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A multi-method approach to circular strategy design: Assessing extended producer responsibility scenarios through material flow analysis of PET plastic in Jakarta, Indonesia

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1. Introduction

The growing reliance on plastic packaging to protect, preserve and transport food, has created multiple negative socio-economic and environmental impacts, particularly those associated with plastic waste and pollution (Haward, 2018). Cities in South-East Asia are often indicated as major sources of plastic pollution. For example, through its rivers, the city of Jakarta (Indonesia) emits an estimated 2000 tons of plastic into the ocean every year (Van Emmerik et al., 2019). To stem this flow, the Indonesian government adopted a roadmap to developing Extended Producer Responsibility (EPR) legislation in 2019 (Regulation of the Minister of Environment and Forestry Number 75, 2019). It specifies how food and plastic production companies are responsible for the upgrading of plastic waste recovery systems. The creation of such regulation is in line with the global vision of a Circular Plastic Economy in which linear waste management systems are re-structured to encourage reduction, collection and re-use of plastics (Ellen MacArthur Foundation, 2015). It is anticipated that the new legislation will foster the adoption of circular plastic strategies including designs for sustainability, take back systems for reuse of packaging and take back systems for recycling of packaging (Minister of Environment and Forestry of the Republic of Indonesia, 2020).

To what extent circular policies, like EPR, will lead to a reduction and recirculation of plastic and reduce pollution as well as lead to social sustainability is difficult to predict for four reasons. The circular economy itself is an ill-defined concept and refers to a plethora of possible so-called R strategies (e.g. reduce, reuse and recycle, see e.g. Kalmykova et al., 2018; Reike et al., 2018) through which resource loops are slowed, narrowed and closed (Friant et al., 2020; Geissdoerfer et al., 2017). Second, it is increasingly questioned to what extent circular economy strategies actually lead to sustainability improvements (Boldoczki et al., 2020; Friant et al., 2020; Geissdoerfer et al., 2017; Korhonen et al., 2018). Third, the context in which such R-strategies are implemented differ (Hahladakis and Iacovidou, 2019), and so too do the sustainability issues that are expected to be resolved by circular economy policies. Finally, as we show through this paper, the context or system in which an R-strategy is implemented co-determines its circularity and sustainability effects. This context, including governmental regulation and enforcement, use and waste management of plastic, and technology and infrastructure available, differs across the world. Also the implementation of EPR differs between developed and developing countries, due to contrasting social, economic and technological factors (Johannes et al., 2021; Park et al., 2018).

Determining how a circular economy policy, like EPR, should be implemented in a particular setting - such as Indonesia - to not only make plastic flows more circular, but also reduce plastic leakage to the environment, is not a straightforward matter (Johannes et al., 2021). EPR can be implemented in different ways, i.e. by making producers collectively or individually and financially or organizationally responsible for the post-consumer stage of a product (Watkins et al., 2017). Moreover, the redesign of urban waste systems to encourage circularity is a complex task and hinges on well-established material management policy (Hahladakis and Iacovidou, 2019; Moreno et al., 2016). This includes considering trade-offs between circularity goals and

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sustainability effects, i.e. ensuring that EPR policy is designed to have a positive impact and does not result in unforeseen and undesirable changes to the system. There is a whole plethora of methods available to inform circular decision making, including Material Flow Analysis (MFA), Life Cycle Assessments (LCA) or Multi-Criteria Decision-Making methods. However, individually such methods are too limited in scope for the level of complexity involved in developing and implementing effective circular policies (Bassi et al., 2020; Boldoczki et al., 2020). Consistent and more advanced impact categories are needed to allow solid comparisons in between LCA studies (Hauschild et al., 2011). For example, LCA studies typically focus on GHG emissions and other common indicators like land and water use (see e.g. Morão and De Bie, 2019), though it is recognised that 'plastic leakage' or 'plastic marine impact' should also be included as an indicator as shown by ongoing method development (Chitaka and von Blottnitz, 2021; Saling et al., 2020).

In this article, we therefore present a study that was based on multiple methods to assess circular policy design and implementation (Bassi et al., 2020; Boldoczki et al., 2020; Creswell and Creswell, 2018; Lonca et al., 2020; Sevigné-Itoiz et al., 2015), which we refer to as a multi-method approach to circular strategy design. We focused on finding a combination of methods that could help adapt the design of a circular policy to the characteristics of the system in which it is implemented and the (un)expected circularity and sustainability effects (Bassi et al., 2020; Boldoczki et al., 2020; Hahladakis and Iacovidou, 2019). We combined multiple methods and both quantitative and qualitative data to allow for: mapping of the system through its resource/product flows (material flow analysis, stage 1), generation of a selection of assessment criteria based on circularity and sustainability goals and system characteristics (stage 2), identification of the potential effects of implementing (different variants of) EPR (e.g. in scenarios, stage 3), and assessment of these variants, strategies or scenarios using the criteria developed (stage 4).

In this article, we will present (see section 3) and evaluate how we operationalised these stages, using MFA, scenario development and a mixed method data gathering approach to develop criteria and assess scenarios for EPR variants in Jakarta (see section 2). The approach uses PET plastic (a major constituent of plastic waste) as an indicator of existing levels of plastic recycling in Jakarta, to model changes to the plastic waste system under different EPR variants. The results (presented in section 4) show a clear indication of one EPR policy variant that best supports the development of a circular plastics economy in Jakarta, whilst potentially reducing plastic pollution. In section 5, we discuss how methodological choices informed the methods and results, and more importantly that this stepwise approach holds promise for a broad range of circular policies and R-strategies beyond Indonesia and plastics. We end the article with some conclusions in section 6.

2. Extended producer responsibility legislation and scenarios in Indonesia

Plastic waste issues in Indonesia are gaining global attention due to the release of around 1 million tons of plastic into the marine environment per year, making the nation the second largest contributor to ocean plastics, globally (Jambeck et al., 2015). As a response to this global concern, the Indonesian government aims to prevent 70% of the current plastic waste from entering the ocean by 2025 (Hendiarti, 2018). In order to achieve this ambition, there is a strong need for legislation to deal with the continued improper handling of plastic waste (Adebayo, 2018). This is why the Indonesian government is implementing extended producer responsibility (EPR) legislation (Johannes et al., 2021; Minister of Environment and Forestry of the Republic of Indonesia, 2020). The legislation stipulates that recollection of plastic waste must be organised, funded and performed by producers, to the amount of 30% of the plastic waste they generate (Minister of Environment and Forestry of the Republic of Indonesia, 2020). At this stage, producers are expected to create waste management plans, to outline how they plan to reduce 30% of their waste at source (Neeteson et al., 2021). In doing so, the plastic waste system in Jakarta is projected to become more circular, with companies expected to change their product design and organise waste recollection systems, to conform to the new rules.

As a regulatory tool (Watkins et al., 2017), a distinction is made between individual or collective extended producer responsibility, i.e. in encouraging the formation of corporate groups to share organisation of waste handling or leaving it to individual companies to perform their own waste recovery. It is also possible to distinguish between financial or organisational responsibility, depending on whether producers pay a fee to an independent body (a Producer Responsibility Organisation - PRO) that organises waste handling or if producer/producer organisations perform handling themselves. Which form is chosen is often contested (Campbell-Johnston et al., 2021).

EPR has predominantly been implemented in the US and the EU, across a range of products including electronic equipment, tyres and plastic packaging (Park et al., 2018). Studies show that EPR can effectively stimulate recovery and recycling of materials, but that there is little direct/closed loop reuse of the material (Campbell-Johnston et al., 2020) nor a focus on circular packaging design (Bassi et al., 2020; Filho et al., 2019). This is even more so in non-OECD countries, because of an absence of a well-established waste management system, existence of a large informal sector and weak regulatory and institutional requirements, which hamper the development of recycling markets and design changes (Johannes et al., 2021; Park et al., 2018).

Because the implementation of EPR in Indonesia is still in the preparation stage, the specific form of EPR to be implemented is unclear (Hajek, 2019; Johannes et al., 2021). Since the announcement of the EPR regulation, large producers, especially food companies like Unilever, Nestle and Danone, have started implementing individual EPR projects. Many also joined the Packaging and Recycling Association for Indonesia's Sustainable Environment (PRAISE) coalition, who recently decided to establish a PRO (Johannes et al., 2021). In this article, three EPR scenarios will be assessed, using the multi-method approach to circular strategy design. We develop these scenarios based on interview information from government advisors (DLH DKI Jakarta) and EPR experts (University of Indonesia, SystemIQ, Waste4Change) (see also Section 3):

- **Scenario 1: Collective Company Collection.** This scenario indicates a collective-organisational form of EPR. A PRO Organisation is set-up between plastic waste producers with shared costs between members. The PRO implements a system of plastic waste collection using hired labour. The PRO builds joint recycling plants to processing and export the collected plastic waste. The annual amount of plastic collected amounts to the required 30% of each producer's plastic waste generation.
- **Scenario 2: Company Tax/Levy.** An individual-financial form of EPR in which plastic producers pay levy on plastic production to the government. The government uses levy funds to increase and improve the municipal collection and recycling system. The value of the levy varies between producer, based on the amounts of plastic waste produced.
- **Scenario 3: External Buy-In.** A collective-financial form of EPR based on the possibility of privatisation of recycling systems. A private recycling organisation, independent to the government and producers, creates a new system of plastic waste collection, processing and re-sale, utilising available labour. Plastic producers invest in this private organisation, with shares dependent on the amount of plastic waste they produce. Collection by the company is ensured to cover at least 30% of total plastic waste production.

3. Materials and methods

This section introduces how we operationalised the four stages of the multi-method approach to circular strategy design using MFA, scenario development (in section 3.1) and by collecting both quantitative and qualitative data (in section 3.2).

3.1. Operationalizing the multi-method approach to circular strategy design

Using a mixed method approach (Creswell and Creswell, 2018, pp. 213–243) by combing a quantitative Material Flow Analysis with qualitative scenario development, it was possible to assess the system (stage 1), generate assessment criteria (stage 2), identify the effects of different variants of EPR (stage 3), and assess these variants' effects using the criteria developed (stage 4).

Stage 1: Assessing the system through a Material Flow Analysis

Essential to the multi-method approach is the analysis of existing material handling systems. Material Flow Analysis (MFA) allows for the generation of assessment criteria and modelling of scenarios (stages 2 and 3). The realism of the built MFA is inherent to the strength of the multi-method approach to circular strategy design. The Material Flow Analysis in our study follows a conventional procedure of planning, inventorying, mapping and data substantiation (Brunner and Rechberger, 2016). **Planning** involved the organisation of data collection based on preliminary sketches. Here a functional unit was also set (t/a) and system boundaries were defined (raw/recycled PET import/-domestic sourcing to environmental leakage). Data collection occurs mostly in the **inventorying** phase. Data from relevant literature was used to generate impressions of the plastic waste system in Jakarta, as well as to estimate the masses of PET that move through the system per year. Field work in Jakarta from March to April 2019 was then conducted to validate and expand on such estimates, through primary data collection (see 3.2). The **modelling** of this data by MFA utilised STAN 2.6 (substance flow analysis) software to display the movement of PET across the plastic waste management chain in Jakarta. PET handling in Jakarta was displayed through a series of arrows and boxes, with PET mass flows added to the software and displayed in arrow thickness, based on their magnitude. To derive such values from raw data and verify the accuracy of calculations, **data substantiation** was performed. The raw data from which values were derived was validated against supporting literature or data from other sources. A further detailing of the MFA method and results is available in the Data in Brief (DiB) article that accompanies this article (Amin et al., Submitted).

Stage 2: Generating Assessment Criteria

The second stage of the multi-method approach to circular strategy design is the generation of assessment criteria. In our study, we defined the criteria based on the material flow analysis and qualitative data derived through interviews, as well as literature on physical indicators of circularity (Niero and Hauschild, 2017; Pauer et al., 2019). The purpose of these assessment criteria was to assess the alignment of EPR scenarios with measurable circularity goals (i.e. criteria).

The first step in this process is to identify positives and negatives within the MFA, on which to base criteria. Material flows were examined alongside many different stakeholders, including relevant experts in Jakarta with extensive knowledge on the systems of plastic waste management in the city and the social constructs that support these. An overview of interviews performed during fieldwork can be seen in the accompanying Data in Brief (Amin et al., Submitted). Through examination of the MFA, we distinguished between 1) the parts of the system that should be protected or enhanced to become more circular (the positives) and 2) the parts of the material flow that create obstacles for material circularity and must therefore be removed or reformed (the negatives).

Second, to convert the positives and negatives into criteria, limits to each positive and negative were set. In the circular transformation of material systems, some changes in the material flow will have knock-on effects on other flows and actors. If a policymaker enacts a policy that boosts one actor or flow in the chain, along the lines of the system positives identified, another actor may be indirectly negatively impacted. Based on the MFA, limits can be added to each positive and negative to ensure that changes with negative side effects are not scored positively. As such, the criteria to assess policy scenarios is defined.

Stage 3: Scenario Development and Modelling

The third stage in our multi-method approach to circular strategy design is to determine the outcomes of different policy scenarios. We determined these by changing flows and processes in the original MFA to visualise the potential impacts of the different scenarios on the system. This meant translating the qualitative policy scenarios (introduced in section 2) into quantitative changes of the material flow for each scenario. These quantitative changes are determined for a selected period of time. Selecting this time period is important and dependent on the anticipated (or desired) speed of the system transition. Consulting experts helped to ensure that the proposed actions were realistic in terms of feasible policy framing and likely physical change.

To identify the system-changes of each scenario, the changes were individually applied to the material flow analysis. Thus, a separate and different material flow map was generated for each scenario, with new PET flows and processes, changed routes of flows and the removal of some flows to reflect the changes likely to occur under each scenario. In generating these material flow maps, editing flows and masses for one material flow lead to increases or decreases of other material flows in the system. For each (physical) change, flows and masses of the material flow were edited, subsequently displaying the associated knock-on effects. The supplementary material presents the calculations done to create an MFA map for each scenario.

Stage 4: Scenario Assessment

The final stage in the multi-method approach to circular strategy design involves the assessment of each scenario, using the criteria developed during stage 2. A scale for criterion fulfilment was developed and used to evaluate the physical material flow changes under each scenario. This evaluation was then translated to a numerical score and totalled, to indicate which scenario best aligns with circularity goals.

To allow for uniform assessment of the EPR scenarios, criteria scoring must be specified in terms of specific change to the system (Milutinović et al., 2017). For each criterion, the physical changes that would classify as unfulfillment of criterion, neutral impact and fulfilment of criterion were defined through so called score parameters and recorded in a *parameter table*. Due to possible knock-on effects, a (positive) change in one part of the system, can create (adverse) effects in other parts of the system. As noted earlier, each criterion specifies the limit at which a negative trade-off is avoided. A physical change that surpasses this limit should be considered as unfulfillment of the criteria. For some criteria the point at which a negative trade-off occurs may be difficult to define. In this case, the material flow analysis can be used to identify the limit.

In the case outlined in this article, scoring was applied uniformly across criteria as the interviews did not offer a legitimate basis to develop a more sophisticated weighing scheme. Fulfilment of criteria was assigned a score of $+1$, neutral impact a score of 0, and unfulfillment of criteria a score of -1. The fulfilment or unfulfillment of criteria was given the same weighted impact on final scores to represent that each criterion was deemed as important as another. In replication of this method, different scoring ranges and criterion weights could be assigned, in line with multi-criteria decision-making methods (Triantaphyllou, 2000).

3.2. Materials

In our study, we applied the multi-method approach to circular strategy design to a single case, that of designing an EPR policy for PET production, use and disposal in Jakarta, Indonesia. To gather the quantitative and qualitative data to implement the approach, we used multiple data collection methods. The strength of using a mixed method approach is that triangulation of data is possible by merging both types of data in a comprehensive analysis of the research problem (Creswell and Creswell, 2018, p. 14). It also fosters trans-disciplinarity as input by policy makers and other stakeholders can ensure that the qualitative components of the approach (developed scenarios, system positives and negatives, criteria developed based on policy goals) are both reliable and support the construction of accurate numerical scoring. This ensures the approach remains relevant for use in designing circular strategies and policies.

In order to implement the multi-method approach, qualitative and quantitative data was collected for stage 1/the MFA, as described in the accompanying DiB article (Amin et al., Submitted). Data for this and stages 2–4 was largely collected during the field work in Jakarta between March and April 2019 (see also the DiB). During this fieldwork 14 different stakeholders of the government, producers, waste handlers and other experts, were interviewed. Surveying and observation were also done at 9 waste handling sites such as junkshops, waste banks, transfer points (TPS), landfill and recyclers. The development of the assessment criteria (stage 2) was largely based on reported system positives and negatives from the interviews. Literature that outlined physical indicators of circular system building was also collected to aid in the identification of system positives and negatives from the MFA. For stage 3/the scenario development and modelling, data was collected by document observation and interviews in Jakarta, to generate the three EPR scenarios. More information about these data collection methods is provided in the Data in Brief (Amin et al., Submitted).

4. Results: A circular strategy design for EPR in Jakarta, Indonesia

In application of the multi-method approach to the case of EPR in Indonesia, results were produced for each stage of the approach. The results of each stage informed those that followed, leading to a final indication of the optimal EPR policy scenario. This section presents the results of each stage in the approach.

4.1. Stage 1: PET material flow analysis of Jakarta

A simplified version of the MFA generated for PET across the plastic waste system in Jakarta can be seen in Fig. 1 below. The figure shows the main routes that PET plastic waste takes, throughout its lifecycle, and the masses of PET handled by each actor in the chain, per year. A full

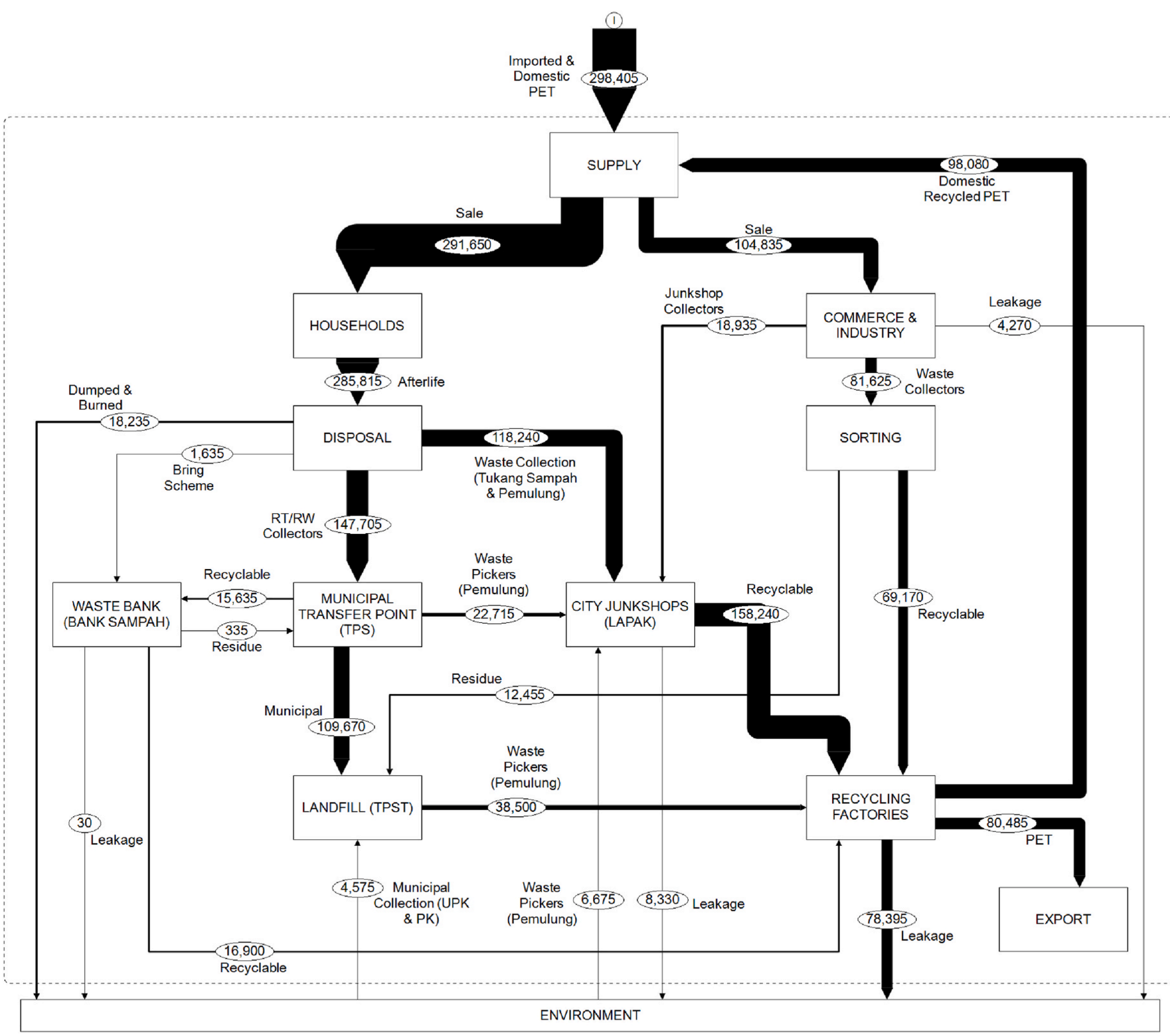

Fig. 1. Simplified MFA diagram for PET plastic packaging in Jakarta, Indonesia (functional unit: t/a).

explanation of the system, with a more detailed MFA and its flows and masses can be found in the Data in Brief article that accompanies this (Amin et al., Submitted).

The system shown in the MFA (Fig. 1) involves the production of approximately 400000 tons of PET plastic packaging per year, made from both raw and recycled PET from domestic and imported sources. The main route of sale from producers is to households, with smaller shares going to commerce & industry (including Jakarta's many markets). Household disposal is conducted through many different means: dumping and burning, municipal collection, informal collection and voluntary recycling through waste banks. The majority of disposed household PET is collected by waste collectors (Tukang Sampah), who gather plastics and transport some material to junkshops, the rest going to Municipal Transfer Points (TPS). Waste pickers (Pemulung) also collect from households and transport their material to Junkshops. Junkshops act as hubs of collection for all informal waste collection/picking from households, commerce & industry, TPS facilities, landfill sites and the environment. A large amount of PET plastic reaches junkshops and is sorted before sale to recyclers. The majority of PET plastic transported to TPS facilities goes on to landfill, with some separation and diversion of recyclables. The small share of material brought by households to waste banks is also sorted and finds its way to recycling factories. Some 250000 tons of PET reach recyclers (~64% of that which enters the system). The majority of this amount is exported or sold domestically as recycled plastic, however a large portion (~30%) is leaked into the environment.

The MFA of Jakarta's plastic waste system above informs the following result for stage 2 in the approach through examination of the flow of PET across the chain.

4.2. Stage 2: assessment criteria for Jakarta's PET system

In stage 2 of the approach, the criteria for scenario assessment are generated. The first step is to identify system positives and negatives. These positives and negatives were identified based on the overarching goals of sustainable reduction of plastic material leakage to the environment, and the circularity goals of the Indonesian government for EPR. As outlined in section 3.1, the positives and negatives were identified in consultation with an array of different stakeholders, including government officials and academic professionals. The list of interviewees can be seen in the Date in Brief article that accompanies this (Amin et al., Submitted).

Identified System Positives:

1. Large amount of recollection from natural areas
2. Multiple transfer points in any route
3. High level of recollection of PET by informal actors (junkshops)
4. Large availability of labour (informal sector workforce)

Identified System Negatives:

5. No centralised collection from households (fragmented collection)
6. Large loss of material to landfill and environment
7. High material leakage from recyclers
8. Large amounts of PET exported (insufficient domestic demand for recycled PET)

Second, based on trade-offs between these positives and negatives, assessment criteria can be formulated. For example, in Jakarta, increased centralised collection of PET from households addresses negative 5 in the list above, but may also result in insufficient material for informal collectors, having major economic effects on these workers. The 8 criteria displayed in Table 1 were developed for the assessment of EPR scenarios, with associated trade-offs also displayed.

Table 1
Assessment Criteria for Jakarta's PET system.

	Criteria	Associated Trade off
1	Recollection schemes should be bolstered but not prioritised over collection of plastic from source or stemming of leakage	Recollection of material from disposal points or the environment must not override collection from source, as material quality is higher at source. Collection from source or reduced leakage works well towards circularity, but environmental collection is also necessary.
2	Transfer points in material routes should be encouraged if the destination is domestic recycled plastic	The more transfer points that plastic material goes through, the more a circular economy is supported, unless the material is exported. When material linearly tends to export, transfer points should be discouraged.
3	Collection by junkshops should be encouraged unless official routes via TPS redirects material to domestic recycled, then junkshop collection should be encouraged only for leakage	Junkshop collection shows promise in redirecting PET to domestic re-use, but should not override existing recycling from TPS. Such recycling routes should remain and be encouraged in tandem.
4	Available labour should be utilised in promoting recycling and domestic circulation	The availability of labour should be utilised to promote recollection and re-use, however it should be ensured that employment for domestic recycling is favoured, to reduce material export.
5	Generation of a central system of collection of plastic from household should be encouraged ensuring that scheme does not override informal collection	The large portion of informal collection should not be replaced by centralised systems, at the risk of collectors losing jobs or established routes ceasing use.
6	Redirection of plastic from landfill to recycling should occur, utilising informal workforce. Joblessness for communities around landfill should be avoided	Recollection of plastics from landfill is already performed by informal pickers. Such recollection should be encouraged without replacing such actors.
7	Recycler leakage should be stemmed as far as possible, without redirection of material to more official routes.	Established routes to recyclers could be overridden by centralised recollection and recycling. Recycler jobs should not be jeopardised in stemming environmental leakage.
8	PET export should be redirected to internal sources, ensuring pricing for sellers remains the same	Redirection of material to domestic means sale prices of material would reduce (more money is made from export). Recycler income should not be negatively impacted from redirection.

4.3. Stage 3: EPR scenario modelling

This section presents the effects of each EPR scenario generated for EPR in Jakarta. How the system would change over the selected period after implementation of a EPR scenario was determined using input from EPR and local waste management experts. Table 2 summarizes the anticipated physical change associated with each form of EPR.

Based on Table 2, three distinct material flow maps were made by adapting the system flow scheme generated during stage 1, see Figs. 2–4. Physical changes to the PET flow were made and knock-on effects were subsequently calculated. The substantiation of these calculations, for each scenario, can be found in the supplementary materials.

Scenario 1: Collective Company Collection.

Fig. 3 shows the material flow for scenario 1, a collective, physical form of EPR. In this scenario, the basic structure of the current PET system remains the same, except for the joint nature of the transfer points and recycling facilities organised by the producer responsibility organisation (PRO).

The collection of waste in this scenario is performed, as is currently the case, directly from source, using the availability of labour to collect and separate household waste from collection points. Since this form of

Table 2
Physical action for EPR scenarios.

EPR scenario	Physical action
Scenario 1: Collective Company Collection; PRO Organisation set-up between companies with shared costs. PRO builds joint recycling plants and handles collection and material export.	PRO set-up between major producers PRO hires collectors to sort recyclables from households Some material bought from junkshops to meet requirements Recycling plants built with shared producer funding Large scale, high-tech pelletising of collected material Sale/export of pellets as profit for PRO Producers divide share of 'removed' plastic to satisfy reduction percentage Trading of funding of system for bigger waste reduction
Scenario 2: Company Tax/Levy Companies pay levy on material production to government; government allocates funds to increase recycling in current system	Material reduction requirement set as tax on producer sales Tax paid into governmental general budget Portion of tax lost through government activity Remaining funds used to increase formality of system More TPS facilities with sorting created Creation of separation and incineration plants at landfill Separated material sent to waste banks, then recyclers
Scenario 3: External Buy-In External organisation creates new private system, utilising available labour. Companies invest in organisation to off-set production.	External organisation with waste handling capacity steps in Private collection of all household waste arranged Collected waste is sent to sorting centres Recyclable material is kept, and residue transported to TPS Organisation processes material and sends to own recycling, feedstock and incineration plants Material/feedstock/energy sold for profit Producers invest in scheme in exchange for material handling shares Shares satisfy reduction requirements of producers

EPR is collective and involves many producers, collective funds would be available. It is likely that producers would trade their required PET recollection amounts, so that all may meet the stipulated targets of the government. The PRO set up between the producers would be able to collect a larger amount from households than stipulated by the legislation, assumed here to be 40% of generated PET. The impetus provided by the PRO allows for more waste collectors to be hired. As a result, it is estimated that the total collection from source increases to 70%, with the remaining 30% of acquisition from junkshop purchase.

In this scenario, the creation of joint recycling facilities is the step that follows collection of material. PET from the collective transfer points would be transported to these recycling facilities, where it would be pelletised. The involvement and financial input from producers would mean more efficient and higher-tech facilities can be developed, for example to allow for much more food-grade PET material to be processed in the joint recycling facilities. This would in turn allow for a greater percentage of material to stay within the system, i.e. 60% of the pelletised PET produced, with the remaining 40% being exported.

Scenario 2: Company Tax/Levy.

Scenario 2 demonstrates a purely individual, economic form of EPR, with producers being required to pay a tax or levy on the amount of PET they bring on the market. Using this tax, the government would increase the amount of official recycling of material at certain points in the chain (see Fig. 4).

Under Indonesian law, the government is not responsible for the collection of waste from households, only transportation from transfer points to end-of-life processes, i.e. landfill facilities. The collection of household PET would therefore remain the same as the current situation, with waste collectors transporting the waste to TPS facilities (Shekdar, 2009). The difference with the current system would be that more TPS facilities would be required to include a separation of incoming material. It is estimated that the current 120 TPS facilities that perform sorting of waste could be increased to 500, roughly half of the total number of facilities. As a result, the diversion of recyclable material from the TPS facilities would be much higher, approximately 4 times the current collection, following the same route to the central waste banks.

PET from the remaining TPS facilities that do not separate waste would continue to landfill where another new process would occur. During fieldwork in 2019, interviews with government officials working at Bantargebang landfill site revealed plans to build an incineration plant on the landfill site. As of 2021, this project is now in pilot stages, with plastic waste a large feed for the waste-to-energy incineration plant (Kristyawan et al., 2021). Whilst little information is publicly available on the funding of the plant, for the purposes of this scenario it is assumed that some funding is acquired through corporate taxes attributed to EPR legislation. Accordingly, a diversion of waste to the new incineration process is indicated in this scenario and can be seen in the adjusted MFA. Within the pilot facility at Bantargebang, recyclable material is reported to be manually separated on conveyor belts (Kristyawan et al., 2021). In this process workers would remove a significant portion of PET, with this being sent to the central waste banks. For this scenario, it is estimated that collection of PET from landfill processes could reach almost 5 times the current collection.

Scenario 3: External buy-in.

The last scenario exhibits a collective, financial form of EPR. In this scenario an external organisation is expected to step in and create an entirely new recycling process in addition to the current system, see Fig. 4.

In this scenario a large amount of collection takes place after household disposal. This is a result from the organisation in question making money from the sale of recycled PET. This would be in addition to the money they would earn from producer buy-in to the scheme. Since the government is not responsible for household waste collection, it is predicted that this organisation would take over the entire collection of household waste from the current collectors. The organisation would hire its own collectors to gather all the household waste and transport it to sorting centres, where the recyclables would be separated. An estimated 80% of household PET would be collected by the hired workers in this scenario, due to the centralised approach and simplified management of having one major household waste collection. The remaining residue and 20% PET material that is estimated to be lost in sorting would then be transported to the TPS facilities, meaning the government would have to handle much less waste. As seen in the material flow scheme, the creation of an official collection and sorting scheme like this would also allow private commercial collectors to feed into the organisation's processes.

Following the collection and sorting of all recyclable material, the material would either be sent to the recycling facility or to an incineration plant dependent on its quality. Around 80% of the material is estimated to go to a recycling or feedstock plant, whilst 20% would end up being incinerated. The remaining material would then be divided by the recycling or feedstock plants, based on its structure. It is assumed here that this split is 50/50. The material sent to the feedstock plants would be processed into its raw state, to be sold directly as a feedstock to the producers again. Due to the likely power and wealth of an organisation capable of creating such a system, it can be said that the majority of material processing will use modern machinery. It can then be estimated that most of the PET processed by mechanical recycling would be applicable for use as a food grade material. As with scenario 2, a split of 60% food grade and 40% non-food grade (to be exported) is estimated. The addition of the feedstock mass and food grade pelletised PET then

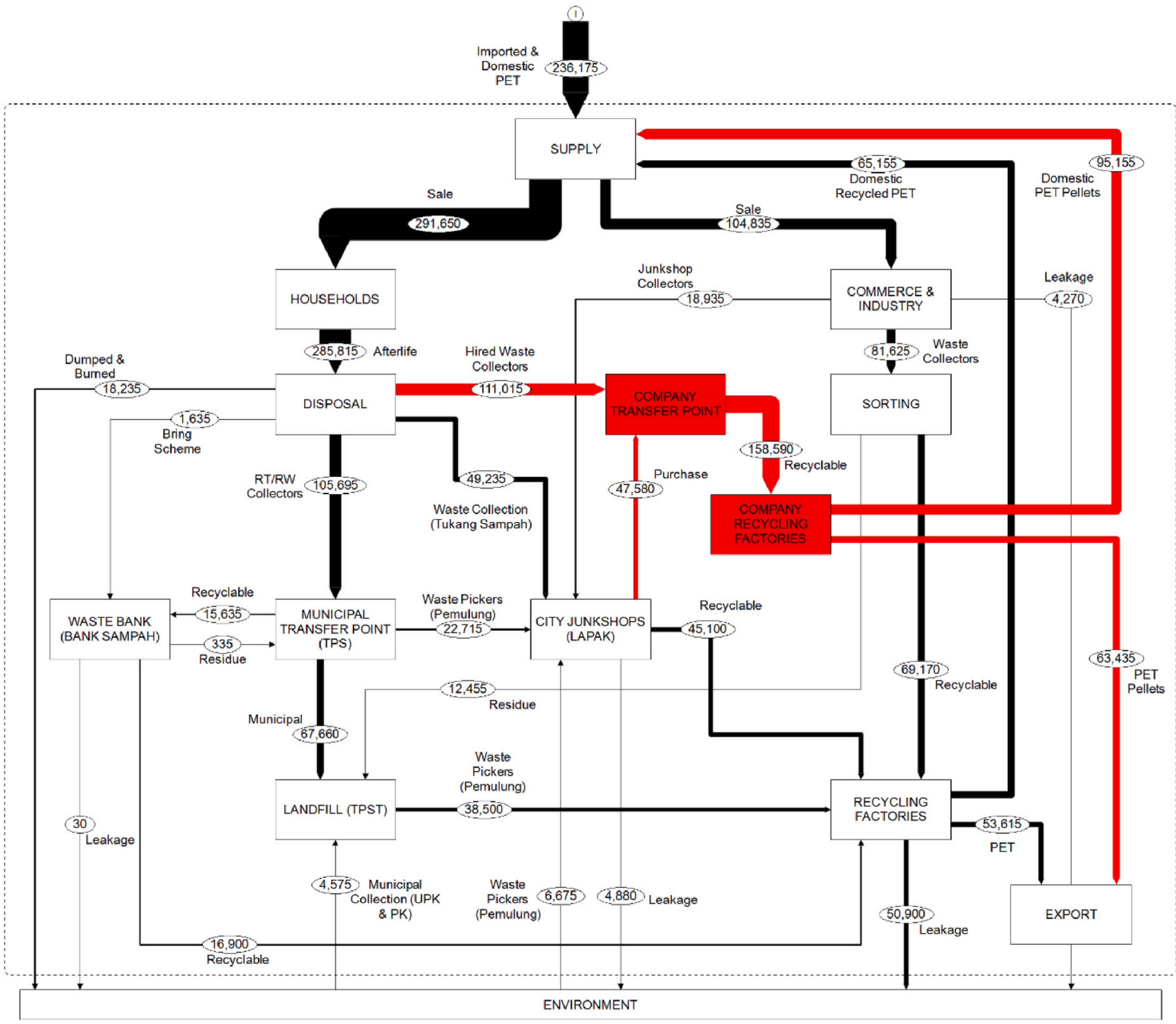

Fig. 2. Scenario 1 MFA diagram (functional unit: t/a).

creates the thick re-supply line to producers, seen in the material flow. The remaining, non-food grade material would be exported.

4.4. Stage 4: EPR scenario assessment

The results of stage 4 are visualised in two separate tables. The first, Table 3, outlines the score parameters of each criterion (defined in stage 2). The first two columns indicate the criteria for which the parameters are set, and the following three columns indicate when fulfilment, unfulfillment or neutral impact scores are assigned.

Using the score parameters set, evaluation of each criterion under each EPR scenario was performed, resulting in the evaluation table (Table 4). The first 2 columns specify the criteria the scenarios are evaluated by, and the final 3 columns stipulate fulfilment of criteria (+1 points), unfulfillment of criteria (−1 points) or neutral impact under each scenario (0 points). Scores were assigned in this uniform manner and without weighting, according to the design outlined in 3.1.

As Table 4 shows, scenario 1, i.e. collective intervention of plastic producers to set up recollection systems, scores highest at 3 points. This scoring suggests that a collective, physical form of EPR should be the focus of further policy design. Scenario 1 scores better due to its closeness to the current system and ability to run parallel to the already existing waste management processes. Scenarios 2 and 3 entail more centralised management of the waste management system, with key areas of the current system not being involved. Informal collection and the pivotal junkshops are not incorporated into these scenarios and therefore the (social) sustainability is challenged. Scenario 1 is able to update the current system utilising available labour and as therefore the preferable form of EPR that could be used as a basis for complete policy design.

5. Discussion

In this article, we proposed using a combination of methods to inform policy design for transitioning towards a circular (plastics) economy. In our study, we operationalised this multi-method approach to circular strategy design, using both quantitative and qualitative data, by using an MFA to assess different EPR scenarios, focusing on identifying the trade-offs involved in choosing a specific form of EPR within the Indonesian PET waste management system in Jakarta. The objective was to on the one hand gain a thorough understanding of the current PET waste system in which EPR is going to be implemented, while on the other hand allowing the assessment of social and environmental sustainability effects of different EPR variants.

Some specific methodological choices were made that influenced the scope as well as the outcome, including the material under consideration, the chosen boundaries of the MFA, the geographical scope, and the use of equal weight of the criteria. Selecting PET as an indication of the level of plastic recycling in Jakarta gives an indication of best-case scenarios, due to the high level of recycling that already exists within a metropolitan area. High recovery rates also exist for PP, HDPE and sometimes LDPE, however, the current waste management

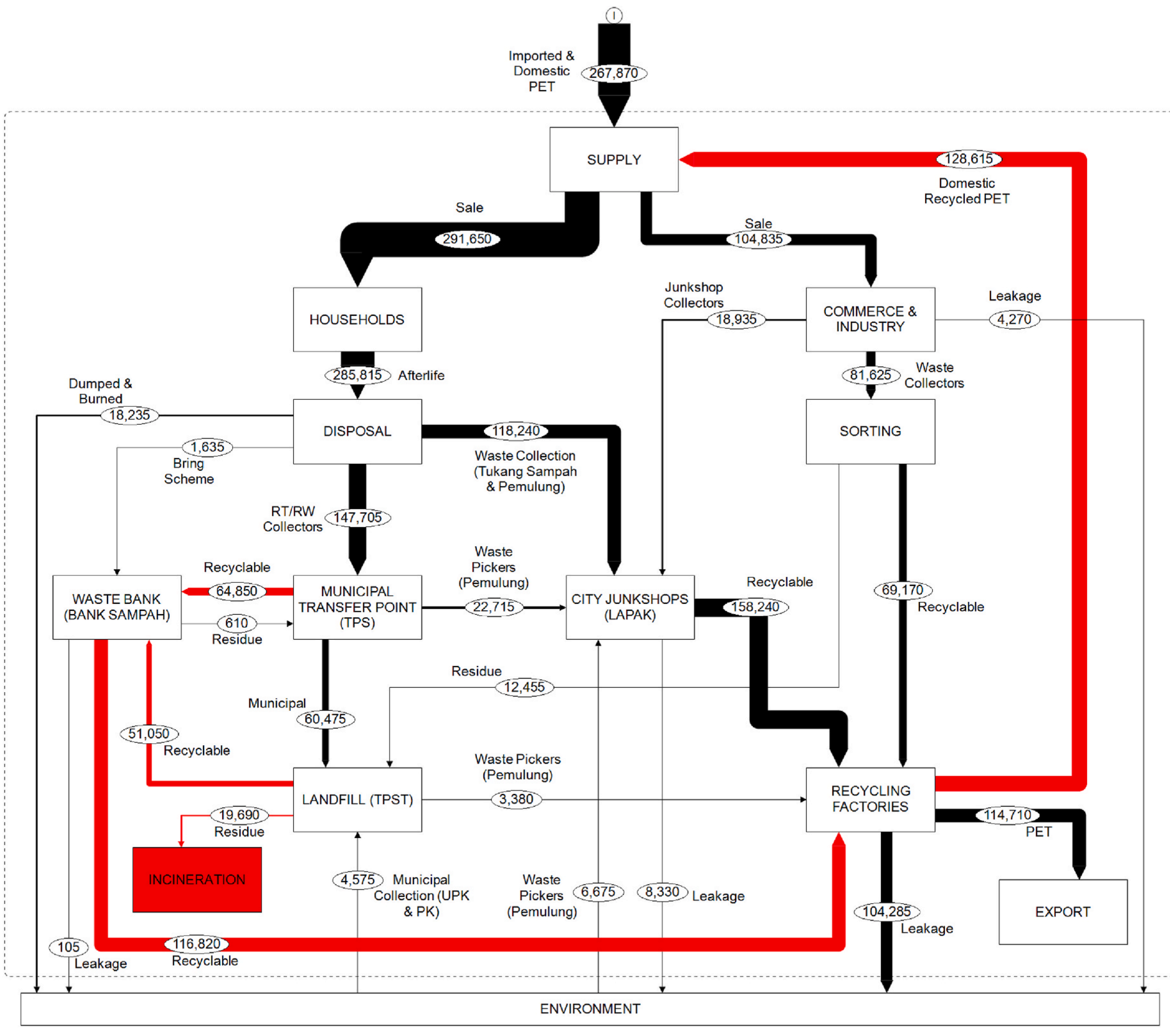

Fig. 3. Scenario 2 MFA diagram (functional unit: t/a).

infrastructure is less equipped to deal with low grade plastic types (Chaerul et al., 2014; Putri et al., 2018). This means that the outcome of this study would change if other plastics would have been taken into account. In addition, the timescale, being set at one year, and the boundaries chosen for the MFA, are also relevant. Whilst taking a one-year time-scale allowed for the collection of data necessary to illustrate the approach, it did not consider long term downcycling effects, and associated material quality losses, with PET. Material losses will likely always occur in the system if products that wear out during use are used over long periods of time (Boldizar and Möller, 2003). Though, there seems no evident limitation on the number of times PET can be recycled, in case super-clean techniques are applied (Welle, 2011), this might be different for other materials. Further modelling for different plastic types, most notably single-use plastics, would be required to draw complete conclusions. The use of uniform weighing for the scenario assessment was chosen because we based the assessment on stakeholder input via interviews, rather than on a more extensive participatory process. These methodological choices as well as their implications should thus be carefully considered as well as communicated to policy makers and stakeholders that might base their positions and policy design upon the outcomes of an application of the approach.

This also goes for the possibility to choose another combination of methods or add another method. For example, more extended types of multi-criteria analysis methods, such as Multi-Attribute Value Theory (see e.g. Deshpande et al., 2020), the Analytic Hierarchy Process (see e.g. Elhamdouni et al., 2022) or Technique for Order Preference by Similarity to Ideal Solution (see e.g. Afrane et al., 2021), and Life Cycle Assessments (Bassi et al., 2020; Chaplin-Kramer et al., 2017; Sevigné-Itoiz et al., 2015) include a more explicit step in which weighing of criteria is considered, which could enhance the assessment of trade-offs in implementing circular policies or strategies. Similarly, while the use of interviews, observation and surveys allowed for developing EPR scenarios that are within the scope of the current decision making and implementation process around EPR in Indonesia, it is also possible to include consensus reaching tools, such as the Delphi method (Campbell-Johnston et al., 2021).

In addition, while the combination of MFA with scenario development allows for a case-specific assessment of a particular circular economy strategy, it can also be applied to other circular economy policies and R-strategies as well as to other materials. It can be used to compare different variants of one policy or strategy, as done in this study, but also to compare different strategies. Given the variety in global resource flows and waste management systems as well as circular economy policies and strategies there is a strong need for tailor-made design of circular economy policies and strategies, particularly when coupled with the desire to improve sustainability (Boldoczki et al., 2021). The use of multiple methods serves as a means to assess circular policies and strategies based on the existing local situation or system as well as desired economic, environmental and social sustainability objectives (Bassi et al., 2020; Boldoczki et al., 2021).

Whether or not different methods can be combined and with what added value is subject to future research. However, important

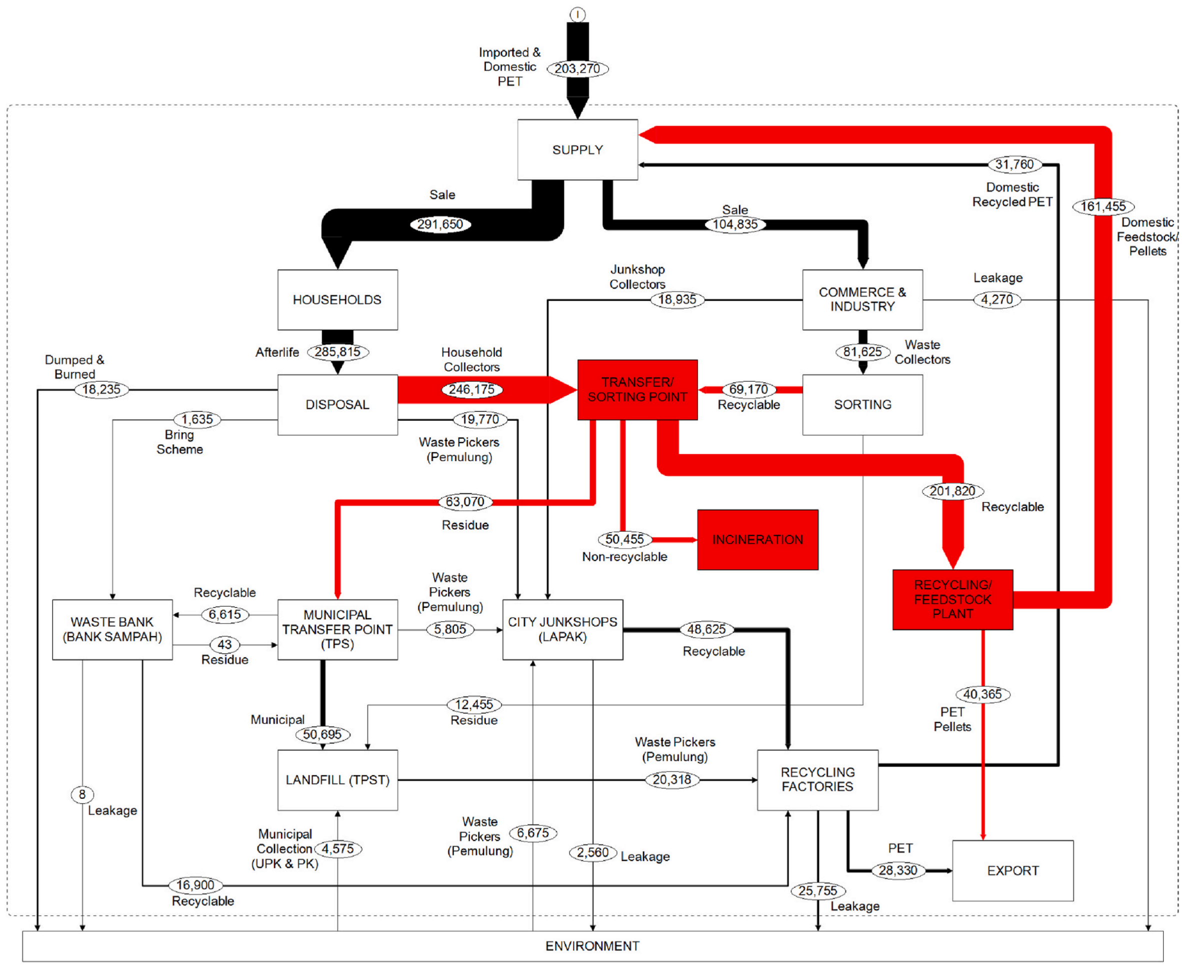

Fig. 4. Scenario 3 MFA diagram (functional unit: t/a).

considerations in the choice of methods are also informed by, first, the type of quantitative data available. Depending on how much (reliable) data is needed to perform a certain analysis and how much is actually available, data collection can grow into an extensive research process. Especially, the applicability of quantitative methods can be comprised in cases where data availability is low. Second, the extent to which the chosen methods rely on strong guidance and input by policy makers differs. This kind of input can ensure that the outcomes of a multi-method approach are tailor-made and find their way into decision making processes. For example, identifying the positives and negatives of the existing situation, the criteria and their weighing, possible scenarios and scenario assessment all require input from relevant stakeholders. This holds particular relevance for the developed criteria and its weighing, which are based on subjective definitions of circularity. However, we hope that as research into and experience with circularity policies grows, mature definitions of system circularity will be generated (Kirchherr et al., 2017). As a result, the definition of circularity goals by policy makers and stakeholders may become more uniform, allowing the process of developing assessment criteria to be grounded in more solid definitions.

6. Conclusions & recommendations

This article has applied a multi-method approach to circular strategy design to be able to evaluate the alignment of a circular policy with the goal of a sustainable and circular plastics economy. The circular design is based on material flow analysis of the existing system on the one hand and the desired sustainability and circular goals on the other hand. We argue that the only way to achieve that is through combining multiple assessment methods. The multi-method approach can be tailor-made to the research objective and question posed in terms of choosing the combination of assessment methods used, balancing quantitative and qualitative data, and ways for co-producing the application of the approach with policy makers and stakeholders. Future research should focus on the added value of different combinations of methods and how available data as well as input by policy makers and stakeholders inform the results and outcomes of the multi-method approach. Moreover, future research should help identify how the multi-method approach to circular strategy design can be used for both comparison of different variants of a particular circular strategy and comparison between strategies.

The application of the approach in our study also generated some practical insights for the further development of EPR in the large metropolis of Jakarta (with a population of more than 10 million inhabitants). The results shows that a collective-physical form of EPR holds the most promise in supporting circular economic transitions. It is therefore recommended that the development of EPR focuses on creating inter-organisational bodies that are able to enhance collection of household waste and the repurposing of plastic material into new products. It should be noted, however, that this recommendation is based on an analysis only of PET plastic, by material flow analysis. It is also noted that resolving data uncertainties through precise measurement and proper input from government and stakeholders would enhance the reliability of the assessment of circular strategies undertaken under the EPR legislation. This is why more transparency in the EPR strategy design process in Indonesia is called for, so that more

Table 3
Parameter Table: Definition of criteria for EPR in Jakarta.

Criteria		Score Parameters		
		Unfulfillment of Criterion	Neutral Impact	Fulfilment of Criterion
1	Recollection schemes bolstered	Recollection of material decreased, or labour/funds redirected to recollection schemes or recollection increased more than diversion of waste streams	No change to recollection schemes	Funding/labour for recollection schemes raised, or additional schemes added without exceeding efforts for collection from source
2	Transfer points encouraged	New routes created with little/no transfer points (to domestic recycled), or material diverted from routes with many transfer points	No change to number of transfer points on main routes	Material redirected to routes with multiple transfer points or major routes redirected through recycling transfer points or non-domestic recycled transfer points removed from major routes
3	Junkshop collection	Material redirected from junkshops to non-recycling routes or junkshop material reduced without alternative recycling route or flow to junkshops not redirected (if new recycling route)	No change to junkshop flows or junkshop flow reduced by redirection of material to new recycling route	Increased material to junkshops if no new recycling route or junkshops used as transfer point in recycling route or material recollection directed to junkshops if new recycling route from source
4	Use of labour	Informal routes decline and no employment of informal workers or new routes created, and new workforce utilised	Informal workers not employed for schemes, but no reduction in informal routes	If informal routes decline, informal workers utilised as labour for official collection or informal collectors employed for new schemes
5	Central household collection	No additional household collection created, or central collection created separate to informal collection that leaves no material	Current collection (RT/RW) made official but no change to processes	New central collection scheme that absorbs informal collection or new central collection that occurs parallel to informal collection
6	Redirection from landfill	No schemes created to sort and separate material at landfill or landfill separation schemes enacted but with private labour	Separation of material at transfer points that lead to landfill but no separation at landfill	Landfill sorting and separation technologies introduced, utilising an informal labour force
7	Stemmed recycler leakage	Material to recyclers redirected to official recycling nodes or no change to recycler leakage	Recollection organised around recycler areas to collect leakage or recyclers required to reduce leakage with no intervention or flow of material to recyclers reduced	Recycler processes improved to reduce leakage with intervention/funding from government/producers
8	PET export redirected	no redirection of exported PET or PET export banned/discouraged without alternative or internal sellers buy more but at reduced price	Some increased purchase from internal sources due to down chain action	PET export banned/discouraged with new market for internal purchase or internal purchase encouraged at same price as export

Table 4
Scenario Scoring and evaluation.

Criteria		Scoring (−1, 0, +1)		
		Scenario 1	Scenario 2	Scenario 3
1	Recollection schemes bolstered	0	0	0
2	Transfer points encouraged	−1	+1	+1
3	Junkshop collection	+1	0	0
4	Use of labour	+1	0	−1
5	Central collection system	+1	0	−1
6	Redirection from landfill	0	+1	−1
7	Stemmed recycler leakage	0	−1	0
8	PET export redirected	+1	0	+1
TOTAL		3	1	−1

accurate and informed analysis of different EPR strategies is possible. It is critical to note that the inclusion of more economic, environmental and social assessment criteria is strongly recommended. Through co-creation techniques and incorporation of the approach into professional decision-support-tools, the applicability of the proposed tactic can be justified. Finally, the approach does not only allow for comparison between the designed EPR scenarios but also provide a reflection on the limitations of EPR for managing the plastic waste system. For example, with regard to EPR for PET in Jakarta, no scenario addressed the main point of leakage identified through material flow analysis, i.e. the recyclers. This highlights the need for additional policies or schemes to facilitate this transition. Such a strength is attributed to the use of material flow analysis as a basis for the assessment of plastic waste management. The approach developed here does not only help to consider already identified policy interventions but can also form the basis for identifying new ones.

CRediT authorship contribution statement

Samir Amin: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **David Strik:** Conceptualization, Validation, Writing – review & editing, Supervision. **Judith van Leeuwen:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.132884.

References

Adebayo, Z., 2018. New road material reducing plastic pollution in Indonesia. The Borgen Project. https://borgenproject.org/plastic-pollution-in-indonesia/. (Accessed 7 December 2021).

Afrane, S., Ampah, J.D., Jin, C., Liu, H., Aboagye, E.M., 2021. Techno-economic feasibility of waste-to-energy technologies for investment in Ghana: a multicriteria assessment based on fuzzy TOPSIS approach. J. Clean. Prod. 318, 128515.

Amin, S., Van Leeuwen, J., & Strik, D. (Submitted). Data insights supporting material flow analysis of PET plastic in Jakarta, Indonesia. Data Brief.

Bassi, S.A., Boldrin, A., Faraca, G., Astrup, T.F., 2020. Extended producer responsibility: how to unlock the environmental and economic potential of plastic packaging waste? Resour. Conserv. Recycl. 162, 105030 https://doi.org/10.1016/j.resconrec.2020.105030.

Boldizar, A., Möller, K., 2003. Degradation of ABS during repeated processing and accelerated ageing. Polym. Degrad. Stabil. 81 (2), 359–366.

Boldoczki, S., Thorenz, A., Tuma, A., 2020. The environmental impacts of preparation for reuse: a case study of WEEE reuse in Germany. J. Clean. Prod. 252, 119736.

Boldoczki, S., Thorenz, A., Tuma, A., 2021. Does increased circularity lead to environmental sustainability?: the case of washing machine reuse in Germany. J. Ind. Ecol. 25, 864–876.

Brunner, P.H., Rechberger, H., 2016. Handbook of Material Flow Analysis, 0 ed. CRC Press. https://doi.org/10.1201/9781315313450.

Campbell-Johnston, K., Calisto Friant, M., Thapa, K., Lakerveld, D., Vermeulen, W.J.V., 2020. How circular is your tyre: experiences with extended producer responsibility from a circular economy perspective. J. Clean. Prod. 270, 122042 https://doi.org/10.1016/j.jclepro.2020.122042.

Campbell-Johnston, K., Munck, M., Vermeulen, W.J.V., Backes, C., 2021. Future Perspectives on the Role of Extended Producer Responsibility within a Circular Economy: A Delphi Study Using the Case of the Netherlands. Business Strategy and the Environment. https://doi.org/10.1002/bse.2856 bse.2856.

Chaerul, M., Fahruroji, A.R., Fujiwara, T., 2014. Recycling of plastic packaging waste in Bandung City, Indonesia. J. Mater. Cycles Waste Manag. 16 (3), 509–518.

Chaplin-Kramer, R., Sim, S., Hamel, P., Bryant, B., Noe, R., Mueller, C., Rigarlsford, G., Kulak, M., Kowal, V., Sharp, R., 2017. Life cycle assessment needs predictive spatial modelling for biodiversity and ecosystem services. Nat. Commun. 8 (1), 1–8.

Chitaka, T.Y., von Blottnitz, H., 2021. Development of a method for estimating product-specific leakage propensity and its inclusion into the life cycle management of plastic products. Int. J. Life Cycle Assess. 26 (7), 1431–1438. https://doi.org/10.1007/s11367-021-01905-1.

Creswell, J.W., Creswell, J.D., 2018. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, fifth ed. Sage publications.

Deshpande, P.C., Skaar, C., Brattebø, H., Fet, A.M., 2020. Multi-criteria decision analysis (MCDA) method for assessing the sustainability of end-of-life alternatives for waste plastics: a case study of Norway. Sci. Total Environ. 719, 137353.

Elhamdouni, D., Arioua, A., Karaoui, I., Ait Ouhamchich, K., Faouzi, E., Aba, B., 2022. The multi-criteria analysis (AHP) method use for the environmental problems management: case of the household waste in Morocco. Euro-Mediterranean Journal for Environmental Integration 1–8.

Ellen MacArthur Foundation, 2015. Delivering the Circular Economy: A Toolkit for Policymakers. Ellen MacArthur Foundation.

Filho, W.L., Saari, U., Fedoruk, M., Iital, A., Moora, H., Klöga, M., Voronova, V., 2019. An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe. J. Clean. Prod. 214, 550–558. https://doi.org/10.1016/j.jclepro.2018.12.256.

Friant, M.C., Vermeulen, W.J., Salomone, R., 2020. A typology of circular economy discourses: navigating the diverse visions of a contested paradigm. Resour. Conserv. Recycl. 161, 104917.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – a new sustainability paradigm? J. Clean. Prod. 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048.

Hahladakis, J.N., Iacovidou, E., 2019. An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): focus on recycling. J. Hazard Mater. 380, 120887.

Hajek, R., 2019, June 11. The Waste Emergency. Inside Indonesia https://www.insideindonesia.org/the-waste-emergency. Retrieved. (Accessed 7 December 2021).

Hauschild, M., Goedkoop, M., Guinee, J., Heijungs, R., Huijbregts, M., Jolliet, O., Margni, M., Schryver, A.D., Pennington, D., Pant, R., Sala, S., Brandao, M., Wolf, M., 2011. Recommendations for Life Cycle Impact Assessment in the European Context—Based on Existing Environmental Impact Assessment Models and Factors (International Reference Life Cycle Data System—ILCD Handbook) (Scientific Analysis or Review, Technical Guidance LB-NA-24571-EN-C). Publications Office of the European Union. https://doi.org/10.2788/33030.

Haward, M., 2018. Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. Nat. Commun. 9 (1), 1–3.

Hendiarti, N., 2018. Combating marine plastic debris in Indonesia. In: Dipresentasikan Pada Science to Enable and Empower Asia Pacific for SDGs. Jakarta, 30 Juli 2018).

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347 (6223), 768–771.

Johannes, H.P., Kojima, M., Iwasaki, F., Edita, E.P., 2021. Applying the extended producer responsibility towards plastic waste in Asian developing countries for reducing marine plastic debris. Waste Manag. Res. 39 (5), 690–702. https://doi.org/10.1177/0734242X211013412.

Kalmykova, Y., Sadagopan, M., Rosado, L., 2018. Circular economy–From review of theories and practices to development of implementation tools. Resour. Conserv. Recycl. 135, 190–201.

Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: an analysis of 114 definitions. Resour. Conserv. Recycl. 127, 221–232.

Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular economy: the concept and its limitations. Ecol. Econ. 143, 37–46.

Kristyawan, I., Shoiful, A., Hendrayanto, P., Santoso, A., 2021. Update on waste reduction performance by waste-to-energy incineration pilot plant PLTSa Bantargebang operations. Earth Environmental Sci. 922 (1), 012059.

Lonca, G., Lesage, P., Majeau-Bettez, G., Bernard, S., Margni, M., 2020. Assessing scaling effects of circular economy strategies: a case study on plastic bottle closed-loop recycling in the USA PET market. Resour. Conserv. Recycl. 162, 105013 https://doi.org/10.1016/j.resconrec.2020.105013.

Milutinović, B., Stefanović, G., Đekić, P.S., Mijailović, I., Tomić, M., 2017. Environmental assessment of waste management scenarios with energy recovery using life cycle assessment and multi-criteria analysis. Energy 137, 917–926.

Minister of Environment and Forestry of the Republic of Indonesia, 2020. National plastic waste reduction strategic actions for Indonesia. Republic of Indonesia (No. 20).

Morão, A., De Bie, F., 2019. Life cycle impact assessment of polylactic acid (PLA) produced from sugarcane in Thailand. J. Polym. Environ. 27 (11), 2523–2539.

Moreno, M., De los Rios, C., Rowe, Z., Charnley, F., 2016. A conceptual framework for circular design. Sustainability 8 (9), 937.

Neeteson, A., Danielson, J., Sihotang, L., Gofur, N.A., Omar, N., 2021. Producer Responsibility in indonesia. SystemIQ.

Niero, M., Hauschild, M.Z., 2017. Closing the loop for packaging: finding a framework to operationalize circular economy strategies. Procedia CIRP 61, 685–690. https://doi.org/10.1016/j.procir.2016.11.209.

Park, J., Díaz-Posada, N., Mejía-Dugand, S., 2018. Challenges in implementing the extended producer responsibility in an emerging economy: the end-of-life tire management in Colombia. J. Clean. Prod. 189, 754–762. https://doi.org/10.1016/j.jclepro.2018.04.058.

Pauer, E., Wohner, B., Heinrich, V., Tacker, M., 2019. Assessing the environmental sustainability of food packaging: an extended life cycle assessment including packaging-related food losses and waste and circularity assessment. Sustainability 11 (3), 925.

Putri, A.R., Fujimori, T., Takaoka, M., 2018. Plastic waste management in Jakarta, Indonesia: evaluation of material flow and recycling scheme. J. Mater. Cycles Waste Manag. 20 (4), 2140–2149. https://doi.org/10.1007/s10163-018-0753-2.

Regulation of the Minister of Environment and Forestry Number 75, no. 75 (2019).

Reike, D., Vermeulen, W.J., Witjes, S., 2018. The circular economy: new or refurbished as CE 3.0?—exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. Resour. Conserv. Recycl. 135, 246–264.

Saling, P., Gyuzeleva, L., Wittstock, K., Wessolowski, V., Griesshammer, R., 2020. Life cycle impact assessment of microplastics as one component of marine plastic debris. Int. J. Life Cycle Assess. 25 (10), 2008–2026. https://doi.org/10.1007/s11367-020-01802-z.

Sevigné-Itoiz, E., Gasol, C.M., Rieradevall, J., Gabarrell, X., 2015. Methodology of supporting decision-making of waste management with material flow analysis (MFA) and consequential life cycle assessment (CLCA): case study of waste paper recycling. J. Clean. Prod. 105, 253–262.

Shekdar, A.V., 2009. Sustainable solid waste management: an integrated approach for Asian countries. Waste Manag. 29 (4), 1438–1448.

Triantaphyllou, E., 2000. Multi-criteria decision making methods. In: Multi-criteria Decision Making Methods: A Comparative Study. Springer, pp. 5–21.

Van Emmerik, T., Loozen, M., Van Oeveren, K., Buschman, F., Prinsen, G., 2019. Riverine plastic emission from Jakarta into the ocean. Environ. Res. Lett. 14 (8), 084033.

Watkins, E., Gionfra, S., Schweitzer, J.-P., Pantzar, M., Janssens, C., ten Brink, P., 2017. EPR in the EU Plastics Strategy and the Circular Economy: A Focus on Plastic Packaging. Institute for European Environmental Policy (IEEP).

Welle, F., 2011. Twenty years of PET bottle to bottle recycling—an overview. Resour. Conserv. Recycl. 55 (11), 865–875.