projected plastic waste increase under the BAU scenario. The sharp increase from 2020 to 2021 (5%) can be explained by the fact that the COVID-19 lockdown and associated changes in consumption impacted on plastic production in year 2020, thus the restart in 2021 was marked by a sharper increase. Thereafter, an annual increase of 1.33% is projected until 2040.

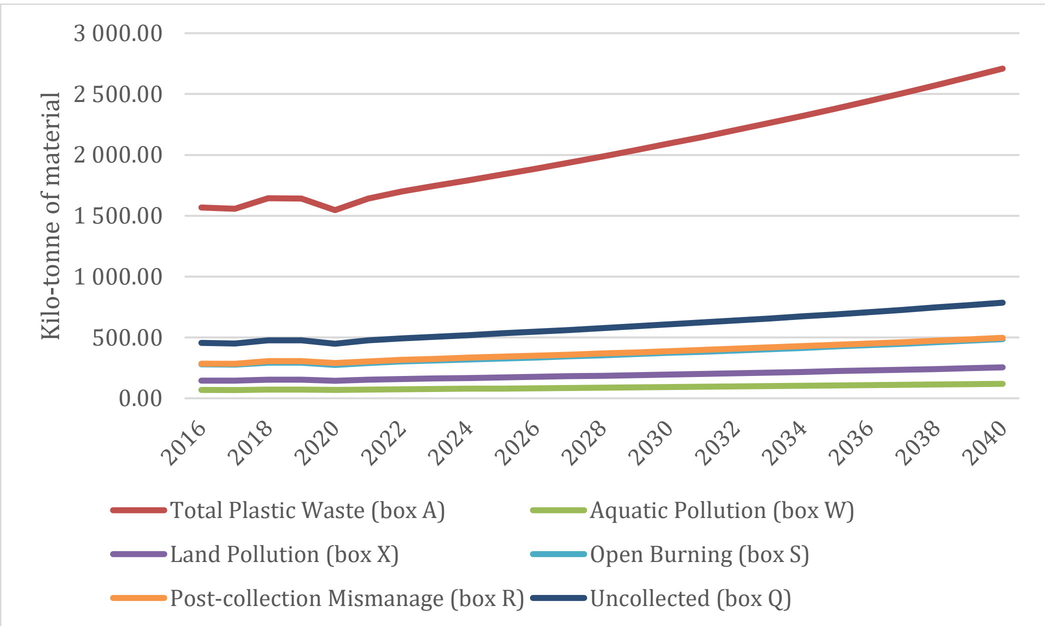


Figure 2: Business-as usual (BAU) waste management and plastic pollution

[6] South Africa - gross domestic product (GDP) growth rate 2027 | Statista

While much of the focus to date, both locally and globally, has been on marine plastic pollution, Figure 3 and Figure 4 highlight that under the BAU scenario, aquatic (fresh water and marine) pollution is a relatively small component (14%) of South Africa's plastic pollution, instead overshadowed by open burning of waste (56%) and terrestrial pollution (30%). Open burning of plastic can have a direct impact on human health through atmospheric pollutants such particulate matter, persistent organic pollutants (dioxins and furans), and polychlorinated aromatic hydrocarbons; as well as emitting greenhouse gases contributing to longer-term climate impacts (Mebratu and Mbandi, 2022). The open burning of waste is also known to disproportionately affect marginalised communities living in close proximity to landfill sites and open dumps, as well as the informal waste sector, who earn a living through the collection of material from these sites (*ibid*). Terrestrial pollution is often visible in South Africa as windblown plastic litter, caught in trees and fences, but also creating a risk to animals, including livestock, through ingestion (Priyanka and Dey, 2018).

4.1.2 Plastic pollution by plastic category

Figure 5 illustrates the different contribution by plastic category to each of the environmental sinks. Considering that plastic waste generated has been assumed to be composed of 50% rigid mono-material, 30% flexible mono-material, and 20% multi-material, the contribution of each type to plastic pollution reveals how recycling, which favours mostly rigid mono-materials, effectively reduces the quantity of these materials leaking to the environment, resulting in multi-materials and flexible mono-materials making up a higher proportion of plastic pollution.

Plastic pollution by plastic category is linked to the value of the different categories for recyclers. Rigid and some flexible plastics are typically collected for recycling, but the multi-materials are more difficult to recycle and have a lower monetary value, so they are often not collected for recycling. Furthermore, the size of the plastics is also a contributing factor to collection, separation and hence recycling – the smaller the product (e.g., bottle tops and sweet wrappers), the less likely it will be collected for recycling.

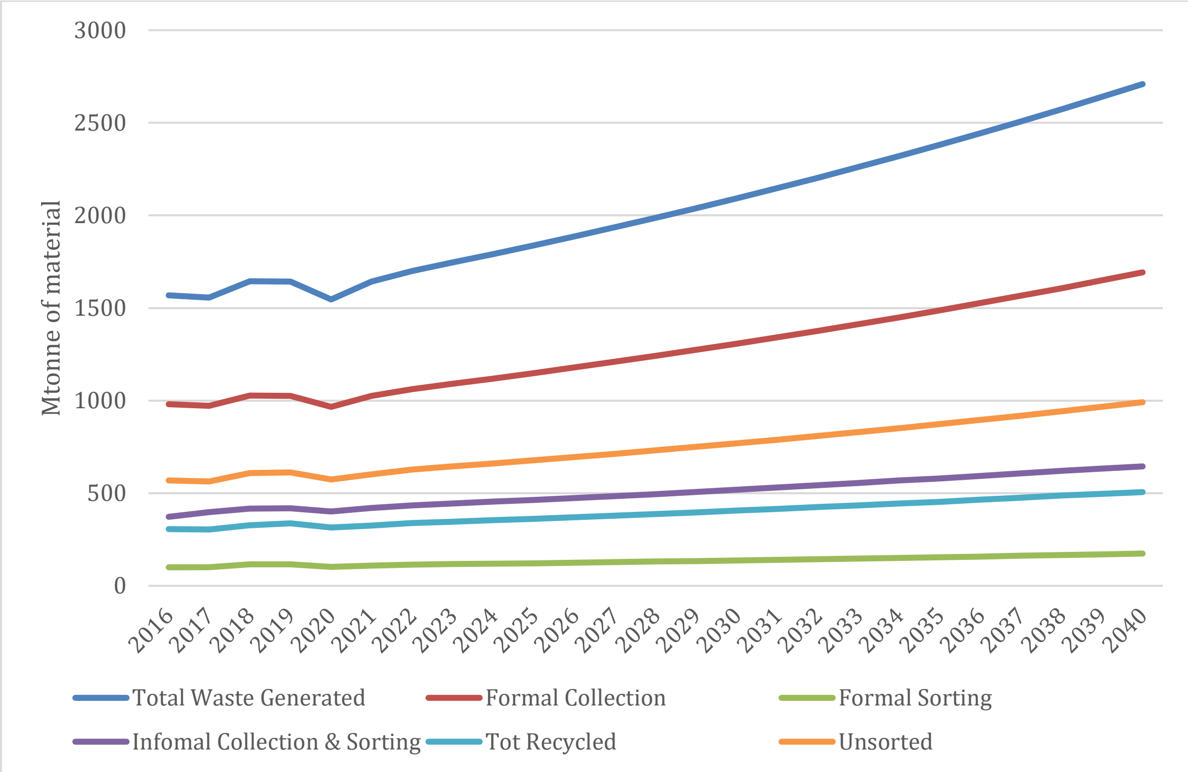
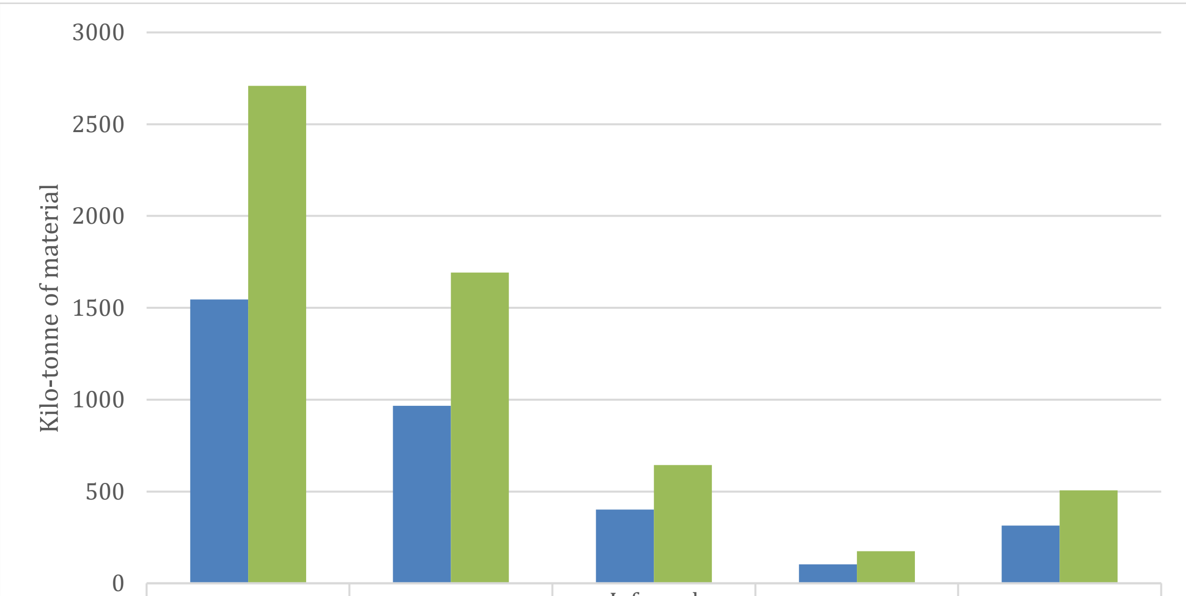


Figure 3: Plastic waste management flows for the Business-As-Usual



	Total Waste Generated	Formal Collection	Informal Colletion & Sorting	Formal Sorting	Tot Recycled
2020	1546	966	402	102	314
2040	2709	1693	645	174	506

Figure 4: Comparison of plastic waste management and recycling for 2020 and 2040 for Business-As-Usual

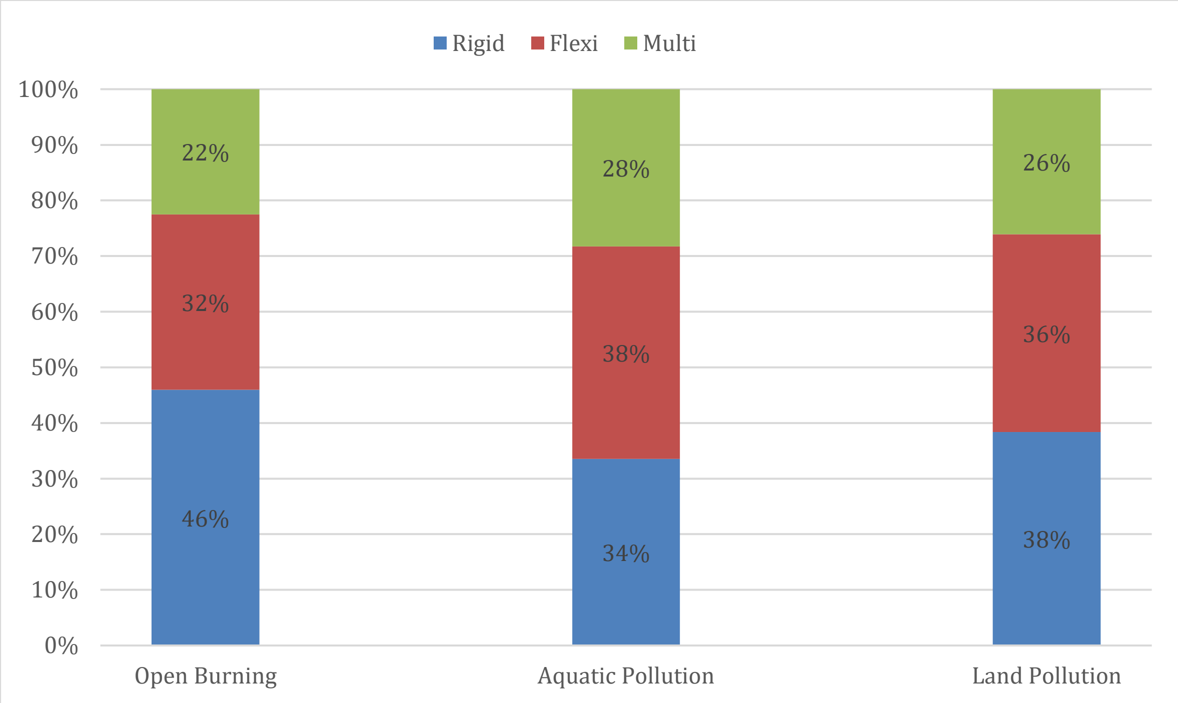


Figure 5: Contribution of each plastic category to plastic pollution (open-burning, aquatic pollution and land pollution) in 2020

4.1.3 Collection

The informal waste sector plays an important role in the South African recycling economy (Viljoen, 2014; Schenk *et al.*, 2019; Samson, 2020), by moving waste from kerbside and landfill into the recycling value chain (OECD, 2016; Godfrey and Oelofse, 2018). It has been estimated that informal waste reclaimers collected around 72% of all post-consumer plastic waste destined for recycling in South Africa in 2017 (Godfrey, 2021). This aligns with what the Pathways tool shows, i.e., that under the BAU Scenario (in 2021), the informal waste sector was responsible for collecting 76% of waste plastic that enters mechanical [Boxes I, J] and chemical recycling [Box K]. Of the total plastic waste generated in South Africa, the informal sector collects a fairly small portion of recyclables (Figure 1, flow B2) as a component of household waste available at kerbside; with the majority of the plastic recovered from landfills (Figure 1, flows N1 and V1). The early split in collection in the systems map shows that the formal sector (typically municipalities) collects 71% (by mass) of the total plastic waste. The bulk of this formally collected plastic then flows directly as mixed municipal waste to landfills (as direct losses (flow C3) and losses from Box E, Mixed collection). Since most of this material is collected as mixed waste (separation at source only accounts for 8%), the high level of contamination often renders it less suitable for recycling.

Of the waste plastic collected by the informal waste sector, an estimated 35% comes from collection at kerbside, what Samson (2020) refers to as "Separation-outside-Source", and 63% from open-dumps or unsanitary landfills (Figure 6).

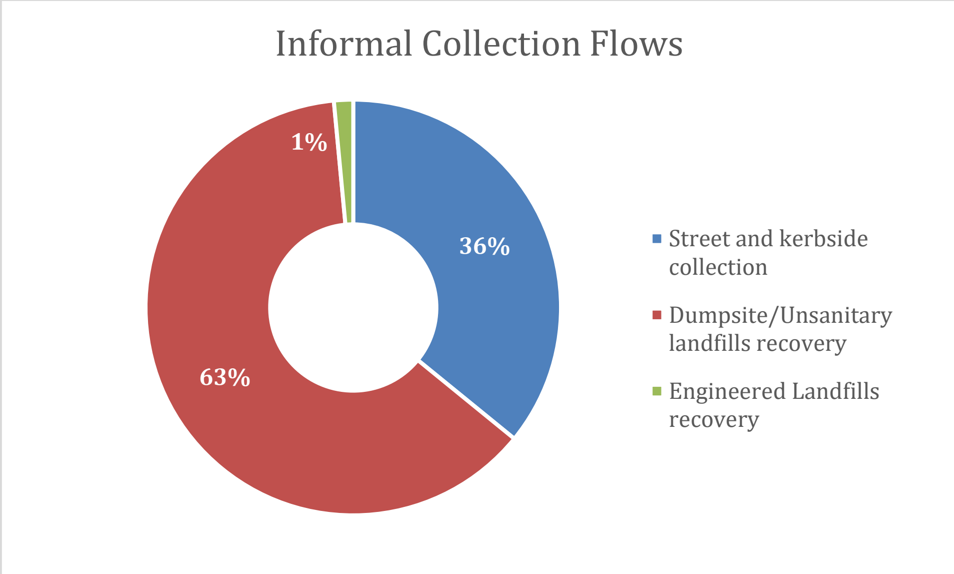


Figure 6: Details on Informally collected plastic waste for Business-As-Usual

The informal waste sector is not active in collecting all types of waste plastics. Understandably, informal waste pickers "cherry-pick" high-value plastics to maximise their earnings. This includes a preference for rigid mono-materials such as PET and HDPE, with lower value plastics, typically multi-layer/multi-material plastics, remaining in the municipal waste stream, with the potential to leak if later mismanaged. The composition of recyclables collected by the informal sector is reflected in the modelling; namely 81% rigid, 15% flexi and 4% multi-material.

Concerns have been raised by municipalities and communities over the direct contribution of the informal waste sector to the leakage of plastic to the environment. Waste pickers often sort the collected recyclables in open spaces, on the banks of streams, or next to stormwater drains, discarding low-value and non-recyclable fractions in these spaces, which ends up polluting terrestrial and aquatic environments. Organisations such as the African Reclaimers Organisation (ARO) have called on government to provide spaces, including covered shelters or buildings, where waste pickers can safely sort and store their material, and responsibly dispose of non-recyclable fractions, and thereby avoid direct discard to the environment. No changes in the practices of informal waste collectors were assumed in the model, although this could clearly provide opportunities for reducing plastic pollution through improved pre-sorting of waste for recycling.

4.1.4 Recycling

In 2020, a total of 378 kt of plastic waste was collected, sorted, and sent to recycling. Figure 7 presents the breakdown of the results, which indicate that "*Mechanical recycling to plastics*" is currently the preferred recycling option in South Africa (note that mechanical recycling includes both closed-loop and open-loop recycling as described in section 2.3.2). "*Mechanical recycling to non-plastics*" (e.g. wood-plastic composites as alternative construction material), is carried out at a limited scale in South Africa, and "*Chemical recycling*" is limited to only one facility.

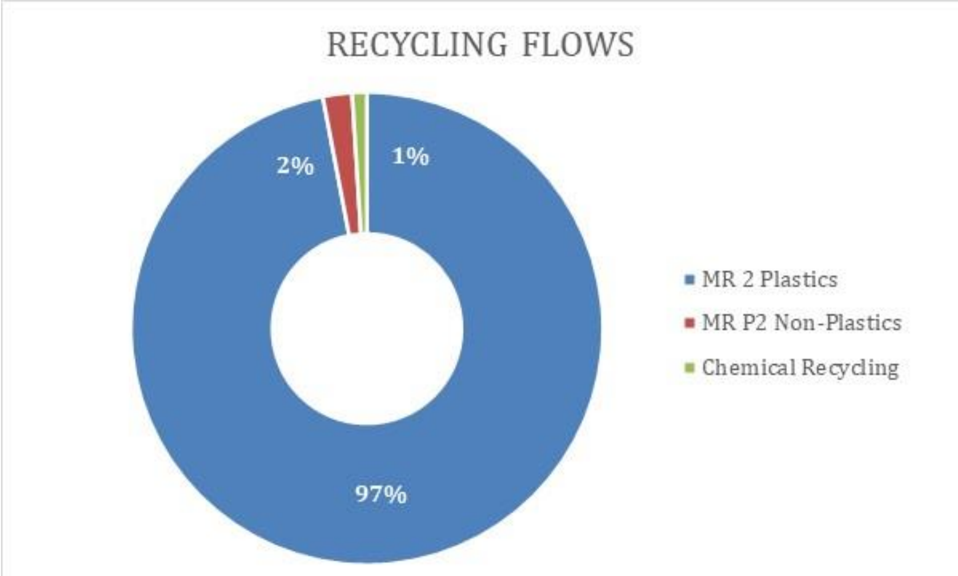


Figure 7: Details on recycling flows (2020) MR= mechanical recycling for Business-As-Usual

4.1.5 Greenhouse gas emissions (GHG)

Assuming no future changes in the carbon-intensity of South Africa's electricity mix and plastic polymer production, and that Sasol can continue to fulfil South Africa's polymer demands[7], it is predicted that GHG emissions associated with plastic production, consumption, and disposal in South Africa will increase by 64% between 2020 and 2040, with the greatest increase being attributed to virgin plastic production, followed by open burning (Figure 8 and Table 3).

The three major contributors to total plastics-related GHG emissions are virgin plastic production (40%), plastic conversion (19%) and open burning (6%). This shows that 90% of the GHG emissions of plastics in South Africa have occurred before the point of plastic use or consumption, and highlights the carbon intensity of the Sasol coal-to-liquids process for plastic polymer production, as well as the energy generation mix, which is dominated by coal power. Although the improper disposal of waste plastics through open burning contributes 6% of the total plastics related GHG emissions, it incurs more GHG emissions than any of the formal waste management systems. Open-burning as a waste management practice is applied to both uncollected and improperly disposed wastes from rural and un-serviced urban households. Following the same assumptions as the global 'Breaking the Plastic Wave' study (Lau *et al*., 2020), it is assumed that 60% of all uncollected and self-help disposed plastic (flow Q1) and 13% of all collected plastics (flow V2) will be subject to open burning, since landfill fires remain a regular occurance at unsanitatry landfills.

[7] On average, 70% of polymer converted to plastic products is local and from Sasol coal-to-liquids, while 30% is imported, thus GHG for virgin plastic production was adjusted accordingly (personal communication with Plastic SA).

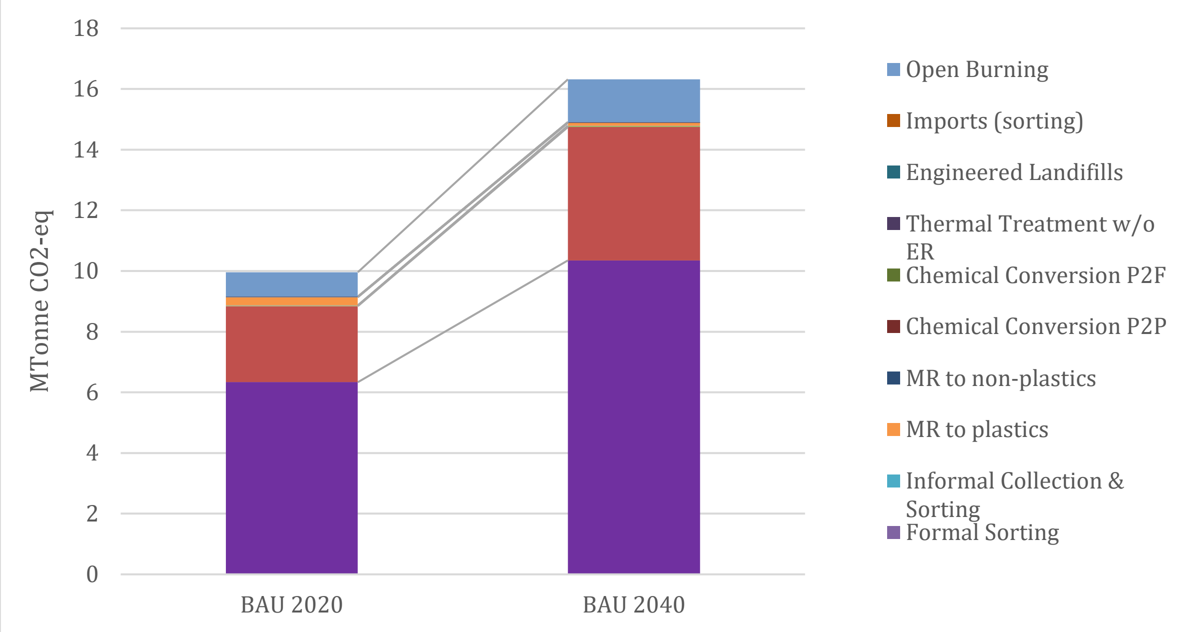


Figure 8: GHG emissions comparison in 2020 and 2040 for Business-As-Usual

Table 3: GHG emissions (Mt CO_2-eq) – all contributions in 2020 and 2040 (BAU scenario)

Value chain stage	Year		% Change in GHG emissions in 2040 compared to 2020	
	2020	2040	per value chain stage	with respect to the total GHG
Virgin plastic production	**6.33**	**10.35**	**63%**	**40%**
Plastic conversion	**2.51**	**4.39**	**75%**	**19%**
Formal collection	0.02	0.03	75%	0.15%
Formal sorting	0.005	0.09	70%	0.04%
Informal collection and sorting	0.00	0.00	-	-
Mechanical recycling to plastics	0.27	0.10	-63%*	-2%
Mechanical recycling to non-plastics	0.005	0.02	-66%*	-0.03%
Chemical conversion P2P	0.008	0.01	20%	0.02%
Chemical conversion P2F	n.a.	n.a.	-	
Thermal treatment with energy recovery	n.a.	n.a.		
Thermal treatment without energy recovery	0.005	0.008	42%	0.02%
Engineered landfills	0.002	0.004	76%	0.02%
Import (sorting)	0.00	0.00	-	
Open-burning	**0.80**	**1.41**	**77%**	**6%**
Total	**9.96**	**16.32**		**64%**

* The GHG emissions for mechanical recycling decreases over time due the specific default emission factors (tonne CO_2-eq/yr/tonne of flow) in the Pathways tool. This may related to improving/greening the energy mix over time and a learning curve for recycling efficiency, which may not be a true reflection of the South African context.

4.1.6 Employment

Figure 9 presents the results for the employment in the plastic value chain, comparing years 2020 and 2040, under the BAU scenario. Table 4 provides a breakdown of employment figure (as potential jobs creation) in each stage of the value chain. The bulk of the employment (full time equivalent, FTE) are in the plastic conversion, collection (formal and informal) and sorting (formal and informal) stages of the value chain (Figure 9). Overall, there is an expected increase in employment under the BAU scenario of 75% between 2020 to 2040 (Table 4). The major increases are observed in plastic conversion (27%) due to an increase in plastic consumption, and in informal collection and sorting (33% in collection and sorting combined) (Table 4).

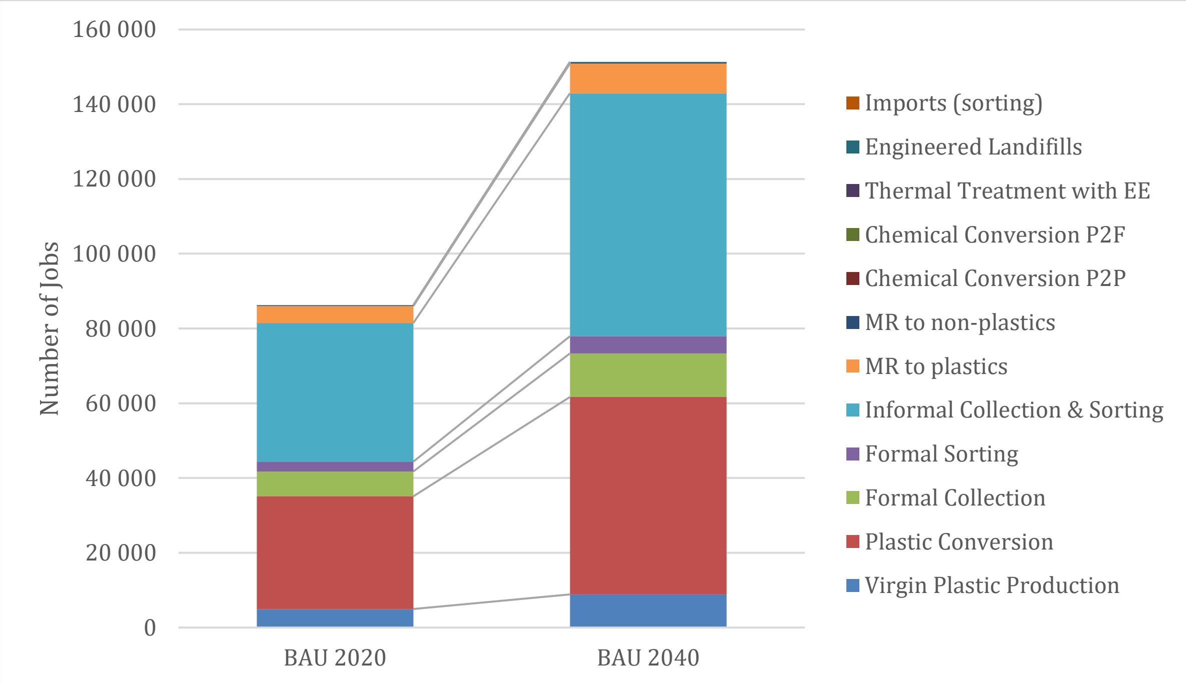


Figure 9: Comparison of employment for 2020 and 2040, under the BAU scenario

4.1.7 Net Costs and Required investment

Net costs refer to costs less revenues in the plastics value chain. For each year, net costs (in million U.S. dollars (USD)) are calculated by summing required OPEX and CAPEX, and subtracting revenues associated with the sale of recycled plastic (Net Costs = OPEX + CAPEX – Revenue). Figure 10 provides the trend of Net Cost from 2016 to 2040 for the BAU scenario, broken down per stage in the value chain stage. It can be seen that the bulk of the costs reside with plastic production. Annexure 5 provides details on the OPEX, CAPEX and Revenues composition and variation.

Table 4: Breakdown of employment between 2020 and 2040 for the BAU scenario

Value chain stage	Employment numbers in the year		% Change in Total employment in 2040 compared to 2020	
	2020	2040	per value chain stage	with respect to the total employment in 2020
Virgin Plastic Production*	4 957	8 855	78.6%	4.5%
Plastic Conversion	30 150	52 826	75.2%	26.3%
Formal collection	6 649	11 649	75.2%	5.8%
Informal collection & sorting	37 108	65 017	75.2%	32.4%
Formal sorting	2 628	4 605	75.2%	2.3%
Mechanical recycling to plastics	4 523	7 945	75.6%	4%
Mechanical recycling to non-plastics	83	136	63.2%	0.06%
Chemical Conversion P2P	14	20	47.2%	0.008%
Chemical Conversion P2F	n.a.	n.a.	n.a.	n.a.
Thermal Treatment with energy recovery	n.a.	n.a.	0	0
Thermal treatment without energy recovery	n.a.	n.a.	n.a.	n.a.
Engineered landfills	159	279	75.7%	0.14%
Import (sorting)	0	0		-
Total	**86 272**	**151 333**		**75%**

*Includes mining raw material, plastic monomer production as well as plastic polymer production

Required investment refers to additional capital costs needed to cope with the additional infrastructure capacity requirements over time. Figure 11 presents the trend over time of the required investments needed in the BAU scenario, for all stages of the plastics value chain. The bulk of the required investments reside with additional infrastructure to produce plastics (35% for virgin plastic production and 28% for plastic conversion) to meet the growing demand; and investments in expanding/upgrading the capacity of sanitary landfills to ensure the safe disposal of plastic waste (33%). Details on how the additional infrastructure capacity is considered are provided in Annexure 5.

In line with the global Breaking the Plastic Wave study, net costs occurring in the future were also adjusted to present value terms, by discounting future costs and benefits to present values. To be consistent with the global study (Lau *et al.*, 2020a, Lau *et al.*, 2020b) a discount rate of 3.5% was applied. In this way, the present value of the cumulative net costs between 2016 to 2040 is calculated at $67 337 million.

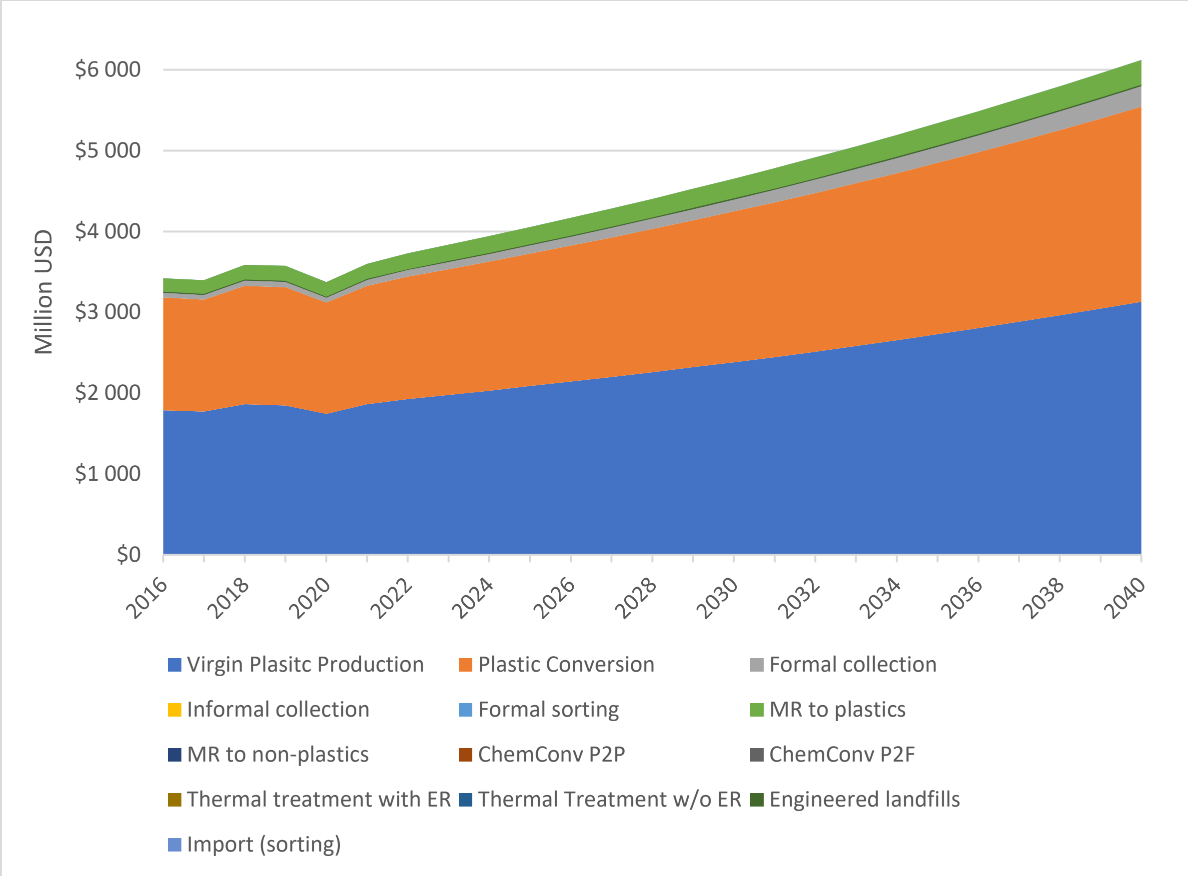


Figure 10: Net costs over time (OPEX+CAPEX-Revenues) for the BAU scenario, expressed in nominal USD, $

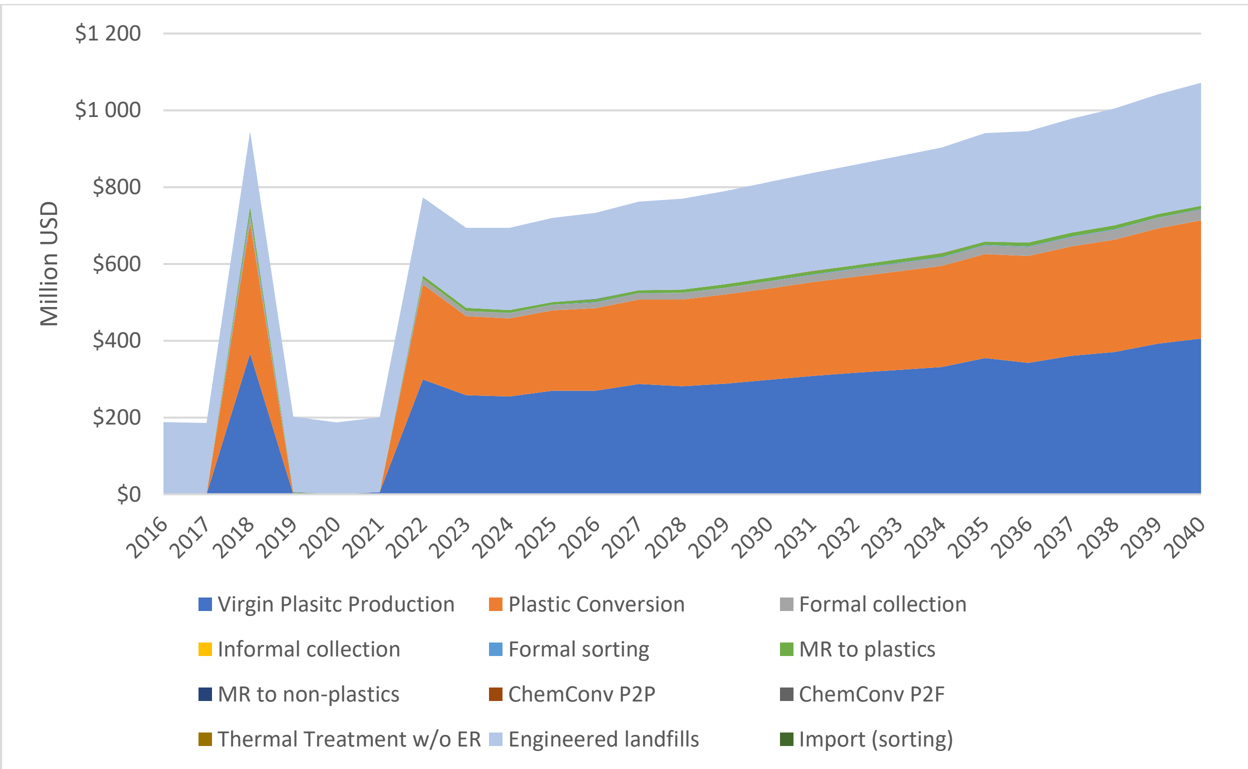


Figure 11: Required investment over time (expressed in nominal USD, $)

4.2 EPR Scenario

The legal framework for waste management in South Africa, and is aimed at "*avoiding and minimising the generation of waste; reducing, re-using, recycling and recovering waste; treating and safely disposing of waste as a last resort [and] preventing pollution and ecological degradation*." A recent government policy amendment requires mandatory Extended Producer Responsibility (EPR) schemes in three sectors- electrical and electronic equipment; lighting; and paper, packaging and some single use products. The EPR regulations require for life cycle analysis (LCA) in order to assess the environmental footprint of products and have specific collection and recycling targets for a period of five years (EPR regulations R1187 of 5 November 2020).

The EPR scenario was developed to meet the target EPR recycling rates, address the increase in post-collection mismanaged plastic waste and reduce plastic pollution (see Annexure 5). The EPR regulations have annual targets to increase collection and recycling rates over a five-year period and there are different collection and recycling targets for various plastic types; with an average net annual increase in the plastic recycling rate target of 3% for all plastics. The EPR scenario is modelled as being implemented in in 2023 for a period of five-years (2023-2027). The collection and recycling rates reached in 2027 were then kept constant for the period 2028 to 2040, under an assumption that no future changes are made to the regulated EPR targets. The EPR scenario therefore provides a conservative approach, with greater potential for impact should the targets be increased and extended beyond 2027.

Several sub-scenarios for the EPR were developed (Table 20 in Annexure 6) to correctly implement the collection and recycling rates. Here the results for the best case (EPR_6) are presented and compared against the BAU scenario.

4.2.1 Pollution flows

A comparison between the BAU and the EPR Scenario is presented in Figure 12 to Figure 16. The graphs provide an indication of the expected outcome that meeting the EPR targets will have in terms of reducing the environmental impact and increasing the recycling of waste plastic by 2040. Figure 12 compares the two scenarios in terms of total plastic pollution; while Figure 13 to Figure 15 illustrate the comparison in terms of specific pollution flows (to water, to land, and open burning); by considering the area under the curve for the period 2023-2040, to derive the total plastic pollution in each scenario. Meeting the EPR targets is predicted to reduce total plastic pollution by 33% over the period 2023-2040, relative to BAU. Aquatic pollution would be reduced by 25% (Figure 13), plastic pollution to land would decrease by 33% (Figure 14) and plastic pollution to air (open burning) by 35% (Figure 15), all relative to BAU.

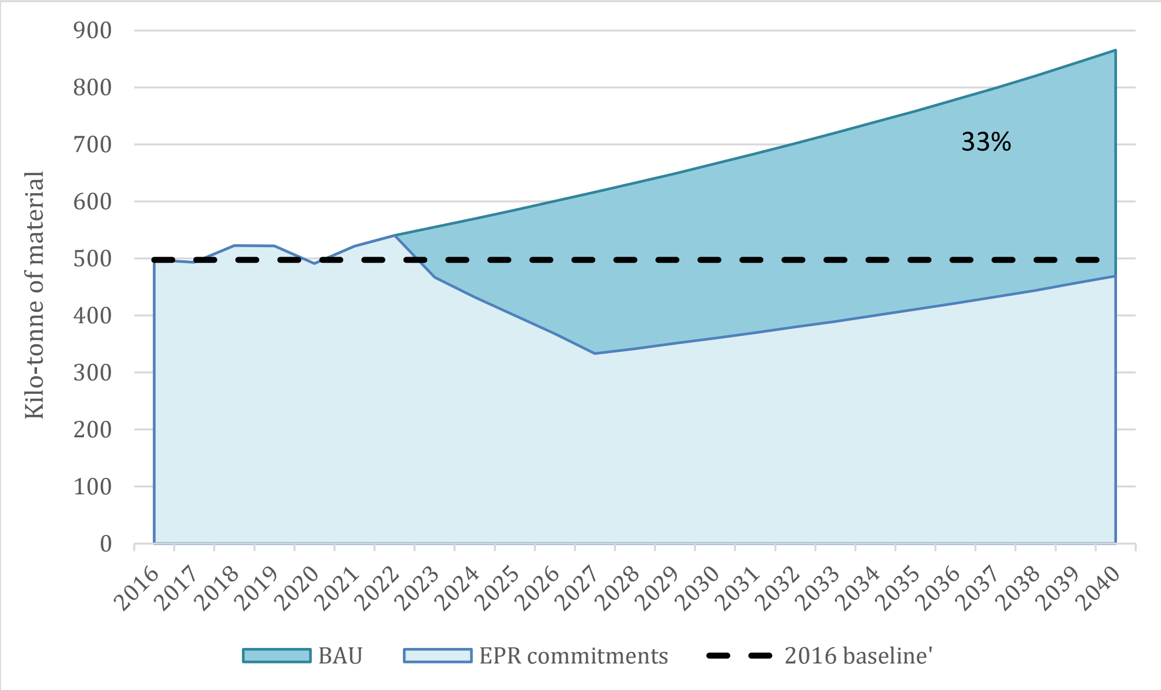


Figure 12: BAU vs EPR trends on Total Plastic pollution

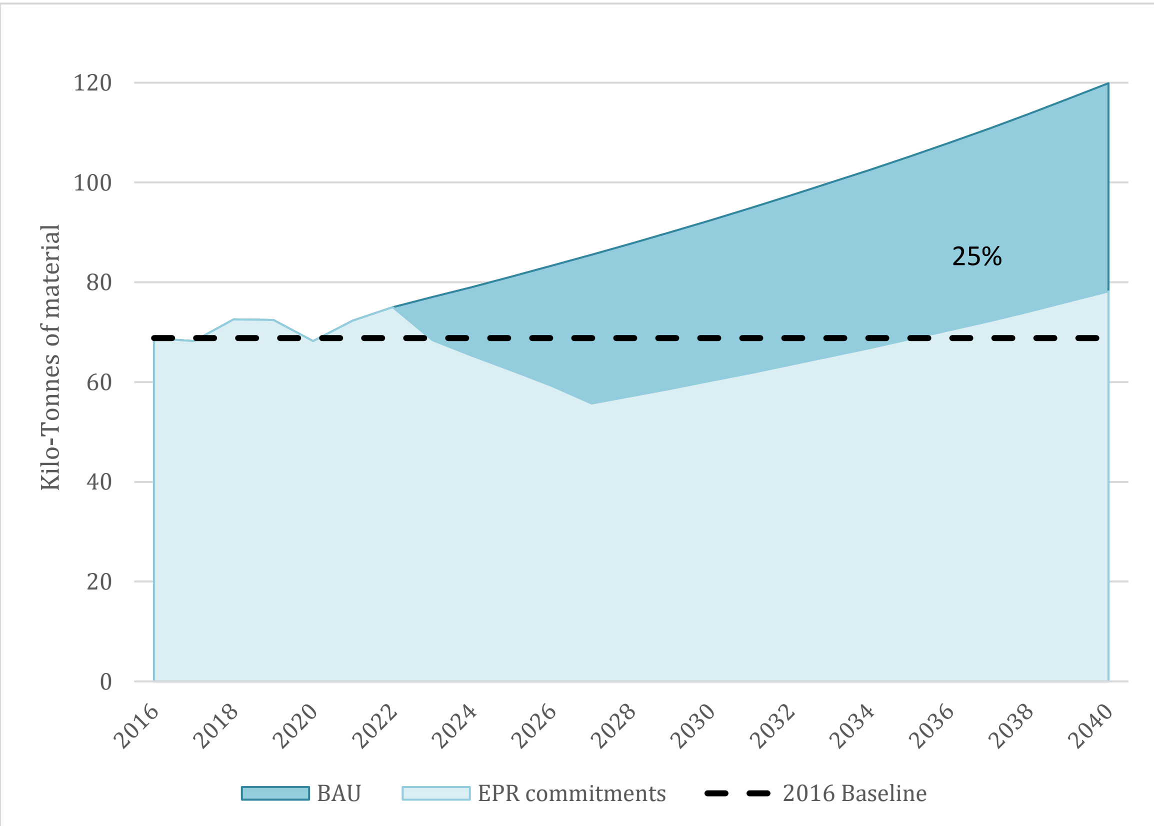


Figure 13: EPR vs BAU trends on aquatic plastic pollution

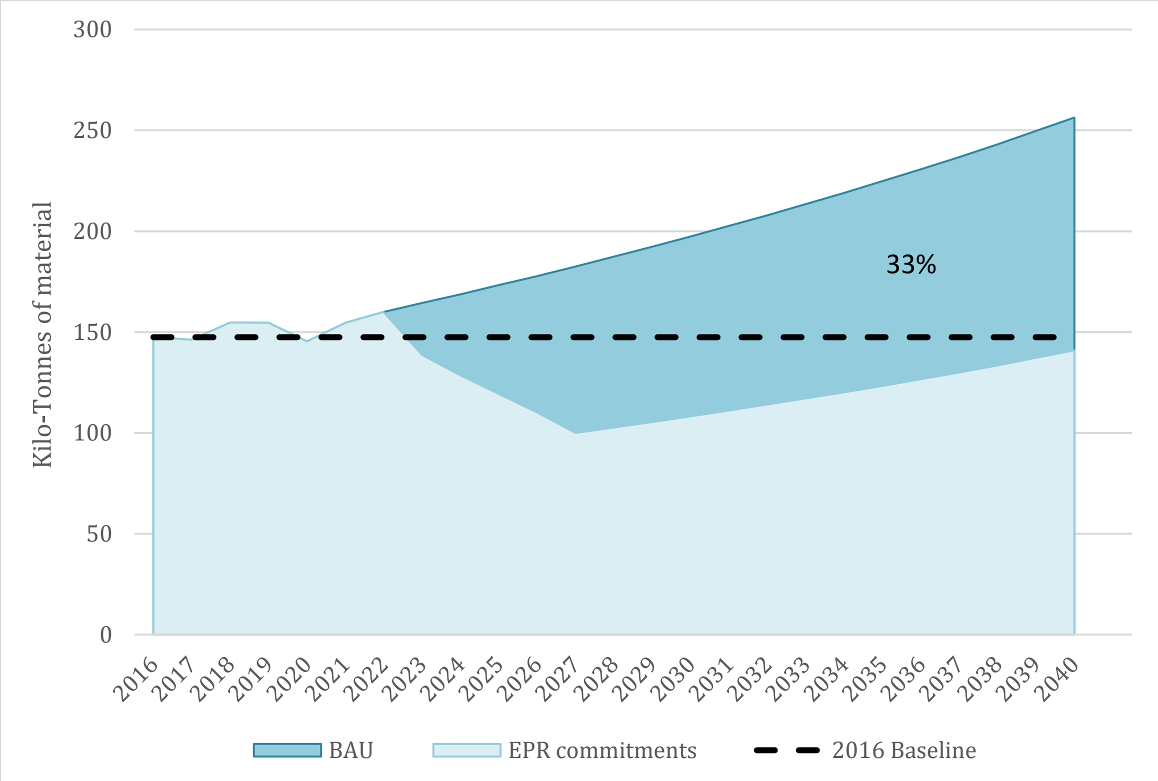


Figure 14: EPR vs BAU trends on land pollution

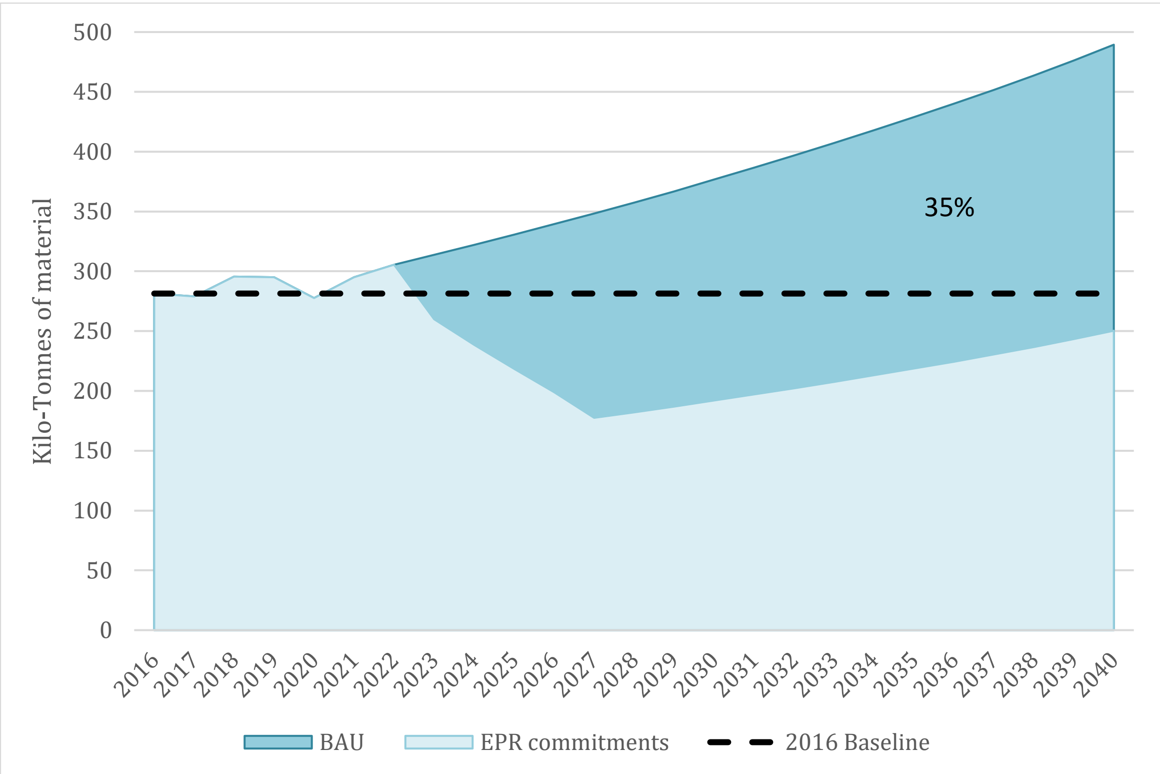


Figure 15: EPR vs BAU trends on open burning of plastic waste

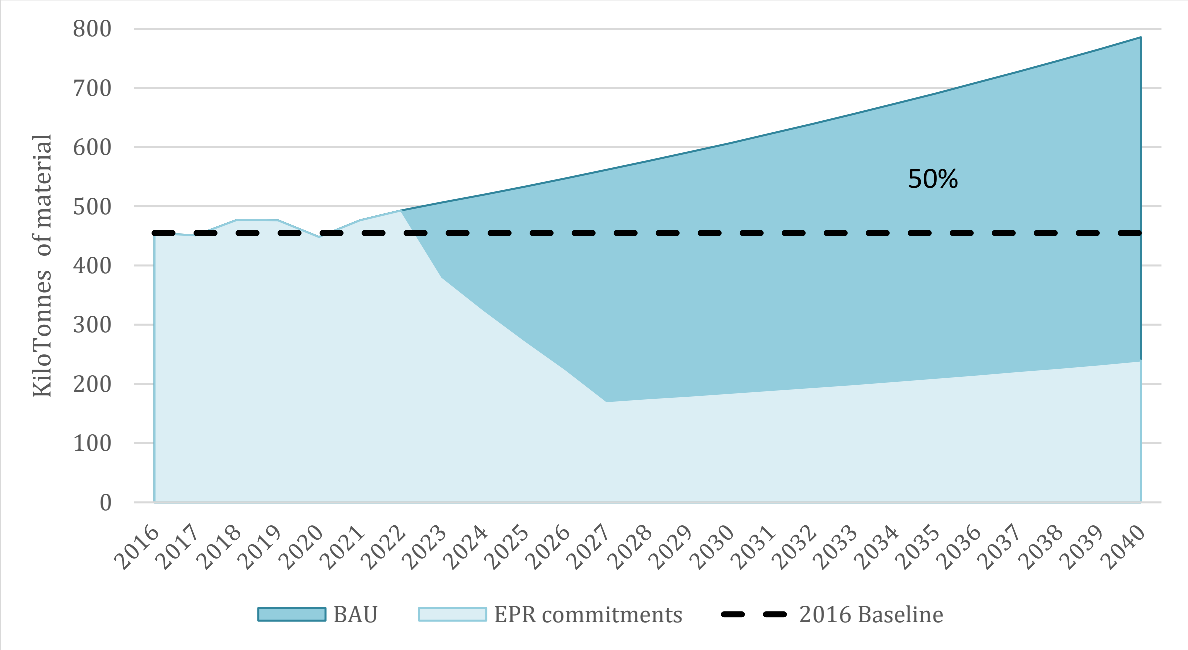


Figure 16: EPR vs BAU trends on uncollected plastic waste

The Pathways tool shows that by achieving the mandated EPR targets, pollution flows to the aquatic, terrestrial, and atmospheric environment are noticeably reduced (33% overall). This is largely due to a sizeable decrease in uncollected waste by 2040 (Figure 16), which will be cumulatively reduced by approximately 50% between 2023 and 2040.

It is perhaps unexpected that the size of the reduction in plastic pollution reduction does not match the increase in collection. This is because with increased collection, but with no improvement in the state of landfills, there is an increase in the amount of post-collection mismanaged waste with disposal to unsanitary landfills, which also contributes to plastic pollution (see Annexure 6).

4.2.2 Plastic pollution by plastic category

Figure 17 presents the comparison between BAU and the EPR scenario in terms of plastic pollution percentages by plastic category in 2040. Compared to the BAU, the composition of the residual plastic waste streams in the EPR scenario has a higher proportion of flexible and multi-materials, as a result of the rigid- materials being preferentially selected for recycling.

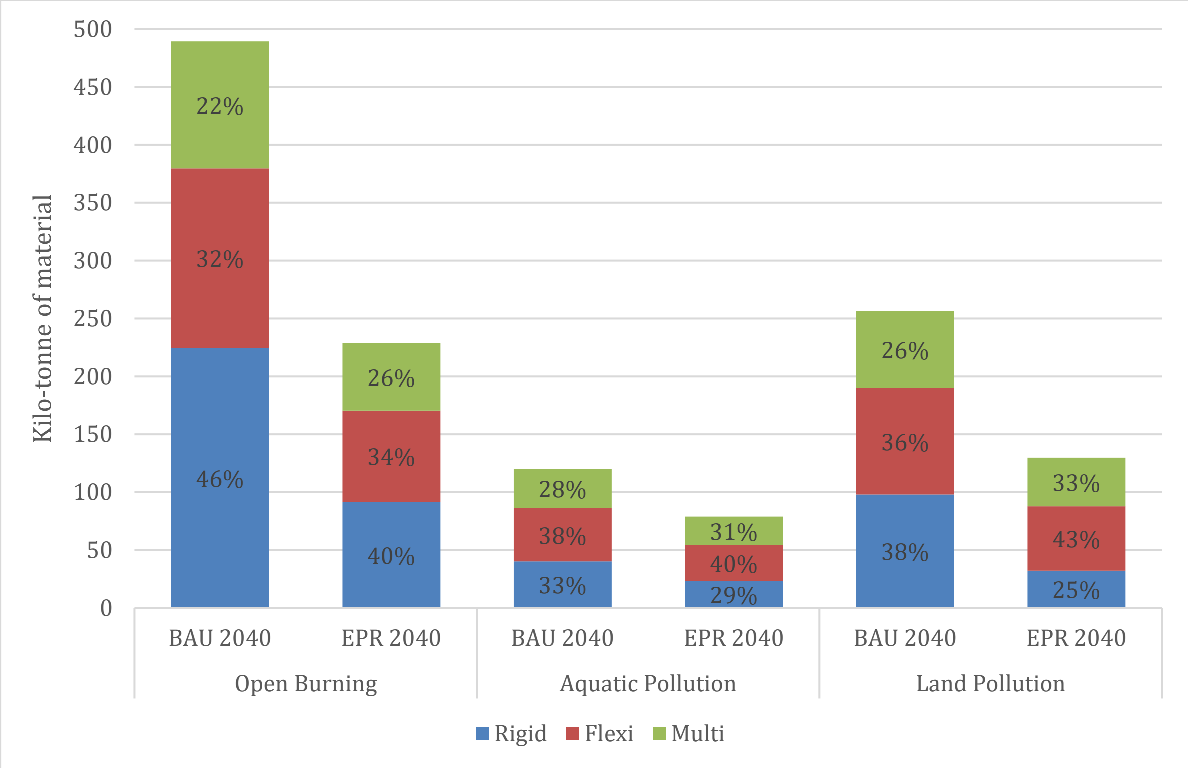


Figure 17: Composition of plastic pollution in 2040 under BAU and EPR scenarios

4.2.3 Collection

Trends in waste management and recycling under the EPR Scenario are presented in Figure 18 to Figure 21. All flows related to waste management and recycling show increases over time, with improved outcomes in 2040 when compared to the BAU scenario, due to more plastic waste being correctly managed in line with the intentions of the EPR Regulations (R1187 of 5 November 2020). Specifically, compared to BAU, the EPR scenario will attain the following over the period 2023-2040:

- An increase of 17% in the formal collection and 277% in the formal sorting of plastic waste. A total of 6514 kt and 9238 kt respectively of additional plastic will be formally collected and sorted as a result of improved collection and sorting patterns (separation at source and sorting of mixed waste);
- A 7% increase in informal collection and sorting, with an additional 900 Kt of plastic waste predicted to be collected and recovered by the informal sector under the EPR scenario;
- A 55% increase in recycling. A total of 5300 kt of plastic waste will be recycled, which includes both “*Mechanical recycling to plastics*”, “*Mechanical recycling to non-plastics*” and “*Chemical recycling*”.

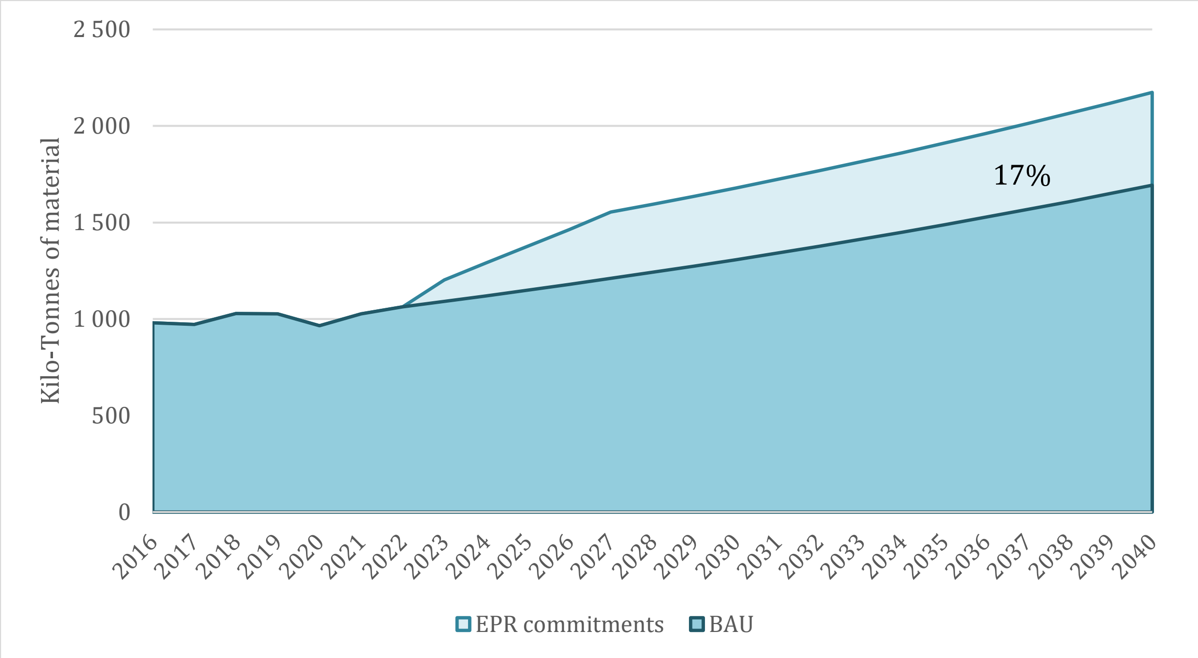


Figure 18: EPR vs BAU trends on formally collected plastic waste

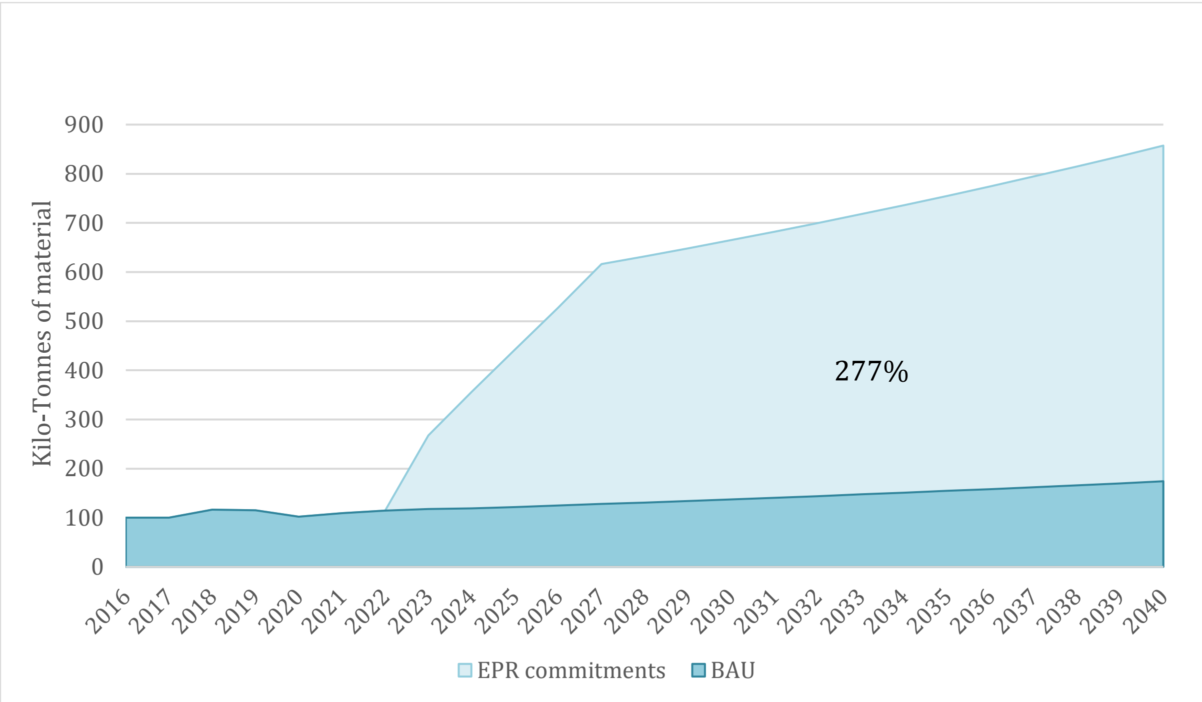


Figure 19: EPR vs BAU trends on formally sorted plastic waste

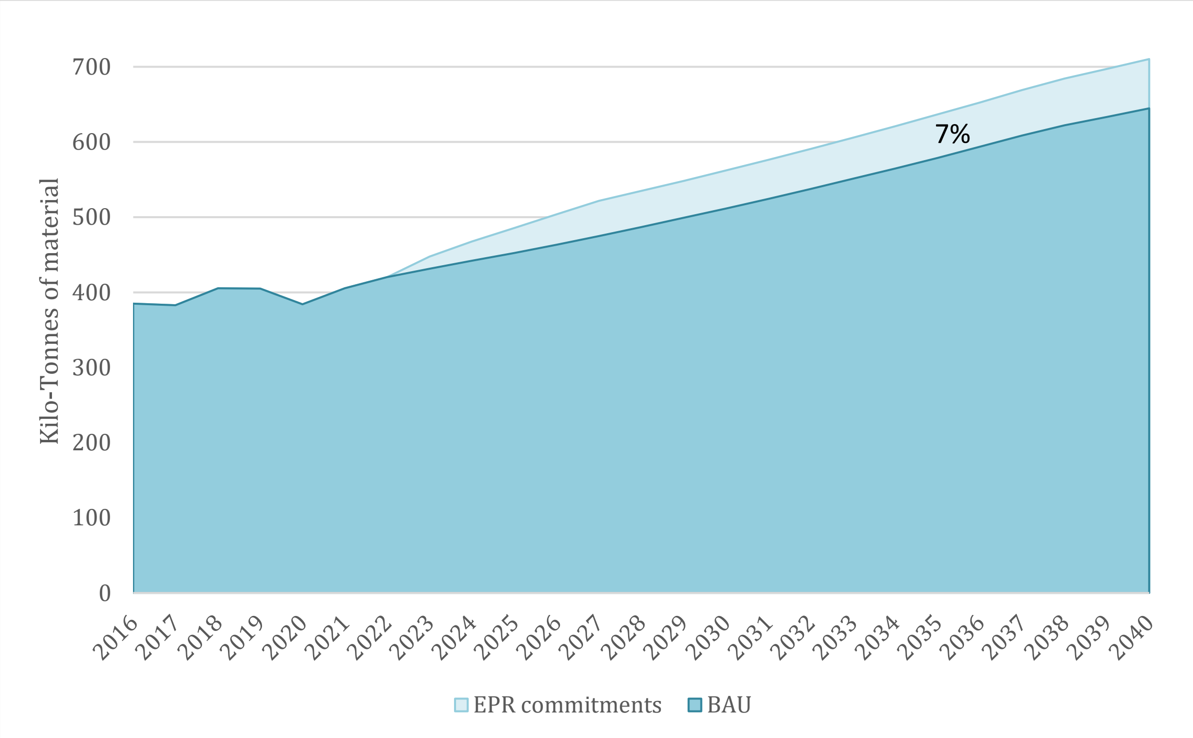


Figure 20: EPR vs BAU trends on informally collected & sorted plastic waste

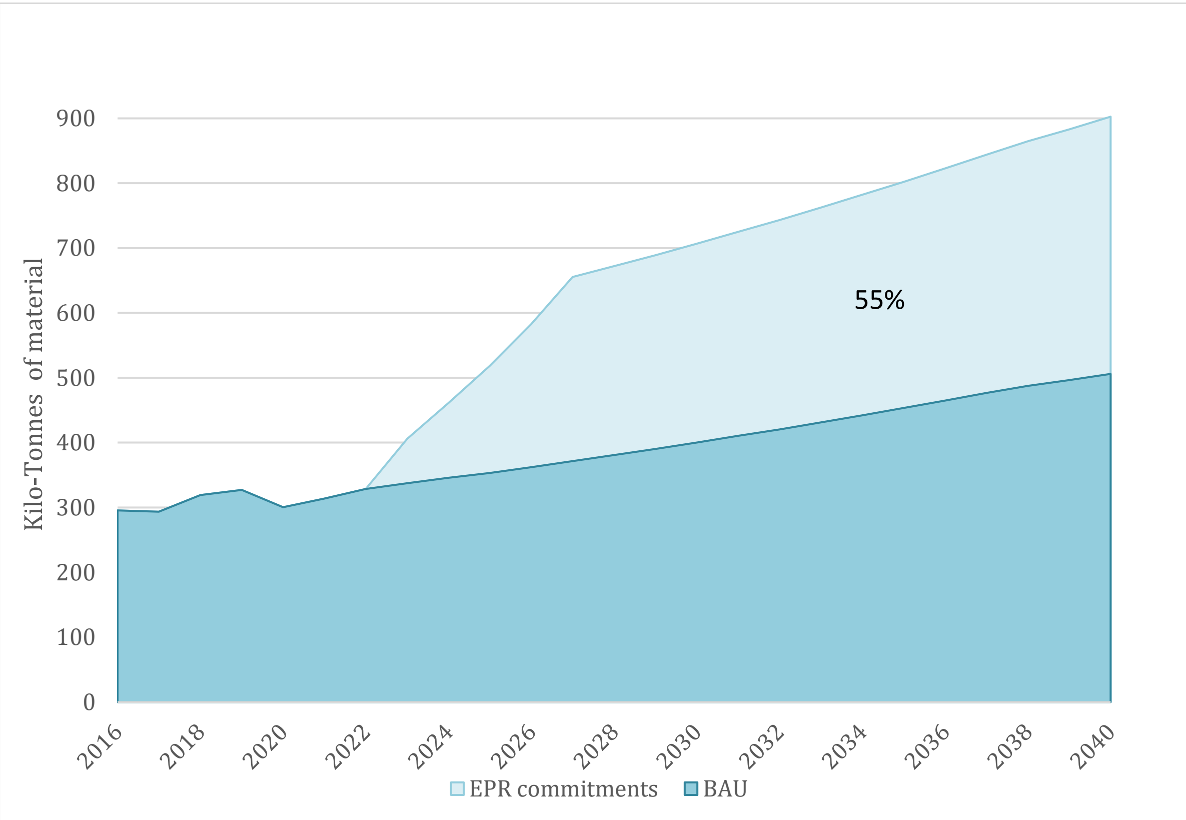


Figure 21: EPR vs BAU trends on plastic waste recycled (mechanical and chemical)

4.2.4 Recycling

The five-year targets of the EPR regulations increase the plastics recycling rate from 19% in 2023 to 35% in 2028 (Figure 22); with a year-on-year increase of approximately 3% across all plastic types.

Improvements in key plastic waste management flows; namely plastics separation at source and improved sorting of mixed waste, are required to meet the recycling targets of EPR. Meeting the EPR targets avoids 33% plastic pollution between 2023-2040, compared to BAU (Figure 12). However, after achieving the EPR legislated target recycling rates for the five-year period (increasing by approximately 3% per annum for 2023-2027), and assuming no further increase in recycling rates thereafter, plastic pollution continues to rise as a result of rising plastic consumption. This illustrates the limited potential of the current legislated five-year EPR targets in substantially reducing plastic pollution over the long-term.

4.2.5 Greenhouse gas emissions (GHG)

Trends in GHG emissions over time are presented in Figure 23. Cumulatively, the EPR Scenario shows a GHG emissions reduction of 12% between 2023-2040, compared to the BAU Scenario. Figure 24 shows the GHG emission composition comparison in 2040 between the BAU and EPR scenarios. The GHG emissions reduction is mainly attributable to more recycled plastics replacing the need for virgin plastic production, and a reduction in the burning of plastic waste.

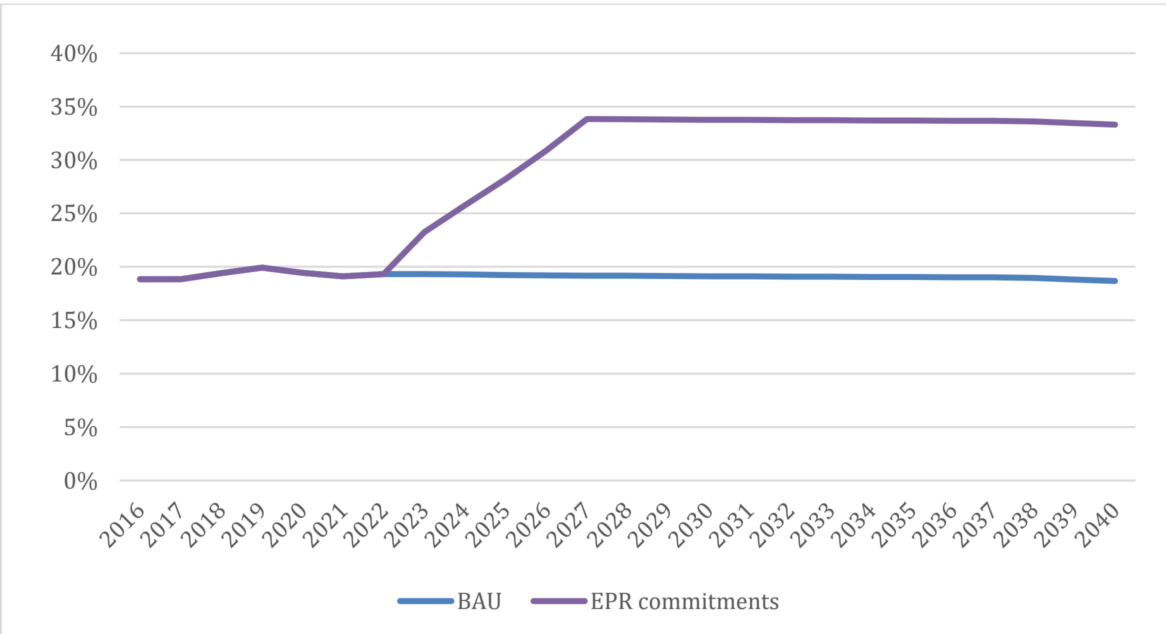


Figure 22: Recycling rate comparison of BAU, and EPR.

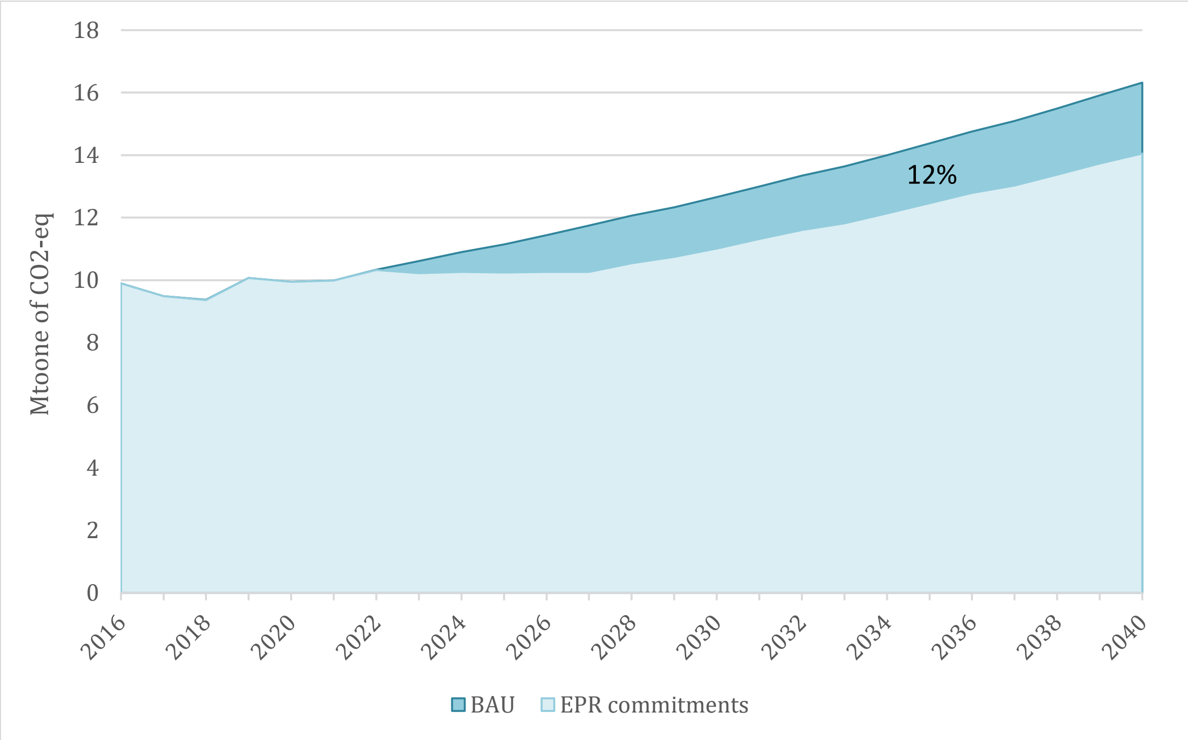


Figure 23: GHG emissions between 2023 and 2040

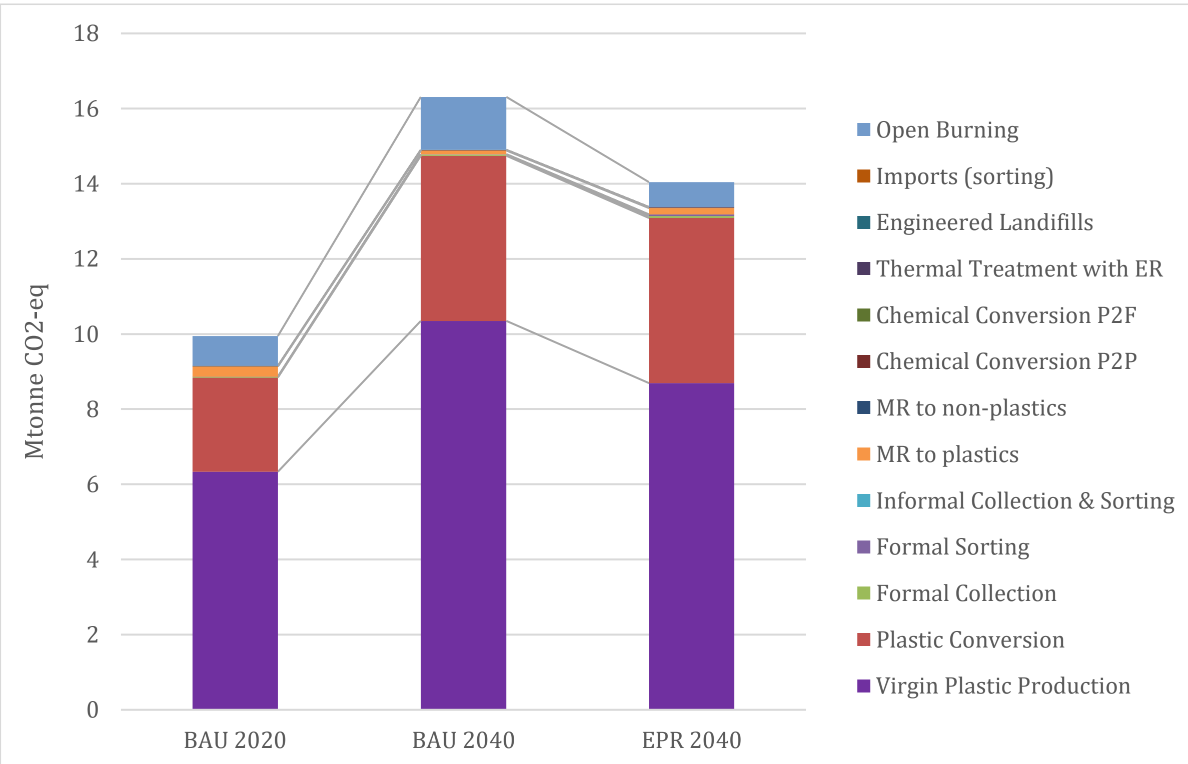


Figure 24: GHG emissions composition reduction between BAU and EPR scenarios in 2040

4.2.6 Employment

Compared to the BAU, the EPR scenario achieves an 18% increase in employment with Informal collection and recycling make up the greatest contribution to employment numbers (Figure 25 and Table 5). Figure 26 and Table 5 present the employment composition comparison in 2040 between the BAU and EPR scenarios.

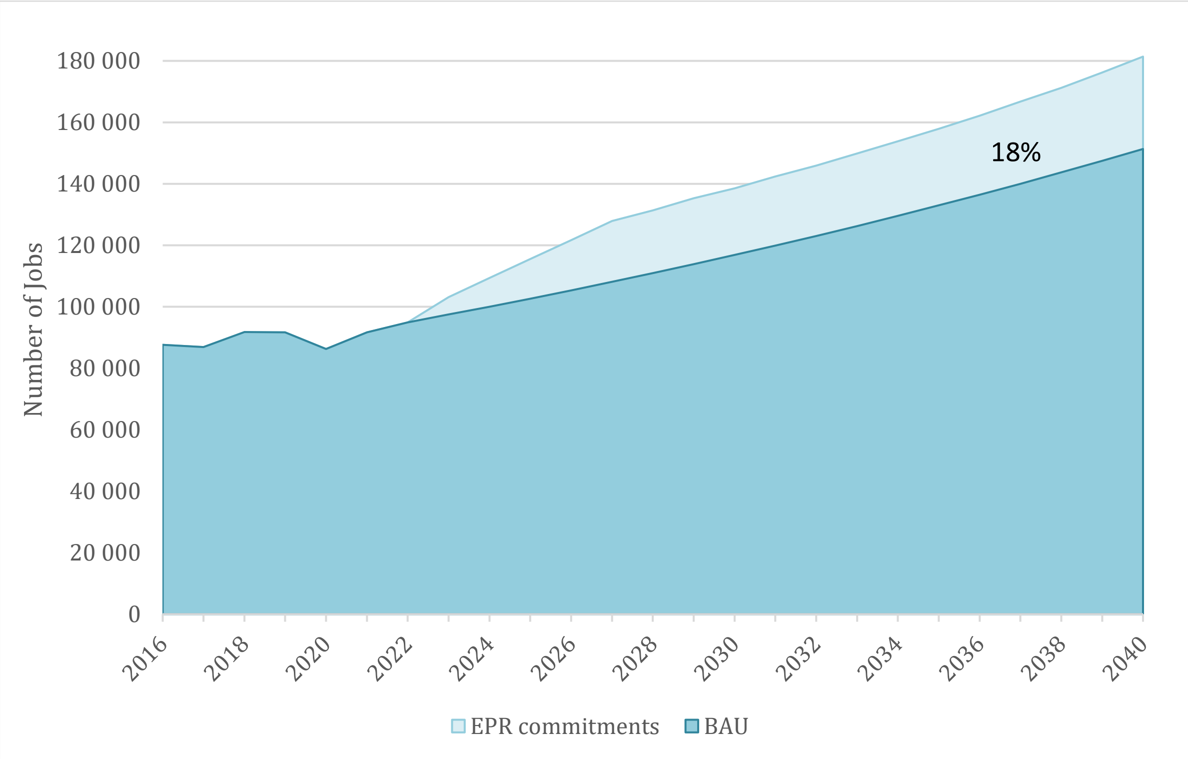


Figure 25: Employment between 2023 and 2040

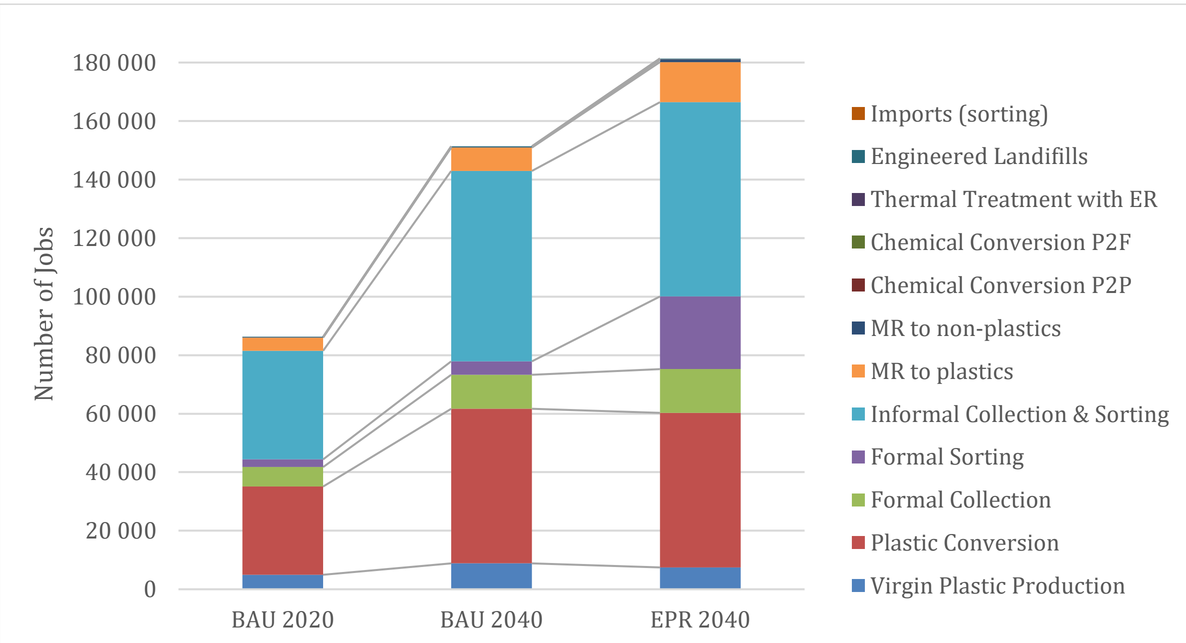


Figure 26: EPR vs BAU employment composition comparison in 2040

Table 5: Breakdown of the potential change in employment in 2040 for the EPR vs BAU scenario

Number of jobs per value chain stage	**Employment in the year 2020**	**Employment in the year 2040**		**% Change in employment in year 2040 for the EPR**	
	BAU	**BAU**	**EPR**	**Employment in each value chain stage**	**Total Employment in plastics in value chain**
Virgin Plastic Production	4 957	8 855	7 442	-15.9%	-0.93%
Plastic Conversion	30 150	52 826	52 826	0	0
Formal collection	6 649	11 649	14 957	28.4%	2.19%
Informal collection & sorting	37 108	65 017	66 400	2.13%	0.91%
Formal sorting	2 628	4 065	24 819	438%	13.36%
MR to plastics	4 523	7 945	13 705	72.5%	3.8%
MR to non-plastics	83	136	897	560%	0.5%
Chemical Conversion P2P	14	20	21	1.96%	0.0003%
Chemical Conversion P2F	n.a.	n.a.	n.a.	n.a.	n.a.
Thermal Treatment with energy recovery	n.a.	n.a.	n.a.	n.a.	n.a.
Thermal treatment without energy recovery	n.a.	n.a.	n.a.	n.a.	n.a.
Engineered landfills	159	279	318	13.8%	0.03%
Import (sorting)	n.a.	n.a.	n.a.	-	-
Total	**86 272**	**151 333**	**181 395**		**19.86%**

Note: The amount of converted plastic remains unchanged between BAU and EPR in 2040 to cope with the demand, but virgin plastics are replaced by recyclate.

4.2.7 Net Costs and Required investment

Figure 27 illustrates the comparison of net costs over time (in nominal terms) between the BAU and EPR scenario, while Figure 28 shows the comparison in required investment. Implementing the enhanced EPR scenario, with improvements in collection patterns (separation at source) and the sorting of collected mixed waste (dirty MRFs), could provide a potential 10% saving in net costs, and a potential 5% saving in required investments. Annexure 5 provides details on the OPEX, CAPEX and Revenue composition and variation, as well as additional infrastructure capacity needs. The net cost in present value terms for the EPR scenario for the period 2016-2040 is $60 990 million, compared to the BAU of $67 337 million; which represents a net cost saving of 10%.

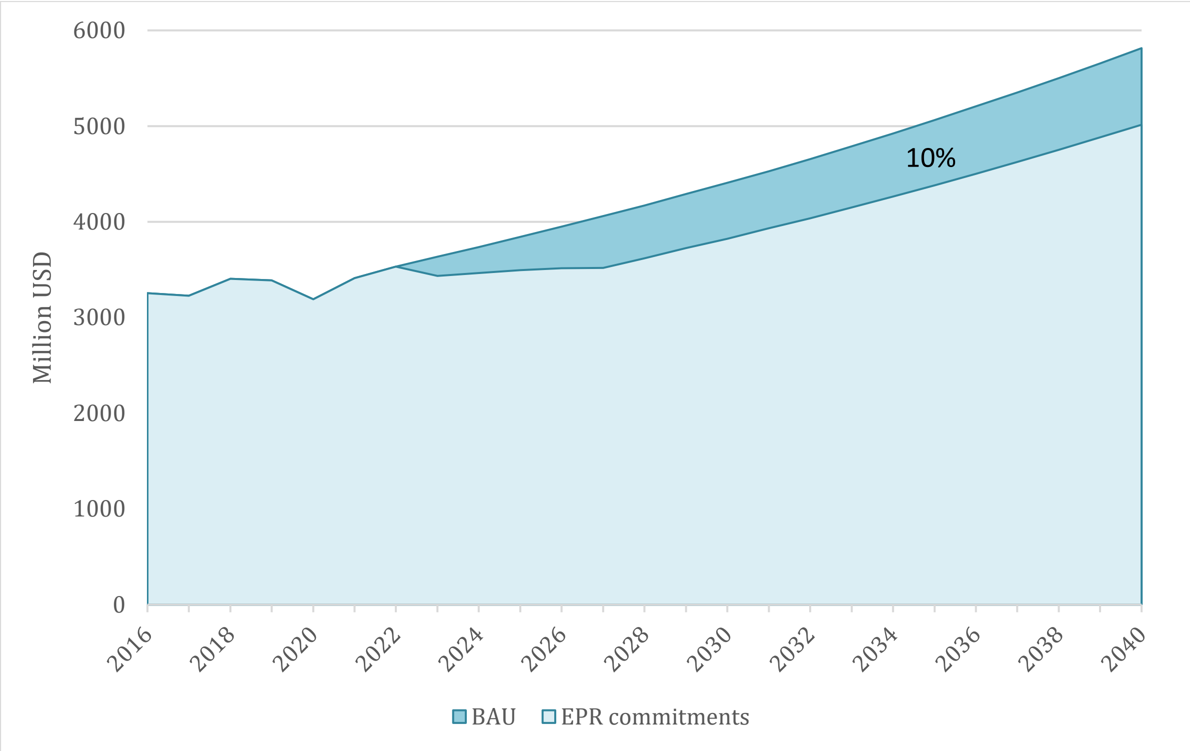


Figure 27: Savings in net costs for the EPR scenario vs the BAU scenario (nominal USD, $, 2016-2040)

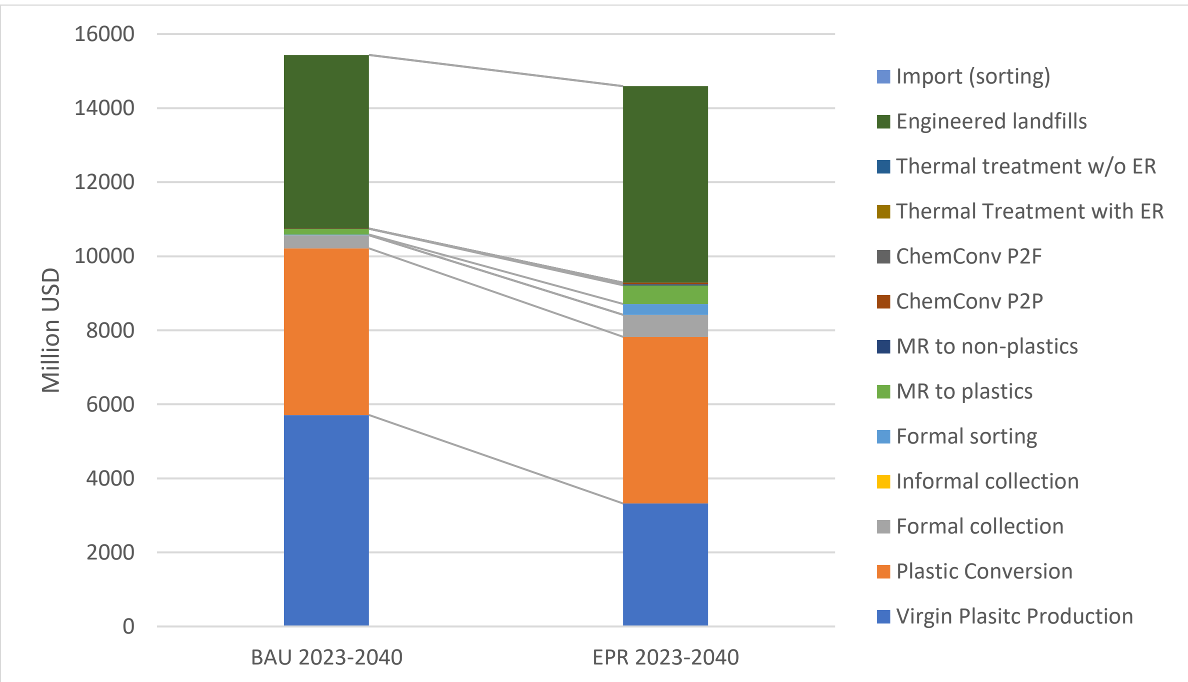


Figure 28: Cumulative required investments between 2023 and 2040 for the BAU vs EPR scenario (nominal USD millions)

4.3 Optimal System Change scenario

Successfully achieving the collection and recycling targets within the Paper and Packaging EPR regulations (R1187 of 5 November 2020) – which requires participation among producers – will significantly reduce plastic pollution (33% less than BAU). However, the EPR scenario still results in 503 kt of plastic pollution in 2040, which is essentially a stabilisation of current levels. Therefore, additional strategies are needed to substantially reduce plastic pollution.

Reducing plastic pollution could be achieved through four key intervention strategies ('levers') either on their own or collectively. These strategies are reducing plastic consumption; substituting plastics with alternative materials; increasing collection and safe disposal to sanitary landfills; or increasing recycling. One of the reasons for the delay in addressing plastic pollution, has been the uncertainty around what actions to take, the cost of these actions, and their impact in terms of reducing plastic pollution. This can result in a 'decision paralysis' with regards to solving the plastic pollution problem. The Scenario Builder within the Pathways tool allows the user to optimise for certain parameters, by allowing variations in flows along the plastics value chain to satisfy a set of defined objectives and achieve an optimal solution[8].

The scenarios were explored within the context of South Africa, with a specific focus on the need to ensure sustainable development. The Optimal System Change Scenario balances the minimisation of plastic pollution with some of South Africa's broader development objectives- minimising greenhouse gas (GHG) emissions, minimising capital costs and maximising employment. This scenario optimisation is carried out by allowing variations in plastic flows (5% change per annum), to identify an optimal solution that balances or "trades-off" these objectives in order to achieve sustainability. There is evidence of a clear trade-off in some of these objectives; for example, a reduction in plastic pollution from increased collection, recycling and disposal to sanitary landfill, typically comes with additional capital costs. The results present alternative scenarios that have different values for these flows in order to satisfy achieving these objectives to varying degrees (see all scenarios in Annexure 8). The pairwise comparisons (Figure 29) of these objectives, that were equally weighted in the optimisation, identified Scenario#17 as the optimal scenario that achieves the best balance between the optimal systems change objectives (reducing plastic pollution, reducing GHG emissions, reducing capital costs, and increasing employment) and this was selected as the Optimal System Change scenario. Of all the scenarios explored, this Optimal System Change is one of the best performers in terms of reducing plastic pollution and GHG emissions, while creating additional employment, and at a substantially lower capital cost; as compared to BAU. The values for plastic material flows under the Optimal System Change scenario are shown in Table 6.

[8] Multi-objective optimization that seeks a Pareto optimal or efficiency state where no preference criterion can be made better off without making at least one individual or preference criterion worse off.

Table 6: The values for optimised plastic flows of the Optimal System Change scenario

Waste management strategy	Flow #	Flow number	Description		Optimal flow (annual change, %)
			From	To	
Collect	1	A1	Box1_WasteGenerated	Box2_CollectedPlastic	4.85%
Collect and Dispose	1	A1	Box1_WasteGenerated	Box2_CollectedPlastic	4.85%
	25	L1	Box12_UnsortedWaste	Box13_UnsortedManagedWaste	3.36%
Collect and Recycle	1	A1	Box1_WasteGenerated	Box2_CollectedPlastic	4.85%
	5	C1	Box3_FormalCollection	Box6_FormalSorting	4.54%
	6	C2	Box3_FormalCollection	Box5_MixedCollection	1.93%
	9	D3	Box4_InformalCollectSorting	Box11_ChemicalConversion	0.93%
	11	E1	Box5_MixedCollection	Box11_ChemicalConversion	4.28%
	12	E2	Box5_MixedCollection	Box12_UnsortedWaste	-4.42%
	13	E3	Box5_MixedCollection	Box6_FormalSorting	2.97%
	14	F1	Box6_FormalSorting	Box9_MechanicalRecyclingtonon-plastics	4.82%
	15	F2	Box6_FormalSorting	Box10_MechanicalRecyclingtoplastics	4.58%
	16	F3	Box6_FormalSorting	Box12_UnsortedWaste	-0.26%
Collect, Recycle and Dispose	1	A1	Box1_WasteGenerated	Box2_CollectedPlastic	4.85%
	5	C1	Box3_FormalCollection	Box6_FormalSorting	4.54%
	6	C2	Box3_FormalCollection	Box5_MixedCollection	1.93%
	9	D3	Box4_InformalCollectSorting	Box11_ChemicalConversion	0.93%
	11	E1	Box5_MixedCollection	Box11_ChemicalConversion	4.28%
	12	E2	Box5_MixedCollection	Box12_UnsortedWaste	-4.42%
	13	E3	Box5_MixedCollection	Box6_FormalSorting	2.97%
	14	F1	Box6_FormalSorting	Box9_MechanicalRecyclingtonon-plastics	4.82%
	15	F2	Box6_FormalSorting	Box10_MechanicalRecyclingtoplastics	4.58%
	16	F3	Box6_FormalSorting	Box12_UnsortedWaste	-0.26%
	25	L1	Box12_UnsortedWaste	Box13_UnsortedManagedWaste	3.36%
Reduce	40		Box25_PlasticDemand	Box1_WasteGenerated	-2.57%
System change: Reduce, Collect Recycle and dispose	1	A1	Box1_WasteGenerated	Box2_CollectedPlastic	4.85%
	5	C1	Box3_FormalCollection	Box6_FormalSorting	4.54%
	6	C2	Box3_FormalCollection	Box5_MixedCollection	1.93%
	9	D3	Box4_InformalCollectSorting	Box11_ChemicalConversion	0.93%
	11	E1	Box5_MixedCollection	Box11_ChemicalConversion	4.28%
	12	E2	Box5_MixedCollection	Box12_UnsortedWaste	-4.42%
	13	E3	Box5_MixedCollection	Box6_FormalSorting	2.97%
	14	F1	Box6_FormalSorting	Box9_MechanicalRecyclingtonon-plastics	4.82%
	15	F2	Box6_FormalSorting	Box10_MechanicalRecyclingtoplastics	4.58%
	16	F3	Box6_FormalSorting	Box12_UnsortedWaste	-0.26%
	25	L1	Box12_UnsortedWaste	Box13_UnsortedManagedWaste	3.36%
	40		Box25_PlasticDemand	Box1_WasteGenerated	-2.57%

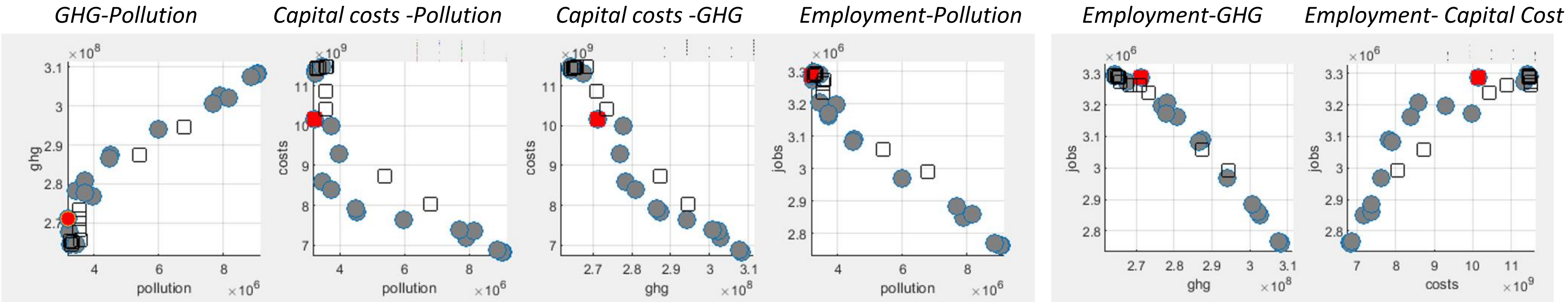


Figure 29: Pairwise comparison of Optimal System Change (scenario#17) objectives. The red dot indicates the pareto value for scenario#17 in terms of achieving objectives of minimising plastic pollution, reducing greenhouse gas emissions, minimising costs and maximising employment

The flows of the Optimal System Change scenario have been grouped according to the possible intervention strategies or 'levers', to understand how various intervention strategies, or a combination thereof, can help achieve a best-case scenario for South Africa. These include:

- **Collect:** Increasing waste collection
- **Collect and Dispose:** Increasing waste collection services and reducing the mismanagement of waste through increased disposal to sanitary landfill
- **Collect and Recycle:** Increasing waste collection and increasing recycling of plastics.
- **Collect, Recycle and Dispose**: Increasing waste collection services, increasing recycling, and reducing plastic waste mismanagement through increasing disposal to sanitary landfill.
- **Reduce demand:** Reduce plastic consumption through re-use, the elimination of unnecessary plastics, new delivery models, and substitution to alternative materials that avoid or reduce the demand for plastics. The optimised gross plastic demand reduction identified in the scenario optimization was manually allocated to account for various demand reduction interventions (re-use, elimination, new delivery models and the substitution of plastics with paper, coated paper and compostable bioplastics)
- **Reduce, Collect, Recycle and Dispose (System Change):** This is a combination of strategies - reduce plastic demand, increase plastic collection, increase recycling, and increase disposal to sanitary landfill.

The plastic demand reduction of -2.57% per annum identified in the scenario optimisation is best termed "Gross Demand Reduction" as it consists of both "Plastic Demand Reduction" and "Plastic Substitution" that were aggregated during optimisation. For detailed analysis, these variables required disaggregation and further attribution. "Plastic Demand Reduction" requires attribution to "re-use", "eliminate" and "new delivery models"; and "Demand Substitution" attribution to "paper", "coated paper" and "compostables". These percentage attributions for "Gross Demand Reduction" are depicted in Figure 30 to show how the value for demand reduction obtained from the Optimal System Change scenario (2.57% absolute annual change in demand, annually compounded) is allocated in the modelling. To achieve the 2.57% annual Gross Demand Reduction, 1.2% was attributed to Demand Reduction as per commitments from global industry (Lau, *et al*., 2020), and the remainder of 1.37% to plastic substitution. A 50:30:20 ratio was then applied to attribute the components of Plastic Demand Reduction ("eliminate", "re-use" and "new delivery models" respectively) and Plastic substitution ("substitute paper", "substitute coated paper" and "substitute compostables" respectively). Based on these splits, the % demand reduction attributed to "eliminate" (0.36%), "re-use" (0.24%), "new delivery models" (0.6%) were derived; and similarly for "substitute paper" (0.69%), "substitute coated paper" (0.41%), and "substitute compostables" (0.27%)- see Figure 30.

As with the global study, the modelling for South Africa shows that there is no single solution to address the plastic pollution problem. An optimal system change intervention requires combined strategies of reducing plastic demand, increasing plastic waste collection and recycling, and increasing the safe disposal of plastics to sanitary landfill, in order to achieve a 63% reduction in plastic pollution, compared to the BAU scenario (Figure 31).

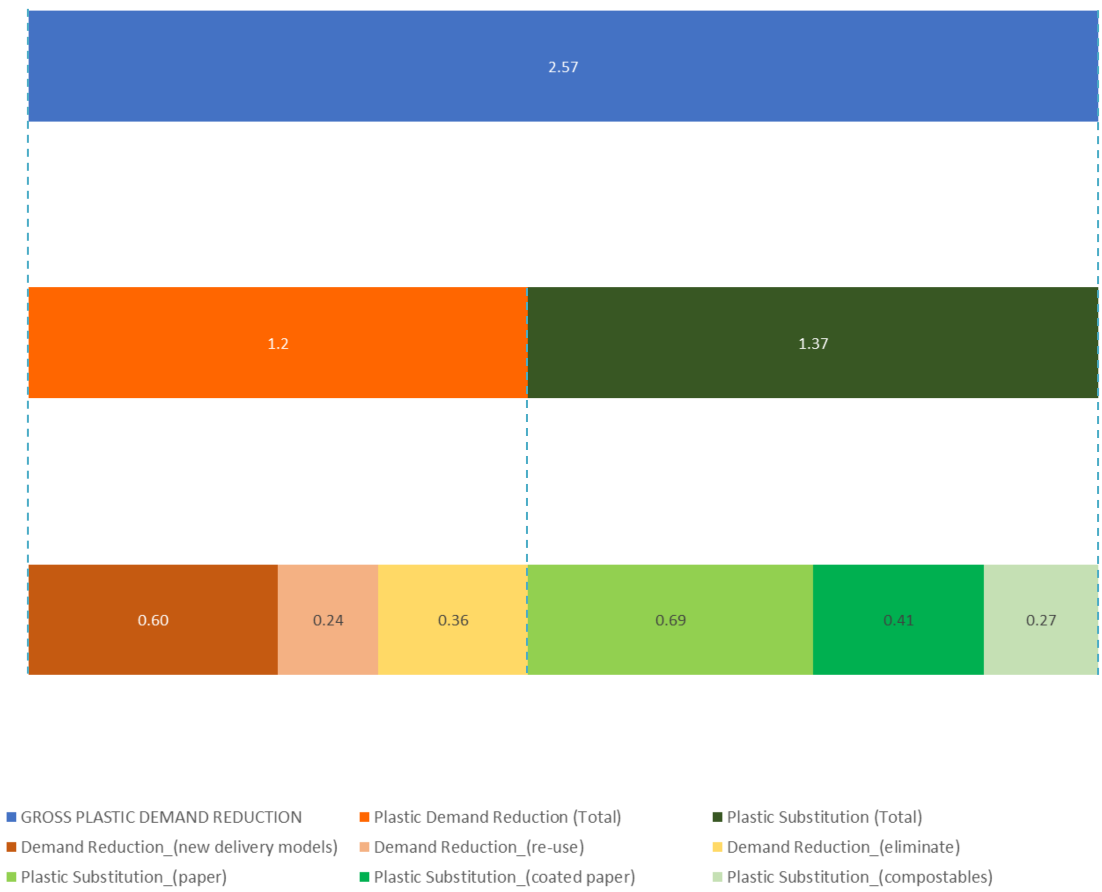
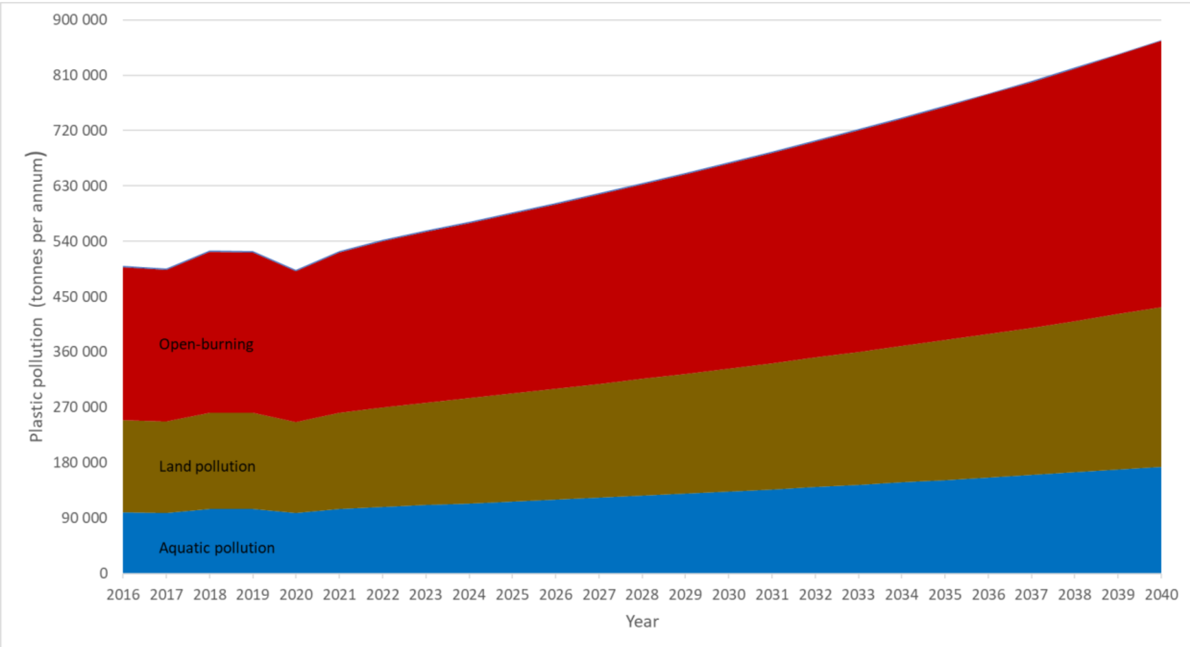


Figure 30: The attribution of the Optimal System Change Gross Demand reduction (2.57% per annum) to the various plastics Demand Reductions and Plastics Substitutions

A.



B.

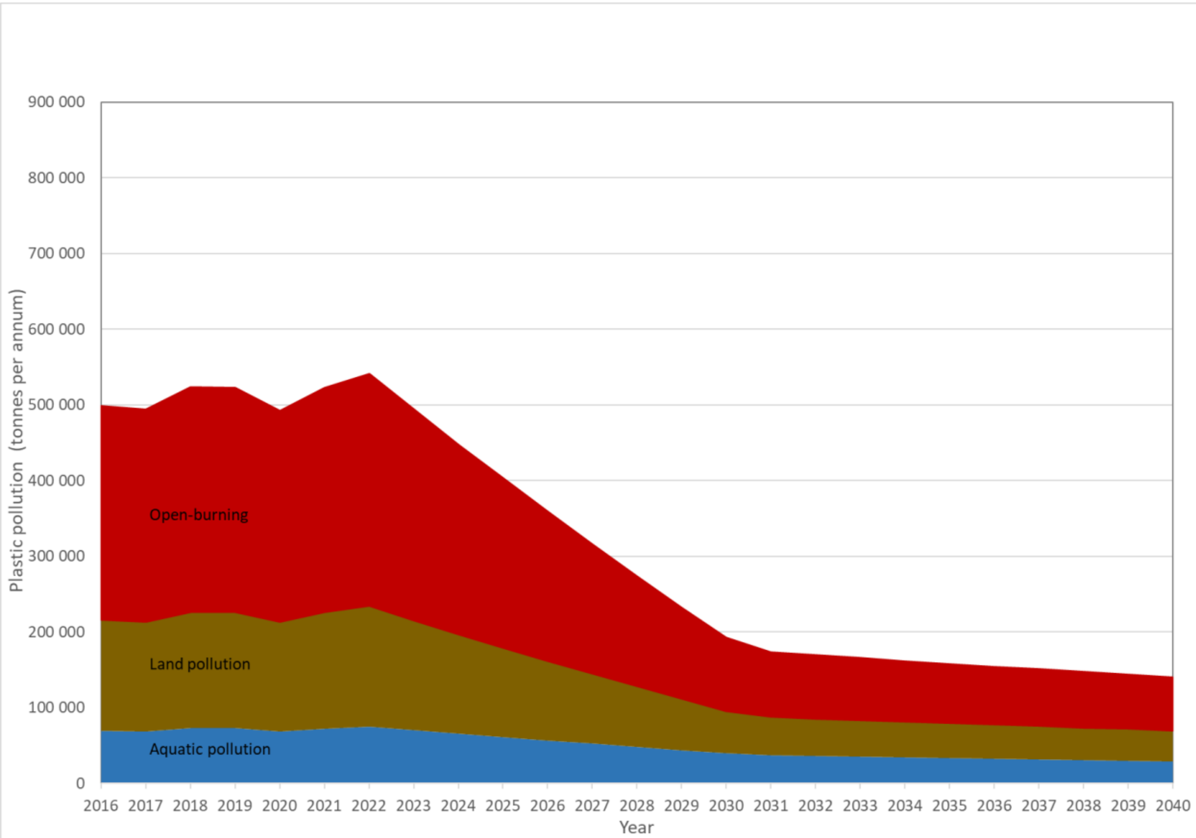


Figure 31: Total plastic pollution under (A) Business-As-Usual with no policies or and measures and (B) Optimal System Change scenario which combines strategies of reducing plastic demand, increasing plastics waste collection and recycling, and increasing the safe disposal of plastics to sanitary landfill. Compared to the Business-As-Usual, the Optimal System Change scenario will reduce plastic pollution (consisting of open-burning, land pollution and aquatic pollution) by 63%.

The results of the Optimal System Change are presented below in terms of the Optimal System Change scenario fulfilling the objectives of minimised plastic pollution, GHG emissions, capital costs (required investment) and maximised employment. The various strategies to achieve system change for each of these objectives are shown in the following figures; namely-

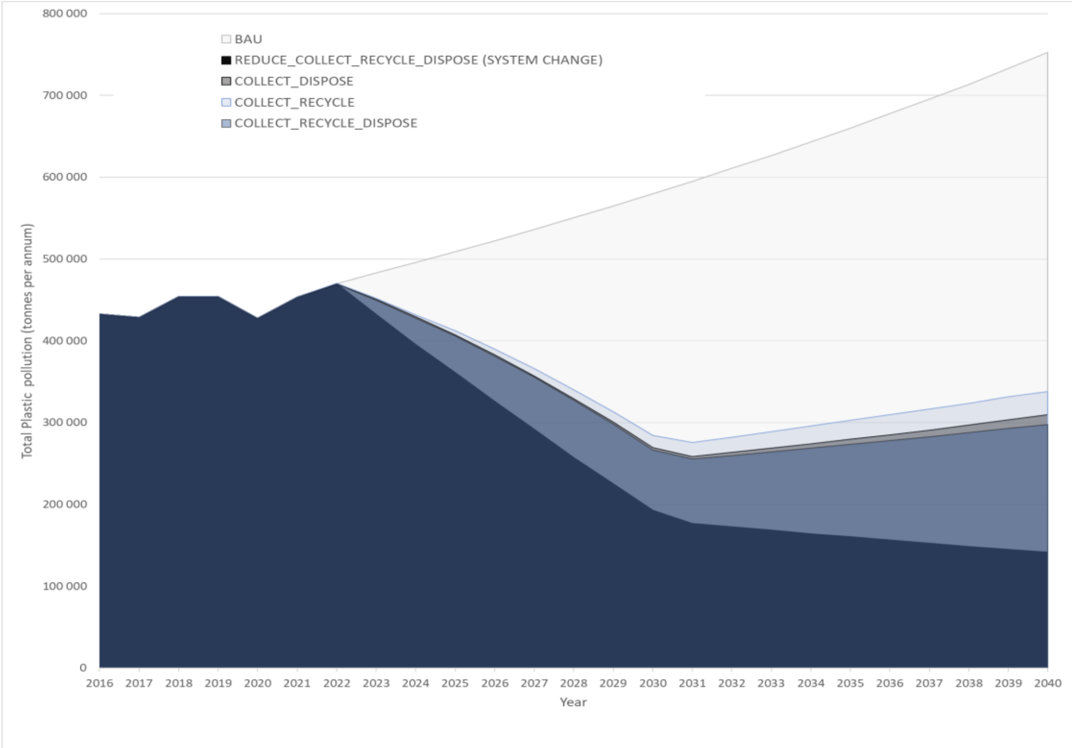
> **A**: The annual values for plastic pollution, defined as the sum of aquatic pollution, land pollution, and open burning, across the 2016-2040 timeline, assuming a date of implementation of system change strategies in 2023;
>
> **B**: The total value over the period 2023-2040, as calculated from the area under the timeline curve;
>
> **C:** The percentage change (% gain/loss) compared to the BAU scenario over the period 2023-2040.

4.3.1 Plastic Pollution

Increasing either *waste collection and disposal*, or *waste collection and recycling*, can substantially reduce plastic pollution compared to the BAU Scenario (47% and 45% reduction, respectively). However, the System Change Scenario (which combines plastic demand reduction with increased waste collection, increased recycling, and increased disposal to sanitary landfill) can substantially reduce plastic pollution, by 63% (6881 kt), compared to the BAU scenario (Figure 32).

In the plastic pollution trendline, it is noteworthy that there is a reduced decline (inflection in the curve) in 2032, as a result of waste collection reaching 100%, such that less additional plastic is available for recycling thereafter; and this is against a backdrop of increasing plastic consumption and waste generation. Given that there will challenges in waste collection from rural households, attaining complete collection by 2032 may be unrealistic, which could be addressed in future analysis by classifying plastic waste as either urban or rural.

(A) Total annual values



(B) Total plastic pollution in tonnes and percentage change

Waste management strategy	Total Plastic pollution 2023-2040 (tonnes)	Plastic pollution % change compared to BAU 2023-2040
BAU	10 948 514	0
COLLECT_DISPOSE	5 757 383	-47
COLLECT_RECYCLE	6 056 041	-45
COLLECT_RECYCLE_DISPOSE	5 674 050	-48
REDUCE_ COLLECT_RECYCLE_DISPOSE (System Change)	4 067 810	-63

(C) Percentage total plastic pollution change per intervention strategy ('lever')

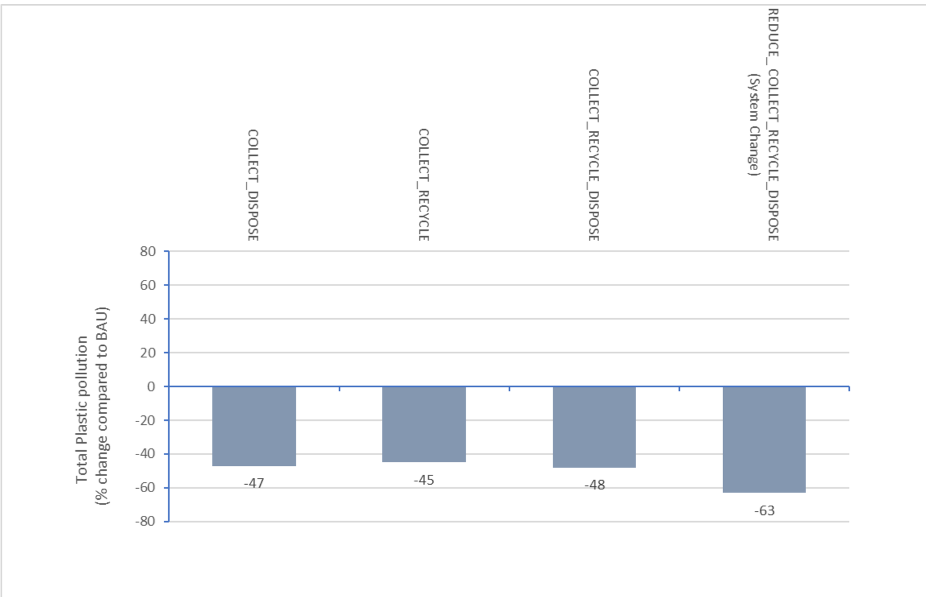
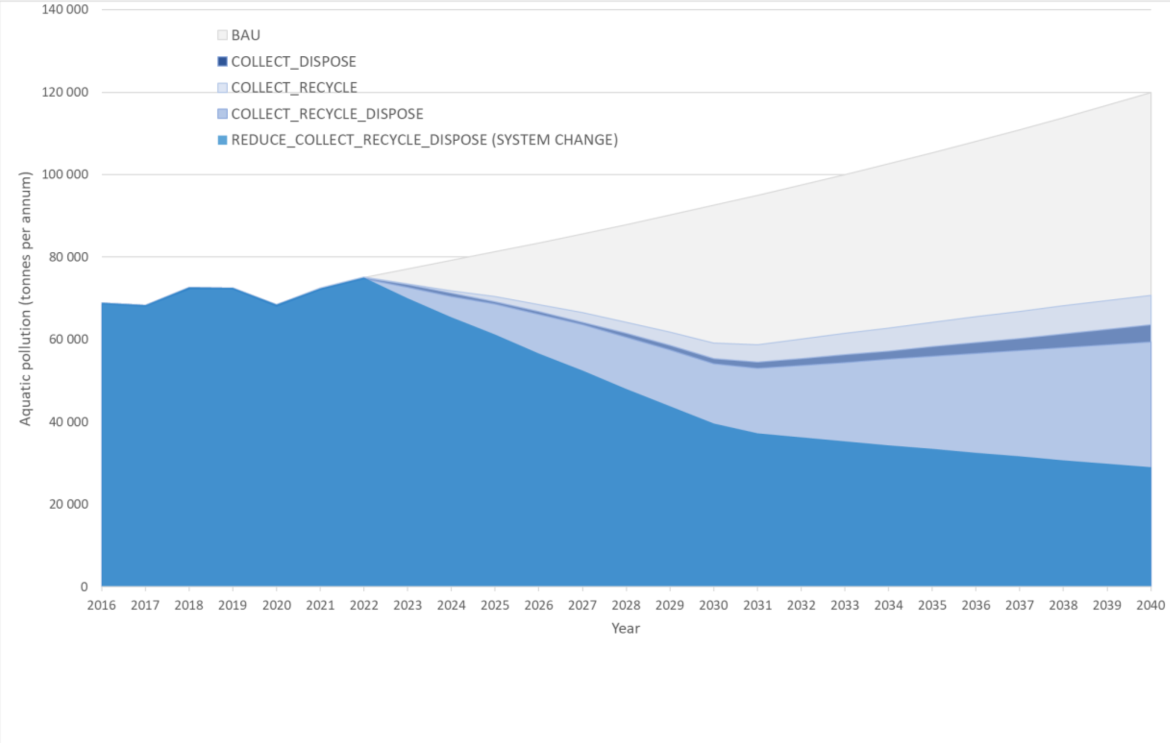


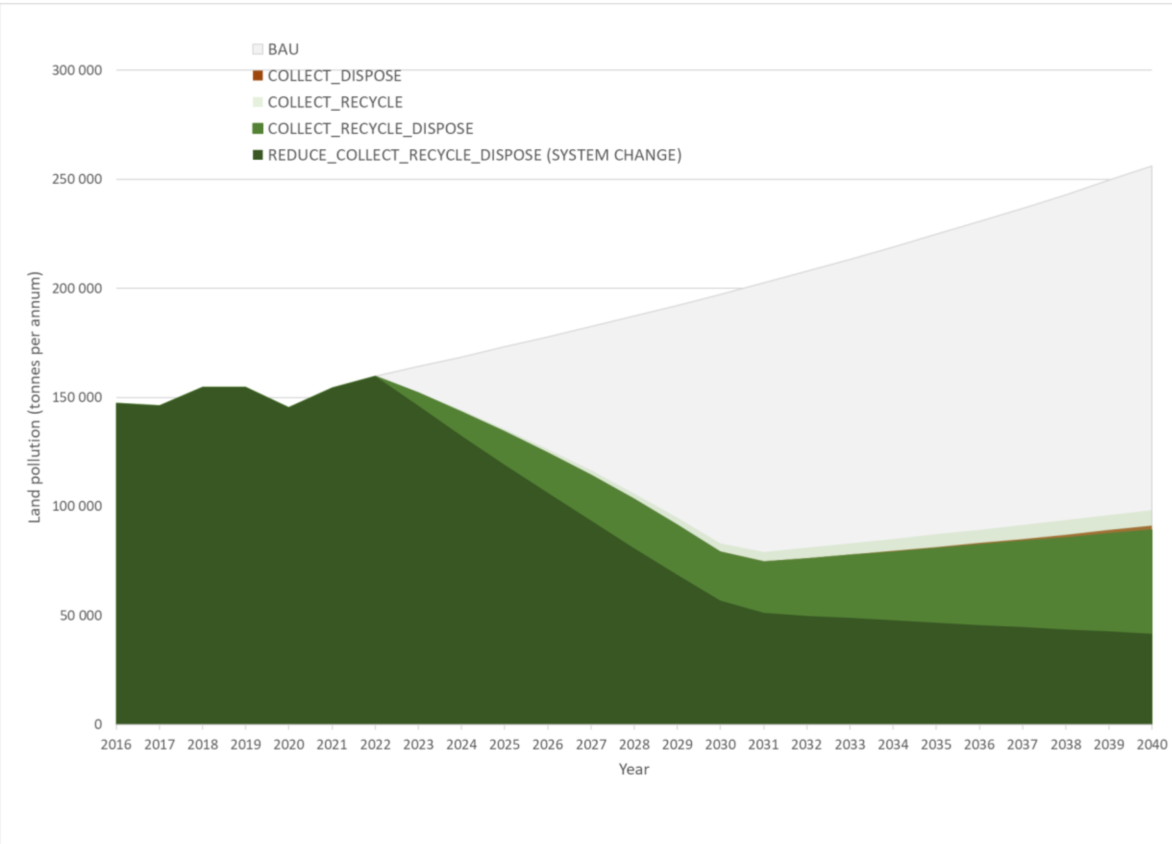
Figure 32: Total plastic pollution (aquatic, land and open-burning combined) for the period 2023-2040

Further details of the plastic pollution in terms of its environmental fate (aquatic, land or air pollution through open burning) is shown in Figure 33 (A-D).

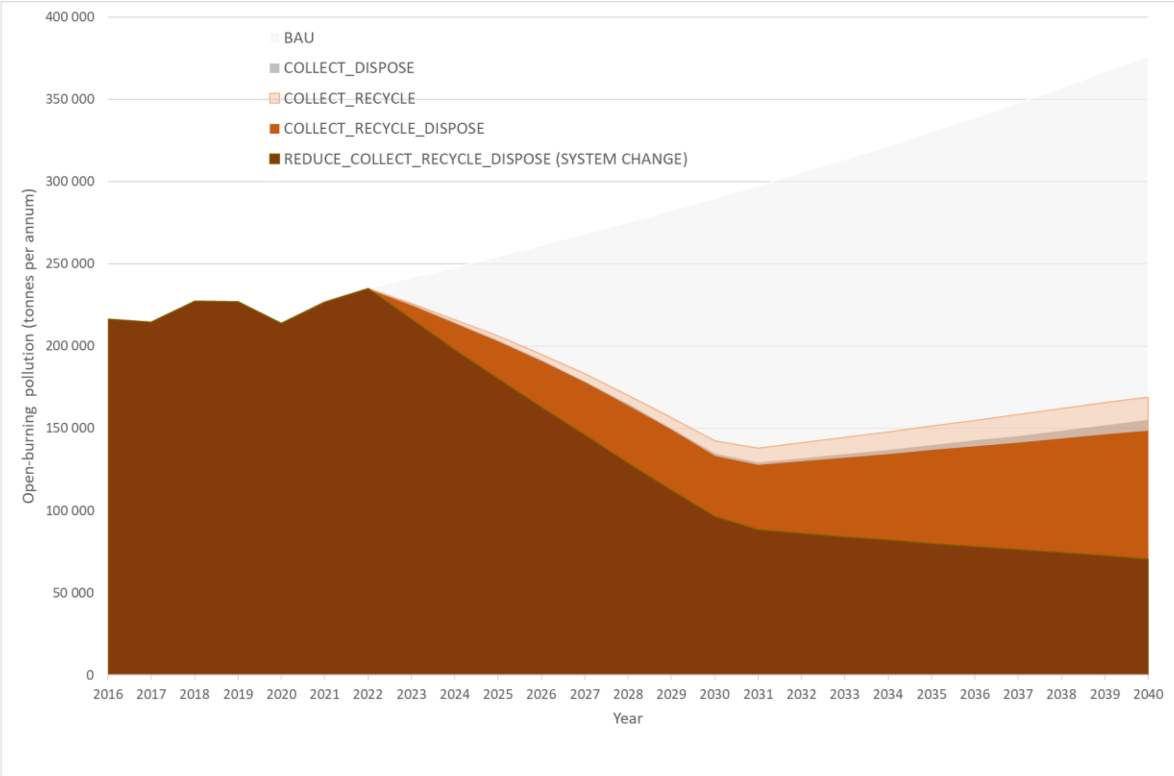
(A) Aquatic plastic pollution



(B) Land plastic pollution



(C) Open-burning



(D) Percentage change (gain/loss)

Waste management strategy	Plastic Aquatic pollution 2023-2040 (tonnes)	Plastic Aquatic pollution 2023-2040 (% change compared to BAU)	Plastic Land pollution 2023-2040 (tonnes)	Plastic Land pollution 2022-2040 (% change compared to BAU)	Plastic Open-burning pollution 2023-2040 (tonnes)	Plastic Open-burning pollution 2023-2040 (% change compared to BAU)
BAU	1 747 675	0	3 726 583	0	5 474 257	0
COLLECT_DISPOSE	1 109 060	-37	1 769 631	-53	2 878 692	-47
COLLECT_RECYCLE	1 183 951	-32	1 844 070	-51	3 028 020	-45
COLLECT_RECYCLE_DISPOSE	1 075 932	-38	1 761 092	-53	2 837 025	-48
REDUCE_ COLLECT_RECYCLE_DISPOSE (System Change)	767 636	-56	1 266 269	-66	2 033 905	-63

Figure 33: Plastic pollution for the period 2023 to 2040. Aquatic plastic pollution, B. Land plastic pollution, C. Open-burning plastic pollution, D. Percentage change

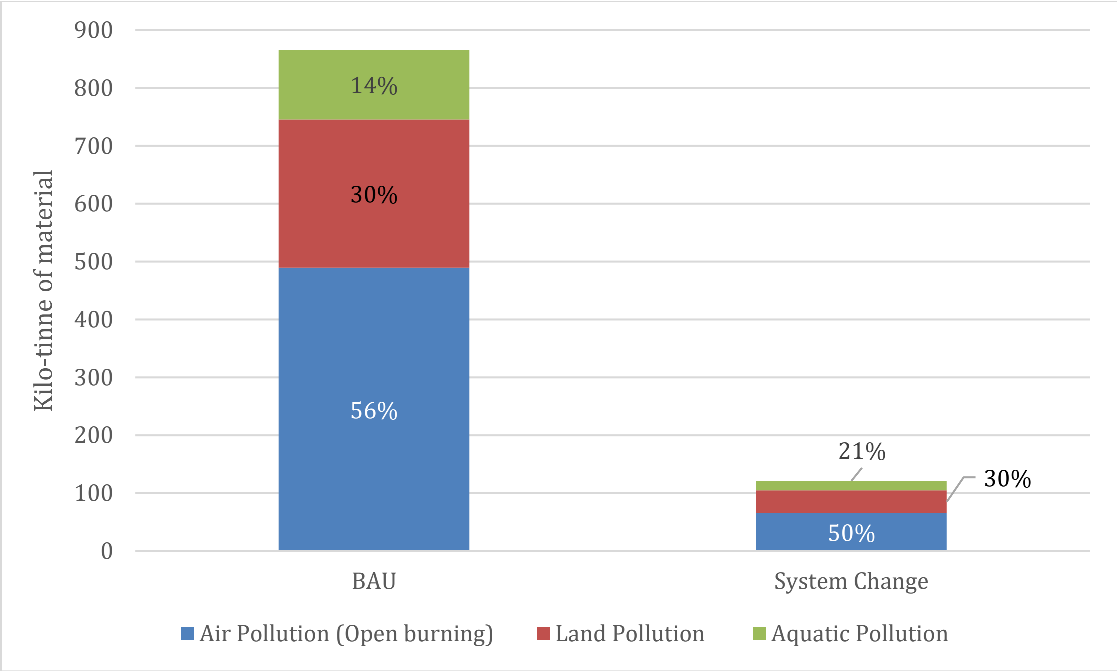


Figure 34: Plastic pollution in the receiving environment (air pollution, water pollution and land pollution) for the business-as-usual (BAU) and Optimal System Change.

In the BAU scenario, approximately 56% of the plastic pollution is air pollution from open burning, 30% land pollution and 14% aquatic pollution (Figure 34). These results highlight that only a relatively small portion (14%) of South Africa's plastic pollution is impacting water (freshwater and marine), with the majority impacting land and the air. The Optimal Systems Change scenario not only reduces the amount of plastic pollution (Figure 32) relative to BAU, but also reduces the proportion of plastic that is burnt, from 57% to 50%. The percentage of plastic pollution to land remains largely unchanged relative to BAU at 30%. Aquatic plastic pollution as a % percentage of total plastic pollution actually increases (from 14% to 21%) relative to air and terrestrial pollution, although the actual quantity (tonnes) leaking into the aquatic environment under the Optimal Systems Change Scenario declines relative to BAU (Figure 34).

4.3.2 Composition of plastic pollution

The composition of plastic pollution between the three plastic types under the BAU and Optimal System Change scenarios is shown in Figure 35. The composition of the plastic pollution is seen to shift from the BAU to the System Change scenario, with a relative reduction in rigid plastics, and a greater proportion of flexible plastics and multi-material plastics. This shift in composition is the result of recycling preferentially removing the rigid plastic materials and effectively increasing the proportion of flexible mono- and multi-materials in the waste stream.

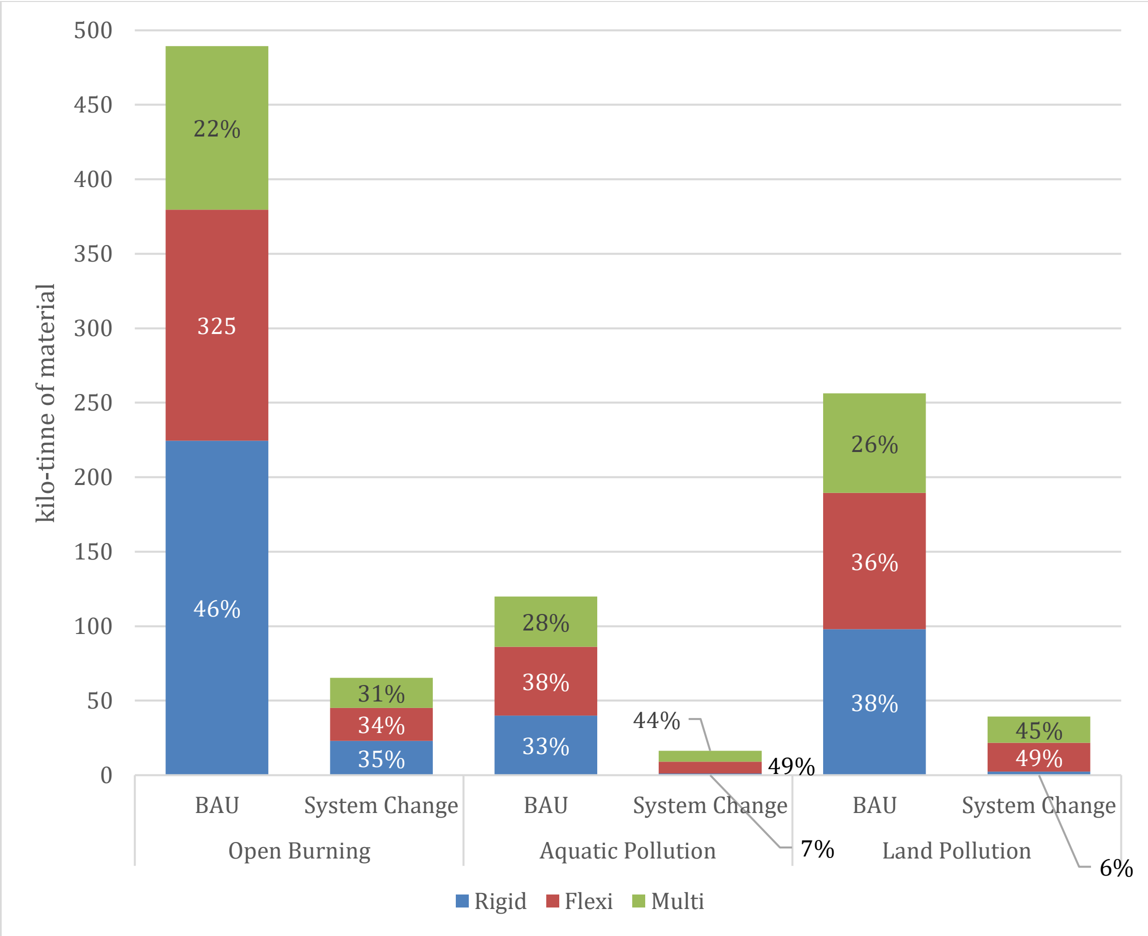


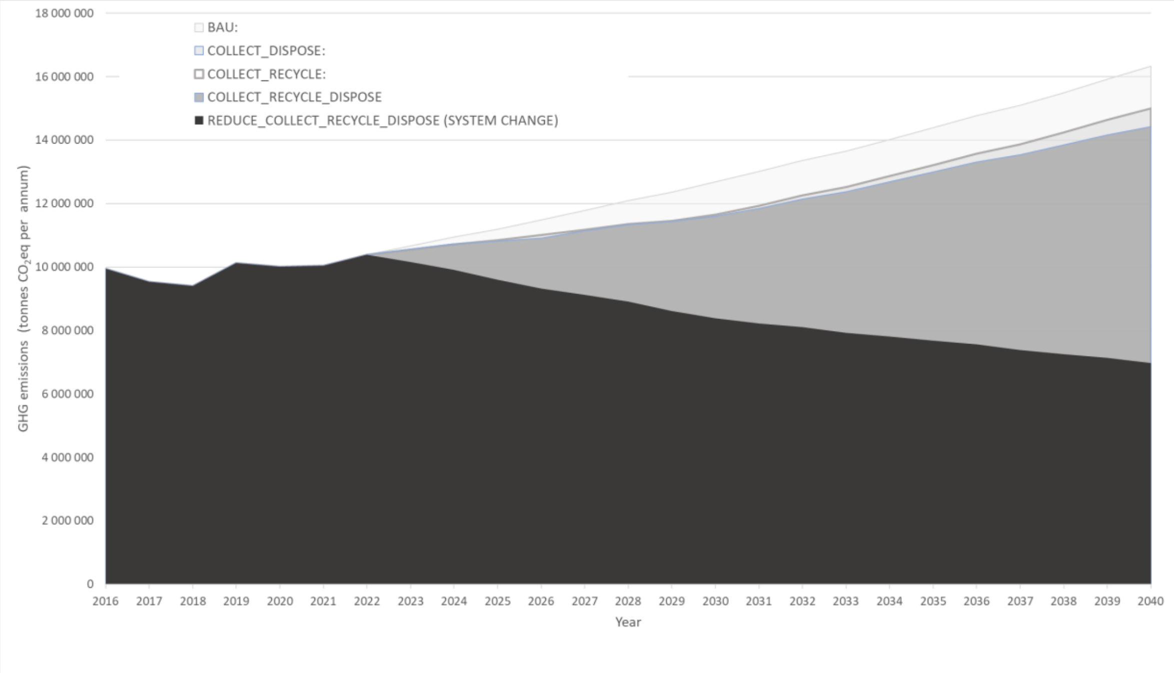
Figure 35: Change in Plastic pollution composition of Business-As-Usual (BAU) compared to Optimal System Change in 2040

4.3.3 Greenhouse gas emissions (GHG)

Increasing '*waste collection, recycling and disposal*' results in a relatively small reduction in GHG emissions (7% to 8% reduction compared to BAU). These relatively small reductions in GHG emissions as a result of improved waste management are due to the fact that virgin plastic polymer production and plastic manufacturing are the main contributor (89%) to total plastics related GHG emissions. Therefore, improving plastics waste management through increasing recycling or safe disposal to sanitary landfill has little effect on GHG emissions (it only avoids some GHG emissions from the open burning of plastic in unsanitary landfills and open-dumps). On the other hand, for the Optimal System Change scenario (which combines plastics demand reduction with increased waste collection, recycling and disposal to sanitary landfill), there is a 37% reduction in GHG emissions, compared to BAU (Figure 36).

Although some reduction in GHG emissions could also be achieved by substantially recycling plastic and thereby reducing virgin plastic production; there are constraints in sorting, energy inputs required for recycling, and a general loss of plastic quality in recycling. Therefore, only a strategy that includes reducing plastic demand (reduction in production and consumption of plastics) will substantially reduce GHG emissions from the plastics sector.

(A) Total annual values, GHG emissions



(B) Total GHG emissions in tonnes CO_2-eq and percentage change

Waste management strategy	Total GHG emissions 2023-2040 (tonnes CO2-eq)	GHG emissions (% change compared to BAU)
BAU	239 282 452	0
COLLECT_DISPOSE	222 904 127	-7
COLLECT_RECYCLE	222 904 127	-7
COLLECT_RECYCLE_DISPOSE	219 899 961	-8
REDUCE_ COLLECT_RECYCLE_DISPOSE	150 082 909	-37

(C) Percentage change per intervention strategy

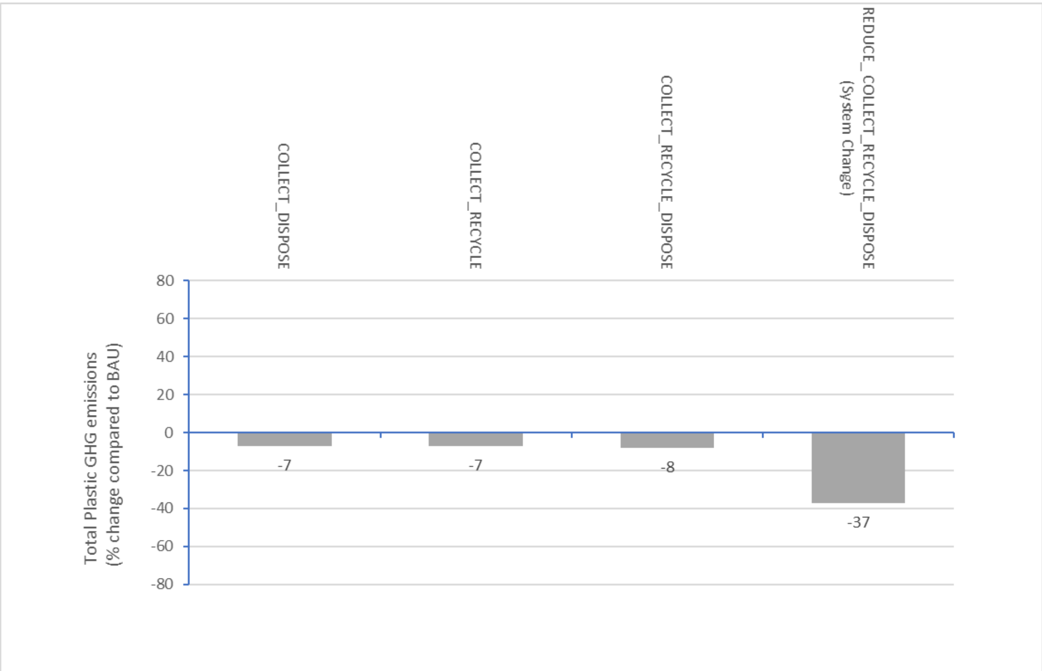
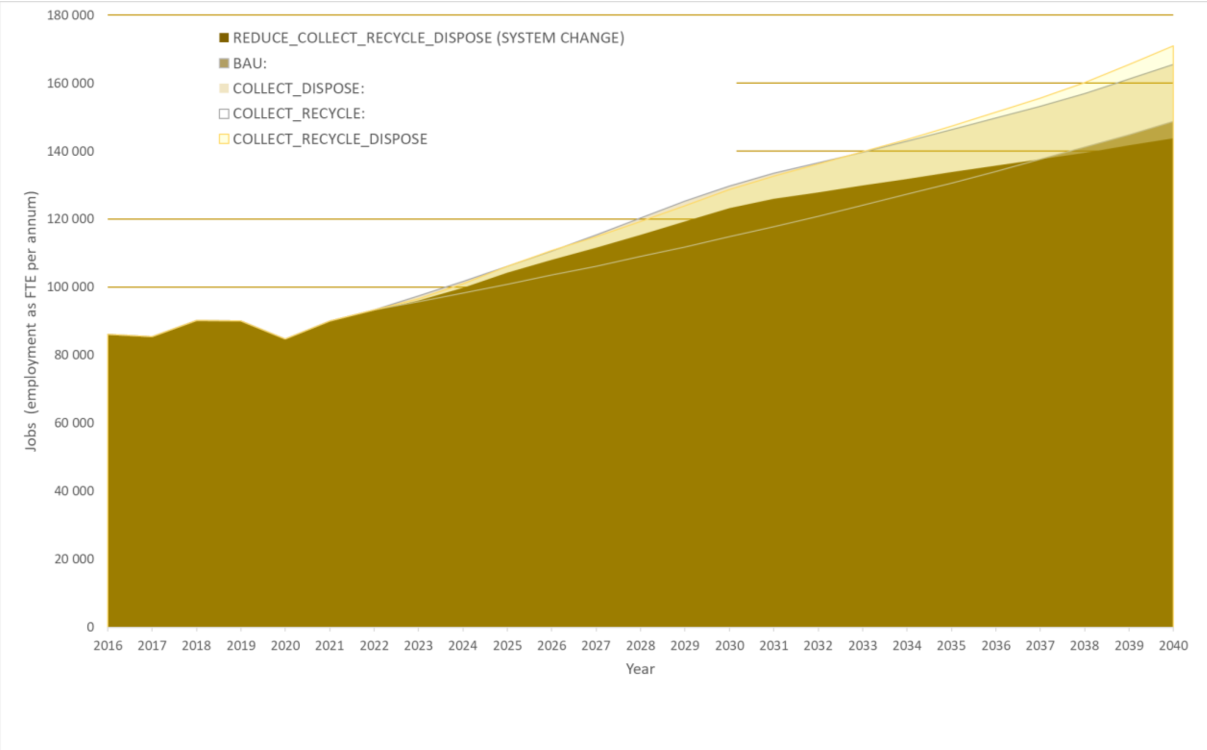


Figure 36: Total GHG for the period 2023 to 2040

4.3.4 Employment

Figure 37 shows that increasing '*waste collection, recycling and disposal*' leads to a 10%-11% increase in employment relative to the BAU scenario. On the other hand, for the optimal system change scenario (which combines plastic demand reduction with increased waste collection, recycling and disposal to sanitary landfill), while there is an increase in employment relative to BAU, the % increase is relatively low (3%). This is due to the fact that there are employment losses associated with reduced plastic demand, but also employment gains associated with increased recycling. In addition, employment gains are also expected in alternative material production (paper, coated paper, and compostables) for substitution, and in new product delivery models, which have not been included in this modelling. Overall, however, there is an increase in employment expected with all scenarios relative to BAU.

(A) Total annual values



(B) Employment-absolute and percentage change (gain/loss)

Waste management strategy	Total employment 2023-2040 (full time equivalent employment numbers)	Employment (% change compared to BAU)
BAU	2 167 522	0
COLLECT_DISPOSE	2 392 660	+10
COLLECT_RECYCLE	2 392 660	+10
COLLECT_RECYCLE_DISPOSE	2 404 882	+11
REDUCE_ COLLECT_RECYCLE_DISPOSE	2 225 765	+3

(C) Percentage change per intervention strategy

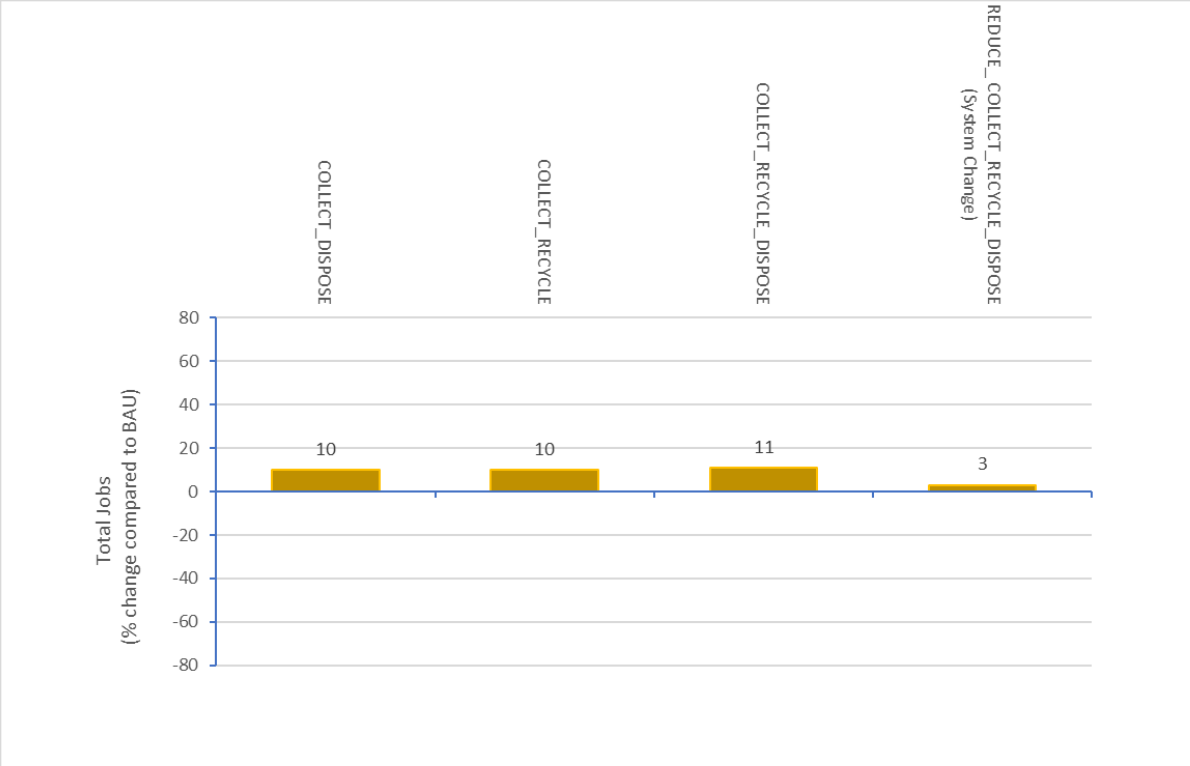


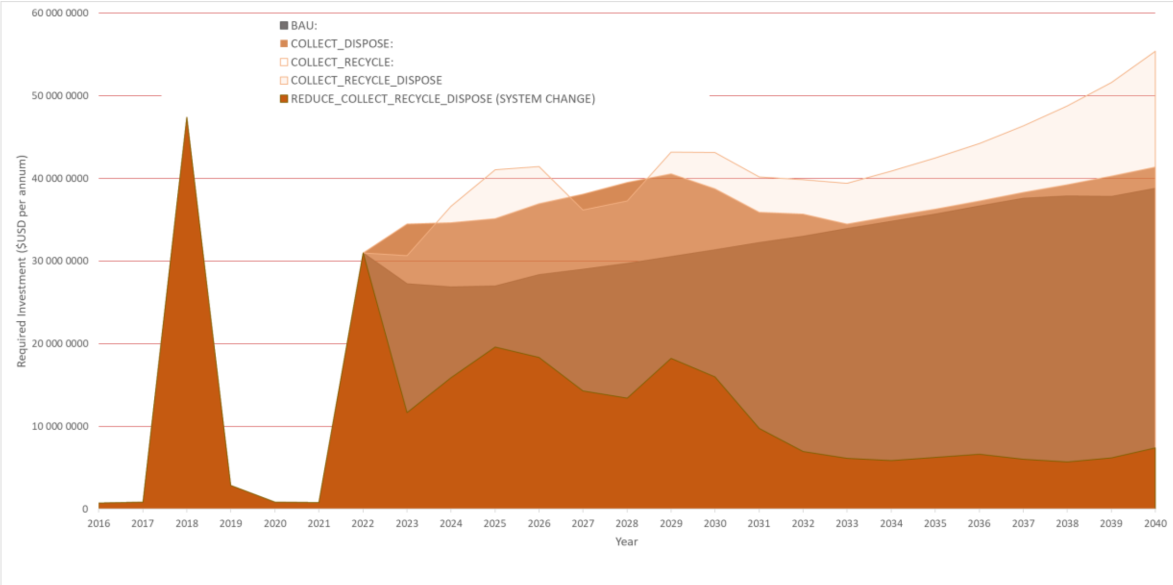
Figure 37: Total employment for the period 2023 to 2040

4.3.5 Net Costs and Required Investment

The capital costs in terms of required investment increase with *'waste collection and recycling'* or *'waste collection and disposal'* by 14%, while an increase in *'waste collection, recycling and disposal'* to sanitary landfill increases capital costs by 29%; compared to the BAU scenario (Figure 38). However, the optimal system change scenario, which combines a '*plastic demand reduction'* with increased *'waste collection, recycling and disposal'*), can substantially reduce capital costs by 67%, compared to the BAU scenario; largely from avoided capital costs associated with plastic production and waste disposal; which offsets the capital costs from increased collection and recycling. The net cost in present value terms of the Optimal System Change for the period 2016-2040 is $19 352 million, compared to the BAU of $67 337 million; which represents a total cost saving of 71%.

While the additional or avoided costs for plastic production, manufacturing, collection, recycling and disposal have been included together with the costs of substitution to alternatives; the costs of plastic reduction by means of re-use, alternative delivery models and elimination have not been included, due to lack of data. Nevertheless, this result does suggest that savings in required investment for plastic production and manufacturing outweigh the added costs for recycling and safe disposal to sanitary landfill; and highlights that reducing plastic demand is an effective and cost saving strategy to reduce plastic pollution.

(A) Total annual values



(B) Capital costs in USD and percentage change (gain/loss)

Waste management strategy	Total Required capital Investment 2023-2040 (USD, $)	Required capital Investment (% change compared to BAU)
BAU	5 887 247 720	0
COLLECT_DISPOSE	6 724 779 574	+14
COLLECT_RECYCLE	6 724 779 574	+14
COLLECT_RECYCLE_DISPOSE	7 586 149 584	+29
REDUCE_ COLLECT_RECYCLE_DISPOSE	1 946 238 667	-67

(C) Percentage change per intervention strategy

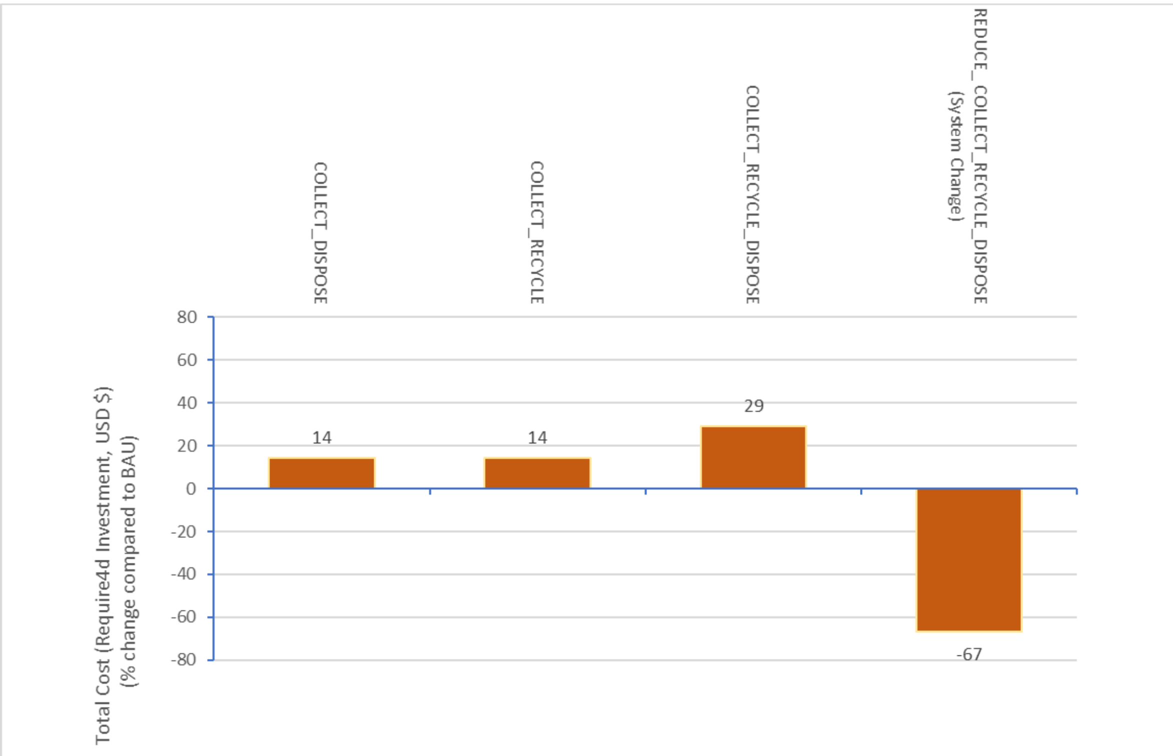


Figure 38: Total capital costs (required investment, in USD) for the period 2023 to 2040

4.3.6 Summary of the Optimal System Change scenario

In summary, **the Optimal System Change scenario, a combined strategy of reducing plastic consumption, increasing collection and recycling, together with the effective disposal of residual plastic material, can avoid 63% of plastic pollution between 2023-2040, compared to business-as-usual.** In addition, between 2023-2040, the System Change scenario can avoid 37% of projected GHG emissions from plastics; decrease capital costs across the plastics value chain by 67%, and an increase employment by 3%; compared to business-as-usual (Figure 39).

The Optimal "System Change" comprises a combination of "Reduce", "Recycle", and "Dispose". The results from each of these individual intervention strategies, as well as from the combined Optimal System Change strategy, in terms of their effectiveness (relative to BAU) in achieving South Africa's development objectives (reducing pollution, reducing GHG emissions, increasing employment and reducing costs), are shown in Figure 39, and are summarized below.

A strategy to **reduce plastic demand** by 2.57% per annum through reducing consumption of plastics and substituting with alternative materials, can avoid 32% of projected plastic pollution by 2040, compared to BAU. In addition, by 2040, reducing plastic demand can avoid 32% of projected GHG emissions and reduce capital costs by 94%. However, on its own, this strategy would also reduce employment in the sector by 25% relative to BAU, due to avoided plastic production and waste treatment.

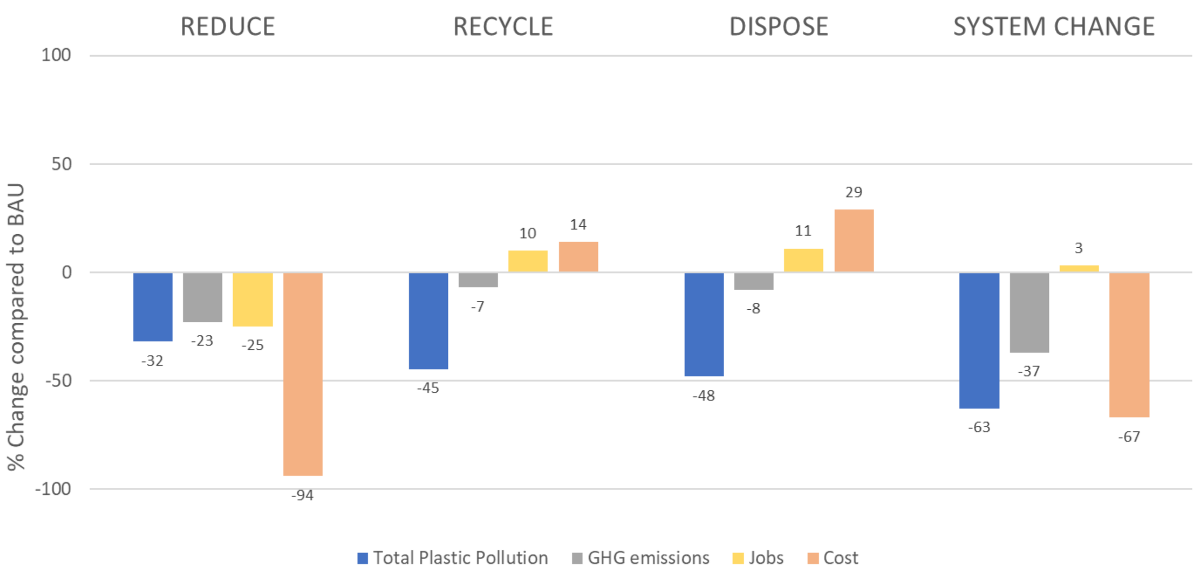


Figure 39: Summary of the strategies that can be used to reduce plastic pollution. The individual strategies of Reduce, Recycle, and Dispose, as well as the combined strategy of Optimal System Change, are compared to BAU; and measured against the objectives of reducing plastic pollution, reducing GHG emission, increasing employment and reducing costs.

A strategy to **increase plastic recycling** through meeting the five-year EPR targets can avoid 33% of projected plastic pollution between 2023-2040, compared to BAU. If recycling targets are extended beyond the five-year period stipulated by EPR, 45% of plastic pollution can be avoided between 2023-2040, compared to BAU. In addition, increasing plastic recycling until 2040 can avoid 7% of projected GHG emissions between 2023-2040; while also increasing employment by 10% . However, this strategy would lead to an increase in capital costs by 10% relative to BAU between 2023-2040, because of the required capital for infrastructure investments in sorting and recycling,

A strategy of increasing **waste collection and disposal to sanitary landfill** can deliver similar benefits in terms of avoiding plastic pollution by 48% between 2023-2040, compared to the BAU. Increased waste collection and disposal can also reduce GHG by 8%, and increase employment by 11%, relative to BAU. However, it would also increase capital costs by 29% between 2023-2040, compared to BAU due to the costs of increasing collection and disposal to sanitary landfill. Given the same increase in the collection of plastic waste, the capital costs (required investment) of increased disposal of plastics waste are approximately 15% greater than the costs of recycling; mainly as a result of the avoided capital costs associated with virgin polymer production as a result of increasing recycling. Furthermore, recycling delays disposal by keeping the plastic in the economy for longer, and thereby delivers greater socio-economic benefits, compared to disposal.

While individual strategies can reduce plastics pollution, compared to the BAU, only a **combined strategy** of **Optimal System Change,** which includes reducing plastic consumption, increasing collection and recycling, together with the effective disposal of residual/non-re-cyclable plastic material, will lead to a substantial 63% reduction in plastic pollution by 2040, compared to business-as-usual. In addition, by 2040, System Change can avoid 37% of projected GHG emissions; decrease required investment by 67% (as a result of avoided capital costs in plastic production, conversion and disposal); as well as increase employment by 3%; compared to business-as-usual.

In short, the Optimal System Change can substantially reduce plastic pollution while also meeting the objectives of reducing GHG emissions, increasing employment, and minimising costs.

5 System Change Strategies

The Optimal System Change Scenario, as shown in Chapter 4, provides the optimal scenario for South Africa in terms of minimising plastic pollution, while also reducing GHG emissions, reducing capital cost, and maximising employment. This chapter describes the key strategies that will need to be put in place in order to ensure that South Africa can achieve the Optimal System Change scenario by 2040.

The Optimal System Change scenario requires a combination of strategies or 'levers' to reduce plastic pollution; namely reduce plastic demand and substitute, increase plastic waste collection and recycling, and increase the safe disposal of plastics to sanitary landfill. These strategies substantially improve plastic waste management and reduce plastic pollution (Figure 40), and are described individually in further detail below.

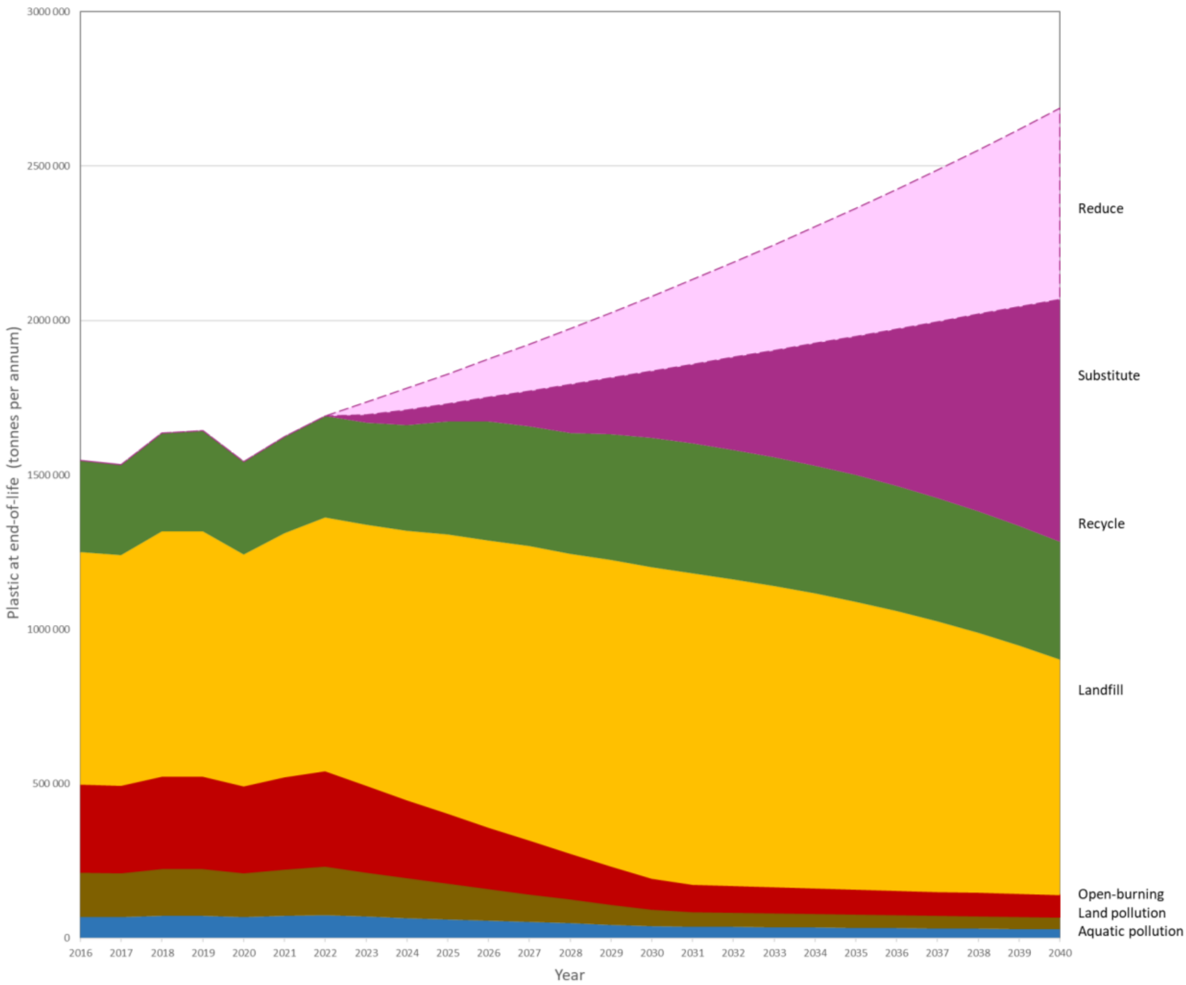


Figure 40: The avoided plastic pollution (tonnes/annum) of the Optimal System Change scenario compared to the Business-As-Usual plastics end-of-life. Plastic pollution (air pollution from open burning, land pollution, and aquatic pollution) is substantially reduced in the Optimal System Change scenario by avoiding plastics reaching end-of-life through reducing and substituting; delaying the plastics end-of-life through recycling; and disposing of residual plastic waste to sanitary landfill where containment can be assured.

5.1 Reduce plastic demand and substitute

Optimal System Change requires a **gross reduction in plastic demand of 2.57% per annum** which avoids 3495 kt of plastic pollution between 2023-2040.

The 2.57% per annum gross reduction in plastic demand can be achieved through a combination of interventions, including:

(i) *Designing for re-use,* which involves a mindset change to keep plastics in the economy as long as possible, and thereby moving towards a more circular economy

(ii) *Switching to new delivery models* to avoid the need for plastics (examples include refill services, shifting products to services, e-commerce, and dispensers)

(iii) *Eliminating* plastic products or components of products that are problematic and/or unnecessary

(iv) *Substituting* of plastics with paper, coated paper, and compostable bioplastics; while ensuring equivalent product functionality and that overall environmental impacts are reduced.

The strategy and action plan to attain this 2.57% per annum **gross demand reduction** will need to be developed, but our modelling approach suggests attributing the reduction as follows:

- "**demand reduction**" which reduces plastics demand by 1.20% per annum; as per commitments from global industry to eliminate, re-use and reduce plastics packaging (Lau, *et al*., 2020). This "demand reduction" was further attributed to:
  - "re-use" (0.24% per annum)
  - "eliminate" (0.36% per annum)
  - "new delivery models" (0.60% per annum)
- "**plastic substitution"** which reduces plastics demand by 1.37% per annum as a result of switching from plastics to an alternative material " was further attributed to:
  - "substitute paper" (0.69% per annum)
  - "substitute coated paper" (0.41% per annum)
  - "substitute compostables" (0.27% per annum)

In terms of reducing plastic pollution, the strategy to reduce plastic demand through re-use, elimination and new delivery models, is a cost-effective strategy to reduce plastic pollution, since it avoids both the need for plastic production, as well as the need for disposal and waste treatment. The net cost in present value terms of the Optimal System Change for the period 2016-2040 is $19 352 million, compared to the EPR of $60 990 and BAU of $67 337 million.

While the additional or avoided costs for plastic production, manufacturing, collection, recycling and disposal have been included together with the costs of substitution to alternatives; the costs of plastic reduction by means of re-use, alternative delivery models and elimination have not been included, due to lack of data. Nevertheless, this result does suggest that savings in required investment for plastic production and manufacturing outweigh the added costs for recycling and safe disposal to sanitary landfill; and highlights that reducing plastic demand is an effective and cost saving strategy to reduce plastic pollution.

Strategically, plastic demand reductions should perhaps focus on flexible mono-materials and multi-materials, that are often problematic for efficient separation and recycling. While there are several bioplastics that could potentially substitute plastic products (and/or the plastic coating on paper products), only some (e.g., PHB, PBS, PBAT, cellophane, starch) are readily biodegradable and fully compostable under both home and industrial conditions. Others (e.g., PLA) are only compostable under industrial composting conditions, where temperature and moisture can be regulated and optimised. (Song *et al*., 2009). Therefore, biodegradable plastic alternatives should be certified according to their composability in home and industrial composting systems and appropriate collection and composting infrastructure should be put in place (European Environment Agency, 2020).

5.2 Increase plastic collection and recycling

Optimal System Change requires an **annual increase of 4.85% in plastics waste collection and a 4.54% increase in sorting of plastic from mixed waste, so that plastic is available for recycling**. This highlights the requirement to improve the recycling rate by improving collection, separation and sorting, particularly through source separation of waste, which enables efficient sorting and quality recyclables to be accessed. Further, **an increase in both mechanical and chemical recycling is needed**; with annual increases of 4.82% for Mechanical Recycling to plastics, 4.58% Mechanical Recycling to non-plastic, and 4.28% Chemical recycling to plastics. Mechanical recycling is the most established and cost-effective solution to recover plastic, and involves the physical separation of plastics from the waste stream. Mechanical recycling can produce recyclate used for plastic products (mechanical recycling to plastics) or non-plastics (mechanical recycling to non-plastics), but only mechanical recycling to plastic products can help to reduce the demand for virgin polymer.

Chemical recycling uses chemical means to extract plastic polymers or monomers for recycling into new products; which may be plastics or fuels. Chemical recycling is currently more costly than mechanical recycling, and therefore better suited to residual plastics after mechanical recycling has been applied, or application to specific plastic products. For example, there are constraints in mechanical recycling of plastics that have had food contact (e.g., food packaging) back into food contact applications), but since chemical recycling is able to extract and purify the plastic polymers or monomers, they may be recycled without loss of quality (closed-loop recycling), and be deemed suitable for food applications. **While chemical recycling currently plays a minor role in recycling of plastics in South Africa, it is set to feature more prominently in the future; especially with the need to access a greater portion of recyclables and meet increasing targets for plastics recycling**.

Given the carbon-intensity of South Africa's energy mix, the supply constraints of energy from limited fossil fuels, and the volatility in fuel prices; there is a growing interest in using plastics for incineration with energy recovery, and in the production of liquid transport fuel. Currently, the plastics-to-fuel production cost is relatively inexpensive compared to the conventional route of liquid petroleum fuel production. Some plastics are unsuitable as a fuel since they contain chemicals that create air pollution problems (HDPE, LDPE and PP are plastic polymers containing only carbon and hydrogen and are suitable as a fuel source, but other plastics such as PET and PVC are less suitable) (Kunwar *et al*., 2016).

Although energy from plastic waste may be an attractive option in the future, the recycling of plastic materials remains the option of choice for material recovery and a circular economy. This highlights the need for strategic planning of the recycling options, so that actions can be coordinated in a timely manner and integrated; and so that plastic waste is recycled according to the waste management hierarchy; and in a way that helps transition South Africa to a circular economy and a more sustainable development path.

The research conducted as part of this project has indicated that there is currently opportunity to increase the recycling rate in South Africa. However, the challenge is to increase the demand for recycled products in order to stimulate the increased collection of recyclable materials. Increased recycling therefore goes hand-in-hand with increased collection of waste, but source separated waste is preferred, since it helps to ensure improved quality of recyclables and therefore of recycled material.

Improved plastic separation at source as well as improved sorting of mixed waste will be needed, and this will require additional infrastructure capacity and capital investments. Compared to the BAU, an additional $1391 million will need to be invested in collection, sorting and recycling infrastructure to meet the EPR recycling targets. However, despite these added capital costs for infrastructure, the avoided costs of plastics production, manufacturing and disposal will result in EPR achieving a 10% cost saving ($6346 million in present value terms) compared to the BAU scenario. Between 2023-2040, this investment will have resulted in the recycling of 5300 kt of plastic, and thereby avoided plastic pollution through the recovery of valuable recyclate, which displaces the need for virgin polymer.

5.3 Increase waste collection services and safe disposal to sanitary landfill

Optimal System Change requires **not only an increase in waste collection by 4.85% per annum,** but also a **3.36% per annum improvement in the management of unsorted waste,** to **ensure the safe disposal and containment of approximately 382 kt per annum of plastics to sanitary landfills.**

An immediate challenge is to improve the management of waste in areas where waste collection is lacking or failing, and to bring nearly 6.7 million South African households into waste collection services. Since more than 87% households in urban areas have regular waste collection services, while in rural areas it is just 13% (Rodseth *et al*., 2020), improved waste collection in rural areas should be a priority. However, addressing the deficiency in waste collection services in remote rural areas provides new challenges, which may require new waste collection and management models.

In many cases where waste management is lacking, open burning is used as a means of waste treatment. Open burning occurs at open dumps consisting of uncollected and improperly disposed waste from rural and un-serviced urban households (60%), as well as waste that has been collected but improperly disposed to non-compliant, unsanitary municipal landfills (13%). The inefficiency of open burning practices casues notable local air pollution from the partial combustion of plastics and associated mixed waste; and this poses a risk to human health, biodiversity and ecosystems.

It is important to note that while increased collection will avoid the plastic pollution associated with un-serviced households disposing plastics to open-dumps, it will increase the plastic waste being disposed to municipal landfills - both sanitary and unsanitary. Therefore, **to prevent open dumps and unsanitary landfills leaking 5274 kt of plastics into the environment between 2023-2040, immediate action is needed to phase out open dumps and improve the design and operation of all landfills, so that they can be classed as sanitary, through the effective cover and containment of plastics *in situ.***

6 Conclusions and recommendations

The conclusions drawn here are based on applying the Pathways tool and the associated scenario builder (Beta version, v1.9.7.9) to South Africa. The Pathways tool provides a systems perspective on the current and projected flows of plastic through the South African value chain. This insight provides the evidence to develop a comprehensive strategy to reduce plastic pollution in South Africa.

The model was run for three scenarios – a *Business-As-Usual (BAU) Scenario*, which assumes no policies or measures for addressing plastic pollution; an *Extended Producer Responsibility (EPR) Scenario*, with five-year targets for increasing recycling according to recent EPR legislation; and an *Optimal System Change Scenario*, which seeks to identify an optimal solution to balance South Africa's sustainable development objectives by minimising plastic pollution, minimising GHG emissions, minimising capital costs, and maximising employment.

Business-As-Usual (BAU) Scenario

Under the BAU scenario, total plastic pollution will almost double (increase by 75%) between 2023 and 2040.
Under a scenario of Business-As-Usual (BAU), with a projected future rising population and increased consumption, there is a projected growth in plastic consumption of 1.33% per annum. The BAU scenario has no policies or measures in place to address plastic pollution, and there are no future changes in the carbon-intensity of South Africa's plastic polymer production, or in the ability of Sasol to meet local polymer demands. Without EPR, and with no new plastics-related policies and measures in place, plastic pollution is set to almost double - from 491 kt in 2020 to 865 kt in 2040. Plastic pollution consists of 57% open burning causing air pollution, 30% land pollution, and 14% aquatic pollution. The open burning of plastic waste is a concern, given the significant impacts to human health from local air pollution (Levis *et al.*, 2017). *Open burning as a waste management practice occurs at open dumps comprised of uncollected and improperly disposed wastes from rural and un-serviced urban households (60%), as well as collected waste that is improperly disposed to non-compliant, unsanitary municipal landfills (13%).*

It is important to note that while increased collection will avoid the plastic pollution associated with un-serviced households disposing plastics to open-dumps, it will increase the plastic waste being disposed to municipal landfills - both sanitary and unsanitary. Therefore, *a recommendation* ***to prevent open dumps and unsanitary landfills leaking 5274 kt of plastics into the environment between 2023-2040, is immediate action to phase out open dumps and to improve the design and operation of all landfills, so that they can be classed as sanitary through the effective cover and containment of plastics in situ.***

Due to the ineffectivenesss of open-burning practices in preventing plastic pollution, and the notable local air pollution impacts, there is a strong recommendation to reduce this practice through compliance and enforcement*.*

Most of the collection for recycling is carried out by the informal waste sector, which collects 76% of waste plastic that enters recycling. The plastic recycling rate is currently[9] 19% of total plastic waste disposed (or 22% of the total waste collected), which indicates that there is an opportunity to increase recycling rates in the move towards a more circular economy.

Analysis of the BAU scenario, reveals that most (89%) of plastic's GHG emissions occurs before plastic use and disposal[10]. The GHG footprint of South African polymer and plastic products is significantly greater than the global average, mainly as a result of the coal-to-liquids process used in the local production of plastic polymers (Sasol), and the carbon-intensity of South Africa's energy supply. ***A recommendation to reduce GHG emissions could involve reducing plastics demand through re-use, elimination and new delivery models; as well as switching from petro-based to bio-based materials***. *However, evidence is required to ensure that these alternatives have equal functionality and offer reduced environmental impacts (thorugh assessment of all environmental impact categories across the whole product life cycle).*

Extended Producer Responsibility (EPR) Scenario

Achieving the collection and recycling targets set out in South Africa's EPR regulations (R1187 of 5 November 2020) can reduce plastic pollution by 33% between 2023-2040, compared to BAU. However, in absolute terms, the reduction in plastic pollution from increased collection and recycling is balanced by growth in plastic consumption; resulting in 2040 levels of plastic pollution being similar to current levels. Extending the EPR targets so that annual improvements in collection and recycling rates go beyond the legislated five-year period, can reduce plastic pollution by 33% between 2023-2040, compared to the BAU. ***It is therefore recommended that the mandatory EPR recycling targets be reviewed and extended beyond the current five-year period, and be supplemented with appropriate targets for plastic re-use, in order to reduce virgin plastic polymer demand.***

The recent EPR legislation sets targets to increase plastic collection and recycling rates (i.e. 5% per annum for single-use packaging and an estimated 3% per annum for all plastics over a period of five years). The inefficiency in plastic collection by the formal system relates to incomplete waste collection services (backlogs) and inefficient sorting of plastic from mixed waste, while the informal sector and formal recycling industry 'cherry pick' high-value materials, leaving vast volumes of plastics uncollected, irrespective of its recyclability. Increasing collection rates will not only increase the feedstock for recycling, but will stimulate innovation and create economies of scale for currently unrecycled materials to be recycled. Since rural households represent the majority of households lacking regular waste collection services, improving waste collection and recycling in rural areas is a priority. Therefore, increasing collection of plastic for recycling will require increased waste collection services (particularly in un-serviced rural areas) and increasing waste service delivery, by introducing innovative collection systems that include waste picker integration.

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[9] In 2020, there was 1546 kt total plastic waste, of which 1350 kt was collected and 301 kt plastic was recycled.

[10] Contribution to the plastics GHG emissions: virgin plastic production 67%, plastic conversion 24%, and disposal from open burning of waste 9%.

Achieving the EPR targets will also require a transition in sorting practices from the current business-as-usual, where plastic recovery by waste reclaimers mostly occurs at landfill sites, to upstream sorting prior to landfill disposal. This will require pre-sorting and/or waste separation at source for increasing the recycling rate and improving the quality of recyclable material. ***A recommendation is to upscale and mainstream waste separation at source, and/or systems that enable more effective and efficient pre-sorting of plastic waste for recycling. This will gather the plastics in one location and make the collection and sorting of certain plastics for recycling more amenable, efficient, and cost-effective.*** Although improving sorting through development of formal waste sorting infrastructure and associated employment will likely incur a significant capital cost, the alternative would be to provide added price incentives for certain polymers that typically have low value, to make them more attractive for collection and sorting by the informal sector.

Optimal System Change scenario

The modelling conducted in this study shows that there is no single solution to address the plastic pollution problem in South Africa. The Optimal System Change Scenario is a combined strategy of reducing plastic consumption, increasing collection and recycling of plastics, and increasing the effective disposal of residual/non-recyclable plastic material to landfill. The Optimal System Change **substantially reduces plastic pollution by 63% between 2023-2040, compared to the BAU.** In addition, between 2023-2040, the Optimal System Change scenario can avoid 37% of projected plastic GHG emissions; decrease capital costs by 67% as a result of avoided capital investments in plastic production, conversion and disposal; and increase employment in the plastics value chain by 3%; compared to BAU. The Optimal System Change therefore has a slight net positive effect on employment in the plastics value chain as compared to BAU. Job losses are associated with reducing plastic demand, while employment gains are associated with increased collection and recycling and the substitution of plastics with alternatives.

The Optimal System Change scenario not only reduces plastic pollution and enables greater employment and economic value to be derived from plastics, but also helps to ensure that the plastics that are disposed, are done so in a manner that contains them in situ (i.e. safe disposal to sanitary landfill). Waste mismanagement occurs for both collected waste disposed to unsanitary municipal landfills, and uncollected waste disposed to open-dumps. *Therefore, immediate action is needed both to phase out open dumps, and to improve the design and operation of all landfills, so that they can be classed as sanitary, through the effective cover and containment of plastics in situ.*

Since recycling preferentially favours rigid mono-materials and, to a lesser extent, flexible mono-materials over multi-material plastics, these materials are removed from the waste-stream as a result of increased recycling. Therefore, compared to the BAU, the System Change scenario has a corresponding change in composition of the plastics disposed; with a proportional increase in multi-materials. The implementation of the Optimal System Change scenario could therefore be enhanced further through innovation and the targeted reduction of multi-materials that are deemed problematic.

A clear recommendation is that a combination of policies and measures will be needed to achieve Optimal System Change; including strategies to:

- **(i) increase plastic waste collection (4.85% per annum) to make plastics more available and amenable to recycling;**
- **(ii) reduce plastic demand (1.20% per annum), by increasing plastic re-use, elimination and new delivery models;**
- **(iii) increase the substitution of plastic (1.37% per annum) with paper, coated paper and compostables;**
- **(iv) increase recycling rates (4.87% per annum) and extend the EPR recycling targets beyond the legislated five year period; and**
- **(v) improve the disposal of plastics to sanitary landfill (3.36% per annum) that effectively function to contain plastics in situ and thereby reduce mismanaged plastic waste and plastic pollution.**

Achieving the full benefits of the Optimal System Change scenario needs concerted action and a collaborative approach between all stakeholders, and a commitment to support the necessary changes across the entire plastics value chain.

7 References

ARO 2022, African reclaimers *https://www.africanreclaimers.org*

Bailey, R. (2020) Github repository: richardmbailey/P2O. Available at: *https://github.com/richardmbailey*

Boucher, J., Billard, G., Simeone, E. and Sousa, J. (2020). The marine plastic footprint. Gland, Switzerland: IUCN. viii+69 pp.

Collins, C. and Hermes, J.C. (2019). Modelling the accumulation and transport of floating marine micro-plastics around South Africa. *Mar. Pollut. Bull.* 139:46–58. *https://doi.org/10.1016/j.marpolbul.2018.12.028*

Department of Environmental Affairs (DEA) (2018). South Africa State of Waste. A report on the State of the Environment. Final Draft report. Department of Environmental Affairs, Pretoria. 112pp.

Department of Forestry, Fishery and Environment (DFFE) (2021). National Waste Management Strategy, 2020. Government Notice 56, Government Gazette 44116 of 28 January 2021.

Godfrey L. (2021). Quantifying economic activity in the informal recycling sector in South Africa. *S Afr J Sci*. 117(9/10), Art. #8921. *https://doi.org/10.17159/sajs.2021/8921*

Godfrey, L. and Oelofse, S. (2018). Historical review of waste management and recycling in South Africa. *Resources*. 6(4):57. *https://doi.org/10.3390/resources6040057*

Goga, T., Harding, K., Russo, V. and von Blottnitz, H. (n.d.). A Life Cycle-based Evaluation of Greenhouse Gas Emissions for the Plastics Industry in South Africa, South African Journal of Science, *accepted for publication*

IUCN-EA-QUANTIS (2020). National Guidance for plastic pollution hotspotting and shaping action, Country report, South Africa, available on-line at *https://www.iucn.org/sites/dev/files/content/documents/south_africa_-_national_guidance_for_plastic_pollution_hotspotting_and_shaping_action.pdf*

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. and Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science*, 347(6223), 768-771. DOI: 10.1126/science.1260352

Kunwar, B., Cheng, H.N., Chandrashekaran, S.R. and Sharma, B.K. (2016). Plastics to fuel: a review. *Renewable and Sustainable Energy reviews* 54:421-428. *https://doi.org/10.1016/j.rser.2015.10.015*

Lau, W.W.Y., Shiran, Y., Bailey, R.M., Cook, E., Stuchtey, M.R., Koskella, J., Velis, C.A., Godfrey, L., Boucher, J., Murphy, M.B, Thompson, R.C., Jankowska, E., Castillo, A.C., Pilditch, T.D., Dixon, B., Koerselman, L., Kosior, E., Favoino, E., Gutberlet,J., Palardy, J.E. (2020a). Evaluating scenarios toward zero plastic pollution. *Science* 369, 1455–1461. *https://doi.org/10.1126/science.aba9475*

Lau, W.W.Y., Shiran, Y., Bailey, R.M., Cook, E., Stuchtey, M.R., Koskella, J., Velis, C.A., Godfrey, L., Boucher, J., Murphy, M.B, Thompson, R.C., Jankowska, E., Castillo, A.C., Pilditch, T.D., Dixon, B., Koerselman, L., Kosior, E., Favoino, E., Gutberlet,J., Palardy, J.E. (2020b). Supplementary material for: Evaluating scenarios toward zero plastic pollution. *Science* 369, *https://www.science.org/action/downloadSupplement?doi=10.1126%2Fscience.aba9475&file=aba9475-lau-sm-rev.1.pdf*

Levis, J.W., Weisbrod, A., van Hoof, G. and Barlaz, M.A. (2017). A review of the airborne and waterborne emissions from uncontrolled solid waste disposal site. *Critical reviews in Environmental Science and Technology.* 47(12): 1003-1041. *https://doi.org/10.1080/10643389.2017.1342513*

Li, W., Tse, H.F. and Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence, and effects. *Sci Total Environ*., 566-567:333-349. *https://doi.org/10.1016/j.scitotenv.2016.05.084*

OECD (2016). Working Party on Resource Productivity and Waste. In: Extended Producer Responsibility – Updated guidance ENV/EPOC/WPRPW(2015)16/ FINAL. Paris: OECD.

Linzer R. and Lange U. (2013). Role and size of informal sector in waste management – a review, Waste Resouce and Management, vol. 166, issue WR2

Mebratu, D. and Mbandi, A. (2022). Open Burning of Waste in Africa: Challenges and opportunities. Engineering X (founded by the Royal Academy of Engineering and Lloyd's Register Foundation) and the United Nations High Level Champions (UNHLC). Available online at *https://engineeringx.raeng.org.uk/media/u4mnsto5/open-burning-final-report_1.pdf*

Pienaar, R.A. and Palm, J.G. (2018). Implementing the waste hierarchy, what does it cost? In: Proceedings of WasteCon 2018. Emperor's Palace, 15-19 October 2018. Institute of Waste Management of Southern Africa, Johannesburg

Country leads the world in plastic recycling (thegreentimes.co.za)

Plastics SA (2020). Recycling Survey 2019. Available online at *Plastics-Recycling-in-SA-2019-Executive-Summary.pdf (plasticsinfo.co.za)*

Plastics SA (2021). Recycling Survey 2020. Available online at *https://www.plasticsinfo.co.za/wp-content/uploads/2021/11/Recycling-Survey-2020-Executive-Summary3.pdf*

Priyanka, M. and Dey, S. (2018). Ruminal impaction due to plastic materials - An increasing threat to ruminants and its impact on human health in developing countries, *Veterinary World*, 11(9): 1307-1315. doi: 10.14202/vetworld.2018.1307-1315

Public Works (2015). Guidelines for the Implementation of Labour-intensive Infrastructure projects under the Extended Public Works Programme. Third edition, 2015. *http://www.epwp.gov.za/documents/Infrastructure/Infrastructure%20incentive%20manual/EPWP_Infrastructure_Guidelines_3rd_Edition_June_2015.pdf*

Rodseth, C., Knotten, P. and Von Blottnitz, H. (2020). A revised approach for estimating informally disposed domestic waste in rural versus urban South Africa and implications for waste management. *S.Afr. J. Sci.* 116(1/2). Art. #5635, 6 pages. *https://doi.org/10.17159/sajs.2020/5635*

Sadan, Z. and De Kock, L. (2020). Plastics: Facts and Futures: Moving beyond pollution management towards a circular plastics economy in South Africa. WWF South Africa, Cape Town, South Africa. *https://wwfafrica.awsassets.panda.org/downloads/wwf_plastics_report_final_2nov2020.pdf*

Samson M. (2020). Whose frontier is it anyway? Reclaimer 'integration' and the battle over Johannesburg's waste-based commodity frontier. *Capital Nat Social*., 31(4):60–75. *https://doi.org/10.1080/10455752.2019.1700538*

Schenck C.J., Blaauw P.F., Swart E.C., Viljoen J.M.M. and Mudavanhu N. (2019). The management of South Africa's landfills and waste pickers on them: Impacting lives and livelihoods. *Dev South Afr*. 36(1):80–98. *https://doi.org/10.1080/0376835X.2018.1483822*

Sorrentino, L. (ed.) (2022). A solution package for plastic pollution – from measurement to action: insights from Eastern and Southern Africa, Southeast Asia, and the Mediterranean. Gland, Switzerland: IUCN. Available online at *https://portals.iucn.org/library/sites/library/files/documents/2022-016-En_0.pdf*

Song JH, Murphy RJ, Narayan R, Davies GB. Biodegradable and compostable alternatives to conventional plastics. Philos Trans R Soc Lond B Biol Sci. 2009 Jul 27;364(1526):2127-39. doi: 10.1098/rstb.2008.0289. PMID: 19528060; PMCID: PMC2873018.

Statistics South Africa (StatsSA) (2022). General Household Survey 2021. Statistical Release P0318. Available online at *https://www.statssa.gov.za/publications/P0318/P03182021.pdf*

The Pew Charitable Trust and SYSTEMIQ (2020). Breaking The Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution. Available online at *https://www.systemiq.earth/wp-content/uploads/2020/07/BreakingThePlasticWave_MainReport.pdf*

TIPS (2021). Trade & Industrial Policy Strategies. Manufacturing Subsectors: others chemicals, rubber and plastics. Available on-line at *Manufacturing_subsectors_other_chemicals_rubber_and_plastics.pdf (tips.org.za)*

United Nations Environment Programme (UNEP) (2021). From Pollution to Solution: A global assessment of marine litter and plastic pollution. Nairobi.

Verster C. and Bouwman H. (2020). Land-based sources and pathways of marine plastics in a South African context. *S Afr J Sci.* 116(5/6), *https://doi.org/10.17159/sajs.2020/7700*

Viljoen J.M.M. (2014). Economic and social aspects of street waste pickers in South Africa. Doctoral dissertation. Johannesburg: University of Johannesburg; *http://hdl.handle.net/10210/12273*

European Environment Agency 2020. Biodegradable and compostable plastics challenges and opportunities PDF - TH-AM-20-009-EN-N - ISBN 978-92-9480-257-6 ISSN 2467-3196 doi:10.2800/552241

von Blottnitz, H., Chitaka, T. and Rodseth, C. (2017). South Africa beats Europe at plastics recycling, but also is a top 20 ocean polluter. Really? Online. Available at: *SA plastics MFA commentary by E&PSE rev1.pdf (uct.ac.za)*

ANNEXURES

Annexure 1: System Diagram

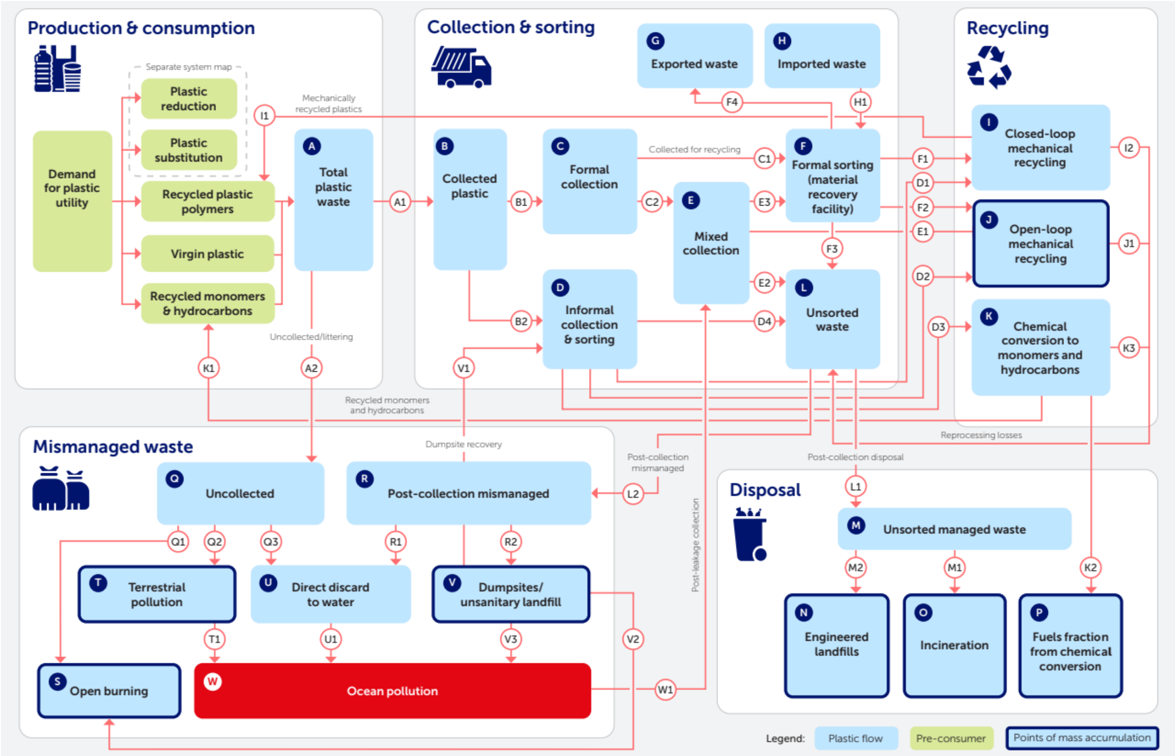


Figure 41: Global systems map from Breaking plastics wave study.

The Pew Charitable Trust and SYSTEMIQ (2020). Breaking The Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution.

https://www.pewtrusts.org/-/media/assets/2020/07/breakingtheplasticwave_report.pdf

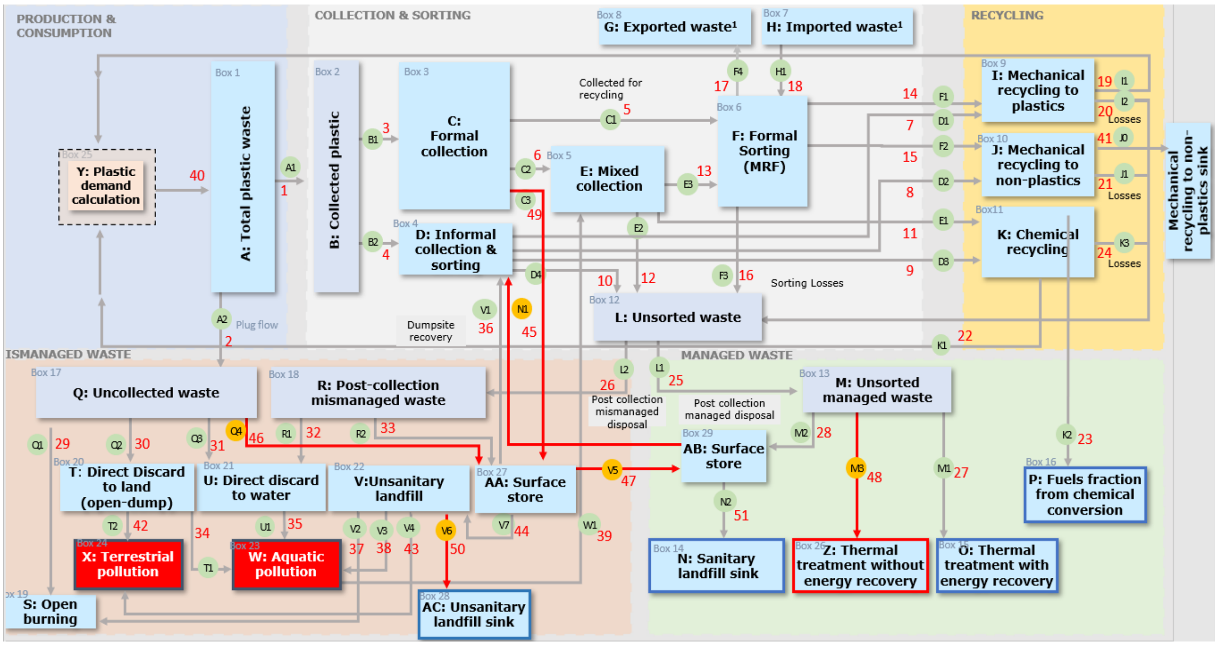


Figure 42: South African systems map with modification and with additional flows indicated in red

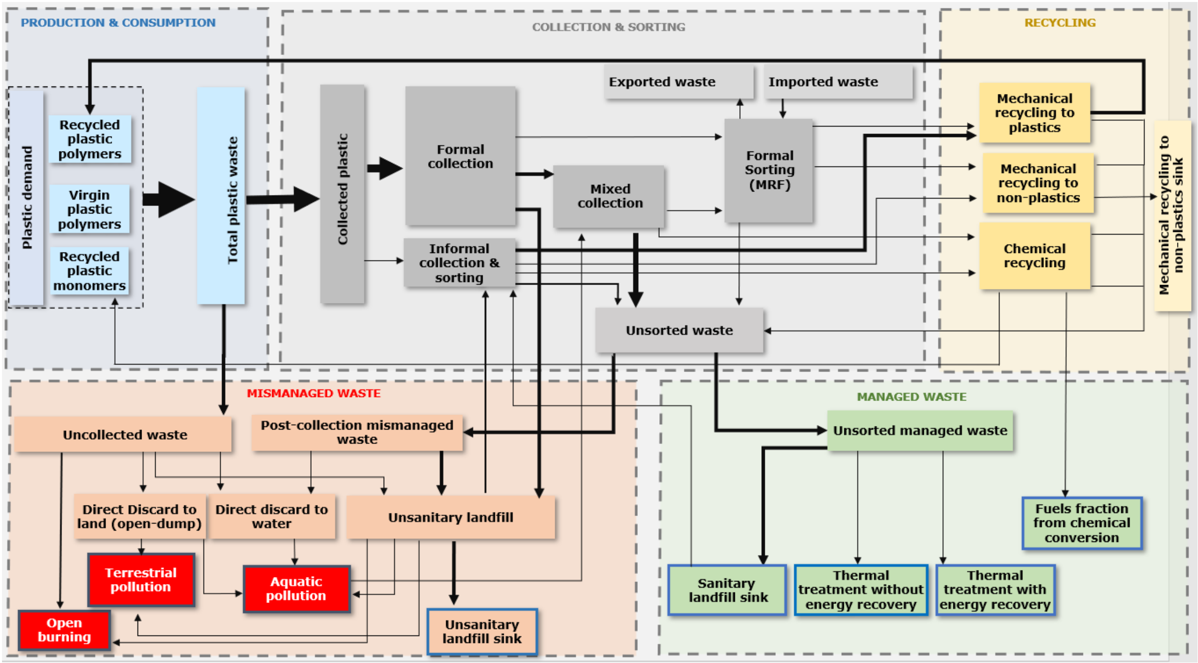


Figure 43: Simplified System map: simplified with arrow width to indicate mass flow for BAU in 2020 (Sankey) using data from table below

Table 7: Approximate values for plastic flows (as % total plastic flow) for BAU in 2020

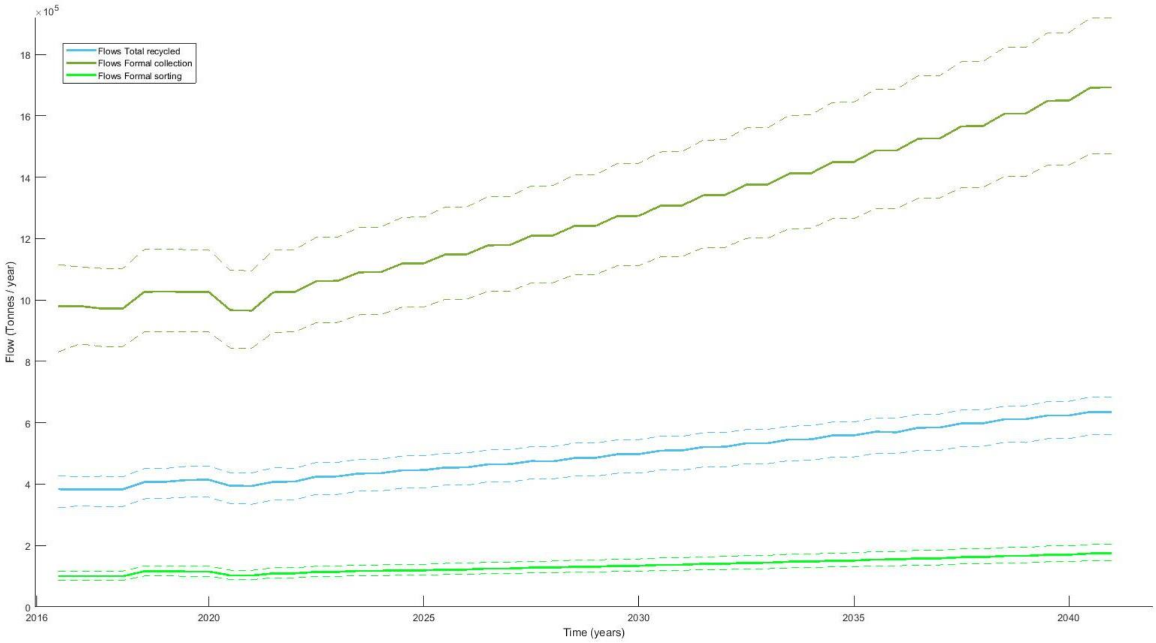
Flow #	Data pedigree level *	Mass of Plastic (t/annum)	% Flow
flow_1	3	1 097 740	71.000%
flow_2	3	448 373	29.000%
flow_3	3	1 054 040	68.160%
flow_4	3	43 918	2.840%
flow_5	2	82 234	5.316%
flow_6	2	486 022	31.422%
flow_7	2	268 294	27.704%
flow_8	2	4 295	0.640%
flow_9	2	2 206	0.108%
flow_10	2	38 514	12.397%
flow_11	2	0	0.000%
flow_12	2	467 037	30.758%
flow_13	2	19 250	1.264%
flow_14	3	41 431	3.923%
flow_15	2	1 092	0.098%
flow_16	3	66 768	5.792%
flow_17	4	2 073	8.719%
flow_18	4	9 819	12.000%
flow_19	3	245 937	24.551%
flow_20	2	63 868	6.880%
flow_21	3	0	0.037%
flow_22	1	2 206	0.107%
flow_23	1	0	0.000%
flow_24	1	0	0.000%
flow_25	3	337 252	29.981%
flow_26	3	299 073	26.587%
flow_27	2	0	0.000%
flow_28	3	333 288	30.145%

Flow #	Data pedigree level *	Mass of Plastic (t/annum)	% Flow
flow_29	4	201 797	15.352%
flow_30	4	112 108	8.529%
flow_31	4	22 423	1.706%
flow_32	4	14 957	1.337%
flow_33	4	248 187	25.396%
flow_34	4	12 458	0.898%
flow_35	4	37 389	2.969%
flow_36	1	263 840	32.323%
flow_37	4	78 432	5.448%
flow_38	4	19 429	1.219%
flow_39	4	148	0.598%
flow_40	2	1 545 600	100.000%
flow_41	4	5 388	0.695%
flow_42	4	99 675	7.231%
flow_43	4	46 801	2.923%
flow_44	4	603 169	31.830%
flow_45	4	5 487	5.100%
flow_46	3	112 108	8.529%
flow_47	3	15 466	0.816%
flow_48	2	4 045	0.000%
flow_49	3	486 022	31.422%
flow_50	4	458 663	32.321%
flow_51	3	343 350	27.004%

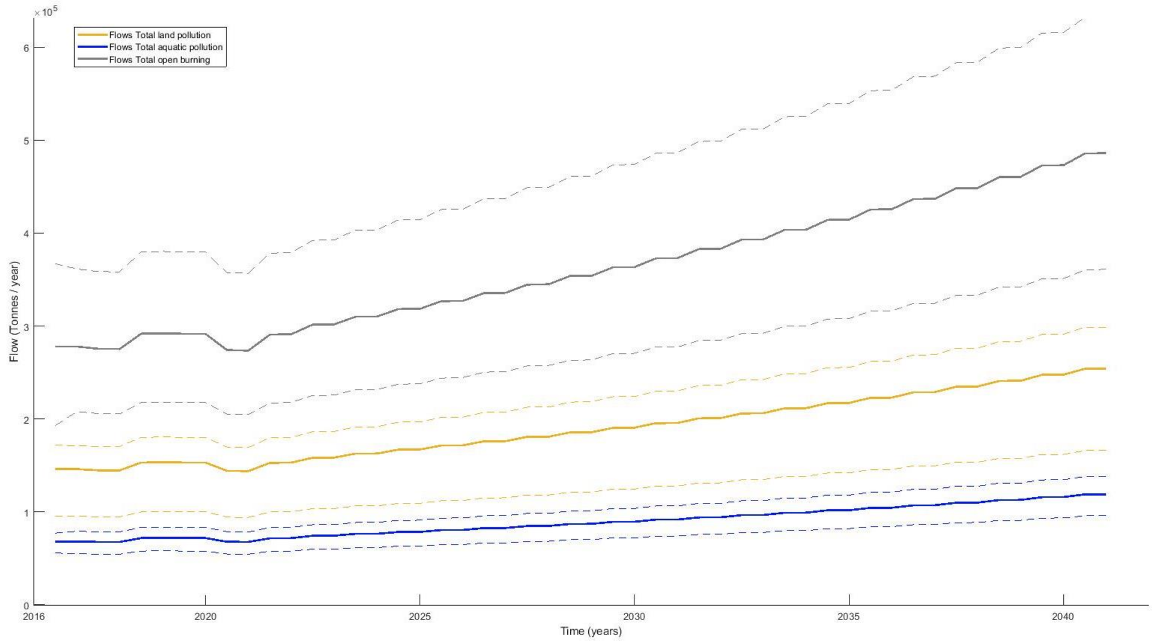
*Data pedigree refers to uncertainty

Data pedigree level	Uncertainty	
1	Low	± 10%
2	Low-Medium	± 20%
3	High-Medium	± 35%
4	High	± 50%

The two graphs below illustrate the effect of uncertainty on key flows in the model for BAU



Waste management flows showing uncertainty interval



Plastic pollution flows showing uncertainty interval

Annexure 2: Key assumptions and data sources

This appendix describes the most important assumptions and data sources that were used for the purposes of building the Business-As-Usual (BAU) scenario for South Africa

Population data (Workdbank)
The estimated South African **population in 2016 is 56 207 649**
and the calculated compound annual growth rate (CAGR) of 1.3% applied for the projection up to 2040 (World Bank) https://worldpopulationreview.com/countries/south-africa-population

Total Plastic Waste (calculated value using industry data)
Sum of locally produced plastic items, imports and recyclate
= (1 518 000 + 148 000 + 295 000) *0.8
= 1 568 800t

The estimate of 1 568 800 is based on industry data for all plastic waste excluding durables (20% less) as follows:

Total locally manufactured plastics (virgin and recycled) = 1 518 000t
Plastics SA statistics on consumption of plastics
STATISTA for GDP growth rate till 2026 then same rate was applied up to 2040.
For plastic projection the GDP growth rate was used as per STATISA: 2021 (5%), 2022 (2.16%), 2023 (1.4%), 2024 (1.3%), 2025 (1.3%), 2026 (1.3%).
Data pedigree uncertainty 1 up to 2020, then 2

Net Imports (durable and packaging) = 148 000t
This data does not refer to imported packaging or packaged goods but in the absence of waste data, it was assumed that imported products and packaging could end up in the MSW. Therefore, net imports of finished and semi-finished products were used for 2016, 2019 and 2020.

For year 2017 (UCT MFA)
For year 2018 (WWF MFA)
http://www.epse.uct.ac.za/sites/default/files/image_tool/images/363/Publications/SA%20plastics%20MFA%20commentary%20by%20E%26PSE%20rev1.pdf
For years 2016, 2019 and 2020 source was SARS HS 3916 up to HS 3926.

Recyclate = 295 000
PlasticsSA data
Data pedigree uncertainty 1 up to 2020, then 2

Annual Plastics Waste Generation per capita (Calculated value using industry data)
Local production only = 27.01 kg/person
Local production + imports + recyclate = 27.9 kg/person

Annual growth in plastic waste generation

Calculated value based on historical data from Plastics SA (base yr 2020 for projections) and projected value from 2021 using STATISTA for GDP growth rate till 2026 then same rate was applied up to 2040. Rates: 2021 (5%), 2022 (2.16%), 2023 (1.4%), 2024 (1.3%), 2025 (1.3%), 2026 (1.3%).

Proportion of plastic waste per mono-material category (CSIR estimate using waste data)

Rigid mono-material plastic = 50%
Flexible mono-material plastic = 30%
Multimaterial = 20%
Data pedigree uncertainty 2

Available waste characterization studies of MSW were analysed to estimate the spilt between the two mono-material categories and the multi-material category. Data at this level of detail were only available for a limited number of municipalities including four metropolitan and three rural local municipalities. For the estimate of multi-material plastics data on Tetrapak were added into the equation.

Landfill capacity used (Upper Middle-Income (UMI) Archetype data)

UMI urban and rural archetype data have landfill capacity at 50 000 metric tonnes/yr.

According to the State of Waste report (DEA, 2018) there are 704 licensed waste disposal sites in South Africa but there is no central database available for monitoring landfill capacity usage at country level. In addition, few landfills are regularly surveyed to determine the available landfill capacity and when it is done, the available capacity is typically reported as operational years remaining before closure. In the absence of local South African data, the UMI urban and rural archetype data were used.

Incineration capacity used – There is no incineration of plastics from the municipal solid waste stream currently in South Africa (Plastics SA), only for the treatment of medical and hazardous waste.

Recycling capacity used (Industry data collected for PlasticsSA)

This information is collected for the annual Plastics Recycling Survey of Plastics SA for 2016 to 2019. Spare capacity data from re-processors were not collected because of the reduced number of respondents due to covid when compared to previous years. Historic data suggest that it should be between 70-80%

Percentage of total plastic waste collected = 71%

Rodseth *et al*., (2020) estimated the income-adjusted domestic waste that is not collected to be 29%. It is therefore assumed that 71% of municipal solid waste is formally collected.

Percent of waste to open burning

Open-burning of uncollected waste is prevalent in South Africa, but there is no official country specific data available. Based on the findings from Wiedinmyer *et al*., 2014 the Breaking the Plastics Wave Study assumptions for open burning of collected plastic waste globally is 13 per cent, while the open burning of uncollected waste in residential areas is 60 per cent (Lau, *et al*., 2020). Therefore, 13%

burning of waste was used in the modelling for the unsanitary landfills (flow V2) and 60% burning of waste for the uncollected and self-help disposal (Q1)

Percentage of plastic waste collected from open-dumps and unsanitary landfills to engineered landfills
2.5% based on Rodseth *et al*., 2020.

Plastic waste in engineered landfill collected and sorted by the informal sector for recycling
0.5% as best estimate based on the combined expert opinion of the South African project partners

Plastic waste in open-dumps / unsanitary landfill collected and sorted by the informal sector for recycling
To determine the plastic waste recovered by the informal sector the following assumption were used:

- *Number of waste pickers*: 58750 informal income opportunities (from Plastic SA Recycling Survey2019, 2020) then translated in FTE resulting in 36 491;
- Estimate of *plastic collection for waste picker (tonnes/person/year)* was sourced from Plastic SA (2014) and compared with what reported in the meta-study on informal sector by Linzer and Lange (2013), which yields to 12 tonnes/person/year when considering FTE employment;
- *Percentages of rigid and flexible mono-material and multi-material items recovered by waste pickers from open-dumps/unsanitary landfills*: PEW provided estimates from both the global study and a pilot test of the Pathways tool from a city in India, similar to the current South African study. South African data from a UNEP funded waste separation at source pilot study involving waste pickers in the Newcastle municipality was compared and augmented with expert knowledge. Hence, the percentages from the Indian pilot study, which favours more the collection of rigid mono-material items, were deemed the best proxy to be used in the South African context.

Annexure 3: Challenges experienced in data collection

The challenges experienced are listed in the Table 8 for future reference and to inform future data collection strategies for modelling purposes.

Table 8: Challenges in data collection

Data Category	Challenge
Data granularity	Recycling rates in South Africa are reported as a % of *locally manufactured virgin plastics*, and not as a % of plastics disposed.
	Data on imported products packaged in plastics are not available
	Data on rigid and flexibles can be calculated, but multi-materials are more difficult to source.
Lack of data / Poor reporting	The split between formally collected and informally collected materials for recycling is typically not recorded by the industry.
	There is a lack of data on open-loop recycling, especially in applications such as road construction and composite bricks for the building industry. Wood replacements data is available.
	Poor reporting of data on MSW by municipalities into SAWIS.
	There is a lack of data on plastics recovery from landfills. This is typically done by the informal sector and often not recorded at landfills.
	There is a lack of data on uncollected waste and the split between the waste management options implemented.
	There is a lack of data on the split between managed and mismanaged waste, e.g., open-dumps and sanitary and unsanitary landfills
	There is lack of data on the combined available landfill airspace in South Africa. Landfill airspace determinations in South Africa are typically done through surveys and reported as years of operational life remaining per landfill. The Pathways tool require data on % of total capacity used at national level.
	There is a lack of data on disposal rates at landfills to guide the estimates for landfill usages.
Waste characterisation	Waste characterisation studies are not available for all municipalities.
	Characterisation studies do not follow standard methodologies and results are not directly comparable.
	In waste characterisation studies, plastics are often reported as a single category combining all different polymers and multi-materials together. Tetra Pak and absorbent hygiene products (AHP), both containing plastics are typically not recorded as plastics. Tetra Pak is often grouped with paper and AHP with hygiene waste.

Annexure 4: Scenario development

1. Business-As-Usual Scenario

Great effort went into developing the Business-As-Usual (BAU) Scenario to ensure a high level of confidence in the data, since it depicts the current plastic waste management in South Africa, and it represents the baseline against which the other scenarios are compared and/or derived. Care was taken to ensure that the data entered into the Pathways tool is the best available data for South Africa, and that the results from applying the tool made sense in the South African context. Only once the BAU scenario results made sense, the other scenarios were developed and introduced for comparison purposes.

The BAU Scenario was built using a combination of historical data covering years 2016-2020 provided by industry (Plastic SA) and data from literature. The data projected to 2040 were either inferred from historical data, i.e., South African projections where possible (e.g., Gross Domestic Product (GDP) growth rate) or using background archetype data from the global model (UMI archetype, urban) as last resort. A consultative process with TAG members, and specifically Plastic SA, was carried out to source data and to inform decision on data apportioned to the three plastic categories.

Historical data formed the basis to depict the BAU Scenario and to derive values representing specific flows required by the Pathways tool. Table 9 provides for further details on the key assumption on data.

Table 9: Detail on historical data sources and calculation (where applicable)

Flow	Data source	Details on values/calculations
ALL Plastic Categories		
Population	The World Bank	Actual data on population up to Yr. 2021
Total Plastic Waste (Box A)	Plastic SA, 2022 , Comtrade and IUCN Plastics Hotspotting report	Refers to total plastic waste excluding durable (20%) as the sum of locally produced plastic products, imports and recyclate production
Total Locally manufactured packaging	Plastic SA, 2022	Actual figures (Yr. 2016-2020)
Net import (durables and packaging)	Plastics SA, 2022 (SARS data – HS 3916 to HS 3926)	Actual figures (Yr. 2016-2020)
Recyclate	Plastic SA	Actual figures (Yr. 2016-2020)
Waste generation per capita	Calculated value	Calculated from Total Plastic Waste and Population
Projected annual growth in plastic waste generation	Informed by historic data	-
Proportion of plastic waste as rigid mono-material plastic	Waste characterization studies of MSW	50%
Proportion of plastic waste as flexible mono-material plastic	Waste characterization studies of MSW	30%
Proportion of plastic waste as multi-material	Waste characterization studies of MSW	20%
Landfill capacity used	UMI archetype data	-
Incineration capacity used	Plastics SA	0%
Recycling capacity used	Plastics SA Recycling Surveys	Actual figure up to Yr. 2020
Percentage of total plastic waste collected – A1	Rodseth *et al.*, (2020)	71%
Percentage of uncollected waste to open burn – Q1	UMI archetype data	60%

Flow	Data source	Details on values/calculations
Percentage of openly burnt plastic in open-dumps – V2	IUCN-EA_QUANTIS (2020)	13%
Percentage of plastic waste collected from open-dumps and unsanitary landfills to engineered landfills – V5	Rodseth *et al*., (2020)	2.5 %
Uncollected waste to m /unsanitary landfills – Q4	(Rodseth et al., 2020) for MSW left uncollected (29%) and IWMP data for the % of plastic in MSW (13%)	Calculated values from total plastic waste p.a.
Plastic waste in engineered landfills collected and sorted by Informal sector for recycling – N1	Calculated value. Used 0.5% as best estimate.	Calculated values from total plastic waste p.a. as 0.5% of the total collected waste (71%).
Formal collection for disposal in engineered landfills, incineration or recycling – B1	Plastics SA (2021)	Rigid and Flexi: 85% Multi: 100%
Total informal household and street collection – B2	Plastics SA (2021)	Rigid and Flexi: 15% Multi: 0%
Formal collection sent to non-engineered landfills – C3	Estimate based on the combined expert opinion of the South African project partners	Calculated value 46.1%: calculated as 50% of the residual of flow B1 after deducting what is collected from S@S
Percentage of formally collected plastic for recycling (S@S) – C1	Plastics SA (2021) Recycling Survey and GreenCape Market Intelligence Analysis: Separation at Source and MRF's.	7.8%
Percentage of formally collected plastic sent to mixed collection -C2	Estimate based on the combined expert opinion of the South African project partners	Calculated value 46.1%: calculated as 50% of the residual of flow B1 after deducting what is collected from S@S
Percentage of informally collected going to CL recycling – D1	Plastics SA Recycling Survey	Rigid and Flexi: 90% Multi: 0%
Percentage of informally collected going to OL recycling – D2	Plastics SA Recycling Survey	1% (Rigid); 3.5% (Flexi); 0% (Multi)
Percentage of informally collected going to Chemical Conversion – D3	Plastics SA Recycling Survey	Calculated value: (tonne to Chem Conv/B1) Rigid:0.6% Flexi 0% and Multi: 0%
Losses from informal collection and sorting – D4	Plastics SA Recycling Survey	Calculated value: (100%-D1-D2-D3) Rigid: 8.3%; Flexi: 9% Multi: 100%
Percentage of formally collected plastic in mixed waste to ChemConv (P2P) – E1	Plastics SA Recycling Survey	0%
Percentage of collected plastic in mixed waste not being recycled – E2	Plastics SA Recycling Survey	Rigid and Flexi: 95% Multi: 100%
Percentage of collected plastic in mixed waste going to MRF – E3	Plastics SA Recycling Survey	Rigid and Flexi: calculated value: 5% (100%-E1-E2) Multi: given value: 0%
Percentage of plastic formally collected sent to CL recycling – F1	Plastics SA Recycling Survey	Rigid and Flexi: 45% based on yield from formal MRFs Multi: 0%
Percentage of plastic formally collected sent to OL recycling – F2	Plastics SA Recycling Survey	1% (Rigid, Flexi and Multi)
Sorting Losses (MRF) – F3	Plastics SA Recycling Survey	Rigid and Flexi 54% (100%-F1-F2) Multi: 99% (100%-F1-F2)
Exported waste – F4	SARS Trade stats	Rigid and Flexi: Actual values (Yr. 2016-2020) Multi: 0
Imported Waste – H1	SARS Trade stats	Rigid and Flexi: Actual values (Yr. 2016-2020) Multi: 0
Share of plastic actually recycled via CL mechanical recycling – I1	Plastics SA Recycling Survey	Rigid: 80% (100%-I2) Flexi: 77.5-74.3% (100%-I2)

Flow	Data source	Details on values/calculations
		Multi: 100%
Losses at CL mechanical recycling – I2	Plastics SA Recycling Survey	Rigid: 19% Flexi: 22.5-25.7% Multi: 0%
Losses at OL mechanical recycling – J1	Plastics SA Recycling Survey	0% (Rigid, Multi, Flexi)
Share of chemical conversion P2P (monomers and hydrocarbons) – K1	Plastics SA Recycling Survey	0% (Rigid, Multi, Flexi)
Share of chemical conversion P2F – K2	Plastics SA Recycling Survey	0% (Rigid, Multi, Flexi)
Losses at Chemical Conversion	Plastics SA Recycling Survey	0% (Rigid, Multi, Flexi)
Percentage of unsorted/mixed waste being managed (for disposal) – L1	UMI data	53 % (Rigid, Multi, Flexi)
Percentage of unsorted waste mismanaged – L2	UMI data	47 % (Rigid, Multi, Flexi)
Proportion of collected waste going to incineration with Energy recovery – M1	Plastics SA Recycling Survey	Calculated value in the range of 1.05-1.2%
Percentage of unsorted managed waste to landfills – M2	Plastics SA Recycling Survey	Calculate value (100%-M1-M3)
Proportion of collected waste going to incineration w/o Energy recovery – M3	Plastics SA Recycling Survey	0% (Rigid, Multi, Flexi)
Post leakage collection from aquatic environment – W1	International Clean-Up campaigns and actions	Actual values (Yr. 2016-2020): Rigid: 88-101 tonne/yr. Flexi: 44-50 tonne/yr. Multi : 9-10 tonne/yr.
Uncollected waste to open-dumps/unsanitary landfills – Q4	Calculated value	Calculated year on year from Q4-ALL and using the split for rigid, flexi and multi
Plastic waste in engineered landfills collected and sorted by informal sector for recycling – N1	Calculated value	Calculated year on year from N1-ALL and using the split for rigid, flexi and multi

Future Projections were inferred from historical data, when possible, else the global UMI archetype data trends were used to fill gaps. Considerable discrepancies between historical data and global trends were resolved by the TAG by preferring using historical data trends for projections. Details on how projections were determined are provided in Table 10.

Table 10: Details of data projections

Flow	Data source	Details on values/calculations
ALL Plastic Categories		
Population	The World Bank	Projection by Percent Growth: CAGR at 1.3% p.a.
Total Plastic Waste (Box A)	Plastic SA	Same as historical data
Total Locally manufactured packaging	Plastic SA and STATISTA	GDP growth rate used for projections for Yrs. 2021 to 2026, then same rate of 2026 up to 2040.
Net import (durables and packaging)	Plastic SA	Average growth rate calculated from historical data and applied to projection from Yr. 2021 up to 2040
Recyclate	Plastic SA	Average growth rate calculated from historical data and applied to projection from Yr. 2021 up to 2040
Waste generation per capita	Calculated value	Calculated from Yr. 2020 and increased by Projected annual growth in plastic waste generation (converted in Kg/person).
Projected annual growth in plastic waste generation	STATISTA	GDP growth rate used for projections for Yrs. 2021 to 2026, then same rate of 2026 up to 2040.
Proportion of plastic waste as rigid mono-material plastic	Waste characterization studies of MSW	Projections same as historical data
Proportion of plastic waste as flexible mono-material plastic	Waste characterization studies of MSW	Projections same as historical data
Proportion of plastic waste as multi-material	Waste characterization studies of MSW	Projections same as historical data
Landfill capacity used	UMI archetype data	-
Incineration capacity used	Plastics SA recycling surveys	0%
Recycling capacity used	Plastics SA Recycling Surveys	Projections considered values within the 70-80% range
Percentage of total plastic waste collected – A1	Rodseth *et al.*, (2020)	Same as historical data
Percentage of uncollected waste to open burn – Q1	UMI archetype data	Same as historical data
Percentage of openly burnt plastic in open-dumps – V2	UMI archetype data	Same as historical data
Percentage of plastic waste collected from open-dumps and unsanitary landfills to engineered landfills – V5	Rodseth *et al.*, (2020)	Same as historical data
Uncollected waste to open-dumps/unsanitary landfills – Q4	(Rodseth *et al.*, 2020) for MSW left uncollected (29%) and IWMP data for the % of plastic in MSW (13%)	Calculated values from total plastic waste p.a.
Plastic waste in engineered landfills collected and sorted by Informal sector for recycling – N1	Calculated value. Used 0.5% as best estimate.	Calculated values from total plastic waste p.a. as 0.5% of the total collected waste (71%).
Rigid and Flexible mono-material, Multi-materials		
Formal collection for disposal in engineered landfills, incineration or recycling – B1	Plastics SA Recycling Survey	Same as historical data
Total informal household and street collection – B2	Plastics SA Recycling Survey	Same as historical data
Formal collection sent to non-engineered landfills – C3	Estimate based on the combined expert opinion of the South African project partners	Same as historical data
Percentage of formally collected plastic for recycling (S@S) – C1	Plastics SA Recycling Survey and GreenCape Market Intelligence Analysis: Separation at Source and MRF's.	Same as historical data

Flow	Data source	Details on values/calculations
Percentage of formally collected plastic sent to mixed collection – C2	Estimate based on the combined expert opinion of the South African project partners	Same as historical data
Percentage of informally collected going to CL recycling – D1	Plastics SA Recycling Survey	Same as historical data
Percentage of informally collected going to OL recycling – D2	Plastics SA Recycling Survey	Same as historical data
Percentage of informally collected going to Chemical Conversion – D3	Plastics SA Recycling Survey	Same as historical data
Losses from informal collection and sorting – D4	Plastics SA Recycling Survey	Same as historical data
Percentage of formally collected plastic in mixed waste to ChemConv (P2P) – E1	Plastics SA Recycling Survey	Same as historical data
Percentage of collected plastic in mixed waste not being recycled – E2	Plastics SA Recycling Survey	Same as historical data
Percentage of collected plastic in mixed waste going to MRF – E3	Plastics SA Recycling Survey	Same as historical data
Percentage of plastic formally collected sent to CL recycling – F1	Plastics SA Recycling Survey	Same as historical data
Percentage of plastic formally collected sent to OL recycling – F2	Plastics SA Recycling Survey	Same as historical data
Sorting Losses (MRF) – F3	Plastics SA Recycling Survey	Same as historical data
Exported waste – F4	SARS Trade stats	Calculated value year on year based on the average of the previous 5 years (Rigid and Flexi); 0 for Multi
Imported Waste – H1	SARS Trade stats	Calculated value year on year based on the average of the previous 5 years (Rigid and Flexi); 0 for Multi
Share of plastic actually recycled via CL mechanical recycling – I1	Flexi: UMI data	Rigid: same as historical data Flexi: 73% Multi: same as historical data
Losses at CL mechanical recycling – I2	Flexi: UMI data (available local data is similar)	Rigid: same as historical data Flexi: 27% Multi: same as historical data
Losses at OL mechanical recycling – J1	Plastics SA Recycling Survey	Same as historical data
Share of chemical conversion P2P (monomers and hydrocarbons) – K1	Plastics SA Recycling Survey	Same as historical data
Share of chemical conversion P2F – K2	Plastics SA Recycling Survey	Same as historical data
Losses at Chemical Conversion	Plastics SA Recycling Survey	Same as historical data
Percentage of unsorted/mixed waste being managed (for disposal) – L1	UMI data	Same as historical data (53%)
Percentage of unsorted waste mismanaged – L2	UMI data	Same as historical data (47%)
Proportion of collected waste going to incineration with Energy recovery – M1	Plastics SA Recycling Survey	Calculated value in the range of 1.05-1.2%
Percentage of unsorted managed waste to landfills – M2	Plastics SA Recycling Survey	Calculate value (100%-M1-M3)
Proportion of collected waste going to incineration w/o Energy recovery – M3	Plastics SA Recycling Survey	Same as historical data
Post leakage collection from aquatic environment – W1	Calculated value	Calculated value year on year based on the average of the previous 5 years
Uncollected waste to open-dumps/unsanitary landfills – Q4	Calculated value	Calculated year on year from Q4-ALL and using the split for rigid, flexi and multi
Plastic waste in engineered landfills collected and sorted by informal sector for recycling – N1	Calculated value	Calculated year on year from N1-ALL and using the split for rigid, flexi and multi

2. Data on cost, employment and GHG emissions

As data on costs were not available for South Africa to the level of detail required for the study, the archetype data for UMI were used instead.

Accounting for employment in the plastics life cycle

Data on employment were scattered and sourced from Plastic SA (2019) as well as a government report on the manufacturing sub-sectors (TIPS, 2021). It was further augmented with urban UMI archetype data trends for both historical data and future projections. Furthermore, informal employment (reported as employment opportunities) were included and converted to Full-time-equivalents (FTE)[11]. The input figures for employment using South African data are shown in Table 11.

Table 11: Input figures for employment

Plastics value chain	Estimated employment at each stage of plastics value chain	Jobs per kilo-tonne of plastics disposed per annum[12]	Sources
Mining and exploration	1 852*	1	Sasol, Plastics SA, 2019
Polymer production	4 074*	3	Sasol, Plastics SA 2019
Conversion	32 194	19.5	TIPS
Collection and Recycling	45 115$	30	Plastics SA, 2019
Total	83 235	54.5	

* Therefore, virgin plastics production is 1 852+4 074= 5 926 or 7% of the total employment

$ Includes 36 491 Full time equivalents in *Informal* sector and 8 624 in the *Formal* Collection and Recycling

The model requires jobs per tonne product for each stage of plastics value chain, and not the jobs per kilo-tonne of plastics disposed per annum as shown in Table 12. For each stage of the plastic value chain, the model clusters the flow(s) that contribute to that specific stage, and then multiply the corresponding amount of plastic (in tonnes) by the number of jobs per tonne for the specific stage (Table 11, column 3). As examples:

- Virgin plastic production: A1+A2-I1-K1
- Plastic Conversion: A1+A2
- Formal sorting: C1+E3+H1
- Informal collection & sorting: B2+N1+V1
- Etc.

Thus, higher amounts of material processed at a specific stage of the value chain (in tonnes), as per virgin plastic production, result in a higher number of jobs; and that led to employment numbers not reflecting the correct size of employment, especially at stages which are labour-intensive (collection and sorting). The correct number of jobs as an input for the model should be related to the total amount of plastic processed at a specific stage of the value chain. To account for this, an adjusting factor was calculated, as shown in Table 12.

[11] Estimated waste collected per informal waste picker is 60kg/day and there are 58 750 informal income opportunities reported by Plastics SA (https://www.plasticsinfo.co.za/wp-content/uploads/2020/10/Plastics-Recycling-in-SA-2019-Executive-Summary.pdf). This equates to 36 491 FTEs with each person working 1 840 hr per annum https://pmg.org.za/committee-meeting/13983/

[12] Plastics disposed 2019 estimated 152 200 tonnes.

Table 12: Jobs input figures to the model

Plastics value chain	Jobs per kilo-tonne plastic disposed	Adjusting Factor	Input to the model jobs per tonne product at each stage of plastic value chain)
Virgin Plastic Production	4		0.004
Plastic Conversion	19.5		0.0195
Formal Collection$	4.3	$\frac{A1+A2}{B1}$	0.006
Formal Sorting$	1.7	$\frac{A1+A2}{C1+E3+H1}$	0.0245
Informal Collection & Sorting	24	$\frac{A1+A2}{B2+N1+V1}$	0.123
Closed Loop MR	3	$\frac{A1+A2}{F1+F2+D1+D2+E1+D3}$	0.015
Open Loop MR	3	$\frac{A1+A2}{F1+F2+D1+D2+E1+D3}$	0.015
Chemical Conversion P2P	1.3	$\frac{A1+A2}{F1+F2+D1+D2+E1+D3}$	0.0065
Chemical Conversion P2F	1.3	$\frac{A1+A2}{F1+F2+D1+D2+E1+D3}$	0.0065
Thermal Treatment (without energy recovery)	N/A*	N/A	0.0
Engineered Landfills	0.1	$\frac{A1+A2}{L1}$	0.00047
Import (sorting)	0	$\frac{A1+A2}{H1}$	0

*No new jobs are created for the thermal treatment without energy recovery as this is carried out as part of existing operations (e.g. burning plastic waste in cement kilns).

$Collection and sorting were apportioned as follows: 20% to *Formal Collection&Sorting* and 80% to *Informal Collection&Sorting*. Thus, of the 30 jobs per kt in Table 11, 6 are allocated in *Formal collection&sorting and* 24 are allocated in *Informal Collection&Sorting*. The UMI archetype provided a figure of 1.7 for *Formal Sorting*, hence *Formal Collection* was calculated as the difference 6-1.7 = 4.3 jobs per kt.

Accounting for GHG emissions in the plastics life cycle

Data for GHG emissions were sourced from Goga *et al*. (2022) and from the UMI archetype when data was not available as shown in Table 13.

Table 13: Historical data and projections on GHG emissions factors

Value Chain Stage	GHG (tonne CO_2eq/yr/ ton of flow)		Source
	Historical data (2016-2020)	Projections (2021-2040)	
Virgin Plastic Production*	4.1-5.2	4.7	Goga *et al.* (2022) and Plastic SA
Plastic Conversion	1.622	1.622	Goga *et al*. (2022)
Formal Collection	0.02	0.02	Global model$
Informal Collection	0	0	Global model
Formal Sorting	0.05	0.05	Global model
Open Loop MR	0.77-0.6	0.6-0.16	Global model
Closed Loop MR	0.77-0.6	0.6-0.16	Global model
Chemical Conversion P2P	3.1 (on average)	2.9 (on average)	Global model
Chemical Conversion P2F	0.45 (on average)	0.25 (on average)	Global model
Thermal Treatment	1.4	1.4	Global model
Engineered Landfills	0.008	0.008	Goga et al. (2022)
Import (sorting)	N.A.	N.A.	Global model
Open Burning	2.9	2.9	Global model

*On average 70% of polymer converted to plastic products is local and from Sasol coal-to-liquids, while 30% is imported, thus GHG for virgin plastic production was adjusted accordingly. Since figure from Goga *et al*. (2022) did not report on local vs imported polymer production, the split was provided by Annabe Pretorius (Plastic SA).

$ Global model refers to the model UMI archetype data from the global model from PEW's Breaking the Plastic Wave report.

Note, that the Business-As-Usual scenario assumes no future changes in the carbon-intensity of South Africa's plastic polymer production and the future ability of Sasol to maintain its market share in local plastic polymer consumption. This Business-As-Usual therefore assumes a projected future path based on current development without any carbon mitigation policy targets and therefore is comparable to the 'Business-As-Usual' of South Africa's Long-term Mitigation Scenario (LMTS)[13].

However, it may not represent the most likely development path, and this will influence the modelled BAU plastics carbon footprint and have implications for the GHG emissions associated with the plastics life-cycle. Therefore, further investigation of the GHG footprint of plastics should consider how decarbonisation of South Africa energy would reduce the plastics GHG footprint in light of South Africa's decarbonisation policy targets; namely the 'Peak-Plateau-Decline' decarbonisation of South Africa from the LMTS, the increasing percentage of renewables in the power supply mix from the Integrated Resource Plan for electricity (IRP2[14]), and the 'Reference' and 'Least-cost' scenarios develop by CSIR Energy Centre[15].

[13] SOUTH AFRICA'S LONG TERM MITIGATION SCENARIOS AND CLIMATE CHANGE POLICY RESPONSE https://climate.ec.europa.eu/system/files/2016-11/south_africa_en.pdf

[14] INTEGRATED RESOURCE PLAN FOR ELECTRICITY (IRP) 2010-2030 https://www.dffe.gov.za/sites/default/files/docs/irp2010_2030.pdf

[15] Wright, J and Calitz, J (2020) Technical Report: Systems analysis to support increasingly ambitious CO2 emissions scenarios in the South African electricity system https://researchspace.csir.co.za/dspace/bitstream/handle/10204/11483/Wright_2020_edited.pdf?sequence=7&isAllowed=y

Accounting for costs in the plastics life cycle

Due to lack of data for costs (OPEX, CAPEX and sales) for the South African context (data were very sparse), the model relied entirely on the UMI urban archetype data (Lau *et al*., 2020b) for costs. Costs (in constant 2018 US dollars) refer to the required investment (capital costs of infrastructure), the operational costs (OPEX) and capital cost (CAPEX). Costs are calculated as a function of modelled plastic flows, with changes in costs due to production scale and technological advancement accounted for through learning curves and returns to scale (ibid).

Table 14 reports the costs, OPEX, CAPEX and sales costs (used to calculate revenues) in 2016 and 2040, the latter as a result of the learning/experience curve. In alignment with the approach in Lau *et al*. (2020b) all costs are reported as NPV (net present value: OPEX+CAPEX-Revenues) to which was applied a 3.5% discount rate (ibid).

A current data shortage on the costs, which should be considered for future (re)assessment of the study are the costs related to the Unsanitary landfills. In the global study, Unsanitary landfills were grouped together with dumpsites, thus no costs were associated with them. In the process of adapting the System Map to make it meaningful for the South African context, the decision of separating out Unsanitary landfills – which constitute about a third of landfills in South Africa (von Blottnitz et al., 2017) and they do offer some levels of waste containment, despite their non-compliant regulatory state – and dumpsites – were considered to directly contribute to land pollution (box T) – was made (Figure 1).

Table 14: OPEX, CAPEX and sales costs used in study (source: Lau et al, 2020b, UMI archetype, urban). Costs are expressed in 2018 USD.

Value chain stage	OPEX (USD per metric tonnes)			CAPEX (USD per metric tonnes)			SALES (USD per metric tonnes)	
	2016	Learning curve	2040	2016	Learning curve	2040	2016	2040
Virgin plastic Production	1013	0%	1013	338	0%	338		
Plastic Conversion	668	0%	668	223	0%	223		
Formal collection	81	-25%	152	35	-25%	65		
Informal Collection	315	0%	315	n.a.		n.a.		
Formal sorting	117	7%	96	39	7%	32		
MR to plastics	452	7%	387	140	7%	120	1157	1157
MR to non-plastics	307	7%	267	90	7%	78	810	810
Chemical Conversion P2P	289	7%	221	116	7%	89	645	645
Chemical Conversion P2F	298	7%	221	116	7%	89	637	637
Thermal treatment with ER	28	0%	28	21	0%	21	34	34
Engineered Landfills	8	0%	8	23	0%	23		
Imports	n.a.		n.a.					

3. Optimal System Change Scenario

The scenario builder of the Pathways tool allows variations in flows along the plastics life-cycle to satisfy a set of defined objectives and achieve an optimal solution[16]. These scenarios were explored

[16] Multi-objective optimization that seeks a Pareto optimal or efficiency state where no preference criterion can be made better off without making at least one individual or preference criterion worse off.

within the context of South Africa and the need to ensure sustainable development that considers People, Planet, and Profit. The objective was to find the optimum in terms of minimising plastic pollution, greenhouse gas emissions, and required investment (capital cost); while maximising employment (collection, sorting, and recycling). The flows for each of these categories are defined below:

Pollution:

Flows:Total_land_pollution
Flows:Total_aquatic_pollution
Flows:Total_open_burning

GHG:

GHG_Plastic conversion
GHG_Formal collection
GHG_Informal collection
GHG_Formal sorting
GHG_Closed loop MR
GHG_Open loop MR
GHG_Chemical conversion P2P
GHG_Chemical conversion P2F
GHG_Thermal treatment
GHG_Engineered landfills
GHG_Import (sorting)
GHG_Open-burning

Employment:

EMPLOYMENT_Plastic conversion
EMPLOYMENT_Formal collection
EMPLOYMENT_Informal collection
EMPLOYMENT_Formal sorting
EMPLOYMENT_Closed loop MR
EMPLOYMENT_Open loop MR
EMPLOYMENT_Chemical conversion P2P
EMPLOYMENT_Chemical conversion P2F
EMPLOYMENT_Thermal treatment
EMPLOYMENT_Engineered landfills
EMPLOYMENT_Import (sorting)
EMPLOYMENT_Open-burning

Required investment (capital cost) :

REQ_INVESTMENT_Plastic conversion
REQ_INVESTMENT_Formal collection
REQ_INVESTMENT_Informal collection
REQ_INVESTMENT_Formal sorting
REQ_INVESTMENT_Closed loop MR
REQ_INVESTMENT_Open loop MR
REQ_INVESTMENT_Chemical conversion P2P
REQ_INVESTMENT_Chemical conversion P2F
REQ_INVESTMENT_Thermal treatment
REQ_INVESTMENT_Engineered landfills
REQ_INVESTMENT_Import (sorting)
REQ_INVESTMENT_Open-burning

The allowed variations in flows along the plastics life-cycle was used to identify an optimal solution that satisfies the aforementioned objectives. Annual flow variations are the % change of the original timeseries (Business-As-Usual), and are annually compounded (i.e., compound annual growth rate, CAGR)

Table 15: Variations in flows allowed to identify the optimal solution

Flows	**Description of flows**		**Allowed annual flow variation for scenario optimisation (%)**	
	From Box	**To Box**	**min**	**max**
1	Box1_WasteGenerated	Box2_CollectedPlastic	0	5
5	Box3_FormalCollection	Box6_FormalSorting	0	5
6	Box3_FormalCollection	Box5_MixedCollection	0	5
9	Box4_InformalCollectSorting	Box11_ChemicalConversion	0	5
11	Box5_MixedCollection	Box11_ChemicalConversion	0	5
12	Box5_MixedCollection	Box12_UnsortedWaste	-5	0
13	Box5_MixedCollection	Box6_FormalSorting	0	5
14	Box6_FormalSorting	Box9_MechanicalRecyclingtonon-plastics	0	5
15	Box6_FormalSorting	Box10_MechanicalRecyclingtoplastics	0	5
16	Box6_FormalSorting	Box12_UnsortedWaste	-5	0
25	Box12_UnsortedWaste	Box13_UnsortedManagedWaste	0	5
40	Box25_PlasticDemand	Box1_WasteGenerated	-5	0

Annexure 5: Details on results on costs for the BAU and EPR scenario

Business-As-Usual

Figure 44 and Figure 45 present the results related to costs (in nominal terms), broken down into OPEX and CAPEX for the BAU Scenario in years 2020 and 2040. Results are reported in USD[17] since the Pathways tool is designed to produce internationally comparable results. Total annual OPEX in 2020 and 2040 is \$2689 and \$4805, respectively; total annual CAPEX in 2020 and 2040 is \$879 and \$1586, respectively.

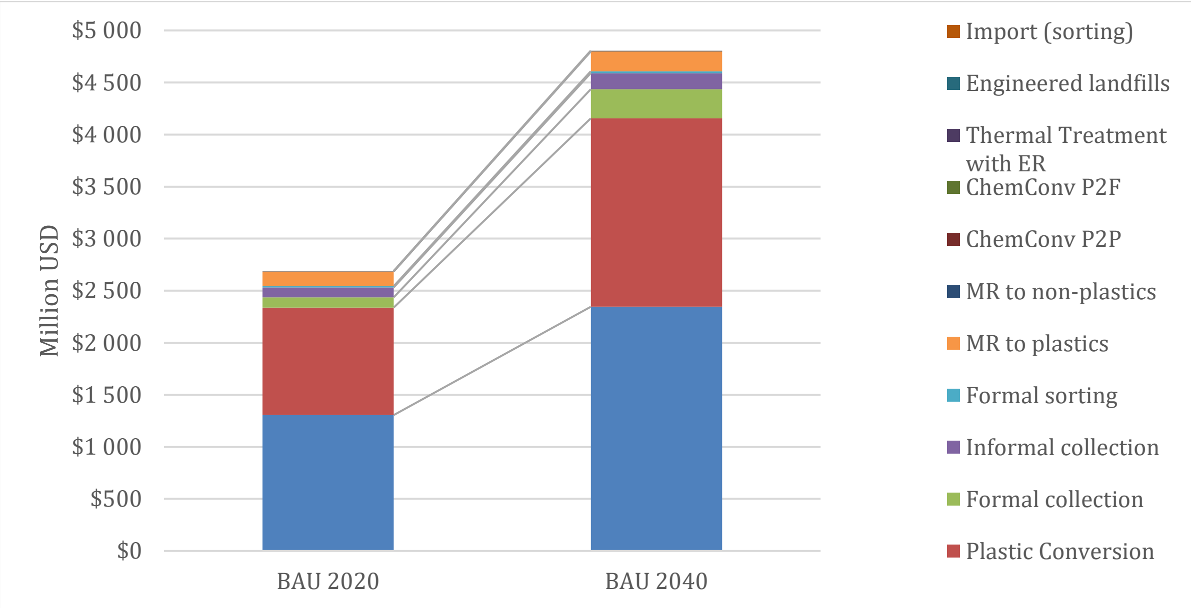


Figure 44: OPEX comparison between years 2020 and 2040

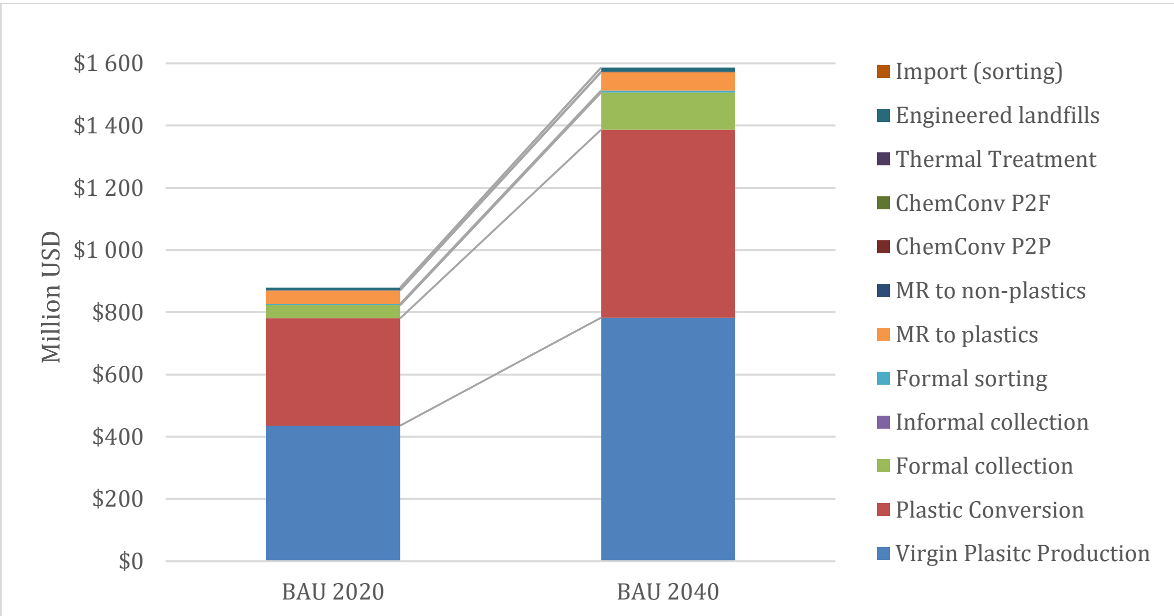


Figure 45: CAPEX comparison between years 2020 and 2040

[17] At the time of drafting of this report the Rand / USD exchange rate was USD 1 = R 16.46

Overall, annual OPEX and CAPEX show an increase of 79-80% over the twenty-year period (2020-2040), mainly following the increasing trend of plastic consumption (Table 16). The majority of both OPEX and CAPEX cost increase rests in virgin plastics production and plastics conversion. The breakdown of the potential 79-80 % increase between year 2020 and 2040 at each stage in the plastics system is provided in Table 16.

Table 16: Breakdown of the increase in OPEX and CAPEX between 2020 and 2040

OPEX and CAPEX per value chain stage	OPEX % change (in 2040 compared to 2020)		CAPEX % change (in 2040 compared to 2020)	
	per value chain stage	with respect to the total OPEX in 2020	per value chain stage	with respect to the total CAPEX in 2020
Virgin Plastic Production	79.6%	38.7%	79.6%	39.5%
Plastic Conversion	75.2%	28.9%	75.2%	29.5%
Formal collection	185.4%	6.8%	185.4%	8.9%
Informal collection & sorting	62.4%	2.21%	n.a.	n.a.
Formal sorting	43.9%	0.21	43.9%	0.21%
MR to plastics	35.5%	1.3%	35.5%	1.7%
MR to non-plastics	30.9%	0.02%	30.9%	0.017%
Chemical conversion P2P	0.4%	0.0001%	0.4%	0.0003%
Chemical conversion P2F	n.a.	n.a.	n.a.	n.a.
Thermal treatment (with energy recovery)	n.a.	n.a.	n.a.	n.a.
Thermal Treatment (w/o energy recovery)	n.a.	n.a.	n.a.	n.a.
Engineered landfills	70.8%	0.068%	70.8%	0.625%
Import (sorting)	n.a.	n.a.		-
Total		**78.6%**		**80.4%**

Figure 46 shows the trends on possible revenue generation over time, which sees a percentage increase of 53%, with the bulk of the increase being in the "*Mechanical recycling to plastics*" stage (98.5%), followed by "*Mechanical recycling to non-plastics*" (1.13%), "*Chemical conversion P2P*" (0.42%) and "*Thermal treatment*" (0.33%). The changes in revenues at each stage in the plastics system is provided in Table 17.

Additional capacity refers to infrastructure capacity, expressed in tonnes needed in each specific stage of the value chain. Required investments refers to additional capital costs needed to cope with the additional capacity. Additional capacity and corresponding required investments are driven by plastic demands/consumption in the first place, so when demands/consumption increase above the historical maximum reached in previous years, so does the additional capacity and required investment (see trend in Figure 13 and Figure 14). The spike in 2018 is due to an increase in plastic demand/consumption, which then flattened out in 2019 and 2020 (no additional capacity required as a result COVID-19), and started to increase again in 2021. Thereafter, growth in future years is projected based on the projected growth of population and per capita plastic demand.

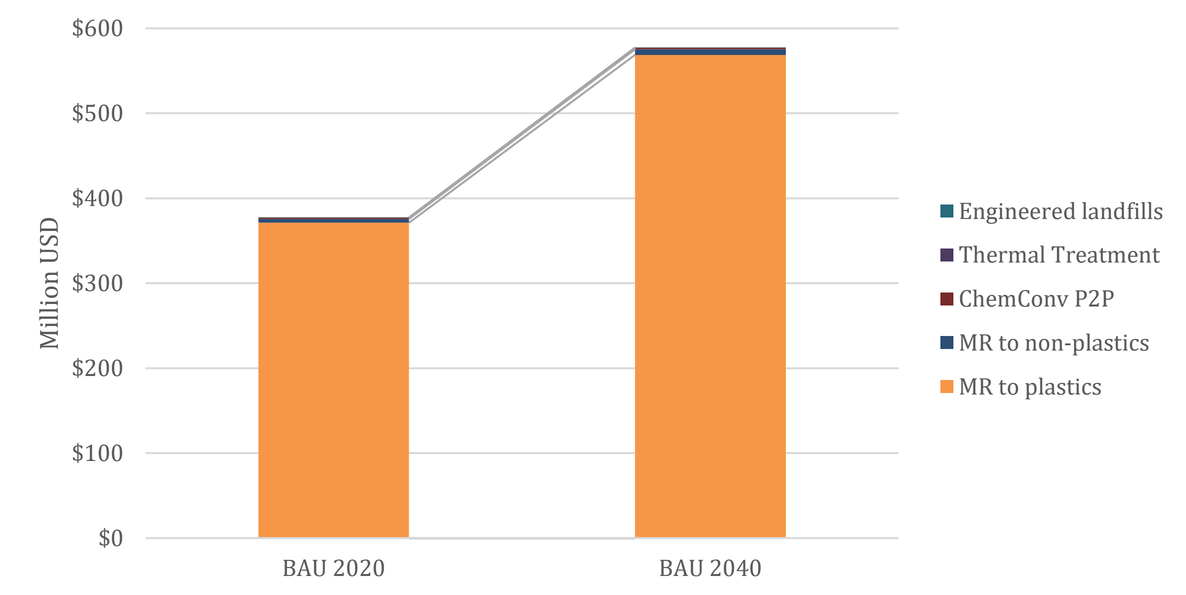


Figure 46: Revenues comparison between 2020 and 2040

Table 17: Variation in revenue generation between 2020 and 2040

Revenues generated (Million USD) per value chain stage	**Year**		**% Change in Revenues generated in 2040 compared to 2020**	
	2020	**2040**	**Per value chain stage**	**with respect to the total Revenue in 2020**
Virgin Plastic Production	n.a.	n.a.	-	-
Plastic Conversion	n.a.	n.a.	-	-
Formal collection	n.a.	n.a.	-	-
Informal collection & sorting	n.a.	n.a.	-	-
Formal sorting	n.a.	n.a.	-	-
Mechanical recycling to plastics	371	569	53.22%	52.38%
Mechanical recycling to non-plastics	4.5	6.5	45.73%	0.54%
Chemical Conversion P2P	1.5	1.9	27.3%	0.11%
Chemical Conversion P2F	n.a.	n.a.		-
Thermal Treatment with energy recovery	n.a.	n.a.		-
Thermal Treatment without energy recovery				
Engineered landfills	0.003	0.006	70.8%	0.00065%
Import (sorting)	n.a.	n.a.		-
Total	333.68	560.85		**53.03%**

As per Figure 47, additional infrastructure will be needed in South Africa between 2020 and 2040 to manage the growth in plastic waste, as will the required investment (Figure 48). Under the BAU Scenario, the bulk of the new capacity and the associated required investment, lies in the upgrade and development of new landfills (76 % additional capacity by 2040, and 33% increase in required investments). Additional infrastructure is also required for plastic conversion (8% additional capacity and a 28% increase in required investment); virgin plastic production (7% additional capacity and 35% increase in required investment); and formal collection (5% additional capacity and 2% increase in required investment). There are relatively minor additional capacity and corresponding investment requirements for the other stages of the value chain.

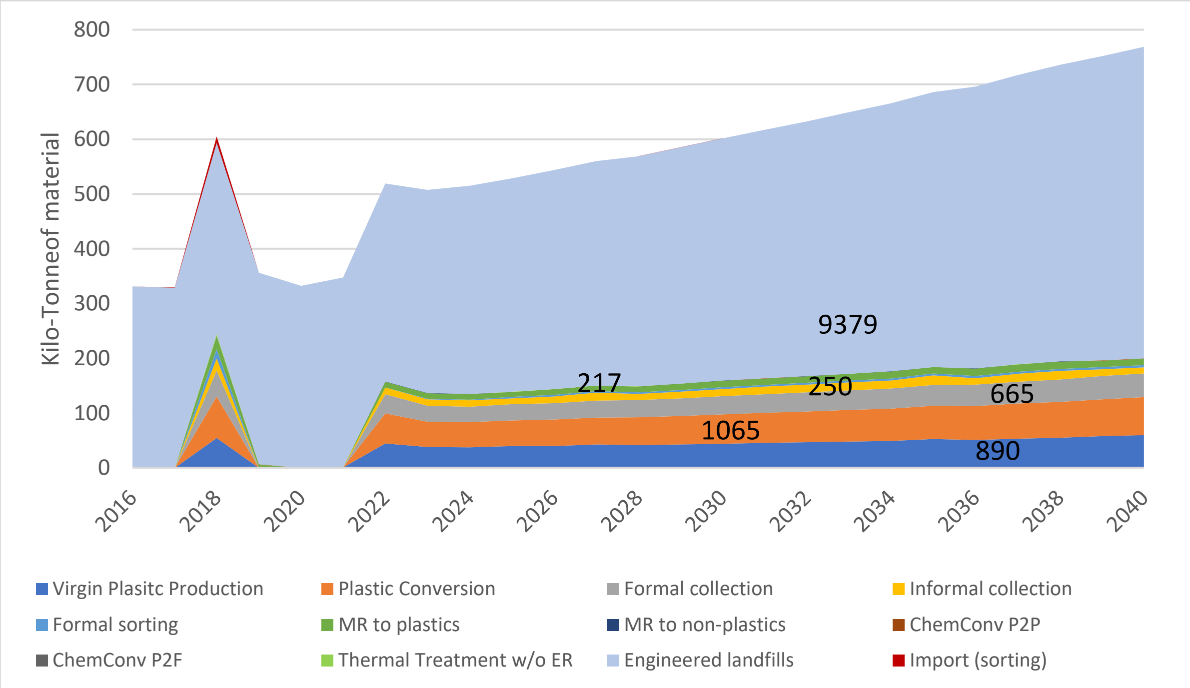


Figure 47: Additional Infrastructure capacity (kt) by 2040

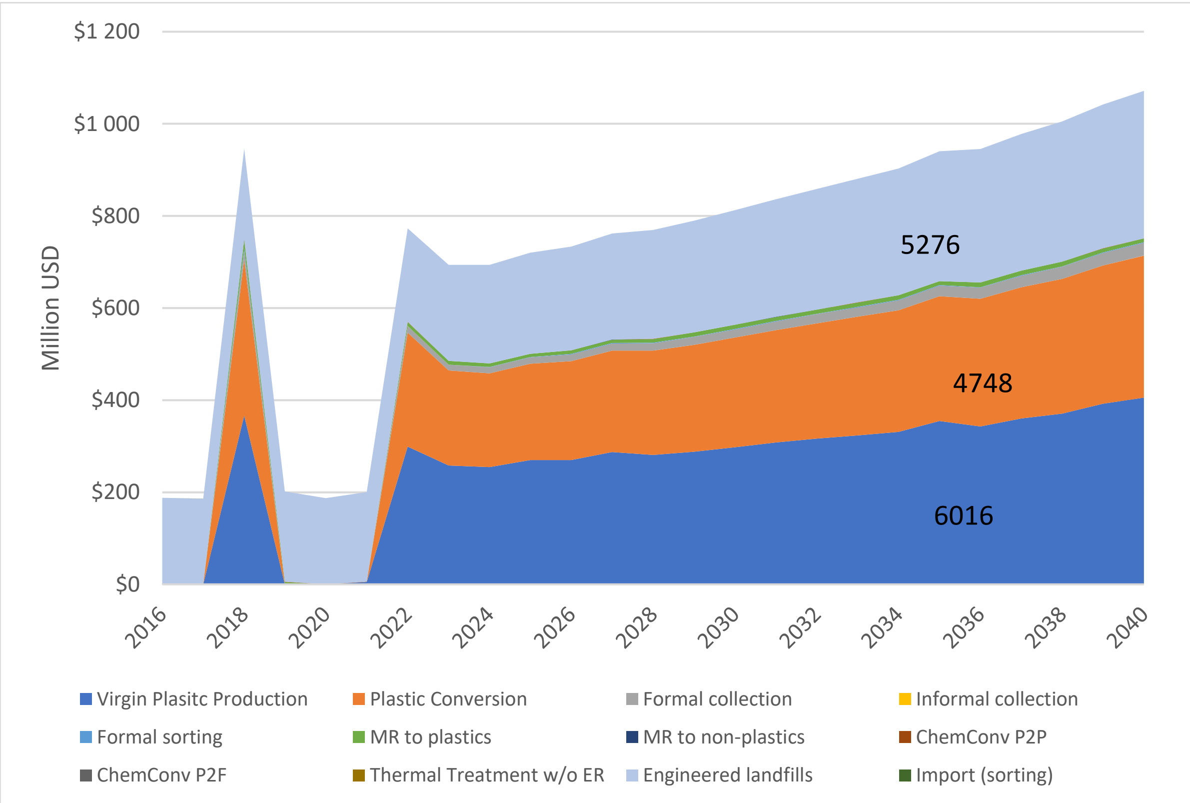


Figure 48: Additional Required investment (USD) by 2040

Extended Producer Responsibility

Figures 49 to 53 present the EPR vs BAU comparison in 2040 for OPEX, CAPEX, and revenues; as well as additional infrastructure capacity and required investment, respectively. All costs are presented in nominal terms. OPEX has an increase of about 80% in 2040 for the BAU and EPR scenarios, when compared with year 2020. The difference between the two scenarios indicates that EPR will require 1% less OPEX in 2040 than BAU mainly relating to a decrease in virgin plastic production replaced by recyclate. Similarly, CAPEX has an increase of 80% in 2040 for the BAU and EPR scenarios respectively, when compared with year 2020, with a difference of 2% between scenarios. Percentage changes (OPEX and CAPEX) per value chain stages are provided in Table 19.

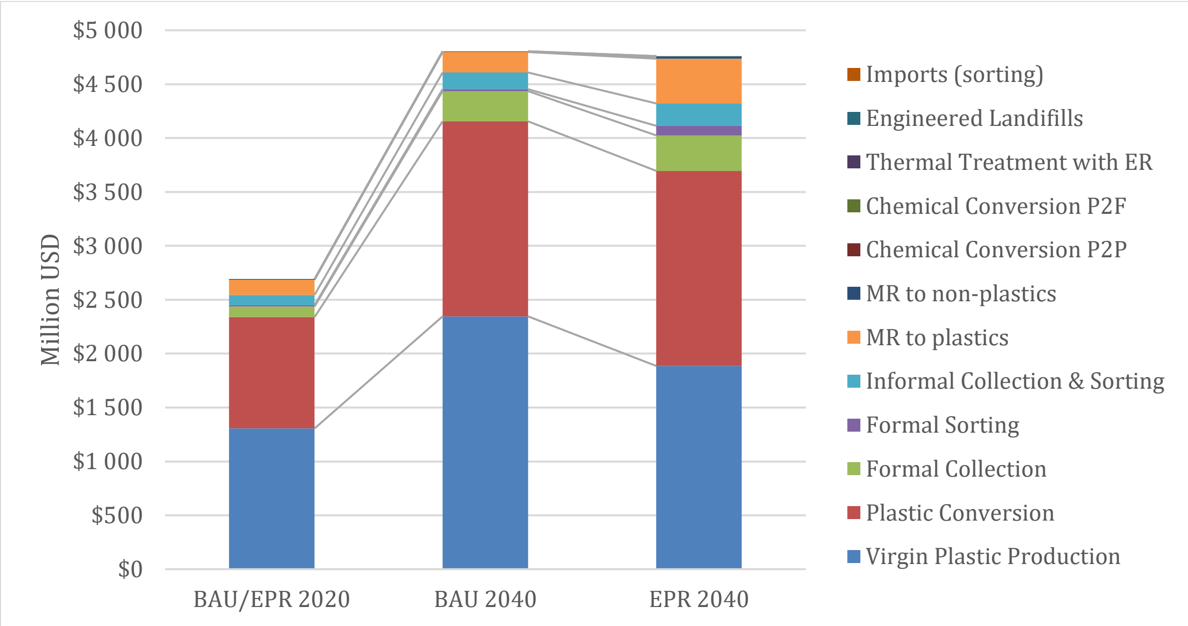


Figure 49: EPR vs BAU OPEX composition comparison in 2040

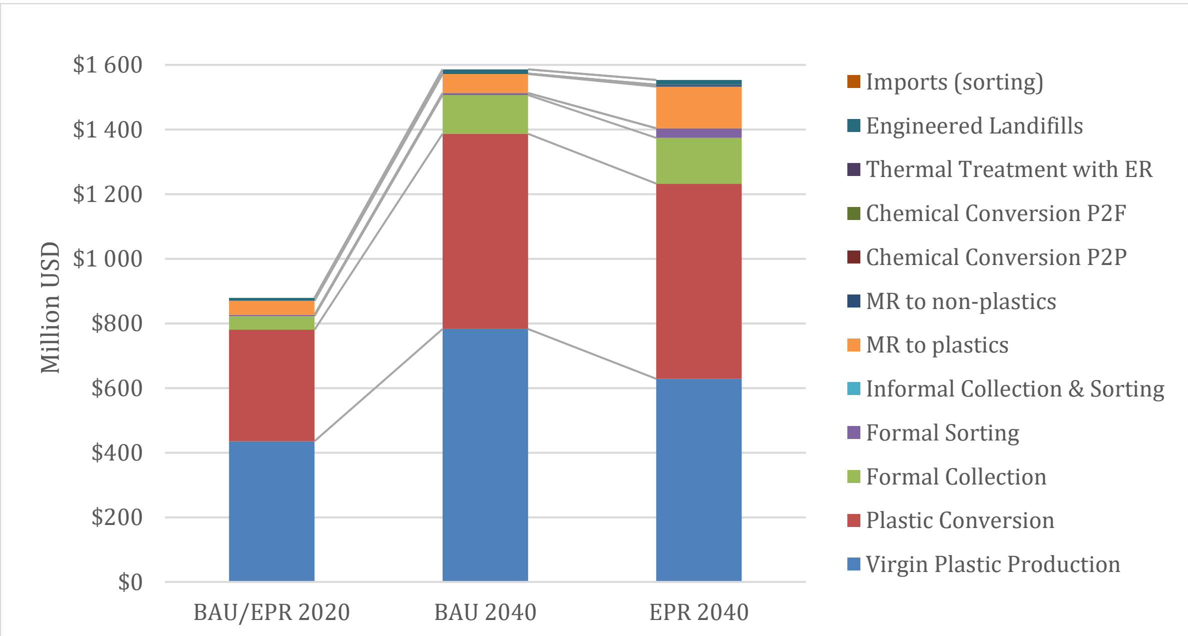


Figure 50: EPR vs BAU OPEX composition comparison in 2040

Table 18: Breakdown of the difference in OPEX and CAPEX in 2040 between BAU and EPR scenarios

Opex and Capex per value chain stage	% Change in OPEX BAU vs EPR in 2040		% Change in CAPEX BAU vs EPR in 2040	
	As per value chain stage	As % of the total	As % per value chain stage	As % of the total
Virgin Plastic Production	-19.65%	-9.6%	-19.65%	-9.7%
Plastic Conversion	-	-	-	-
Formal collection	17.7%	1.03%	17.7%	1.34%
Informal collection & sorting	34.14%	1.1%	34.14%	-
Formal sorting	395%	1.5%	395%	1.51%
MR to plastics	118%	4.7%	118%	4.38%
MR to non-plastics	774%	0.35%	774%	0.31%
Chemical conversion P2P	26.32%	0.004%	26.32%	0.011%
Chemical conversion P2F	n.a.	n.a.	n.a.	n.a.
Thermal Treatment with energy recovery	n.a.	n.a.	n.a.	n.a.
Thermal Treatment without energy recovery	n.a.	n.a.	n.a.	n.a.
Engineered landfills	10%	0.01%	10%	0.08%
Import (sorting)	-	-	-	-

Revenues that can be generated are illustrated in *Figure* 51 and show a 55% and 187% increase in year 2040 for BAU and EPR scenarios respectively, when compared with year 2020, with a difference of 125% between scenarios. The bulk of the additional revenues in 2040 lays in the "*Mechanical recycling to plastics*" (116% BAU vs EPR), followed by "*Mechanical recycling to non-plastics*" (8.7%), chemical conversion (0.1%).

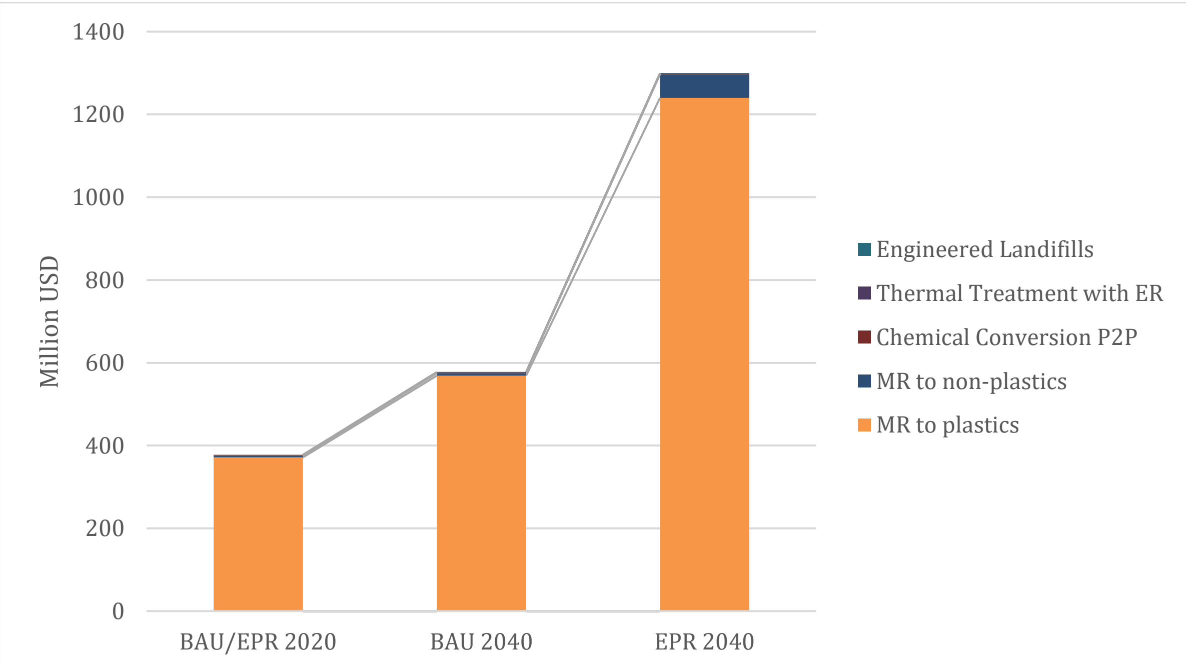


Figure 51: EPR vs BAU revenue composition comparison in 2040

Figure 52 compares the additional capacity required between 2023-2040 for the BAU and EPR scenarios. To meet the EPR targets, an additional infrastructure capacity of 20% is needed between 2023 and 2040, mainly related to the disposal of plastic waste sanitary landfills as a result of the increased collection of mixed waste (9%), formal collection (4%), formal sorting (6.1%) and mechanical recycling (3.6%). Overall, required investment shows a decrease of 13%, mainly due to a decrease in virgin plastic production, which is replaced by increasing amounts of recyclate. In terms of required investments, costs are mainly in formal collection and sorting, and recycling with $1392 million to collect, sort and recycle plastic waste; which will avoid $2391 million in additional capital investment to produce virgin polymers.

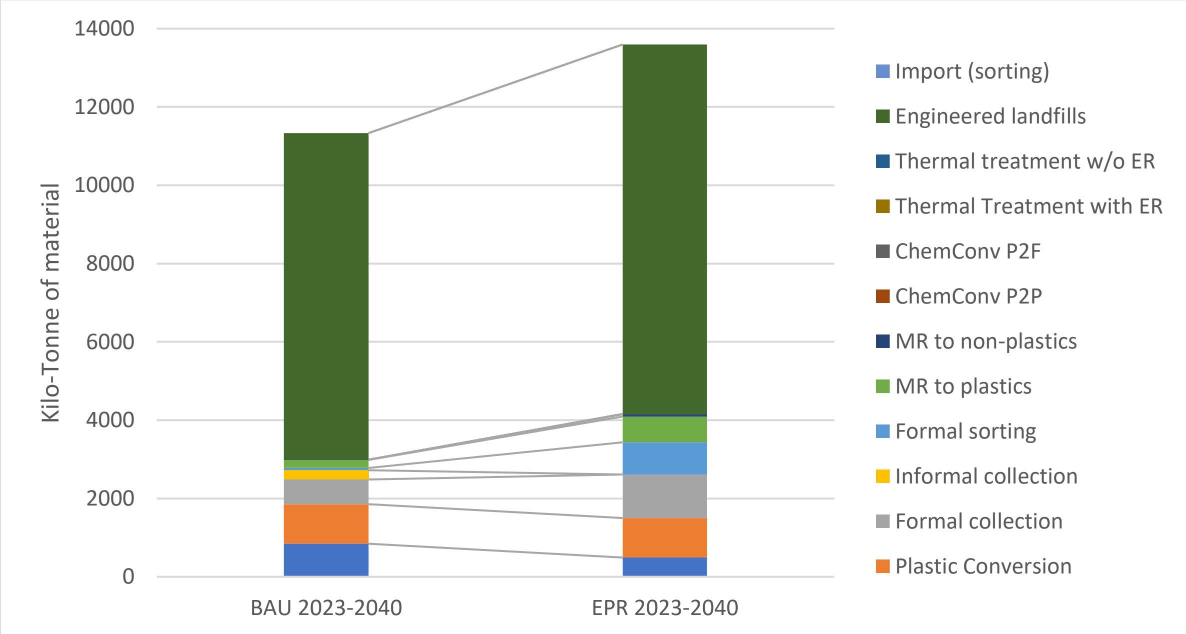


Figure 52: BAU and EPR cumulative additional capacity 2023-2040

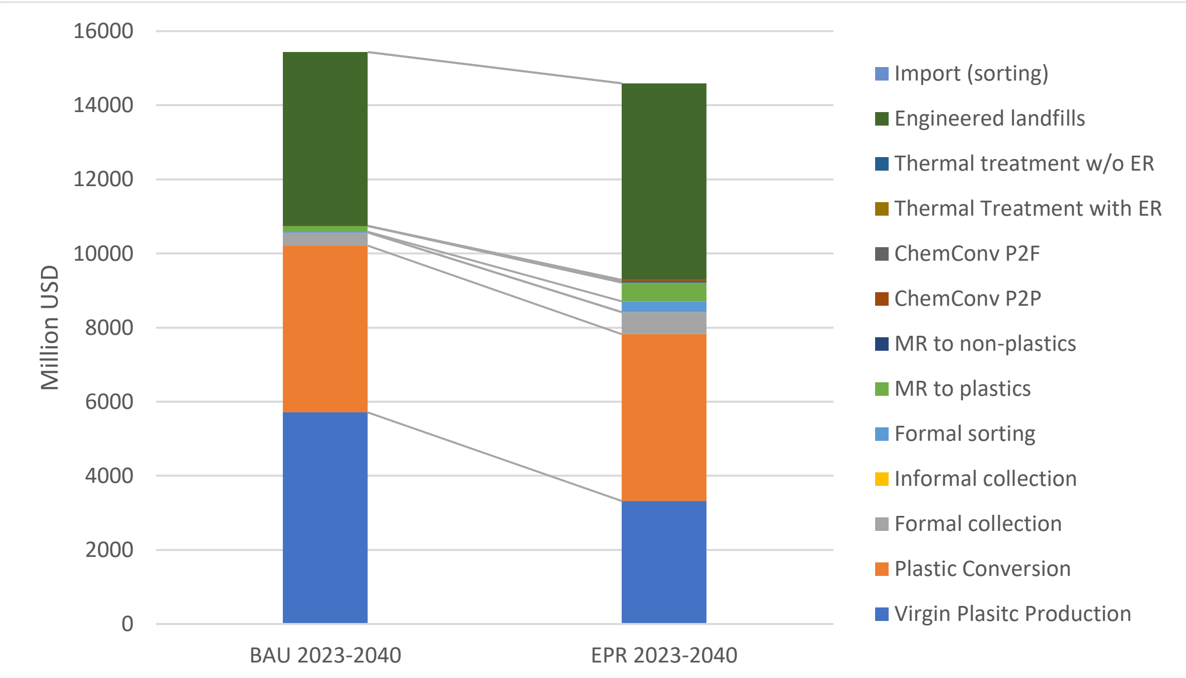


Figure 53: BAU and EPR cumulative required investment between 2023-2040

Annexure 6: Details on the EPR Scenario modelling and results

EPR scenario modelling

To understand the impacts of meeting the EPR targets, an EPR scenario was developed with targets for collection and recycling. Specifically, the EPR regulations and notices (DFFE, 2021) which provide annual targets for collection and recycling of paper, plastic, and single use products for a five-year period (2023-2028) were used and thereafter the recycling rate achieved in 2028 (as% of flows) was maintained up to 2040.

The EPR targets for plastic products are clustered into categories by plastic type and/or whether they are single-use products, whereas the Pathways tool cluster plastics into the three main categories, namely rigid mono-material, flexible mono-material and multi-materials. Thus, plastic products (and their targets) were aggregated into the three categories required to run the Pathways tool (Table 19). Final targets for the three plastic categories were calculated as weighted averages of the plastic products falling under the specific categories. Table 19 provides a summary of the targets per plastic category as an excerpt of the EPR regulations and reports the weighted averages for collection and recycling rates as well as the percentage increase which were used in the EPR scenario.

Table 19: EPR regulation targets, weighted averages and percentages increases for rigid mono-material, flexible mono-material and multi-material plastics

Rigid Mono-material						
Products	**Rates**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
PET Beverage Bottle	Collection %	60.00%	64.00%	66.00%	68.00%	70.00%
	Recycling %	54.00%	58.00%	59.00%	61.00%	65.00%
Polyolefins Rigid packaging	Collection %	55.00%	57.00%	60.00%	61.00%	64.00%
	Recycling %	39.00%	42.00%	45.00%	48.00%	52.00%
Polyvinyl Chloride* (Rigid and Flexi)	Collection %	6.00%	6.50%	7.00%	7.50%	8.00%
	Recycling %	5.00%	5.50%	6.00%	6.50%	7.00%
Polystyrene (expanded and High impact)	Collection %	22.00%	27.00%	33.00%	40.00%	48.00%
	Recycling %	20.00%	25.00%	30.00%	36.00%	43.00%
Single-Use products$ (PS, HDPE, PET & PP)	Collection %	60.00%	65.00%	70.00%	75.00%	80.00%
	Recycling %	30.00%	35.00%	40.00%	45.00%	50.00%
Percentage increases applied in the modelling	Collection %	13.17%	2.06%	2.42%	1.75%	2.46%
	Recycling %	4.5%	4.7%	4.6%	4.8%	4.8%
Flexible mono-material						
Products	**Rates**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
Plastic flexible (PET)	Collection %	10.00%	20.00%	30.00%	40.00%	50.00%
	Recycling %	9.00%	18.00%	27.00%	36.00%	45.00%
Polyolefins Flexible packaging	Collection %	58.00%	60.00%	62.00%	64.00%	66.00%
	Recycling %	44.00%	46.00%	48.00%	50.00%	52.00%
Polyvinyl Chloride* (Rigid and Flexi)	Collection %	6.00%	6.50%	7.00%	7.50%	8.00%

	Recycling %	5.00%	5.50%	6.00%	6.50%	7.00%
Percentage increases applied in the modelling	Collection %	4.2%	4.7%	3.7%	3.3%	3.0%
	Recycling %	3.8%	4.0%	3.2%	2.9%	2.7%
Multi-material / Multilayers						
Products	**Rates**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
Polyolefins Multi-layer films packaging	Collection %	15%	20%	25%	30%	35%
	Recycling %	11%	15%	20%	25%	30%
Tetrapak #	Collection %	10%	15%	20%	25%	30%
	Recycling %	5%	10%	15%	20%	25%
Percentage increases applied in the modelling	Collection %	5%	5%	5%	5%	5%
	Recycling %	5%	5%	5%	5%	5%
Plastic ALL^						
	Rates	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
Percentage increases applied in the modelling	Collection%	7.20%	3.64%	3.24%	3.01%	3.07%
	Recycling %	3.19%	3.45%	3.35%	3.45%	3.45%

* The splits between rigid and flexible PVC were obtained from SAVA)
$ To avoid double accounting the split between Single-use and durable plastics were gathered from von Blottnitz (2017).
# Data for Tetrapak packaging has been added in the multi-material category to be consistent with respect to what was).
^ A lumped collection rate was also determined for ALL plastic categories to account for an increase in Flow A1.

The targets develop were included in the EPR data collection spreadsheet as percentage increases from the BAU scenario from year 2023 onwards and several EPRs scenarios were explored. Table 20 provides a summary of the changes in the system (refer to Figure 1), i.e., the corresponding flow which has been increased following the EPR targets. Since flows that leave a stage (i.e., a box in the system map) must balance to 100%, increasing specific flow(s) results in reduction of others (those indicated in brackets in Table 20).

Table 20: EPR scenarios explored to improve the mismanagement of waste

EPR \ Flows	Collected plastics A1	Mechanical recycling F1, F2 (F3*)	Mixed Collection C2 (C3*)	Formal sorting (Dirty MRF) E3 (E2*)	Formal sorting S@S (Clean MRF) C1 (C3*)
EPR_1	☑	☑			
EPR_2	☑	☑	☑		
EPR_3	☑	☑		☑	
EPR_4	☑	☑	☑	☑	
EPR_5	☑	☑			☑
EPR_6	☑	☑		☑	☑

Table 21 details the % increase in the corresponding flows for the collected plastic and formal sorting, impacting on the corresponding outflows. The total plastic collection (Flow A1) has also been adjusted accordingly to reflect the increased collection rates achieved by meeting the targets; and Table 22 summarises the expected change in the flows in line with meeting the EPR targets for scenario 5 and 6.

Table 21: Expected changes in collection and recycling percentages in line with EPR targets

Flow	BAU values	EPR values					
		Y1 (2023)	Y2 (2024)	Y3 (2025)	Y4 (2026)	Y5 (2027)	Y6 - >2040
Plastic ALL							
Percentage of total plastic waste collected – A1	71%	78.2%	81.8%	85.1%	88.1%	91.2%	91.2%
Rigid Mono-material							
Percentage of plastic formally collected sent to CL recycling – F1	45%	49.5%	54.1%	58.7%	63.5%	68.4%	68.4%
Sorting Losses – F3	54%	49.6%	44.9%	40.3%	35.5%	30.7%	30.7%
Flexible Mono-material							
Percentage of plastic formally collected sent to CL recycling – F1	45%	48.8%	52.7%	56.5%	60.3%	64.2%	64.2%
Multi-material / Multilayers							
Percentage of plastic formally collected sent to OL recycling – F2	1%	6.0%	11.0%	16.0%	21.0%	26.0%	26.0%
Sorting Losses – F3	99%	94.0%	89.0%	84.0%	79.0%	74.0%	74.0%

Table 22: Changes in the flows for EPR_5 and EPR_6

Flow	BAU values	Y1 (2023)	Y2	Y3	Y4	Y5	Y6->2040
		EPR value					
Plastic ALL (same for EPR_5 and EPR_6)							
Percentage of total plastic waste collected – A1	71%	78.2%	81.8%	85.1%	88.1%	91.2%	91.2%
Rigid Mono-material (EPR_5)							
Proportion of formally collected plastic for recycling (Separated at source)– C1	7.8%	21.3%	25.6%	29.4%	33.0%	36.9%	36.9%
Formal collection sent to non-engineered landfills – C3	46.1%	39.4%	37.2.%	35.3%	33.5.9%	31.6%	31.6%
Percentage of plastic formally collected sent to CL recycling – F1	45%	49.5%	54.1%	58.7%	63.5%	68.4%	68.4%
Sorting Losses – F3	54%	49.6%	44.9%	40.3%	35.5%	30.7%	30.7%
Flexible Mono-material (EPR_5)							
Proportion of formally collected plastic for recycling (Separated at source)– C1	7.8%	12.8%	17.9%	22.9%	27.9%	33.0%	33.0%
Formal collection sent to non-engineered landfills – C3	46.1%	41.1%	36.0%	31.0%	26.0%	20.9%	20.9%
Percentage of plastic formally collected sent to CL recycling – F1	45%	48.8%	52.9%	56.1%	59%	61.7%	61.7%
Multi-material / Multilayers (EPR_5)							
Proportion of formally collected plastic for recycling (Separated at source)– C1	7.8%	12.8%	17.9%	22.9%	27.9%	33.0%	33.0%
Formal collection sent to non-engineered landfills – C3	46.1%	41.1%	36.0%	31.0%	26.0%	20.9%	20.9%
Percentage of plastic formally collected sent to OL recycling – F2	1%	6.0%	11.0%	16.0%	21.0%	26.0%	26.0%

Flow	BAU values	Y1 (2023)	Y2	Y3	Y4	Y5	Y6->2040
Sorting Losses – F3	99%	94.0%	89.0%	84.0%	79.0%	74.0%	74.0%
Rigid Mono-material (EPR_6)							
Proportion of formally collected plastic for recycling (Separated at source)– C1	7.8%	21.3%	25.6%	29.4%	33.0%	36.9%	36.9%
Formal collection sent to non-engineered landfills – C3	46.1%	39.4%	37.2.%	35.3%	33.5.9%	31.6%	31.6%
Percentage of plastic formally collected sent to CL recycling – F1	45%	49.5%	54.1%	58.7%	63.5%	68.4%	68.4%
Sorting Losses – F3	54%	49.6%	44.9%	40.3%	35.5%	30.7%	30.7%
Percentage of formally collected plastic in mixed waste not being recycled– E2	95%	81.5%	77.2%	73.4%	69.8%	65.9%	65.9%
Percentage of collected plastic in mixed waste going to MRF – E3	5%	18.5%	22.8%	26.6%	30.2%	34.1%	34.1%
Flexible Mono-material (EPR_6)							
Proportion of formally collected plastic for recycling (Separated at source)– C1	7.8%	12.0%	16.6%	20.3%	23.6%	26.6%	26.6%
Formal collection sent to non-engineered landfills – C3	46.1%	41.93%	37.26%	33.56%	30.31%	27.31%	27.31%
Percentage of plastic formally collected sent to CL recycling – F1	45%	48.8%	52.7%	56.5%	60.3%	64.2%	64.2%
Percentage of formally collected plastic in mixed waste not being recycled– E2	95%	90.8%	86.2%	82.5%	79.2%	76.2%	76.2%
Percentage of collected plastic in mixed waste going to MRF – E3	5%	9.2%	13.8%	17.5%	20.8%	23.8%	23.8%
Multi-material / Multilayers (EPR_6)							
Proportion of formally collected plastic for recycling (Separated at source)– C1	7.8%	12.8%	17.9%	22.9%	27.9%	33.0%	33.0%
Formal collection sent to non-engineered landfills – C3	46.1%	41.1%	36.0%	31.0%	26.0%	20.9%	20.9%
Percentage of plastic formally collected sent to OL recycling – F2	1%	6.0%	11.0%	16.0%	21.0%	26.0%	26.0%
Sorting Losses – F3	99%	94.0%	89.0%	84.0%	79.0%	74.0%	74.0%
Percentage of formally collected plastic in mixed waste not being recycled– E2	100%	95%	89.9%	84.9%	79.9%	74.8%	74.8%
Percentage of collected plastic in mixed waste going to MRF – E3	0%	5%	10.1%	15.1%	20.1%	25.2%	25.2%

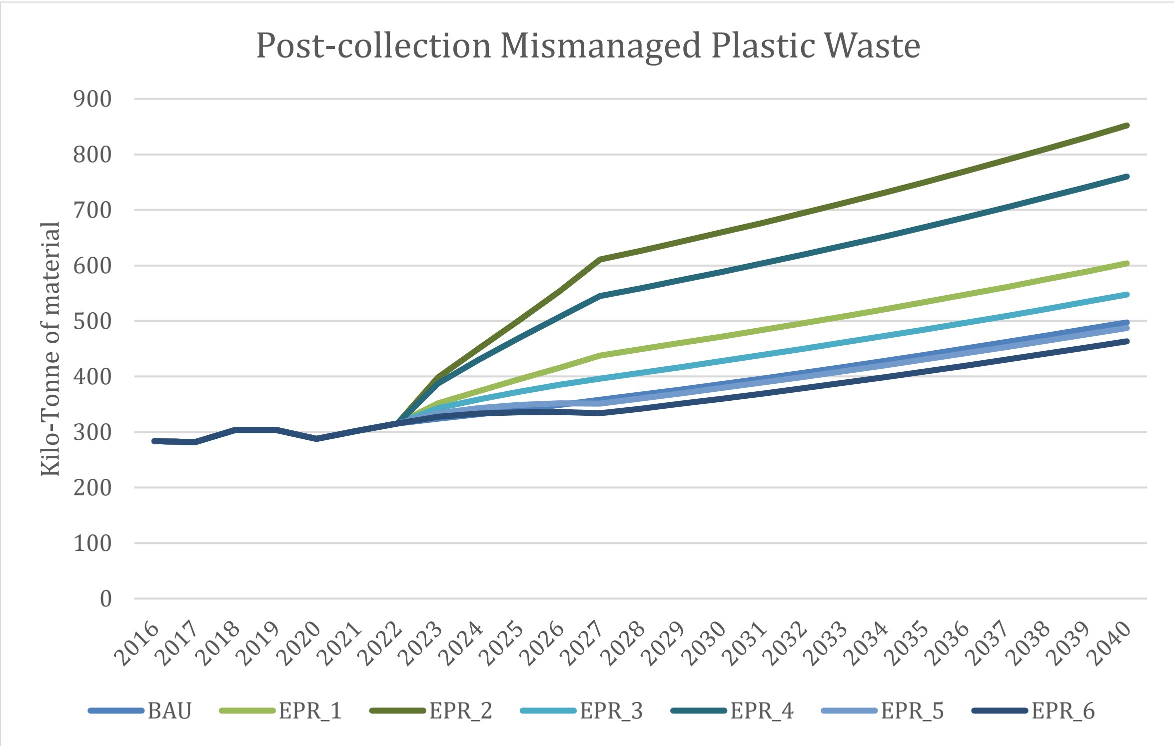
Enhanced EPR Scenario Results

This section presents all the results of the EPR scenarios developed. The best EPR (EPR 6) is the one presented in the section 4.2.

As shown in Figure 54 achieving the mandatory plastic collection and recycling targets as set out in South Africa's paper and packaging EPR regulations, results in the unintended increase in post-collection mismanaged plastic waste. This is the direct result of an increase in unsorted waste (Box L) as a result of mixed MSW collection (Box E). In an effort to address this issue, a series of possible EPR scenario were explored as per Table 20.

As per Figure 54, which for ease of reading reports the trends only, two of the best EPR scenarios explored (increased collection, formal sorting at clean and/or dirty MRF, and increased mechanical recycling, EPR_5 and EPR_6) showed effective improvement (i.e., lower trend than BAU) of mismanaged plastic waste. Changes in the model and the corresponding flows affected are indicated in Table 22.

A.



B.

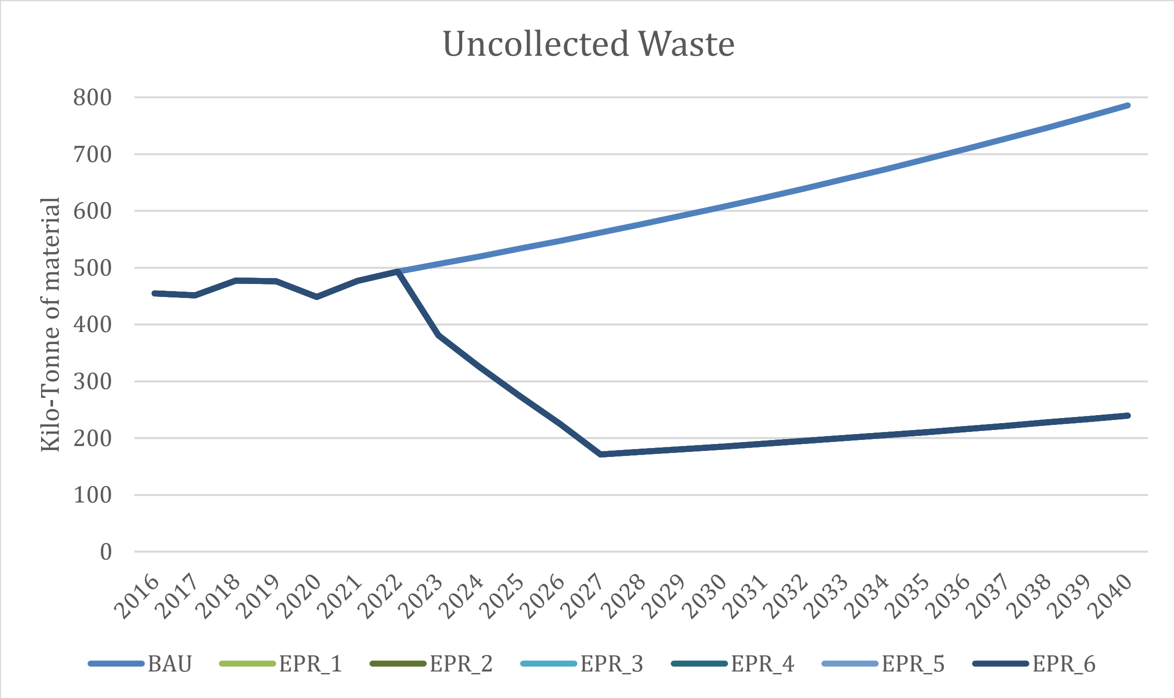


Figure 54: Comparison of Post-collected mismanaged plastic waste (A) and Uncollected plastic waste (B)

Results are presented for the following scenarios:

- EPR_1 – baseline scenario based only on improvement on collection and recycling w/o modifying collection patterns. It meets the collection targets but not the recycling as per ERP and highlighted an unintended consequence of increased post-collection mismanaged plastic waste (PCMPW) through mixed waste;
- EPR_5 – focus on improving S@S, in other words what is formally collected for recycling so to meet the recycling targets;
- EPR_6 – focus on improving S@S and sorting of mixed waste (dirty MRFs) to avoid the unintended consequences of having an increase in post collection mismanaged waste due to more plastic waste being collected in first instance – this is the best case presented and discussed in section 4.2.

Figure 55 to Figure 60 show comparisons of pollution flows as well as informal collection and sorting, formal sorting and recycling of BAU, EPR_1, EPR_5 and EPR_6 Scenarios:

- Increased collection, formal sorting at clean and/or dirty MRF, and increased mechanical recycling (EPR_5 and EPR_6) present further percentage reduction of 6% (clean MRF) and 8% (clean and dirty MRF combined) respectively on aquatic pollution, when considering plastic waste accumulation over time (2023-2040) compared to EPR_1 (only increased collection and mechanical recycling). Additional 106 kt and 130 kt of plastic waste contributing to aquatic pollution can be avoided by scenario EPR_5 and EPR_6 respectively.
- Increased collection, formal sorting at clean and/or dirty MRF, and increased mechanical recycling (EPR_5 and EPR_6) show a further 2% reduction of land pollution on top of the 31% achieved by EPR_1 (only increased collection and mechanical recycling), when considering plastic waste accumulation over time (2023-2040). Additional 80 kt of plastic waste

contributing to land pollution can be prevented due to improvement at the level of clean and dirty MRF.

- Increased collection, formal sorting at clean and/or dirty MRF, and increased mechanical recycling (EPR_5 and EPR_6) show a slight improvement in open burning resulting in an additional percentage reduction of 2.5% (clean MRF) and 3% (clean and dirty MRF combined) respectively, compared to EPR_1 scenario (only increased collection and mechanical recycling), when considering plastic waste accumulation over time (2023-2040). An additional 200 kt of plastic waste subjected to open burning can be prevented due to improvement at the level of Clean and dirty MRF.
- Uncollected plastic waste as well as formal collection remain unchanged when compared to only increased collection and mechanical recycling (EPR_1).
- Informal collection and sorting show that EPR_1 (only increased collection and mechanical recycling) will initially have better results, but in the long term, 2040, EPR_6 (including increased sorting at both clean and dirty MRFs) has the best results, with an approximately 1,000 kt of plastic waste to be reclaimed by the informal sector over the 2023-2040 period.
- Formal sorting trends of increased collection, formal sorting at clean and/or dirty MRF, and increased mechanical recycling (EPR_5 and EPR_6) show a potential percentage improvement up to 230% (clean MRF) and 277% (clean and dirty MRF combined) respectively compared to the only increased collection and mechanical recycling (EPR_1). An additional 7,700 kt (EPR_5) and 9,240 kt (EPR_6) could be sorted for recycling over the 2023-2040 period under the EPR scheme using only clean or both clean and dirty MRFs respectively.
- Total plastic waste recycled (which is mainly mechanical recycling to plastics) trends for increased collection, formal sorting at clean and/or dirty MRF, and increased mechanical recycling (EPR_5 and EPR_6) show potential percentage improvement of an additional 22% (clean MRF) and additional 25% (clean and dirty MRF combined) respectively compared to the increased collection and mechanical recycling only (EPR_1) scenario, with an additional 4,650 kt and 5,300 kt of plastic waste being potentially recycled.

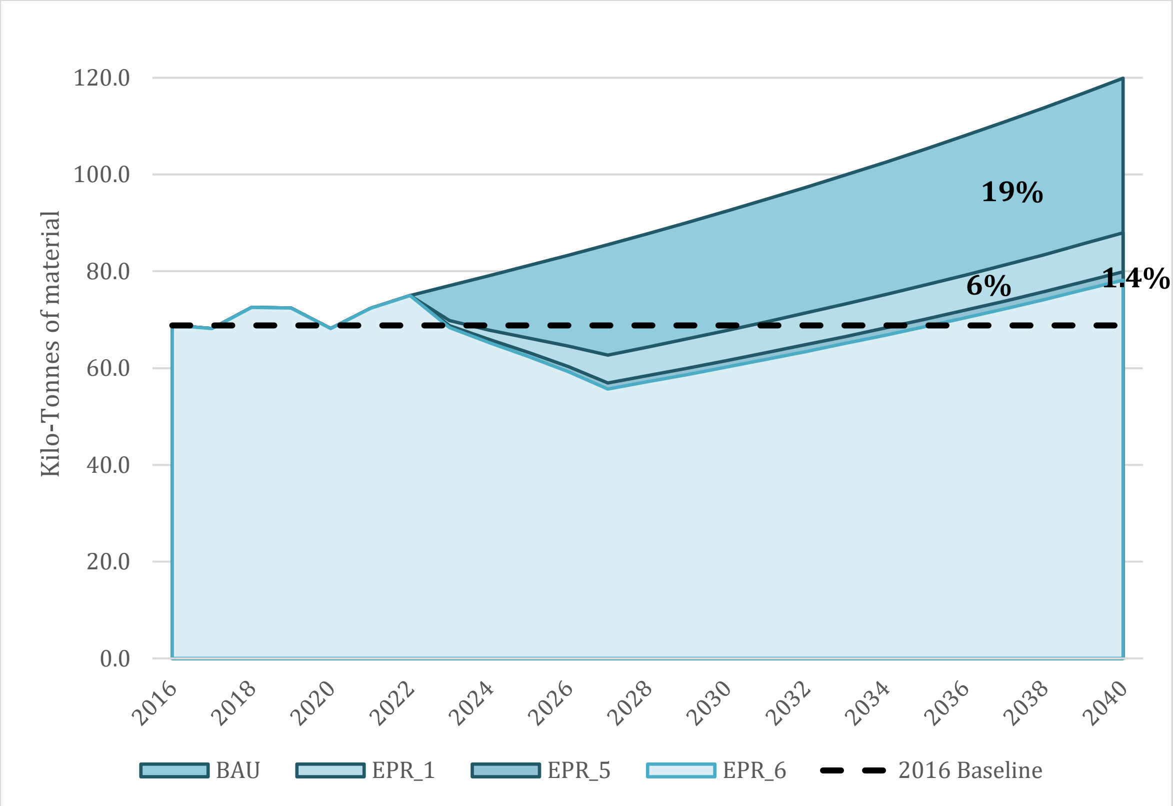


Figure 55: Aquatic pollution trends comparison

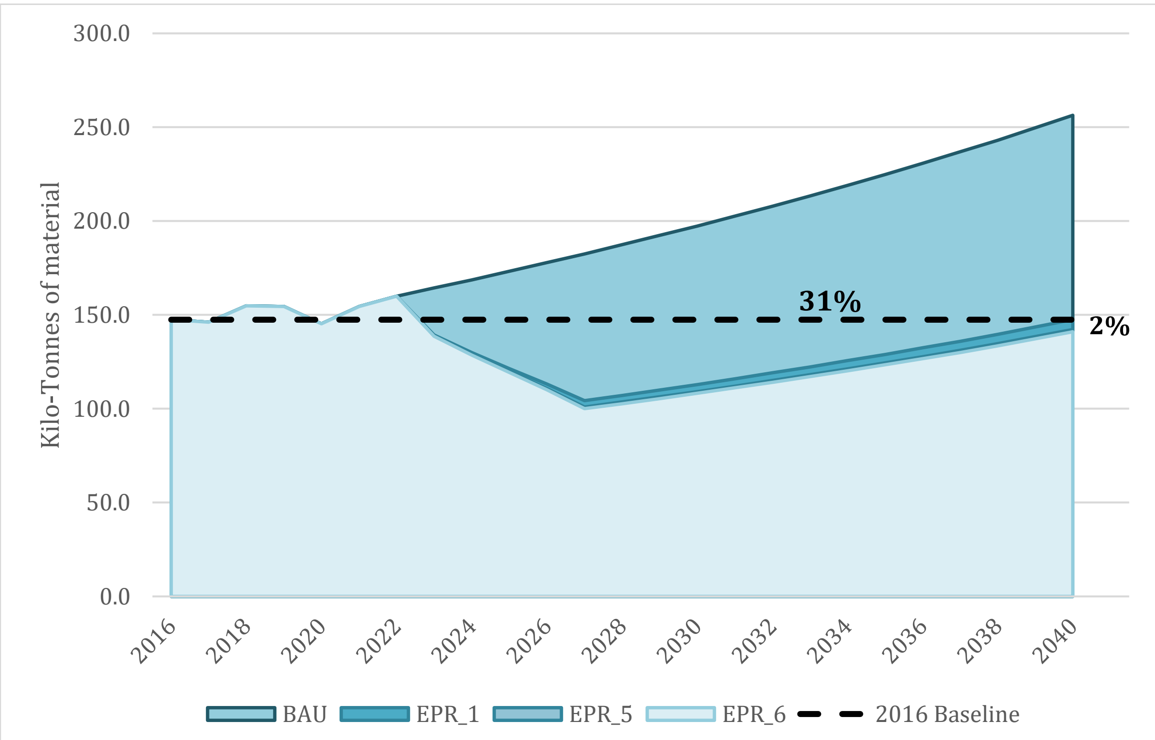


Figure 56: Land pollution trends comparison

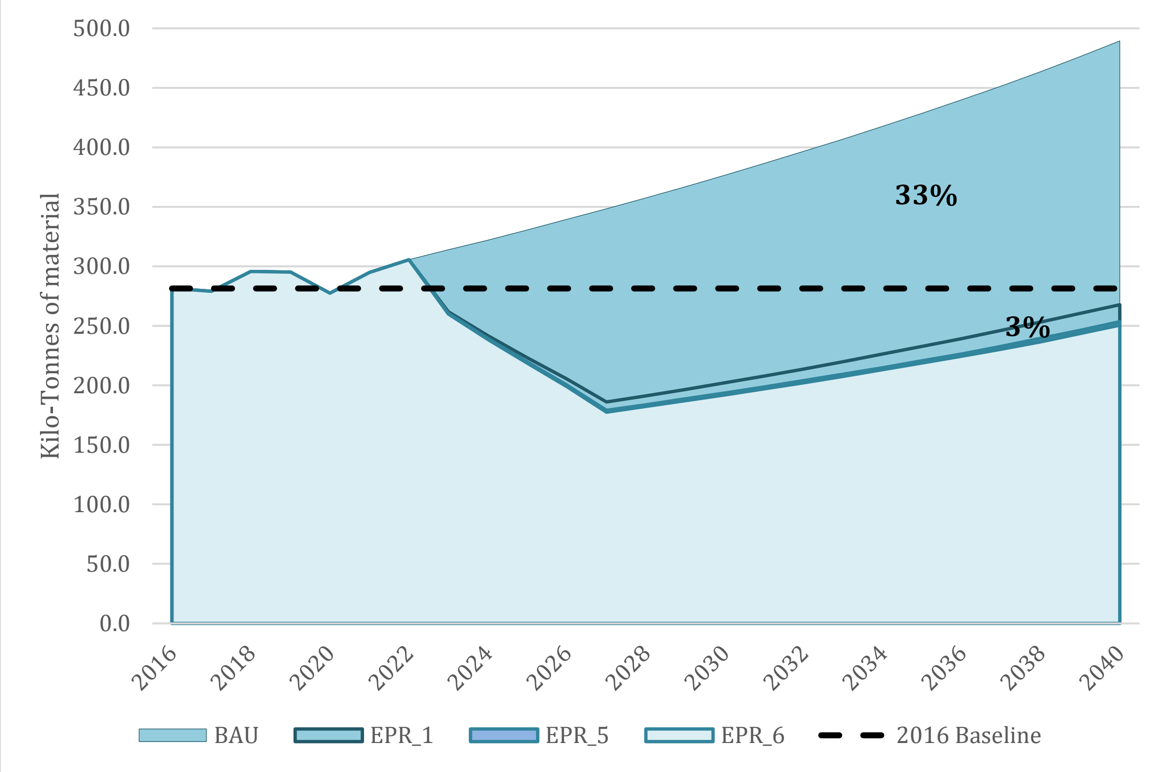


Figure 57: Open-burning trends comparison

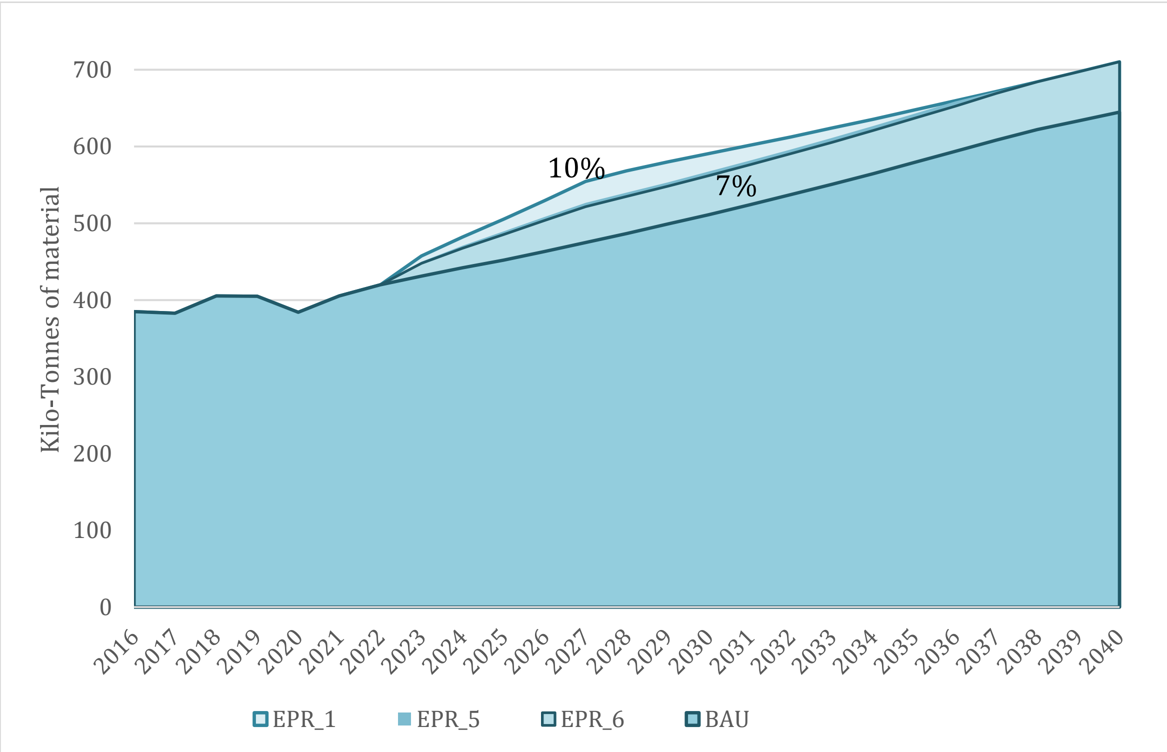


Figure 58: Informal collection and sorting trends comparison

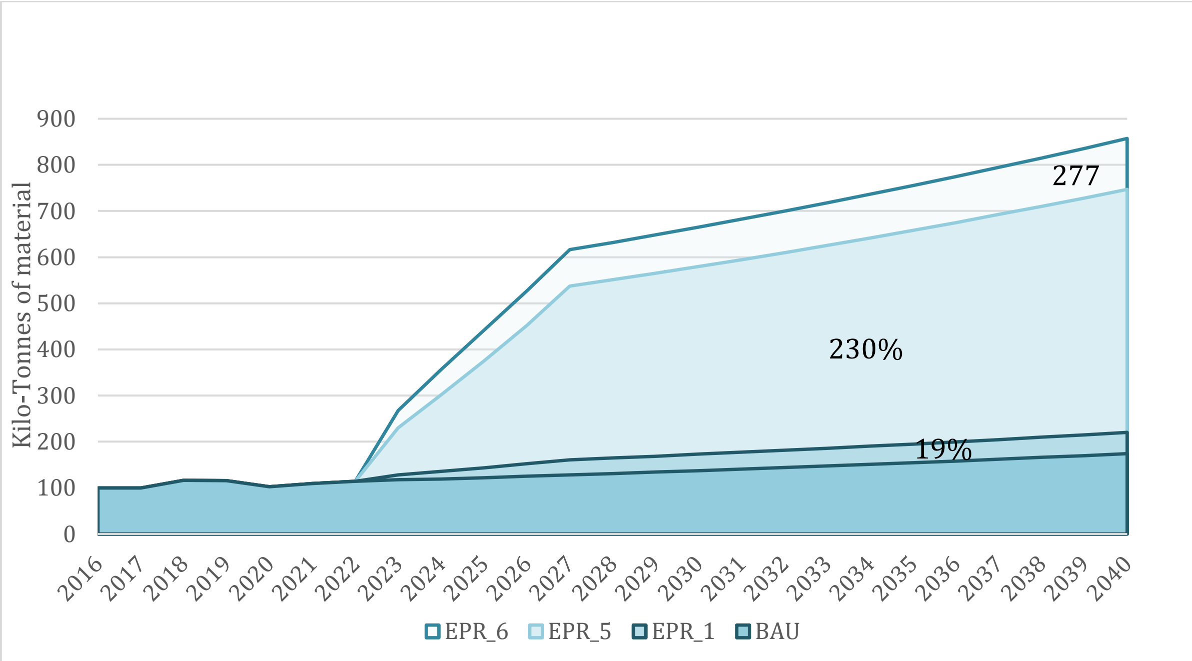


Figure 59: Formal sorting trends comparison

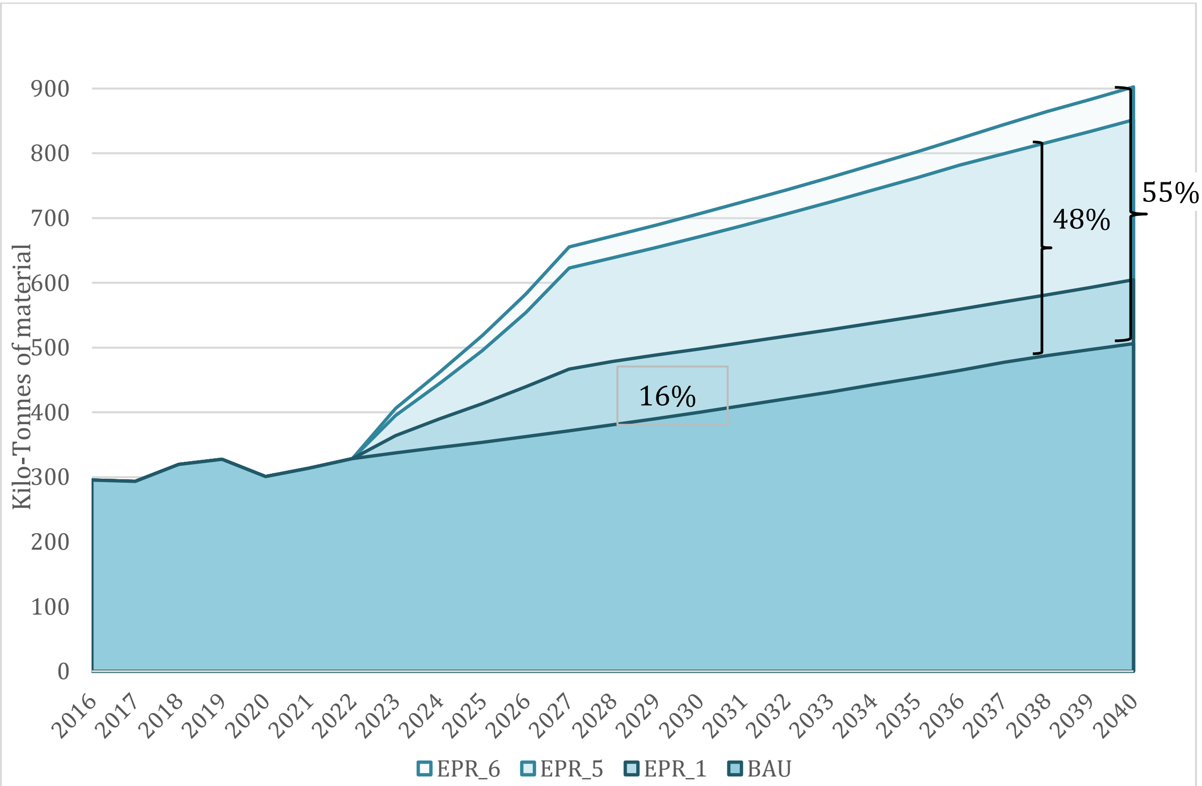


Figure 60: Total recycled plastic trends comparison

GHG emissions

Figures 61 and 62 illustrate the potential GHG emission reduction in the explored enhanced EPRs scenarios as cumulative and in 2040:

- Increased collection and mechanical recycling (EPR_1) shows a 6.2% reduction of GHG emission compared to BAU scenario in 2040 (see section 4.2.5);
- Increased collection, sorting at clean MRF and mechanical recycling (EPR_5) shows a 12% reduction of GHG emission compared to BAU scenario in 2040 mainly due to a decrease in virgin plastic production due to increased recycling reducing the need for virgin material (-8.3% less GHG emission compared to BAU) and an additional 0.6% reduction in open burning of plastic waste on top of the 4% already observed in EPR_1 (increased collection and mechanical recycling);
- Increased collection, sorting at clean and dirty MRFs, and mechanical recycling (EPR_6) shows a 14% reduction GHG emission compared to BAU scenario again due to further drop in virgin plastic production with increased recycling (about -10% less GHG emission compared to BAU) and an additional 0.7% reduction in open burning of plastic waste on top of the 4%% already observed in EPR_1 (increased collection and mechanical recycling);

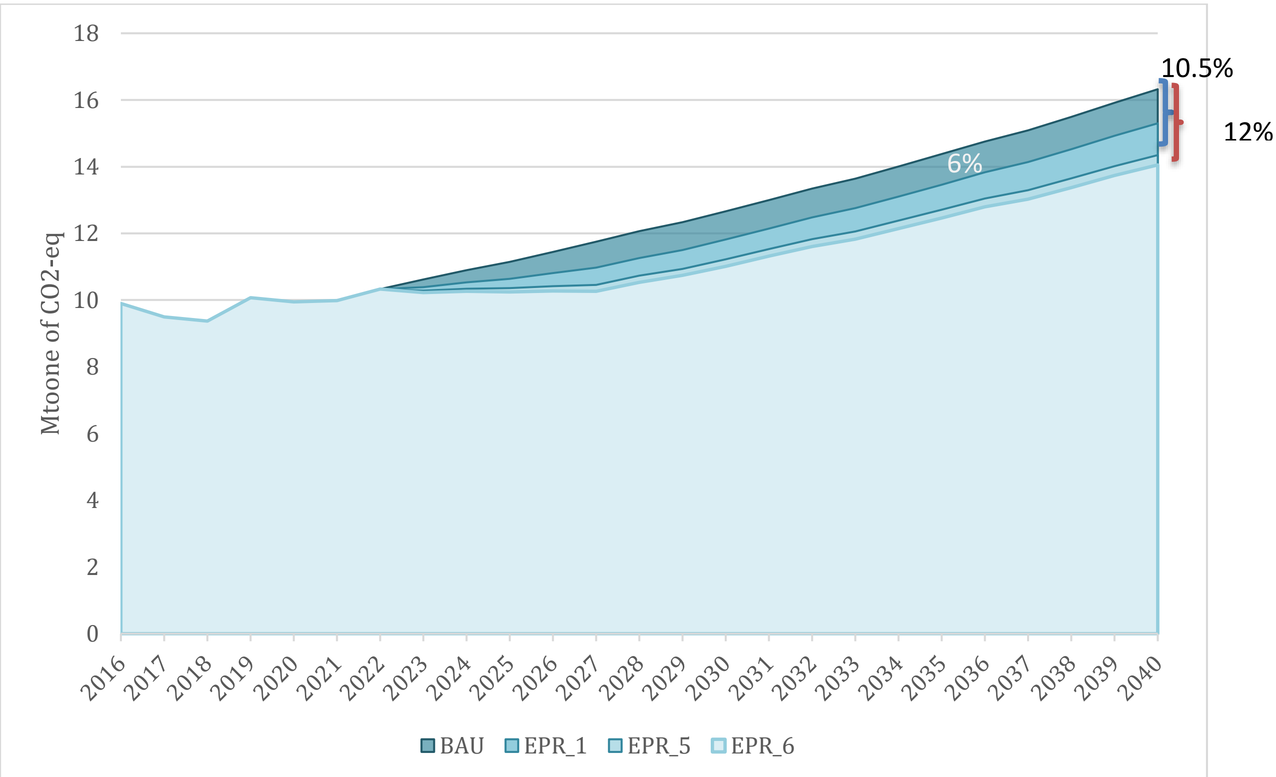


Figure 61: Cumulative GHG emission saving between 2023 and 2040

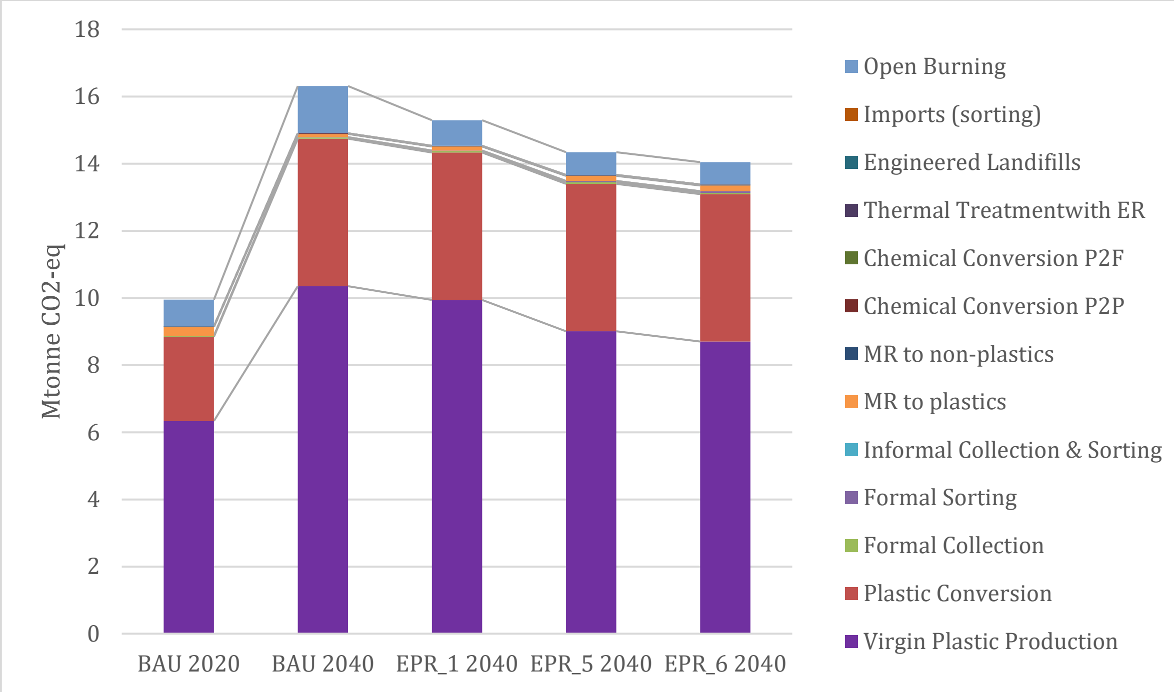


Figure 62: GHG emissions composition reduction between BAU and EPRs scenarios in 2040

Employment

Results for employment are illustrated in Figure 63 (as trends) and where the BAU/EPR 2020 employment figures are compared with the BAU and the different EPR scenarios explored in 2040. Cumulative, employment increase by 9.3%, by 15% and by 17.5% by 2040 for EPR_1 (increased collection and mechanical recycling), EPR_5 (increased collection, sorting at clean MRFs, and mechanical recycling) and EPR_6 (Increased collection, sorting at clean and dirty MRFs, and mechanical recycling) scenarios when compared to the BAU.

Specifically, in 2040 (Figure 64):

- employment in virgin plastic production sees a slight decline in the EPR scenario: -3.95% (EPR_1), -13% (EPR_5) and -15.9% (EPR_6) due to more plastic waste being recycled.
- employment in formal collection increase of about 28.4% for all three EPR scenario – EPR_5 and EPR_6 aim at increasing the formal sorting and recycling stages;
- employment in formal sorting increase by 26.4% (EPR_1, increased collection and recycling), by 334% (EPR_5 increased collection, sorting at clean MRFs and increased recycling) and by 438% (EPR_6, increased collection, sorting at clean and dirty MRFs and increased recycling), due to more plastic waste being pushed to formal sorting facilities through increased targets at flow C1 and E3 (Figure 1);
- Job in informal collection and sorting increase of about 4.37% for all three EPR scenario – EPR_5 (dirty MRF) and EPR_6 (dirty and clean MRF) aim at increasing the formal sorting and recycling stages only;
- employment in MR to plastics shows an increase of 18% (EPR_1, increased collection and recycling), of 59% (EPR_5, increased collection, sorting at clean MRFs and increased recycling) and 72%% (EPR_6, increased collection, sorting at clean and dirty MRFs and increased recycling) due to more plastic waste coming from formal sorting facilities;
- employment in MR to non-plastics doubled (105.4%) for EPR_1, increased collection and recycling, showed a 4- and 5- fold increase (446% and 560%) for EPR_5 and EPR_6 scenario respectively, coming from formal sorting at clean and/or dirty MRFs;
- An 8.2% increase in employment was observed for the Chemical Conversion (P2P) stage for all three EPR scenarios;

- employment at the engineered landfill stages showed an when compared to the BAU scenario: -+20% (EPR_1 and EPR_5) and 14% (EPR_6) for engineered landfills. The declining in EPR 6 is mainly due to more waste being recovered at the level of clean and dirty MRF, thus not reaching the disposal stage.

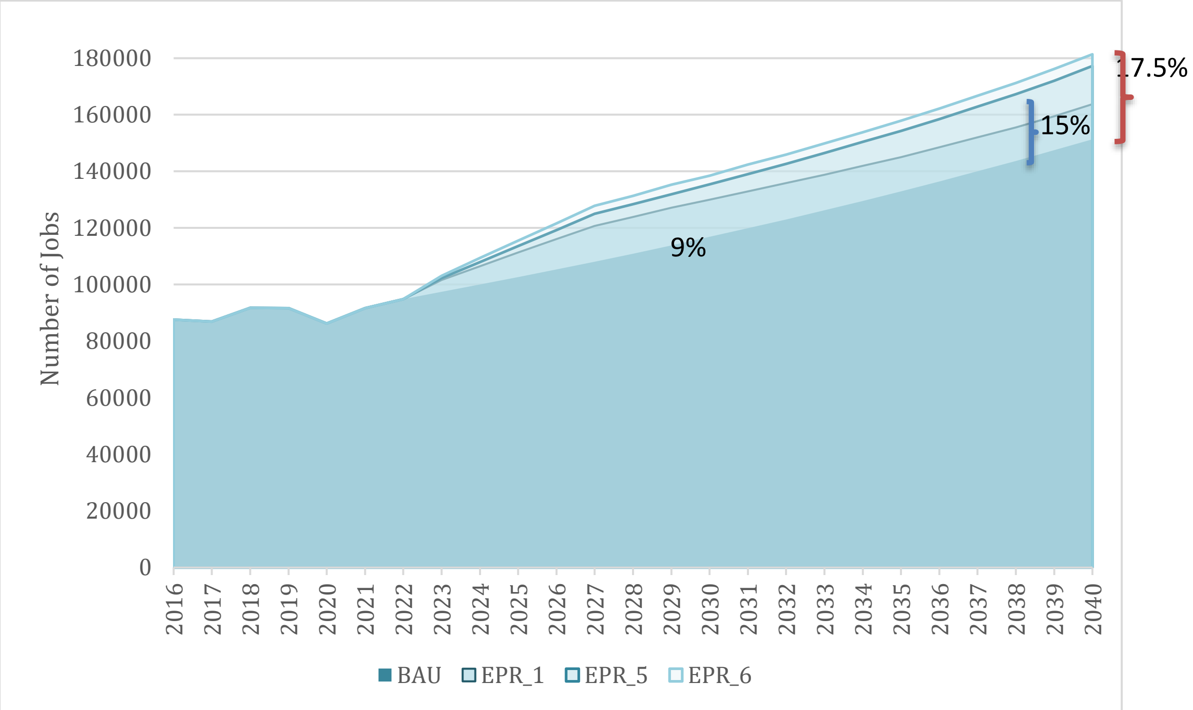


Figure 63: Employment trend between 2023 and 2040

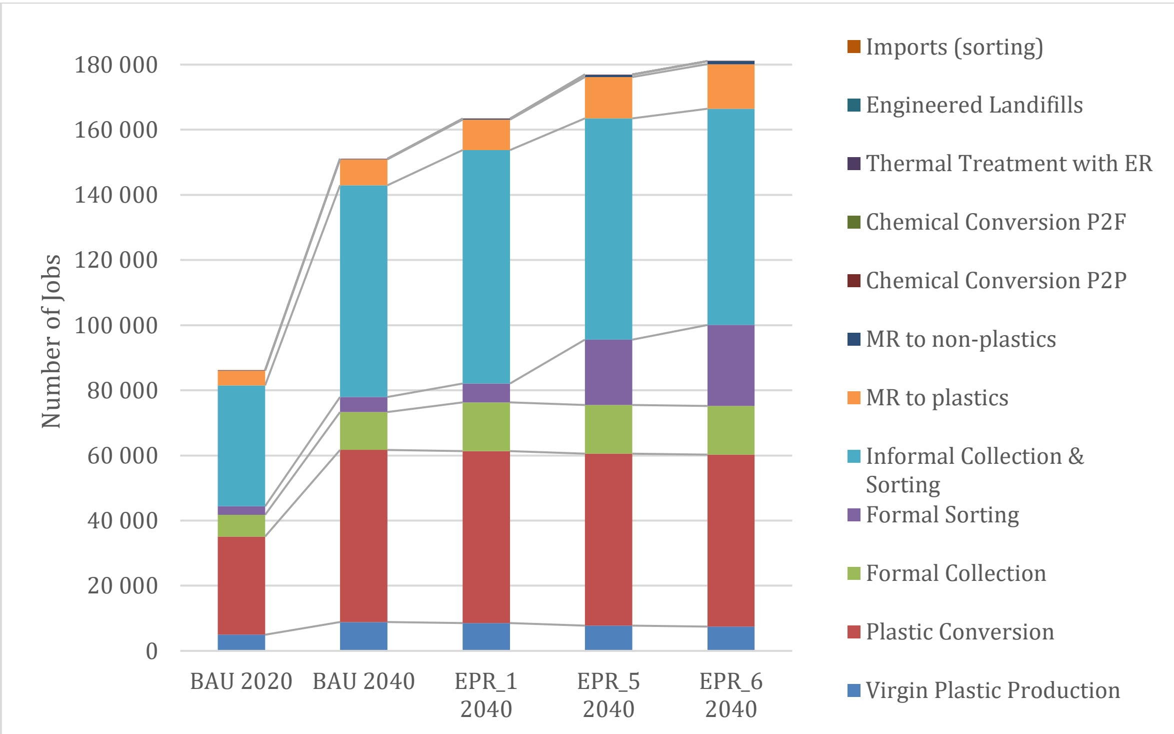


Figure 64: EPRs vs BAU employment comparison based on FTE.

Costs and Required investment

Figure 65, Figure 66 and Figure 67 present the EPRs vs BAU comparison in 2040 for OPEX, CAPEX, revenues as well as additional infrastructure capacity and required investment, respectively. All costs are in terms of nominal values.

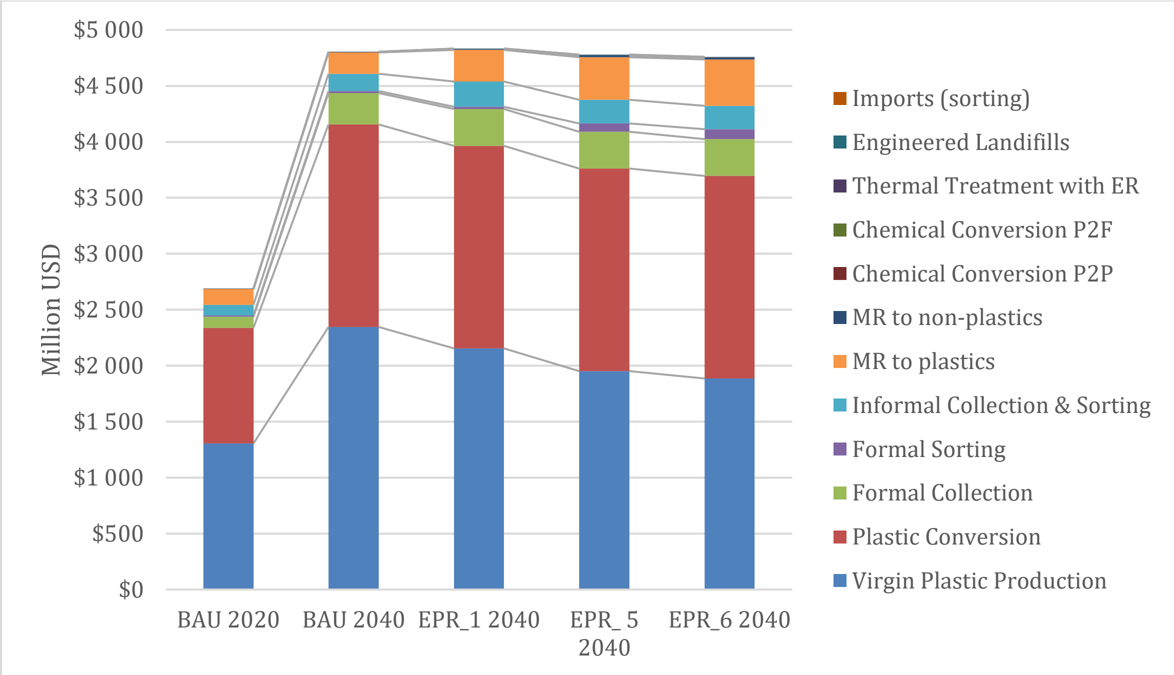


Figure 65: EPRs vs BAU OPEX composition comparison in 2040

OPEX show an increase of 75-79% from year 2020 to 2040 for both BAU and EPR scenarios, with decimal difference between EPR scenarios. Similarly, CAPEX increased from 74% (BAU in 2040) to 97% (EPR_6 in 2040). The reason for these differences is the difference in allocation of the operational and capital costs among the stages of the value chain. Specifically in 2040:

- Virgin plastic production OPEX and CAPEX could decline from 76.8% (BAU) to 49.6% (EPR 6, including both clean and dirty MRFs);
- Plastic conversion OPEX and CAPEX remain unchanged;
- Formal collection OPEX and CAPEX could increase from 75.2% (BAU) to 125% (all EPRs);
- Informal collection OPEX and CAPEX could increase from 67.7% (BAU) to 84.6% (EPR 6, including both clean and dirty MRFs);
- Formal sorting OPEX and CAPEX could increase from 70% (BAU) to 736.7% (EPR 6, including both clean and dirty MRFs);
- MR to plastics OPEX and CAPEX could increase from 68.4% (BAU) to 186.2% (EPR 6, including both clean and dirty MRFs); and
- OPEX and CAPEX in MR to non-plastics could increase from 53.9%(BAU) to 852% (EPR 6, including both clean and dirty MRFs);
- Chemical conversion OPEX and CAPEX could increase from 43.6% (BAU) to 55.4% (all EPRs);
- OPEX reduction are observed for thermal treatment – from 42.9% (BAU) to 32.9% (EPR_6, including both clean and dirty MRFs) – and for engineered landfills – from 72.72.4% (BAU) to

61.5% (EPR 6, including both clean and dirty MRFs) due to less waste being disposed/treated.

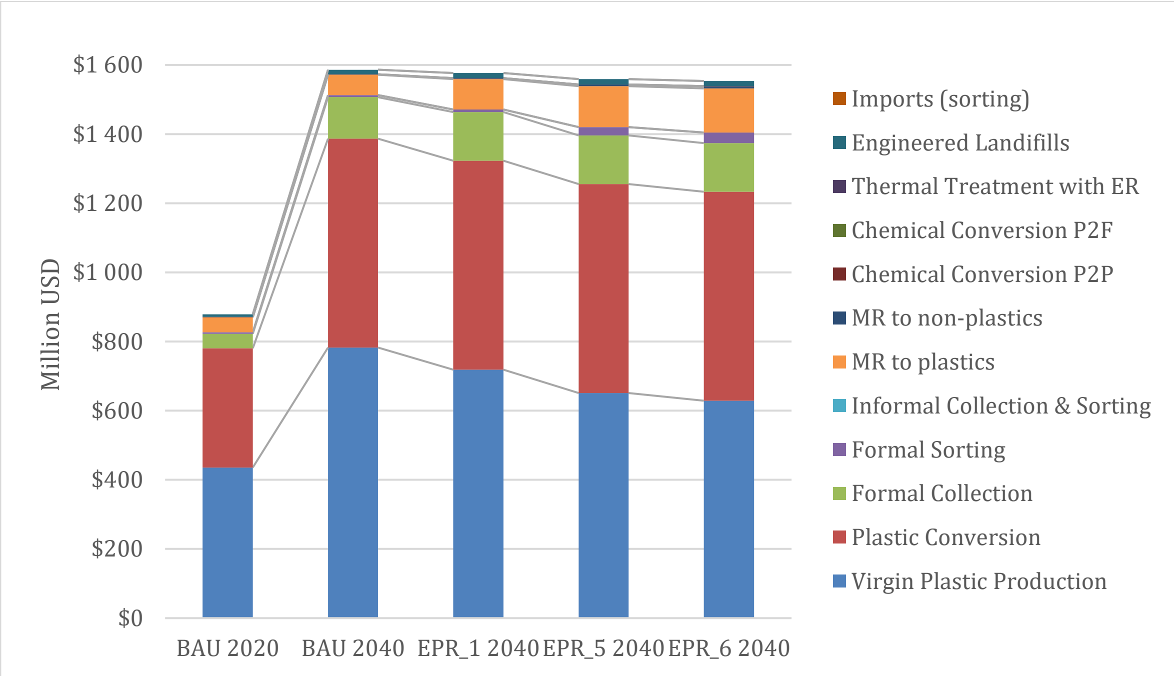


Figure 66: EPRs vs BAU CAPEX composition comparison in 2040

Revenues that can be generated are illustrated in Figure 67 and show a 68% (BAU), 100% (EPR_1, increased collection and mechanical recycling), 167% (EPR_5, increased collection, sorting at clean MRFs and mechanical recycling) and 182% (EPR_6, increased collection, sorting at clean and dirty MRFs and mechanical recycling) increase in year 2040, when compared with BAU/EPR in 2020. The bulk of additional revenues in 2040 lays in the MR to plastics: +17.6% (EPR_1), +60% (EPR_5) and + 69% EPR_6), followed by MR to non-plastics which could double in 2040 (+105% for EPR_1) up to 6-fold increase (+518% for EPR_6) in 2040.

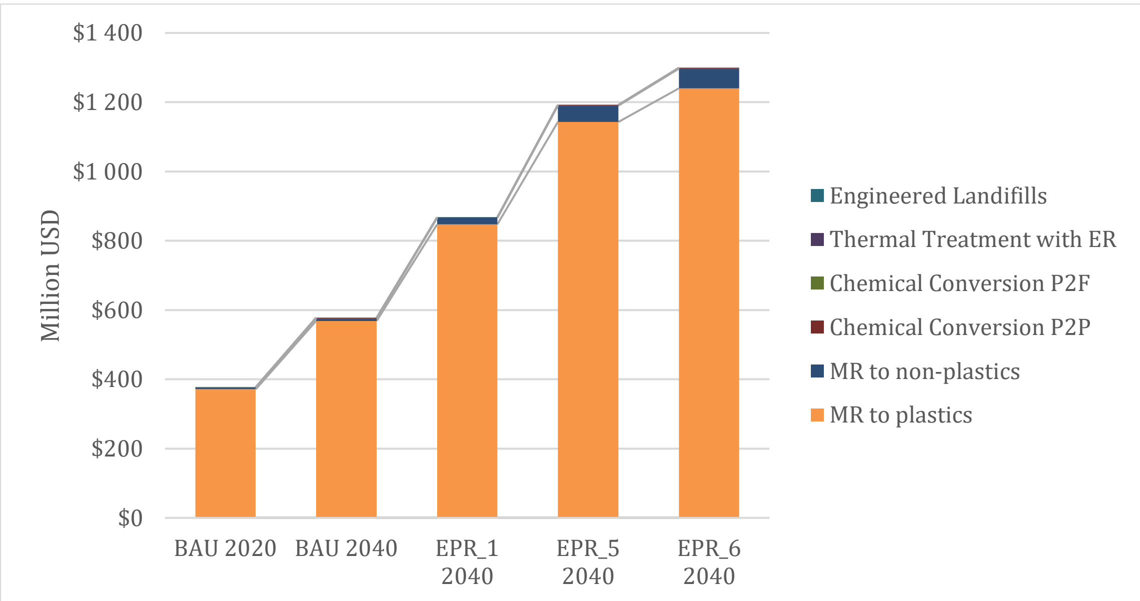


Figure 67: EPRs vs BAU Revenues composition comparison in 2040

Additional infrastructure capacity, mainly related to disposal of plastic waste in engineered landfills, and required investment are shown in Figure 68 and Figure 69 which reports the EPR1, EPR_5 and EPR_6 needs for 2040. To meet the target of EPR_1 additional capacity (23%) is needed for engineered (sanitary) disposal, which translates in a 5% increase in investment required when compared with the BAU scenario for the same year; EPR_5 and EPR_6 requires less additional capacity compared to EPR_1 in terms of landfills since less plastic waste will be disposed, but would require additional capacity – 7% and 5% for EPR_5 and +9.2% and 6% for EPR_6, compared to EPR_1 – and investments (3.4% for EPR_5 and 4.5% for EPR_6 when compared with EPR_1) in the formal sorting and MR to cope with the increasing plastic waste sorted and recycled.

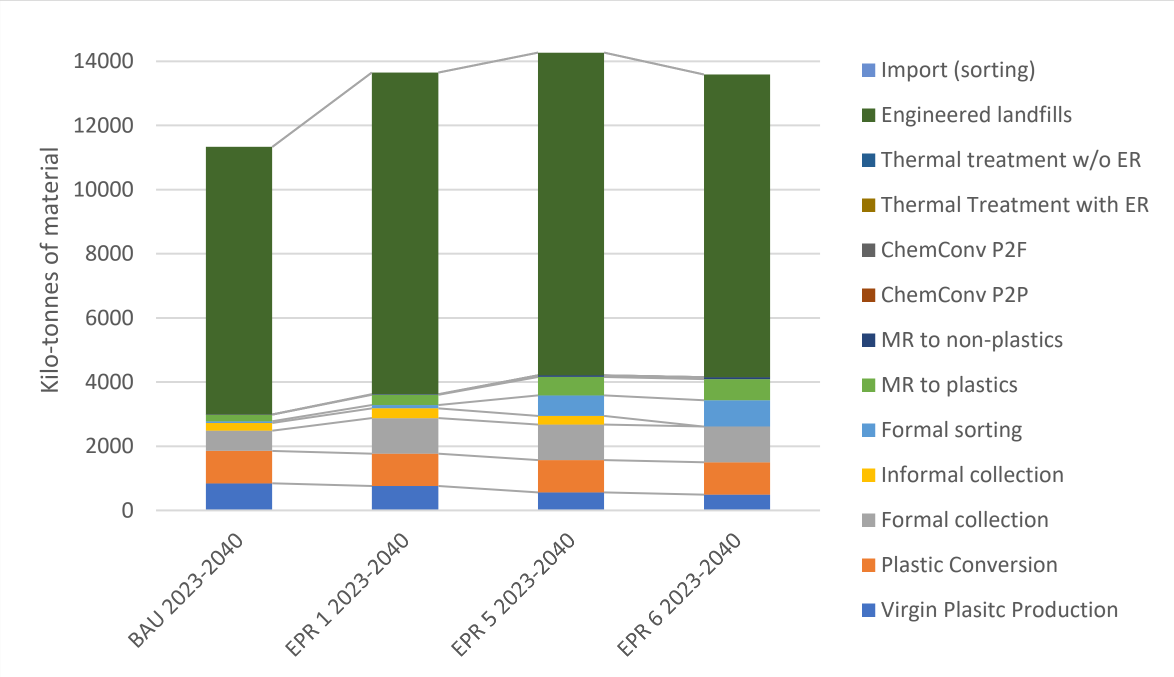


Figure 68: EPRs vs BAU cumulative additional capacity between 2023 and 2040

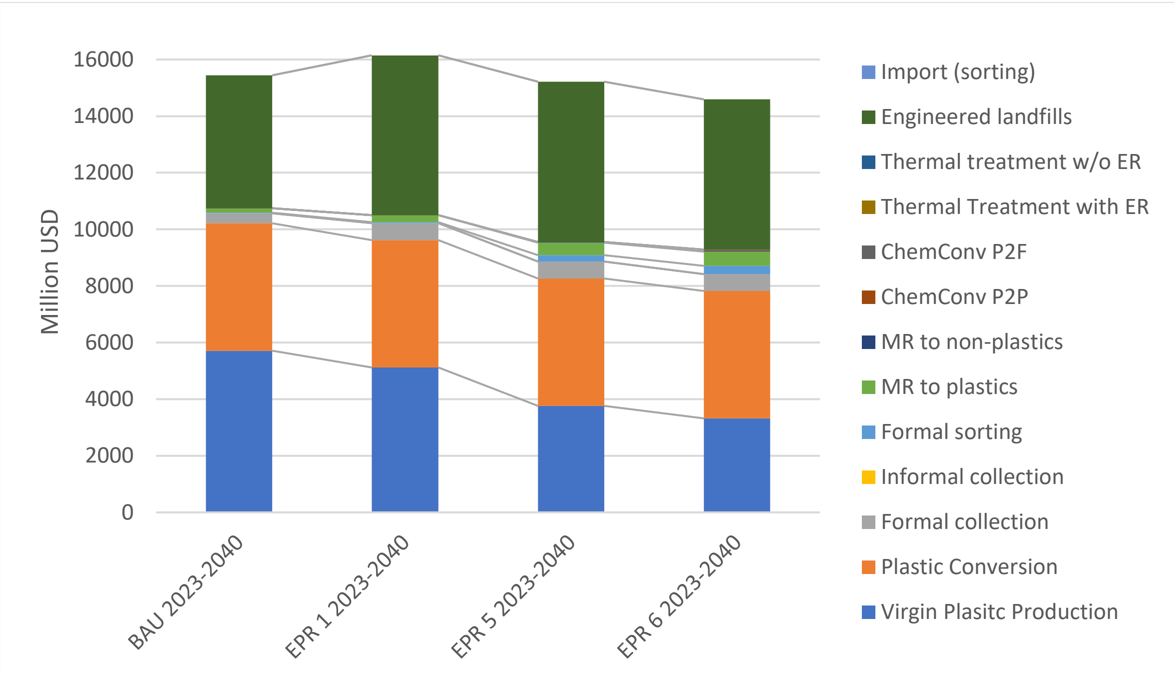


Figure 69: EPRs vs BAU cumulative required investment between 2023 and 2040

Annexure 7: The importance of using local data

Great effort was put in to source the best available data representing the South African context, so to limit the reliance on the global model and/or UMI archetype data. Using data to better represent the local context aims at improving results accuracy.

Specifically, here we are presenting a comparison between some key flows and related results when using the UMI archetype data for growth rates of plastic waste production and GHG emission based on global model data.

Plastic waste growth demand rate:

- South Africa was based on the GDP growth rate (see Table 9 and Table 10);
- UMI archetype data: 4.2 % fixed – CAGR (compound annual growth) model.

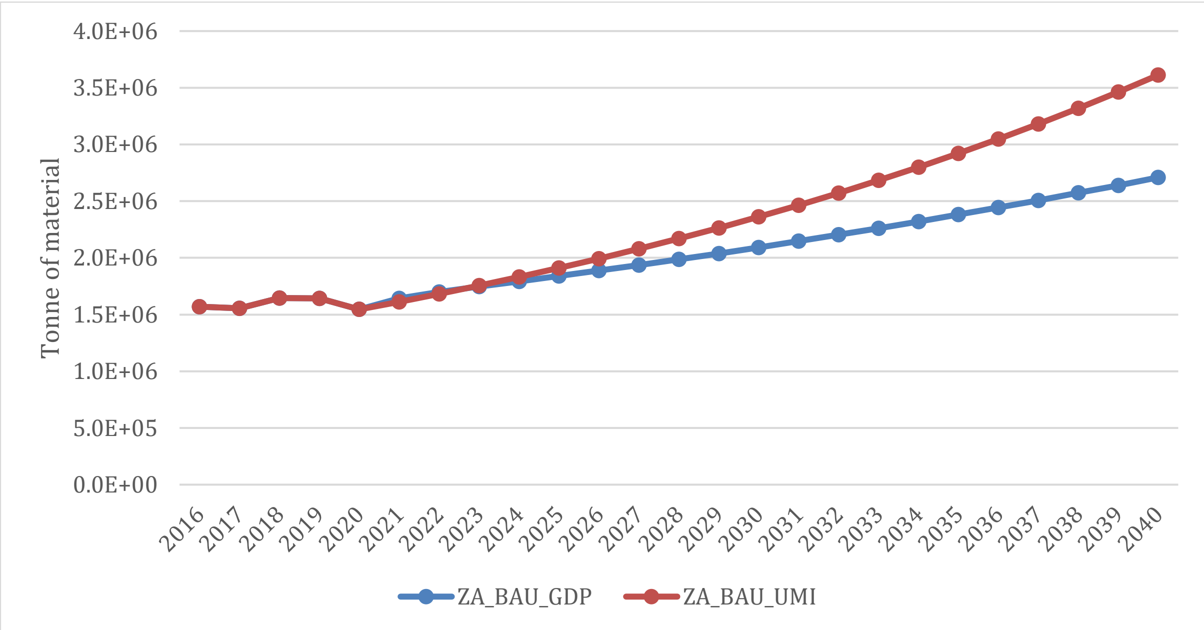


Figure 70: Total Plastic Waste Generated projections based on SA GDP growth rate or UMI growth rate

Figure 70 presents a comparison between the total plastic waste generated, which is the entry point form which everything else is calculated by the Pathways app. The difference between the BAU scenario - how it has been modelled using the GDP growth rate to model the plastic waste demand growth over time– and how it would have looked like if the UMI archetype data would have been applied is of 25% (in 2040).

Global GHG emission factors

South African emission factors were derived for as many as possible stages of the plastic value chain and Table 13 provides details on where lack of South Africa GHG emission factor data was replaced by global data. However, when using only emission factor from the Global model, GHG results underestimate the current local context of 23% (2016) and 19% (2040) (Figure 71).

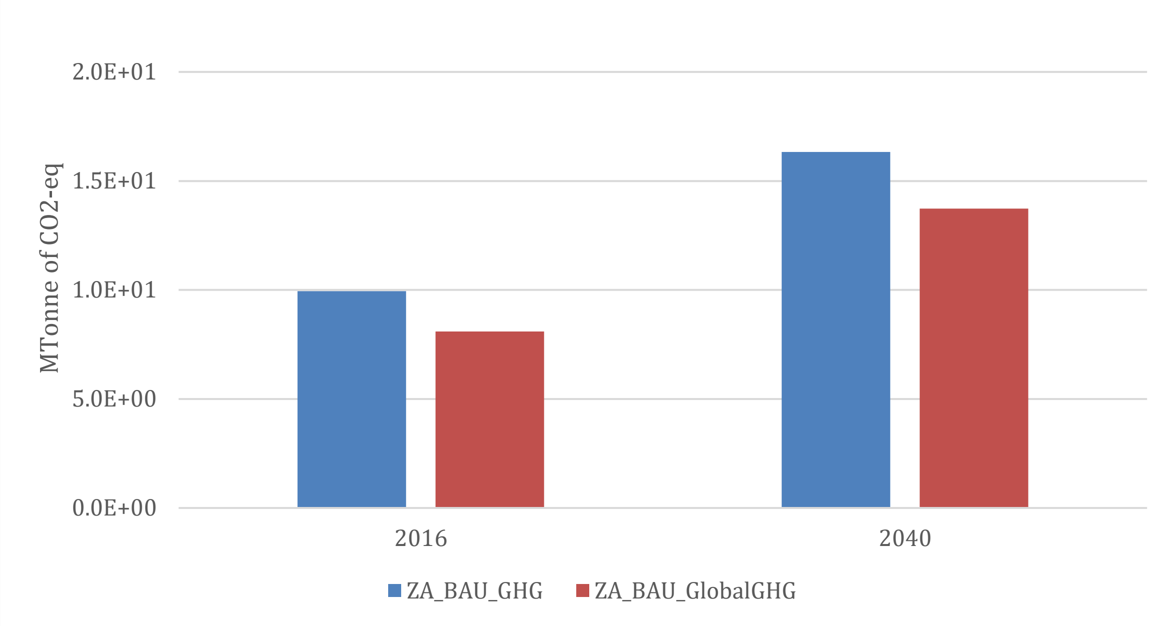


Figure 71: GHG emissions comparison between BAU scenario using South Africa GHG emission data and GHG emission from the global model

Employment

High uncertainty remains on the numbers to accurately represent the informal sector "employment". Data from Plastics SA Recycling Survey (2019) reports on informal income opportunities and those were used throughout the study.

Other relevant data on the informal employment in collection and sorting were those coming from the Pew Global Study "Breaking the Plastic Wave" and is the median among 16 studies cities in China, Brazil, Colombia, Peru, Mexico, Cambodia, and Romania, which assumed:

- A calculated year on year estimate which yields a 200k informal pickers (on average) using the following assumption: SA population on a specific year and the share of informal sector (0.332%). different splits for the rigid mono-material, flexible mono-material and multi-material categories: 15%, 83% and 2% respectively.

Due to the relationship between employment and flow V1 (i.e. what the informal sector recovers from open-dumps/unsanitary landfills), results can vary and different impacts are reflected on: employment, recycling, and to a lesser extent on pollution flows (aquatic, land pollution and open burning). The comparisons are presented in Figure 72 to Figure 77 below.

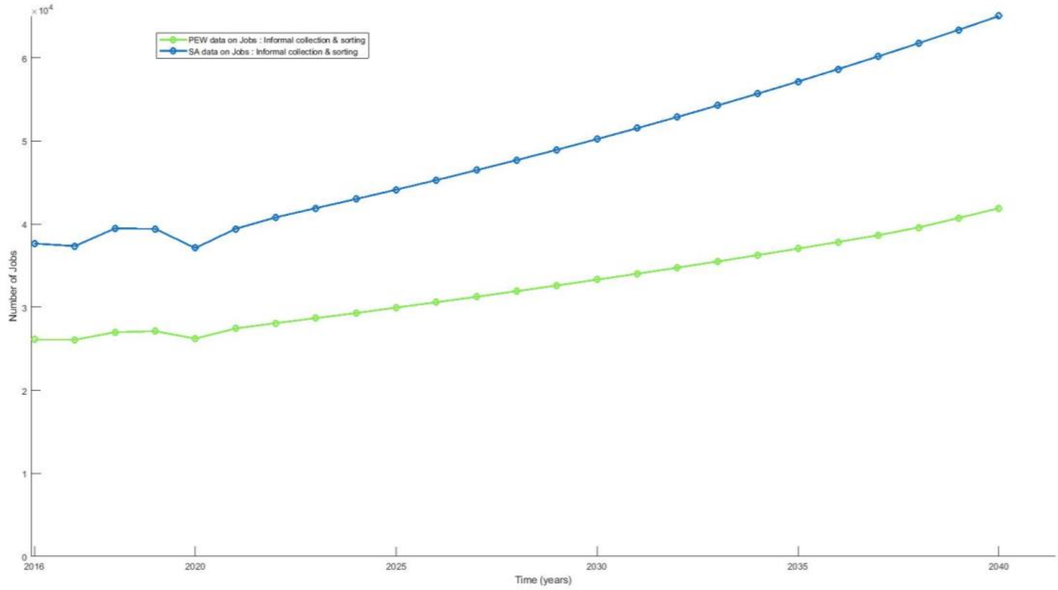


Figure 72: Employment trend comparison when different inputs of V1 and employment are used employment employment

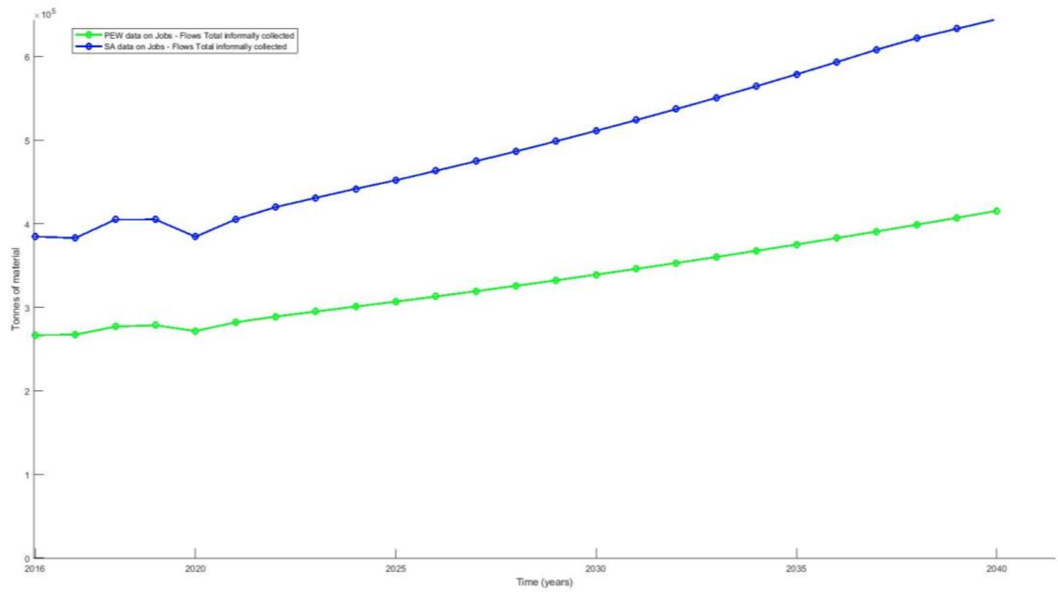


Figure 73: Informally collected plastic waste trends when different inputs of V1 and employment are used employment

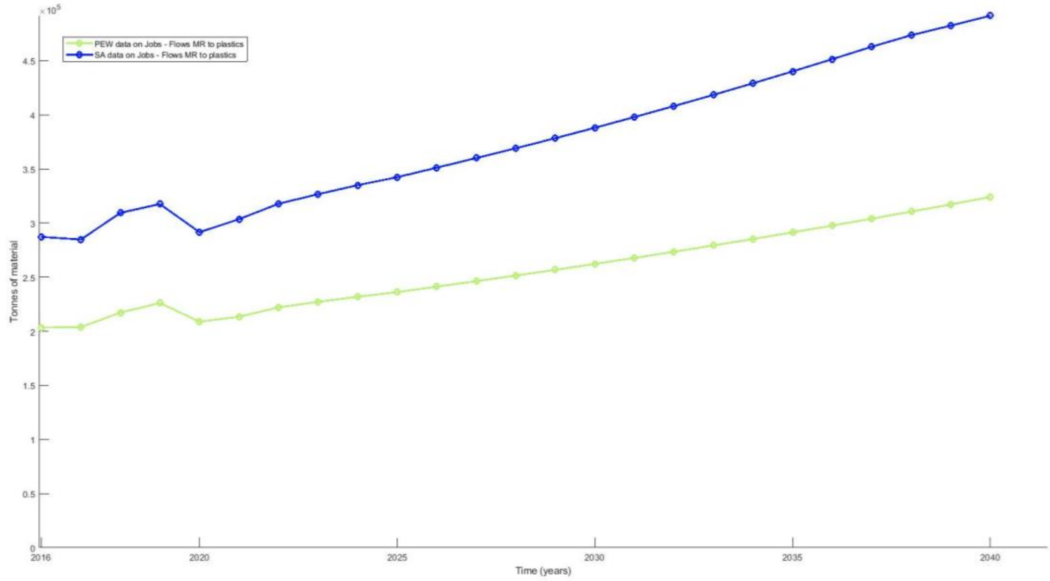


Figure 74: Mechanical recycling to plastics trend comparison when different inputs of V1 and employment are used

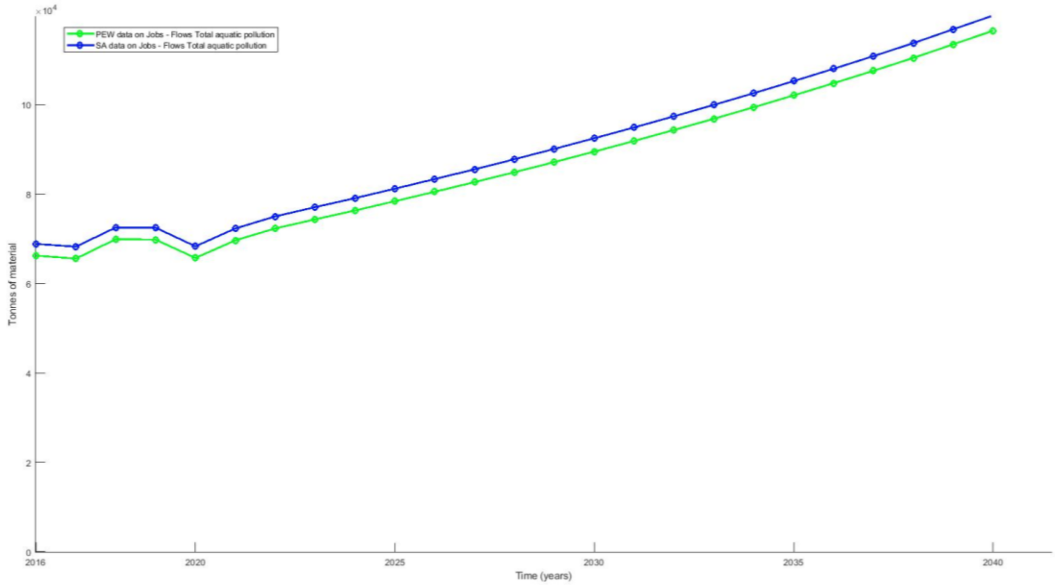


Figure 75: Aquatic pollution trend comparison when different inputs of V1 and employment are used

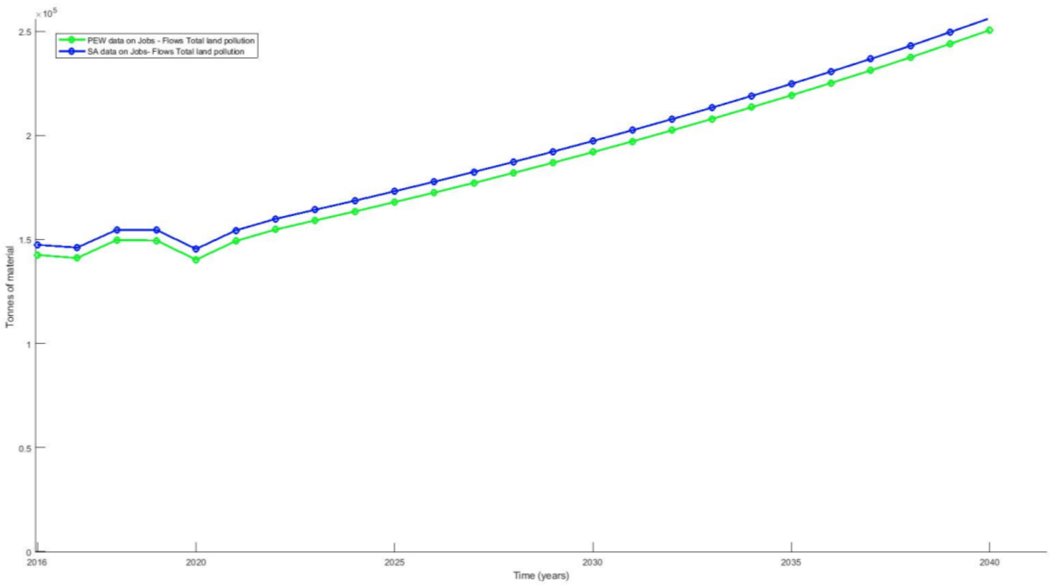


Figure 76: Land pollution trend comparison when different inputs of V1 and employment are used

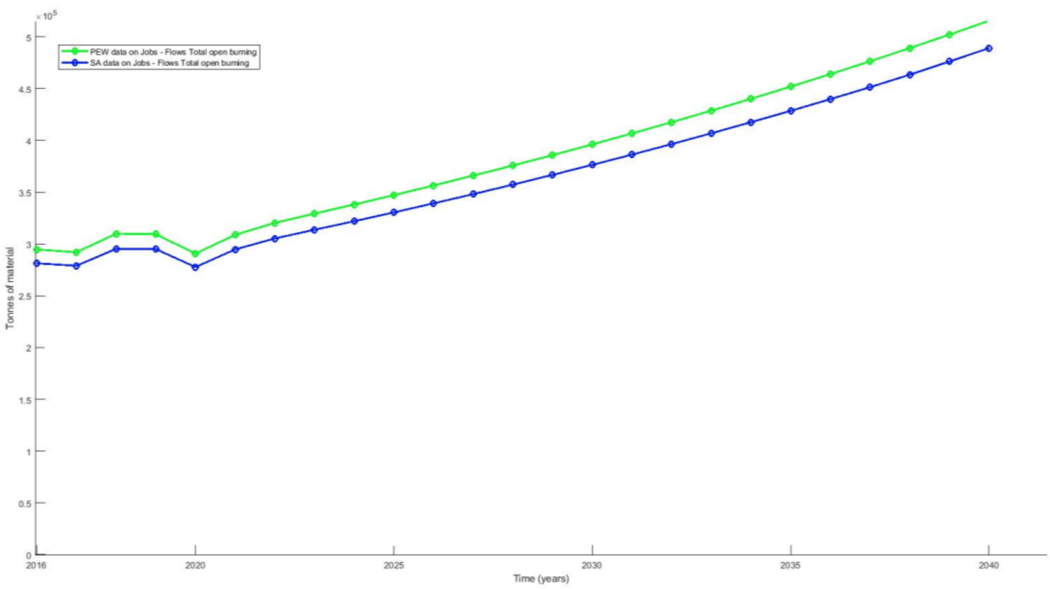
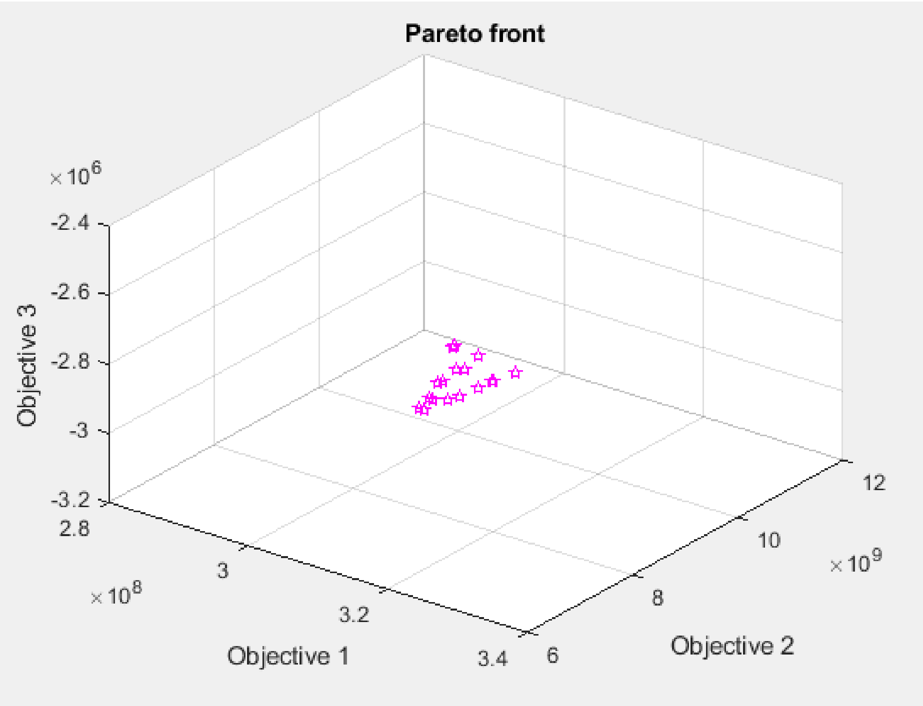


Figure 77: Open-burning trend comparison when different inputs of V1 and employment are used

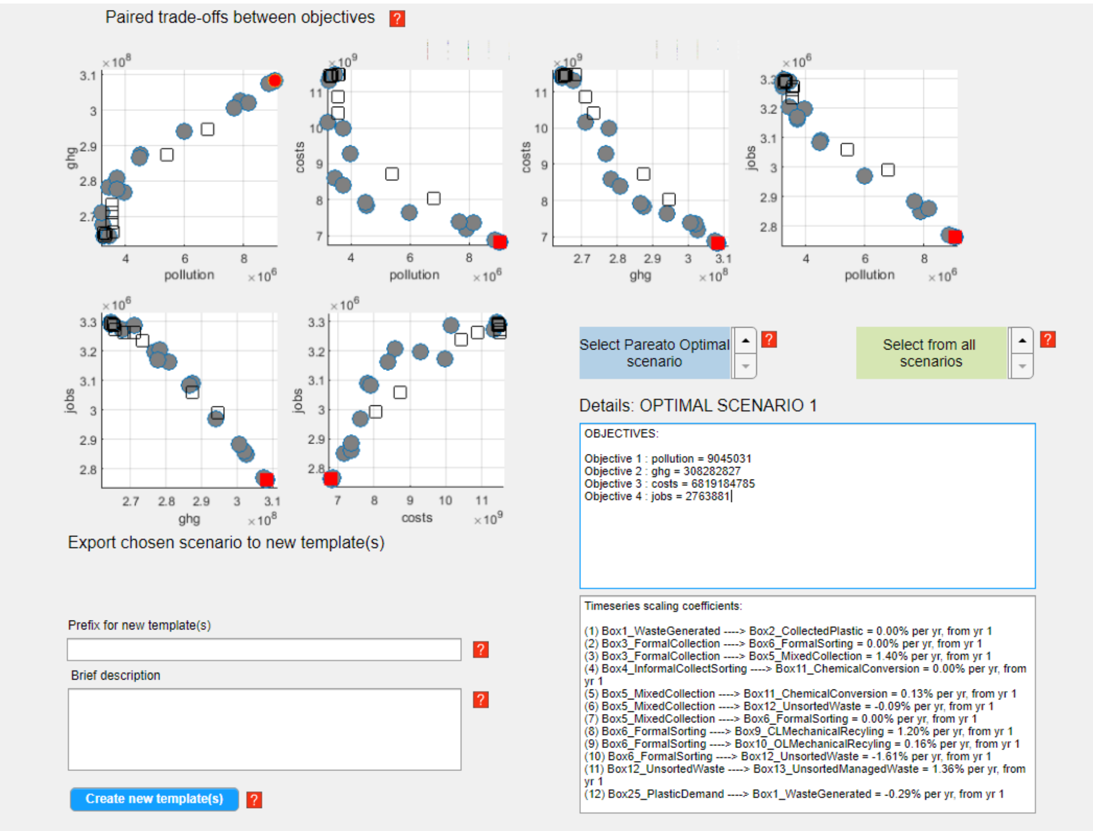
The three examples presented serves to highlight that, when applying Global Models to a specific local context, it is crucial to source and apply key data representing the local socio-economic background (growth rate, GHG emission, employment etc.). The consequence of using archetype data (UMI) or global data, which cluster together countries with a range of different socio-economic contexts, is that outcomes might result in under- (e.g., GHG emissions) and/or over-estimates (the plastic waste generated) which compromise the accuracy of the study and the recommendations drawn.

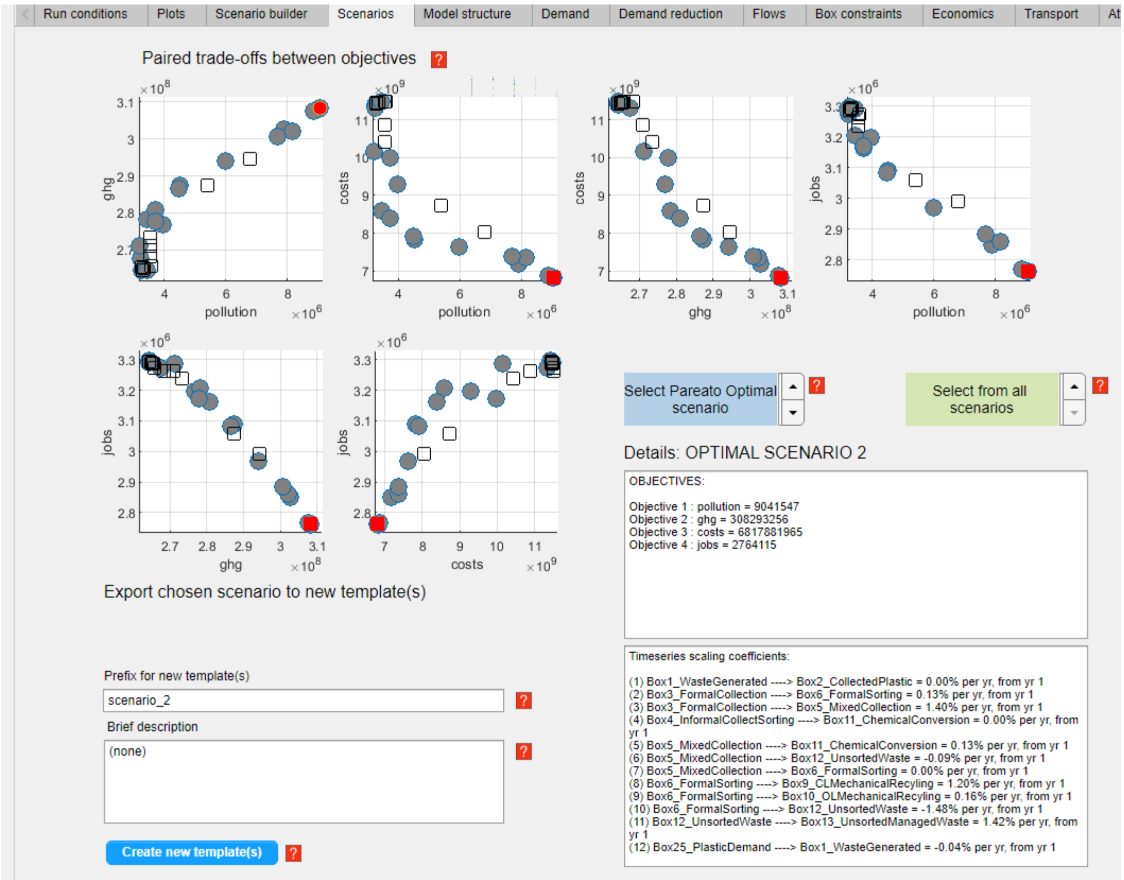
Annexure 8: Optimal System Change scenario

The Pareto front from optimization with the objectives of minimising pollution, minimising GHG, minimising required investment (capital cost) and maximising employment.



All 18 scenarios identified with the Optimal System Change optimisation.




Run conditions
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Model structure
Demand
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Paired trade-offs between objectives
ghg
pollution
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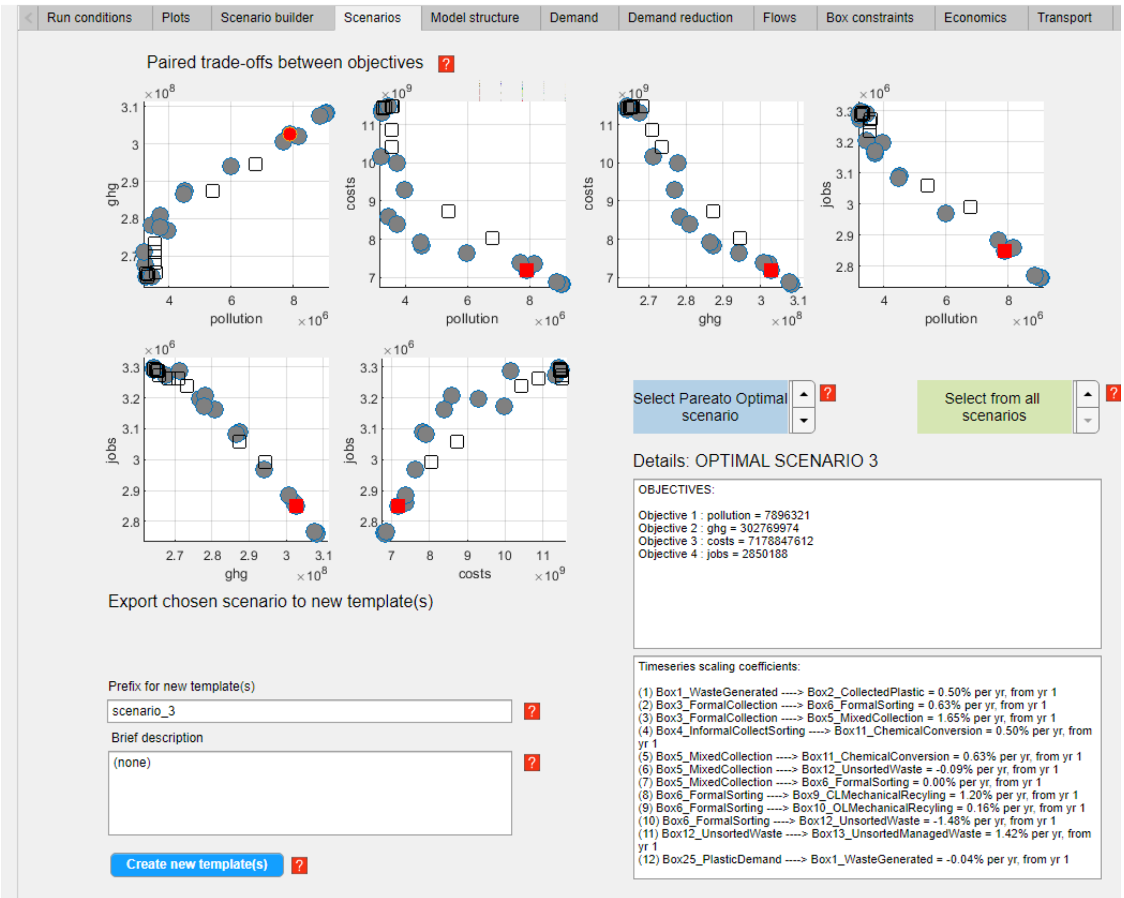
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 2
OBJECTIVES:
Objective 1 : pollution = 9041547
Objective 2 : ghg = 308293256
Objective 3 : costs = 6817881965
Objective 4 : jobs = 2764115
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 0.00% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 0.13% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.40% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 0.00% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 0.13% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -0.09% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 0.00% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 1.20% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 0.16% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.48% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.42% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.04% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_2
Brief description
(none)
Create new template(s)


Run conditions
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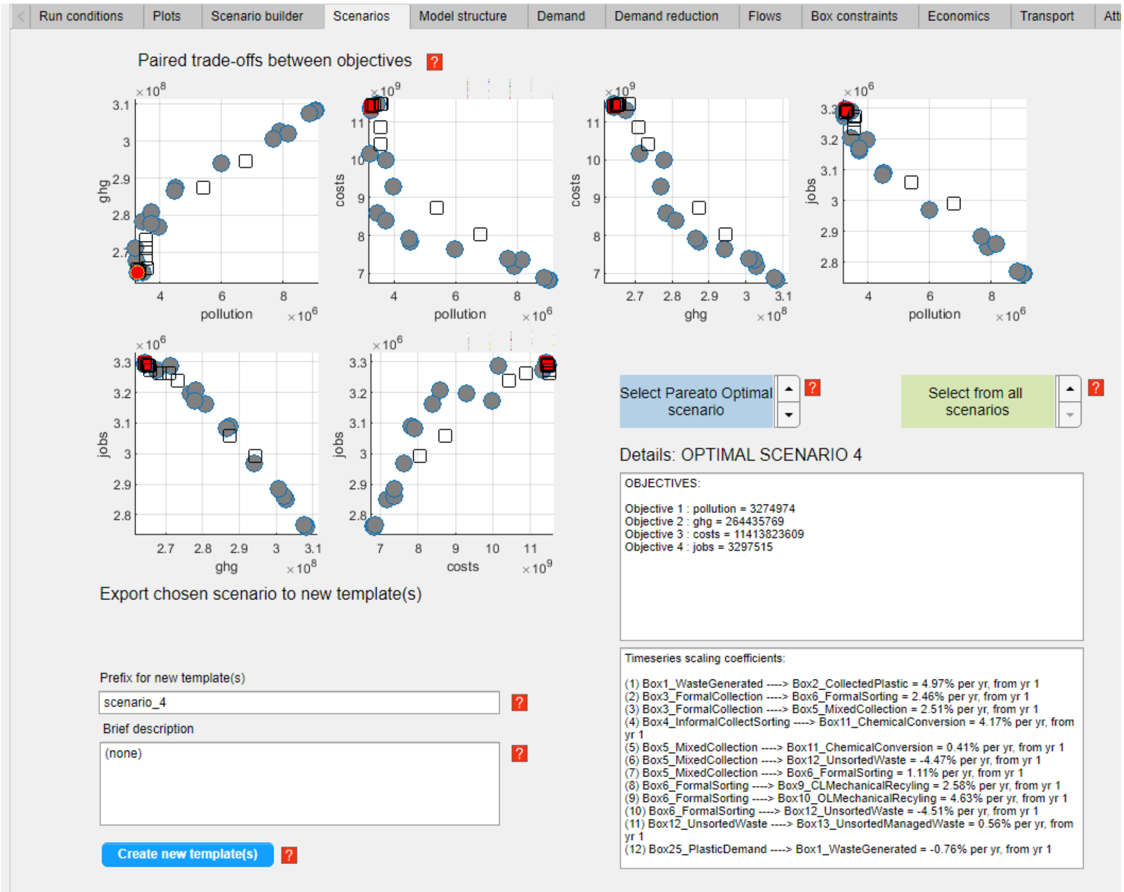
Paired trade-offs between objectives
ghg
pollution
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 3
OBJECTIVES:
Objective 1 : pollution = 7896321
Objective 2 : ghg = 302769974
Objective 3 : costs = 7178847612
Objective 4 : jobs = 2850188
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 0.50% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 0.63% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.65% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 0.50% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 0.63% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -0.09% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 0.00% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 1.20% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 0.16% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.48% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.42% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.04% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_3
Brief description
(none)
Create new template(s)


Run conditions
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ghg
costs
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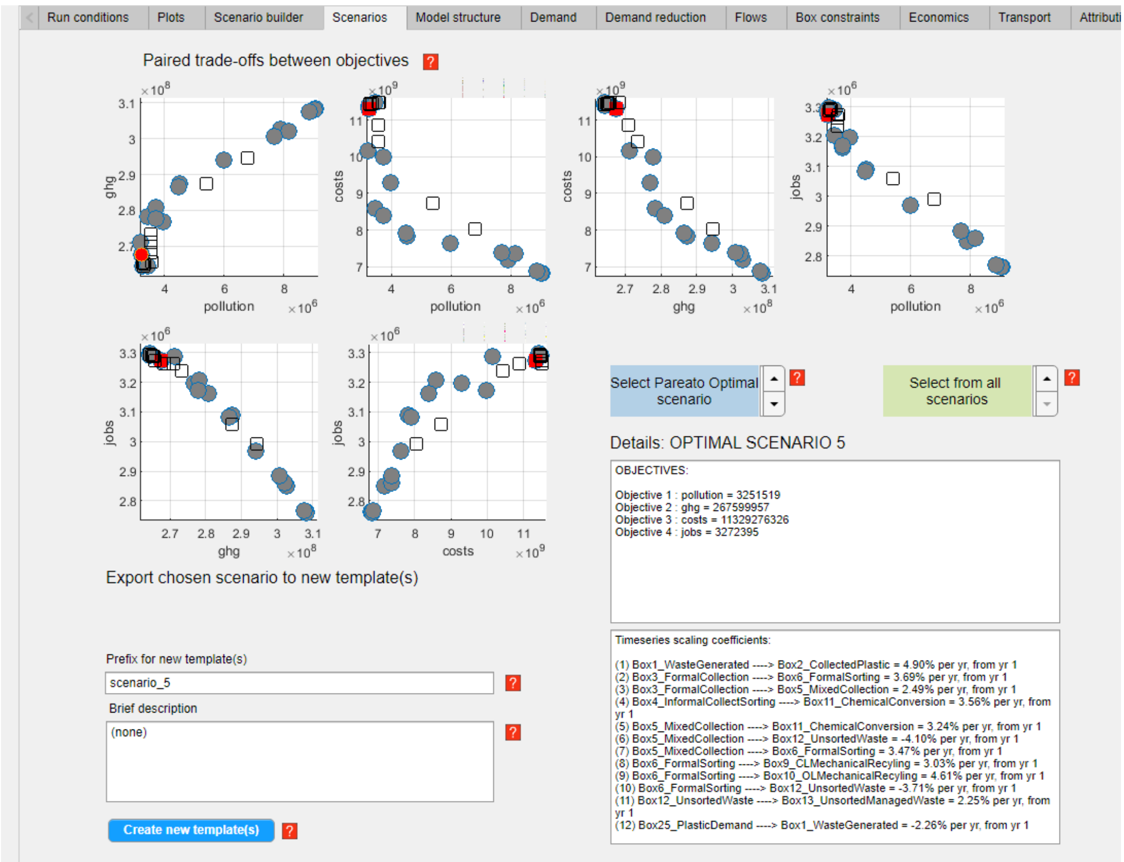
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 4
OBJECTIVES:
Objective 1 : pollution = 3274974
Objective 2 : ghg = 264435769
Objective 3 : costs = 11413823609
Objective 4 : jobs = 3297515
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 4.97% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 2.46% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 2.51% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 4.17% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 0.41% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -4.47% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 1.11% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.58% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 4.63% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -4.51% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 0.56% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.76% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_4
Brief description
(none)
Create new template(s)


Run conditions
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Paired trade-offs between objectives
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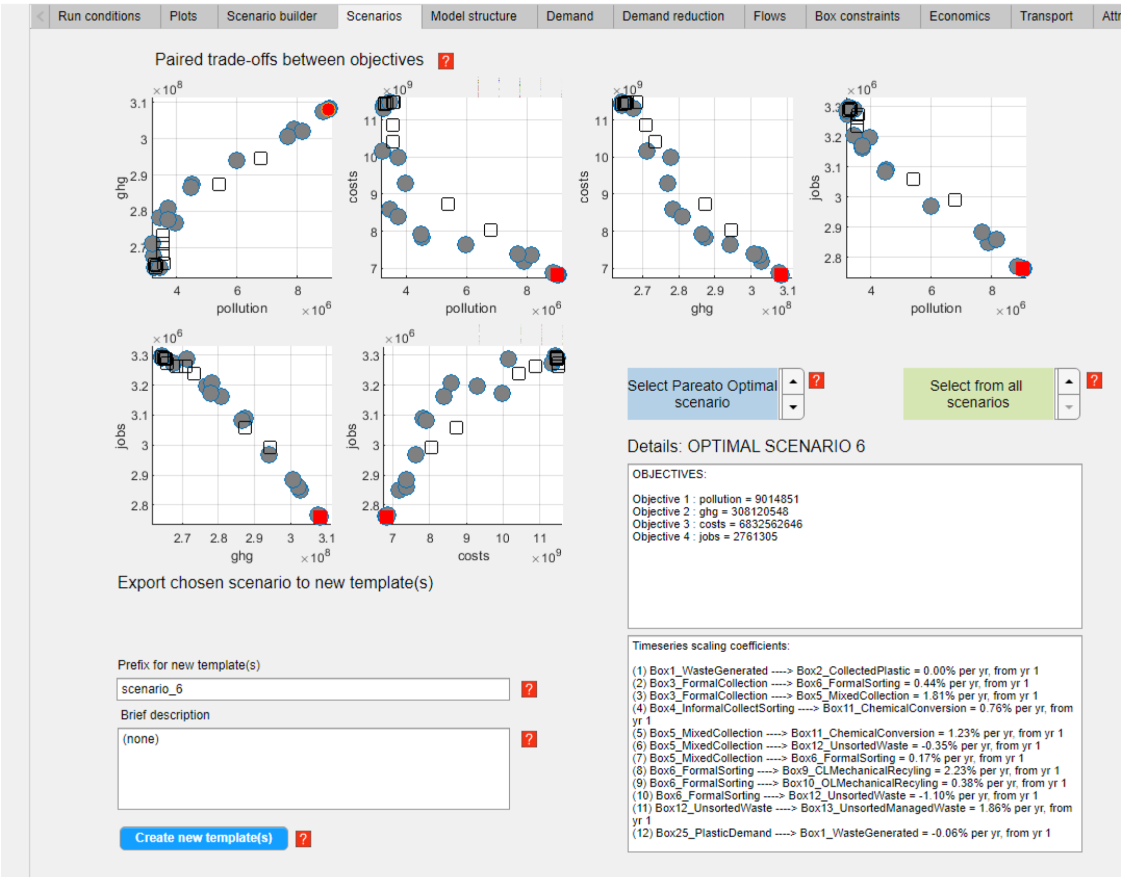
ghg
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 5
OBJECTIVES:
Objective 1 : pollution = 3251519
Objective 2 : ghg = 267599957
Objective 3 : costs = 11329276326
Objective 4 : jobs = 3272395
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 4.90% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 3.69% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 2.49% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 3.56% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 3.24% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -4.10% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 3.47% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 3.03% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 4.61% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -3.71% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 2.25% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -2.26% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_5
Brief description
(none)
Create new template(s)


Run conditions
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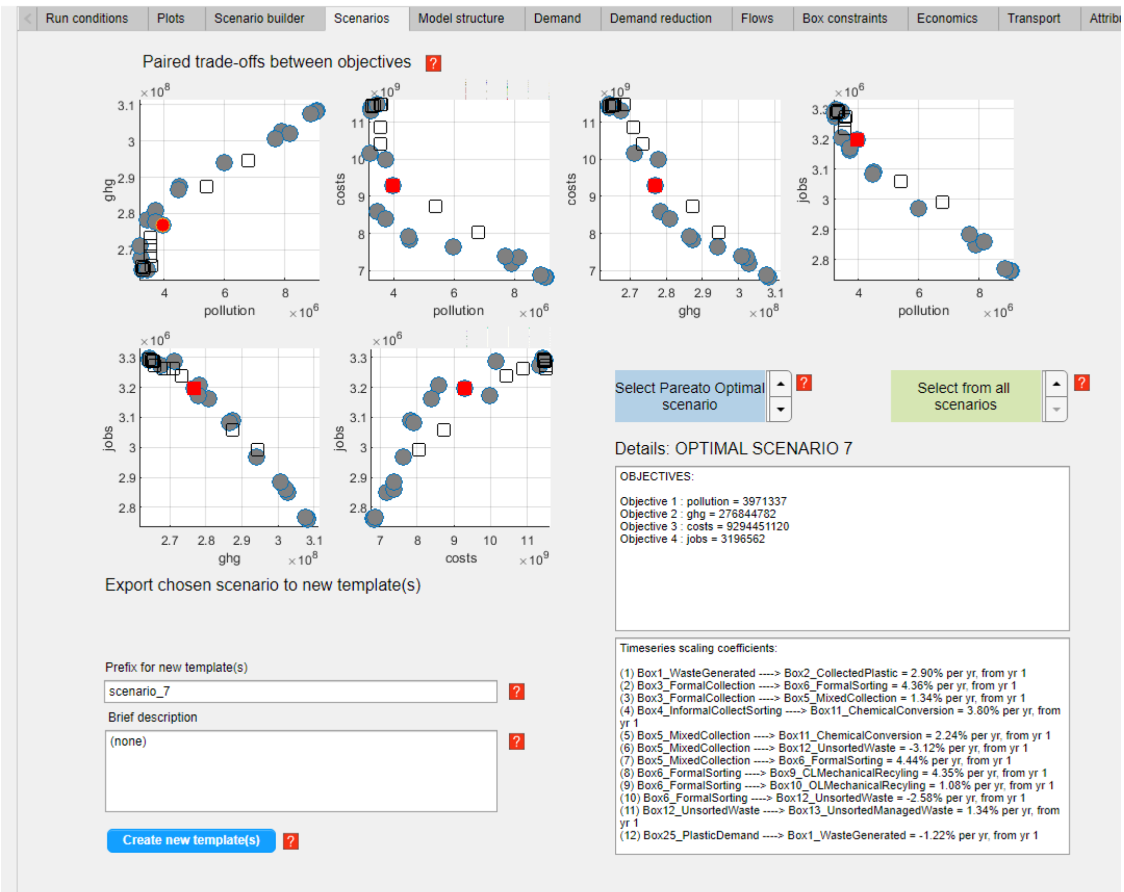
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 6
OBJECTIVES:
Objective 1 : pollution = 9014851
Objective 2 : ghg = 308120548
Objective 3 : costs = 6832562646
Objective 4 : jobs = 2761305
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 0.00% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 0.44% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.81% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 0.76% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 1.23% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -0.35% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 0.17% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.23% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 0.38% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.10% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.86% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.06% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_6
Brief description
(none)
Create new template(s)


Run conditions
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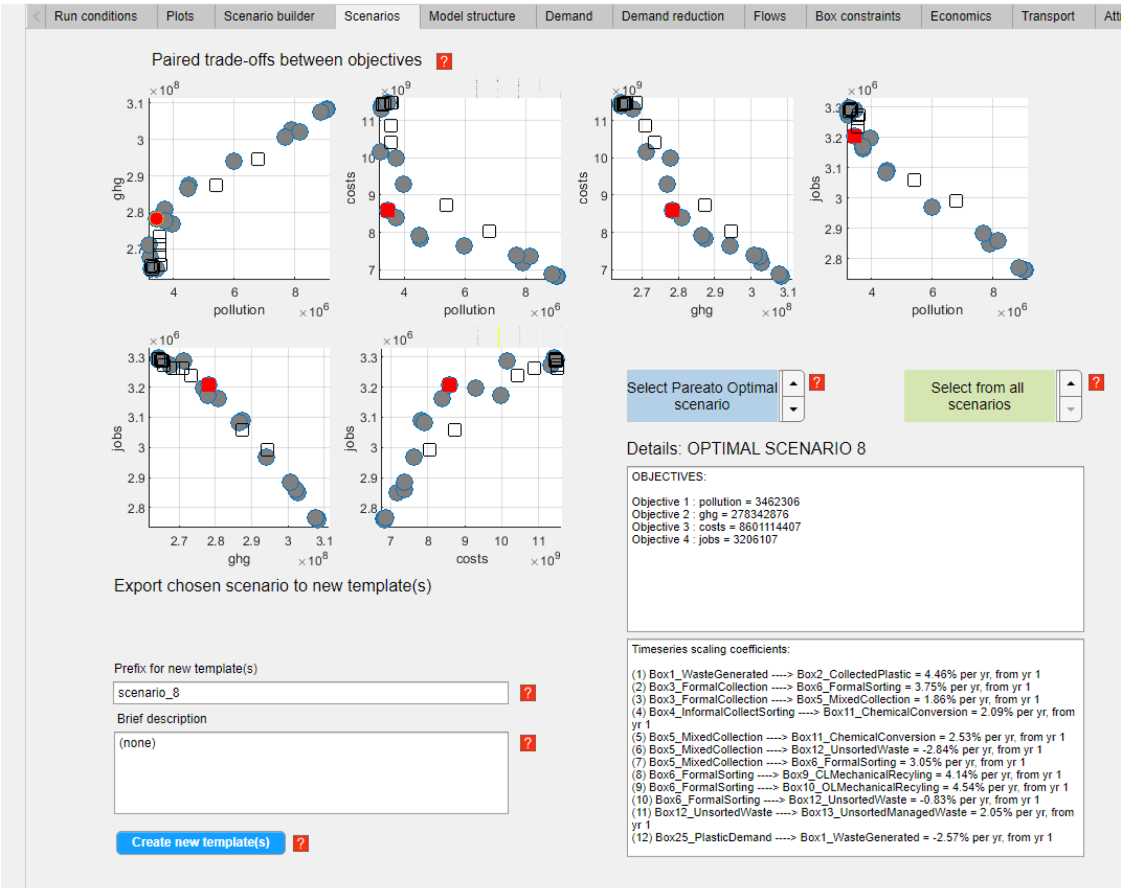
Paired trade-offs between objectives
ghg
pollution
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 7
OBJECTIVES:
Objective 1 : pollution = 3971337
Objective 2 : ghg = 276844782
Objective 3 : costs = 9294451120
Objective 4 : jobs = 3196562
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 2.90% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 4.36% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.34% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 3.80% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 2.24% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -3.12% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 4.44% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 4.35% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 1.08% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -2.58% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.34% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -1.22% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_7
Brief description
(none)
Create new template(s)


Run conditions
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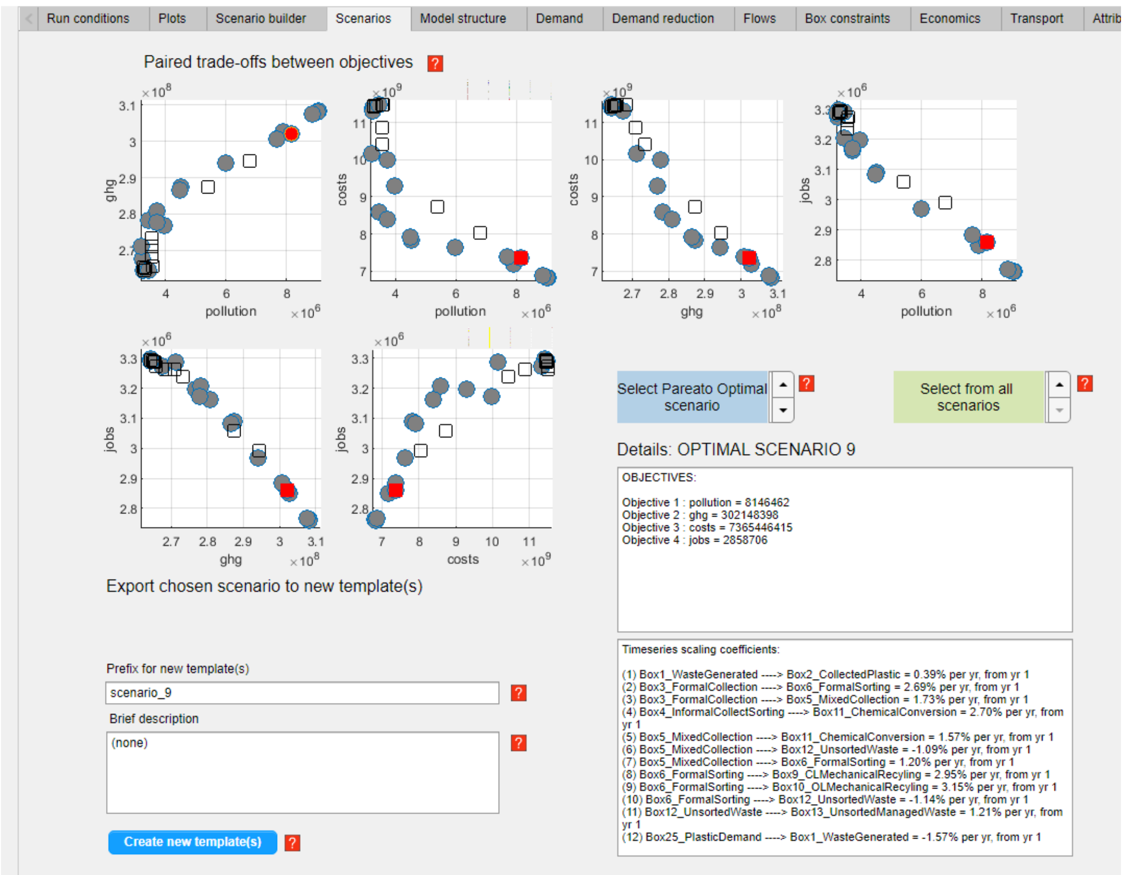
pollution
ghg
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 8
OBJECTIVES:
Objective 1 : pollution = 3462306
Objective 2 : ghg = 278342876
Objective 3 : costs = 8601114407
Objective 4 : jobs = 3206107
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 4.46% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 3.75% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.86% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 2.09% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 2.53% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -2.84% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 3.05% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 4.14% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 4.54% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -0.83% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 2.05% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -2.57% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_8
Brief description
(none)
Create new template(s)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Paired trade-offs between objectives
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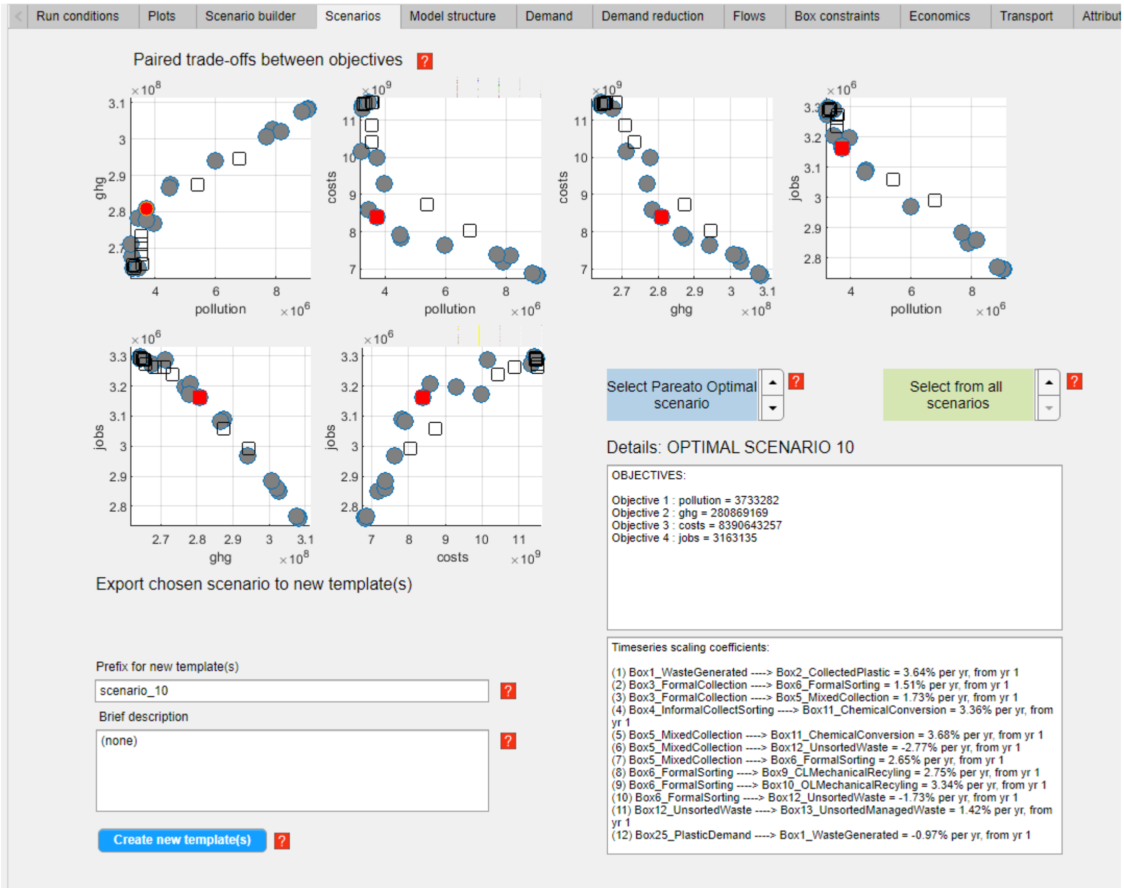
ghg
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 9
OBJECTIVES:
Objective 1 : pollution = 8146462
Objective 2 : ghg = 302148398
Objective 3 : costs = 7365446415
Objective 4 : jobs = 2858706
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 0.39% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 2.69% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.73% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 2.70% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 1.57% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -1.09% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 1.20% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.95% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 3.15% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.14% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.21% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -1.57% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_9
Brief description
(none)
Create new template(s)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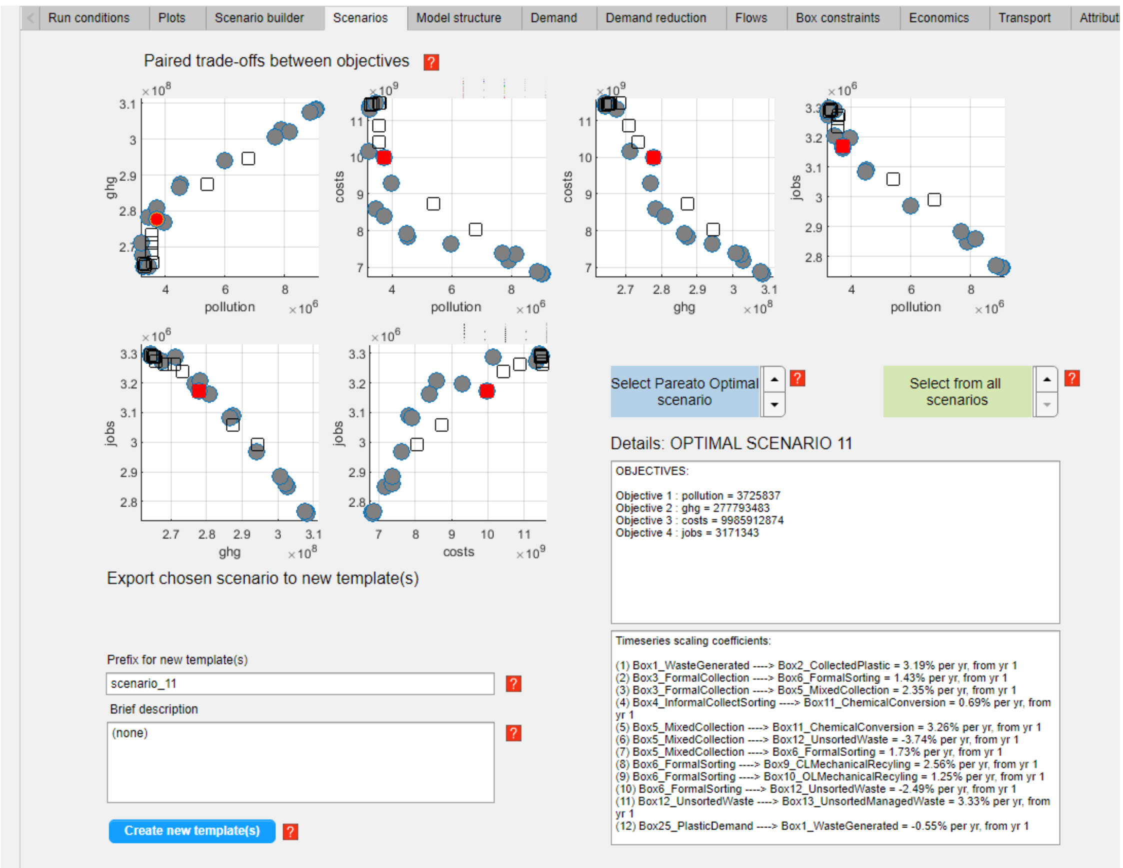
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 10
OBJECTIVES:
Objective 1 : pollution = 3733282
Objective 2 : ghg = 280869169
Objective 3 : costs = 8390643257
Objective 4 : jobs = 3163135
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 3.64% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 1.51% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.73% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 3.36% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 3.68% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -2.77% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 2.65% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.75% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 3.34% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.73% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.42% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.97% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_10
Brief description
(none)
Create new template(s)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Paired trade-offs between objectives
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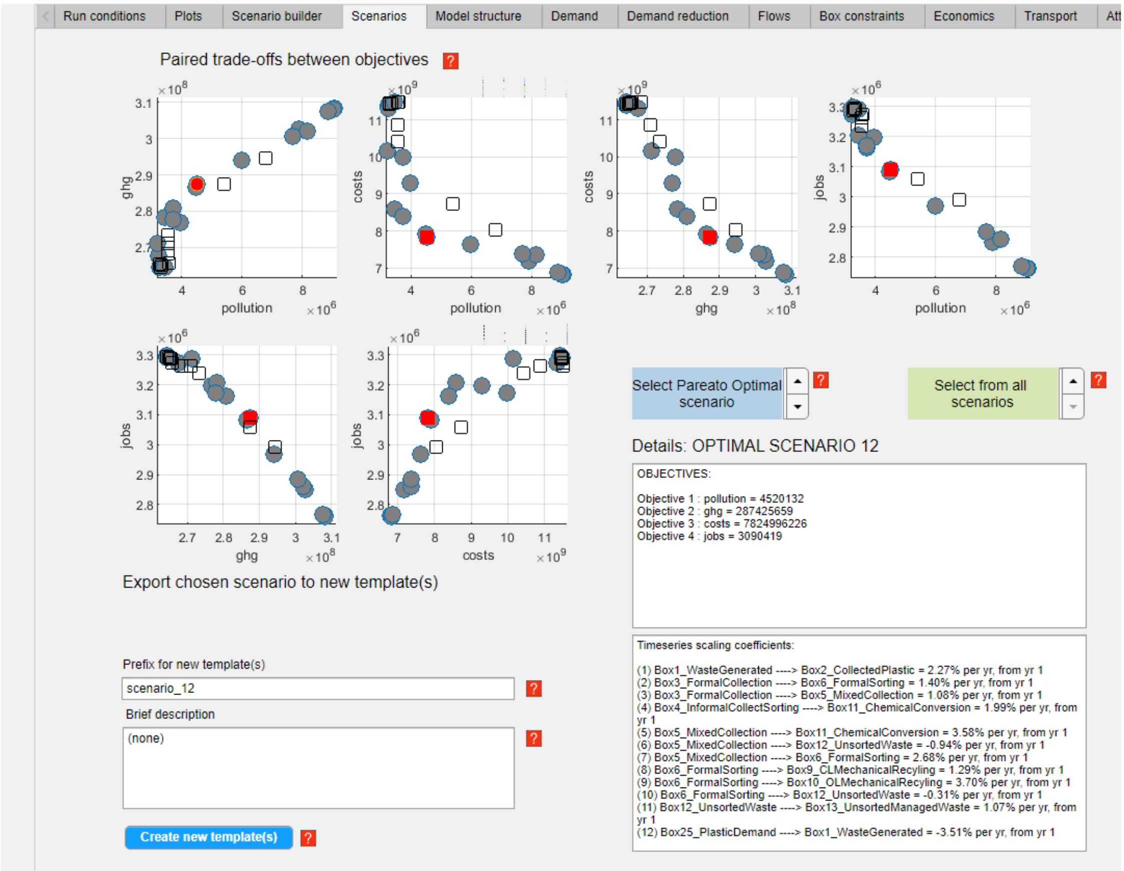
ghg
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 11
OBJECTIVES:
Objective 1 : pollution = 3725837
Objective 2 : ghg = 277793483
Objective 3 : costs = 9985912874
Objective 4 : jobs = 3171343
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 3.19% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 1.43% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 2.35% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 0.69% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 3.26% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -3.74% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 1.73% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.56% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 1.25% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -2.49% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 3.33% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.55% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_11
Brief description
(none)
Create new template(s)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Paired trade-offs between objectives
ghg
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costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 12
OBJECTIVES:
Objective 1 : pollution = 4520132
Objective 2 : ghg = 287425659
Objective 3 : costs = 7824996226
Objective 4 : jobs = 3090419
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 2.27% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 1.40% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.08% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 1.99% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 3.58% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -0.94% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 2.68% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 1.29% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 3.70% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -0.31% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.07% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -3.51% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_12
Brief description
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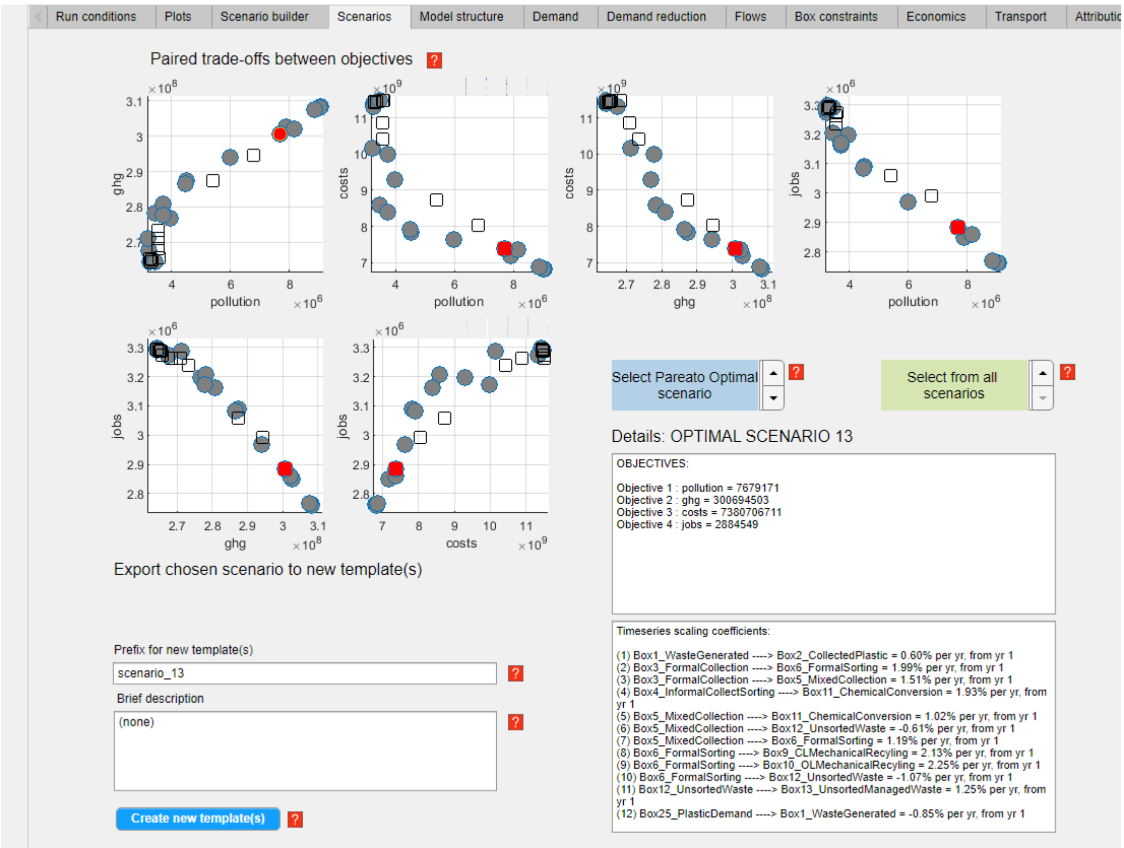
Create new template(s)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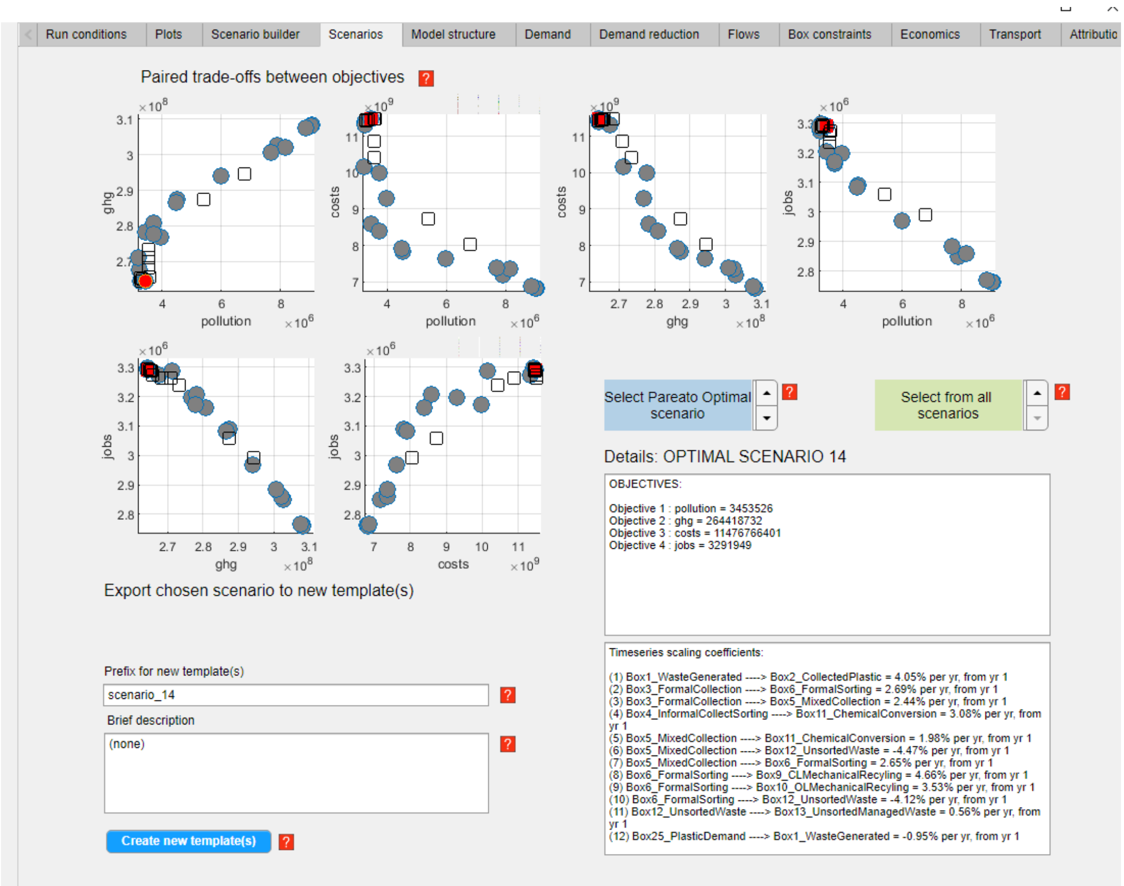
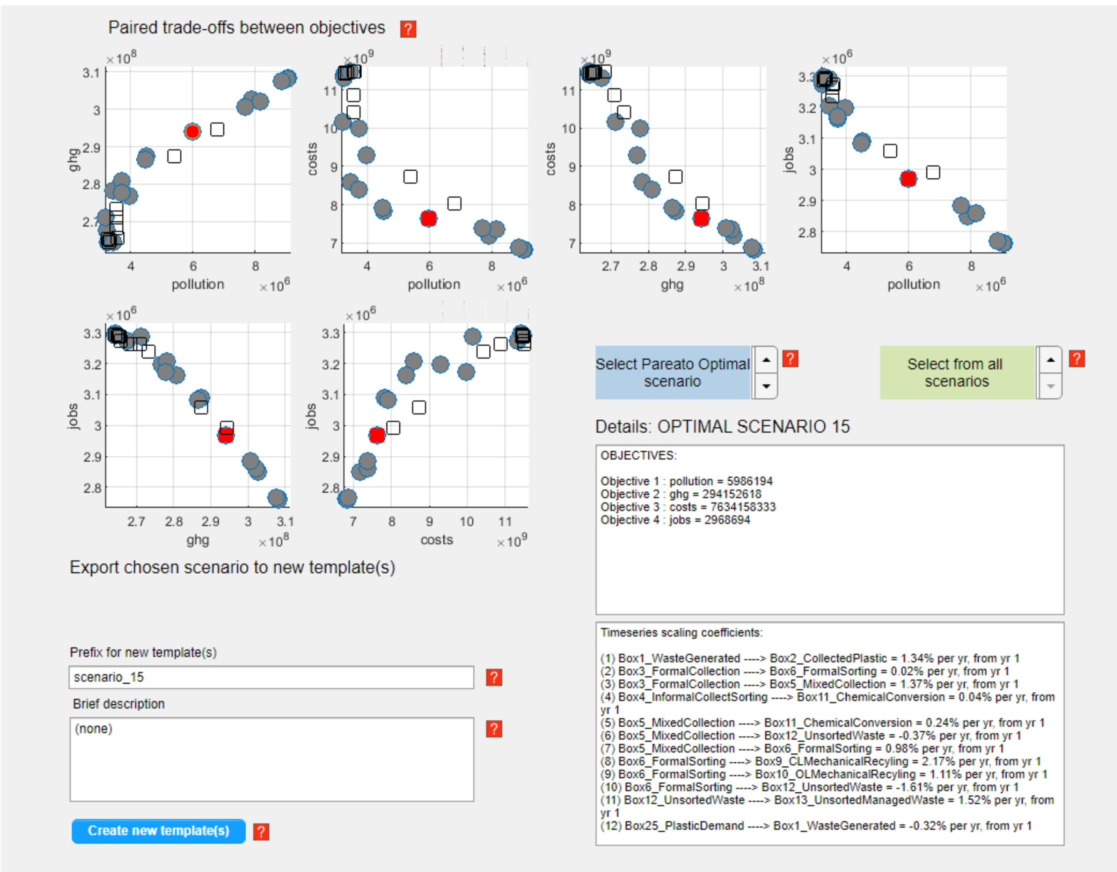
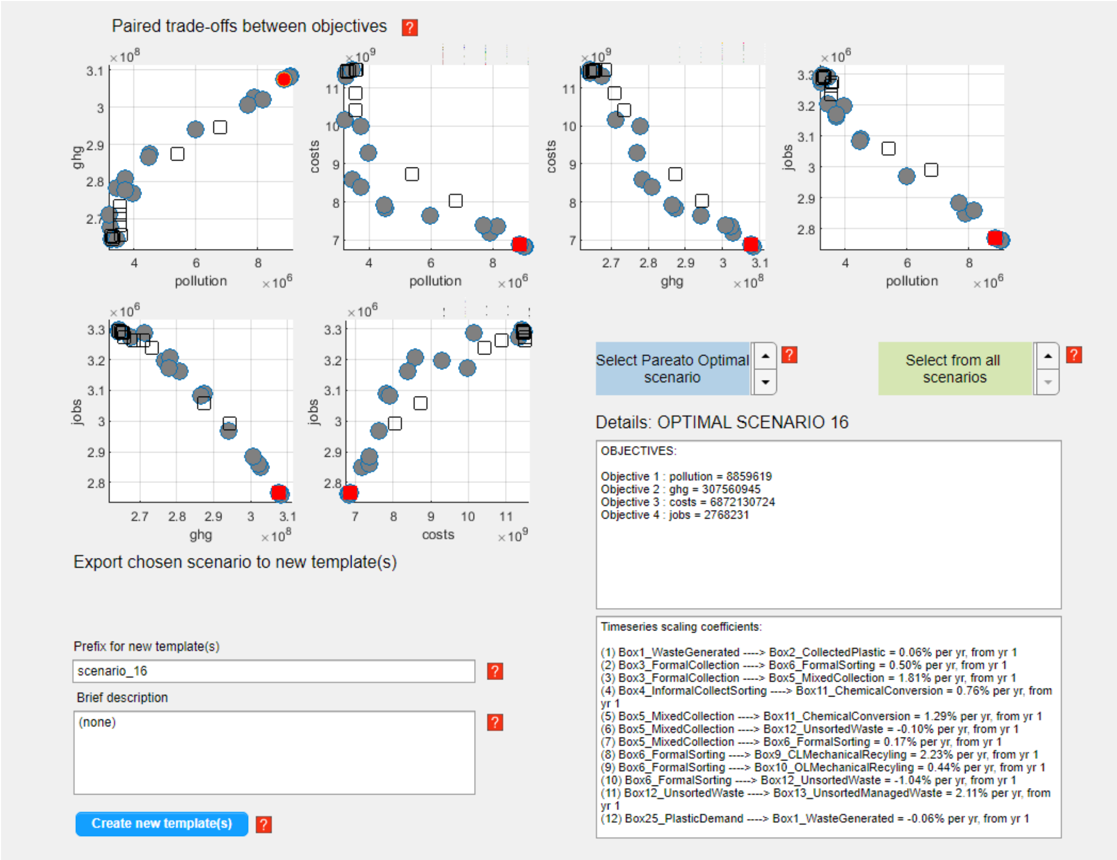
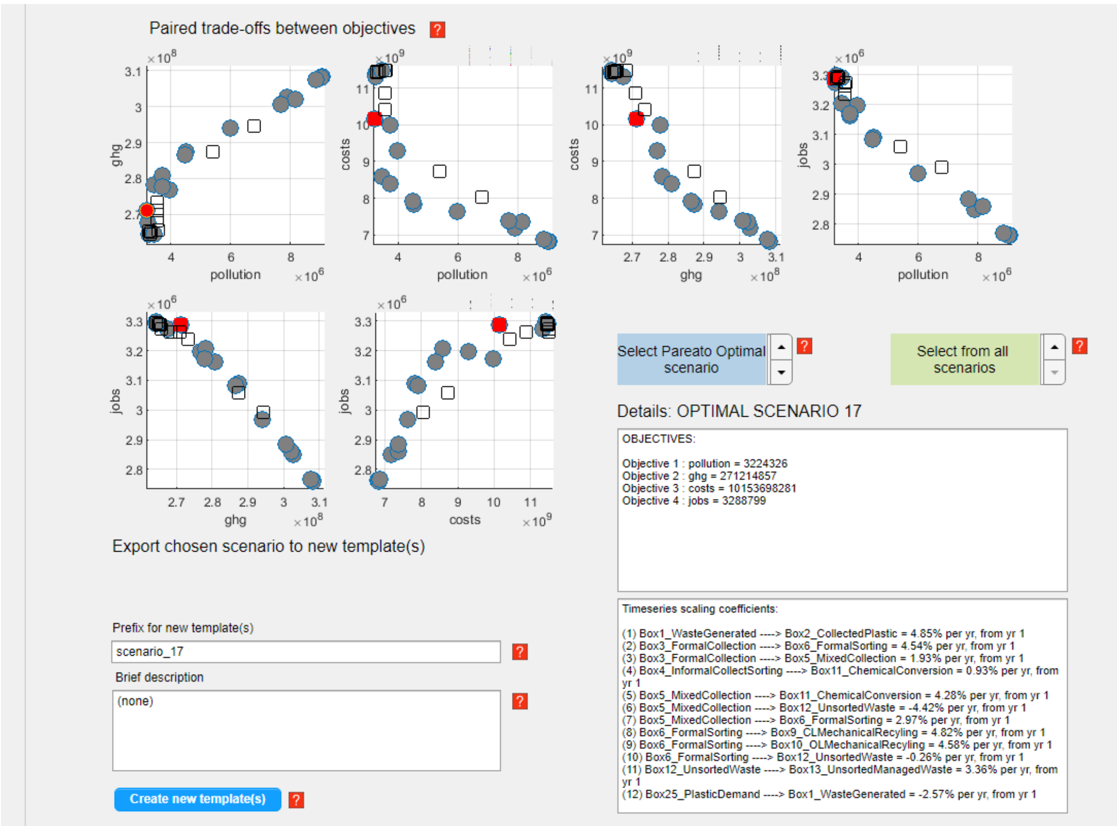
Paired trade-offs between objectives
ghg
pollution
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 13
OBJECTIVES:
Objective 1 : pollution = 7679171
Objective 2 : ghg = 300694503
Objective 3 : costs = 7380706711
Objective 4 : jobs = 2884549
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 0.60% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 1.99% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.51% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 1.93% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 1.02% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -0.61% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 1.19% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.13% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 2.25% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.07% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.25% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.85% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_13
Brief description
(none)
Create new template(s)

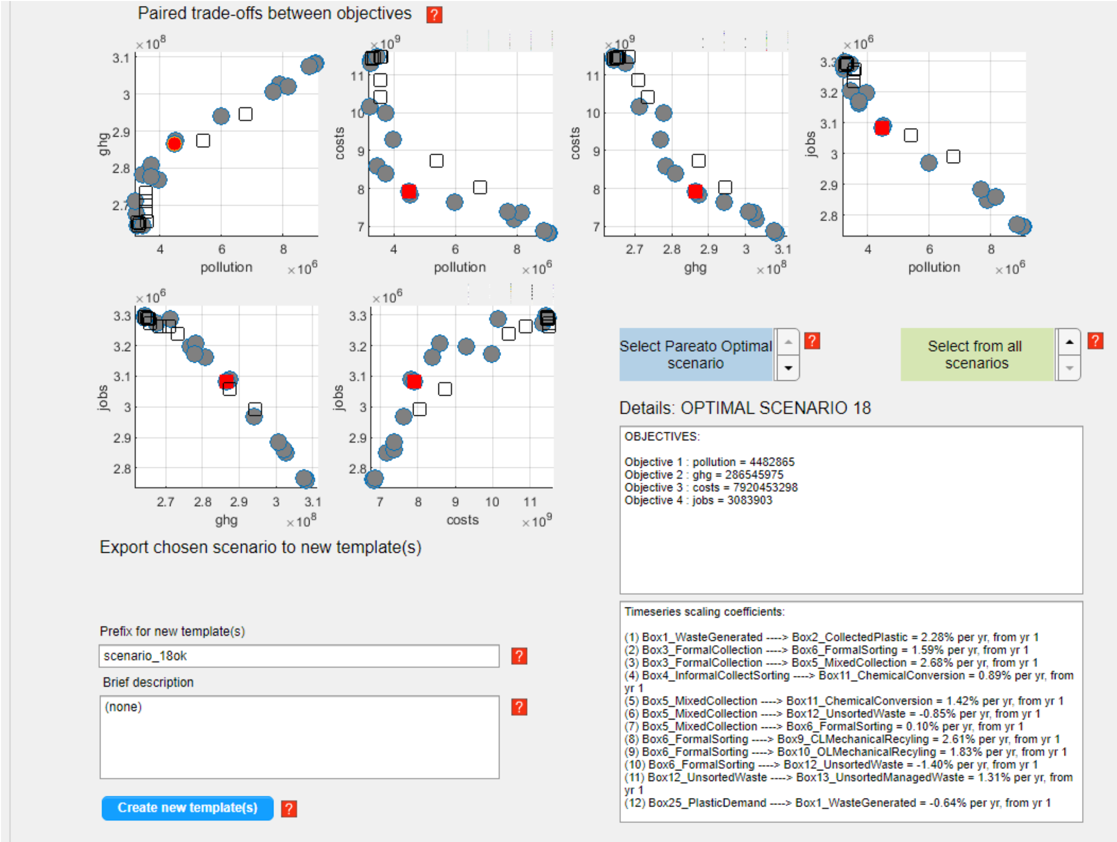

Run conditions
Plots
Scenario builder
Scenarios
Model structure
Demand
Demand reduction
Flows
Box constraints
Economics
Transport
Attributio
Paired trade-offs between objectives
ghg
pollution
costs
jobs
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_14
Brief description
(none)
Create new template(s)
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 14
OBJECTIVES:
Objective 1 : pollution = 3453526
Objective 2 : ghg = 264418732
Objective 3 : costs = 11476766401
Objective 4 : jobs = 3291949
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 4.05% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 2.69% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 2.44% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 3.08% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 1.98% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -4.47% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 2.65% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 4.66% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 3.53% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -4.12% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 0.56% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.95% per yr, from yr 1


Paired trade-offs between objectives
ghg
pollution
costs
jobs
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_15
Brief description
(none)
Create new template(s)
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 15
OBJECTIVES:
Objective 1 : pollution = 5986194
Objective 2 : ghg = 294152618
Objective 3 : costs = 7634158333
Objective 4 : jobs = 2968694
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 1.34% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 0.02% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.37% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 0.04% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 0.24% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -0.37% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 0.98% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.17% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 1.11% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.61% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 1.52% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.32% per yr, from yr 1


Paired trade-offs between objectives
ghg
pollution
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 16
OBJECTIVES:
Objective 1 : pollution = 8859619
Objective 2 : ghg = 307560945
Objective 3 : costs = 6872130724
Objective 4 : jobs = 2768231
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 0.06% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 0.50% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.81% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 0.76% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 1.29% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -0.10% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 0.17% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 2.23% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 0.44% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -1.04% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 2.11% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -0.06% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_16
Brief description
(none)
Create new template(s)


Paired trade-offs between objectives
ghg
pollution
costs
jobs
Select Pareato Optimal scenario
Select from all scenarios
Details: OPTIMAL SCENARIO 17
OBJECTIVES:
Objective 1 : pollution = 3224326
Objective 2 : ghg = 271214857
Objective 3 : costs = 10153698281
Objective 4 : jobs = 3288799
Timeseries scaling coefficients:
(1) Box1_WasteGenerated ----> Box2_CollectedPlastic = 4.85% per yr, from yr 1
(2) Box3_FormalCollection ----> Box6_FormalSorting = 4.54% per yr, from yr 1
(3) Box3_FormalCollection ----> Box5_MixedCollection = 1.93% per yr, from yr 1
(4) Box4_InformalCollectSorting ----> Box11_ChemicalConversion = 0.93% per yr, from yr 1
(5) Box5_MixedCollection ----> Box11_ChemicalConversion = 4.28% per yr, from yr 1
(6) Box5_MixedCollection ----> Box12_UnsortedWaste = -4.42% per yr, from yr 1
(7) Box5_MixedCollection ----> Box6_FormalSorting = 2.97% per yr, from yr 1
(8) Box6_FormalSorting ----> Box9_CLMechanicalRecyling = 4.82% per yr, from yr 1
(9) Box6_FormalSorting ----> Box10_OLMechanicalRecyling = 4.58% per yr, from yr 1
(10) Box6_FormalSorting ----> Box12_UnsortedWaste = -0.26% per yr, from yr 1
(11) Box12_UnsortedWaste ----> Box13_UnsortedManagedWaste = 3.36% per yr, from yr 1
(12) Box25_PlasticDemand ----> Box1_WasteGenerated = -2.57% per yr, from yr 1
Export chosen scenario to new template(s)
Prefix for new template(s)
scenario_17
Brief description
(none)
Create new template(s)

Optimal System change scenario #17, modified for -2.57% plastic demand



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