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Integrating material flows into macro-economic mo- delling: assessing material productivity as a KPI for circular economy policies

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Integrating material flows into macro-economic modelling: assessing material productivity as a KPI for circular economy policies

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Summary

This report extends a previously developed Computable General Equilibrium (CGE) model for Belgium to include material productivity indicators. This extension was used to assess the impact of three circular economy (CE) policy scenarios on the GDP/DMI indicator as a measure for material productivity. The analysis shows that i) increasing the share of waste and recycled materials in production leads to lower material productivity, due to higher material inputs and lower GDP when production methods are not adapted, ii) improving the quality of recycling slightly increases GDP while reducing material inputs, and iii) restricting waste exports to third countries has only a limited macroeconomic effect.

To do this, a new methodological framework was developed to integrate material flow data into the CGE model. Material coefficients were added that represent the kilograms (kg) of material extracted per unit of domestic production and the kg of material imported per unit of imports. Two types of coefficients were used: one based on domestic extraction and linked to the agricultural and mining sectors, and another based on imports, calculated using trade data and material conversion tables. These coefficients were matched to economic sectors using input-output tables, making it possible to estimate DMI and calculate the GDP/DMI indicator under each policy scenario.

Three circular economy policy measures, inspired by the European Commission's Circular Economy Action Plan, were evaluated:

1. **Increasing the share of waste and recycled materials as inputs** leads to a rise in imported materials, as the waste and recycling sector cannot meet the new demand. Manufacturing output drops due to higher production costs (seeing as the model does not include adaptation of production methods), and GDP decreases. Seeing as material use increases while GDP falls, material productivity worsens. This outcome highlights the need to combine such measures with investments in innovation and infrastructure.
2. **Improving recycling efficiency** lowers the cost of waste and recycled goods as inputs, making them more competitive. This results in higher domestic production, lower material imports, and a small increase in GDP. As a result, GDP/DMI improves slightly.
3. **Restricting waste exports to third countries** causes only minor changes. Waste and recycling goods are now processed domestically instead of being exported, leading to a small increase in investment demand, while GDP and DMI remain largely stable. The effect on material productivity is limited.

This report studied how extending CGE modelling with material coefficients can help to better understand the GDP/DMI indicator and what drives changes in material productivity. Instead of using the model to only evaluate the effects of circular policy measures on the indicator, it allowed us to break down the indicator and analyse the underlying economic and material mechanisms that impacted material productivity. In the first scenario, for example, the intention was to reduce material input, but the opposite happened due to unchanged production methods and limited processing capacity in the waste and recycling sector. Understanding these dynamics is of significant importance when designing policies for the circular economy. In that respect, the results might indicate a possibility that not all dedicated CE policy measures would automatically lead to a decrease in the material productivity.

Samenvatting

Dit rapport bouwt verder op een eerder gebruikt Computable General Equilibrium (CGE) model voor België: het werd uitgebreid met indicatoren voor materiaalproductiviteit. Hiermee werd de impact van drie beleidsscenario's voor de circulaire economie (CE) geanalyseerd op de BBP/DMI-indicator als maatstaf voor materiaalproductiviteit. De analyse toont aan dat i) een hoger aandeel afval en gerecycleerde materialen in productie leidt tot een lagere materiaalproductiviteit, door meer materiaalgebruik en een lager BBP indien productiemethoden niet aangepast worden, ii) hoogwaardige recyclage het BBP licht doet stijgen terwijl het materiaalgebruik daalt, en iii) beperken van afvalexport naar niet-EU landen slechts een beperkt macro-economisch effect heeft.

Om dit mogelijk te maken, werd een nieuwe methodologie ontwikkeld om materiaalstromen te integreren in het CGE-model. Materiaalcoëfficiënten werden toegevoegd die weergeven hoeveel kilogram materiaal wordt ontgonnen per eenheid binnenlandse productie, en hoeveel kilogram ingevoerd per eenheid aan import. Twee soorten coëfficiënten werden gebruikt: één op basis van binnenlandse ontginning, gelinkt aan de landbouw- en mijnbouwsectoren, en één op basis van invoer, berekend met behulp van handelsdata en omrekeningen naar kg. Deze coëfficiënten werden aan economische sectoren gekoppeld via input-outputtabellen, waardoor het mogelijk werd om de DMI en de BBP/DMI-indicator per scenario te berekenen.

Drie beleidsmaatregelen uit het Circular Economy Action Plan van de Europese Commissie werden geëvalueerd:

1. **Een verhoogd aandeel afval en gerecycleerde materialen als input** leidt tot meer materiaalimport, omdat de binnenlandse afval- en recyclagesector de extra vraag niet kan volgen. De productie in de maakindustrie daalt door hogere kosten (aangezien het model veronderstelt dat de productiemethoden niet aangepast worden), waardoor ook het BBP daalt. Omdat het materiaalgebruik toeneemt terwijl het BBP daalt, daalt de materiaalproductiviteit. Onze resultaten tonen aan dat zulke maatregelen best worden ondersteund met investeringen in innovatie en infrastructuur.
2. **Efficiëntere recyclage** maakt afval- en recyclageproducten goedkoper en competitiever. Dit verhoogt de binnenlandse productie, verlaagt de materiaalimport, en zorgt voor een lichte stijging van het BBP. Hierdoor verbetert de BBP/DMI-indicator lichtjes.
3. **Beperking van afvalexport naar derde landen** zorgt slechts voor kleine veranderingen. De verwerking van afval gebeurt voortaan binnenlands, wat leidt tot een lichte toename in de investeringsvraag. BBP en DMI blijven grotendeels stabiel. De impact op materiaalproductiviteit is beperkt.

Dit rapport onderzocht hoe het uitbreiden van CGE-modellering met materiaalcoëfficiënten kan bijdragen aan een beter begrip van BBP/DMI als indicator voor materiaalproductiviteit en de onderliggende drijfveren van veranderingen in de materiaalproductiviteit. In plaats van het model enkel te gebruiken om de effecten van circulaire beleidsmaatregelen op de indicator te evalueren, maakte deze aanpak het mogelijk om de indicator te ontleden en de onderliggende economische en materiaaldynamieken te analyseren die een impact hebben op materiaalproductiviteit. In het eerste scenario was het bijvoorbeeld de bedoeling om het

materiaalgebruik te verlagen, maar het omgekeerde gebeurde door onveranderde productieprocessen en een beperkte verwerkingscapaciteit in de afval- en recyclagesector. Inzicht in deze dynamieken is van groot belang bij het vormgeven van circulair beleid. In dat opzicht suggereren de resultaten dat niet alle typisch circulaire maatregelen automatisch zullen leiden tot een daling in de materiaalproductiviteit.

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1. Introduction

In general, there are four important indicators for material use in a region. A calculation for these indicators was first developed by Eurostat (2018), and these indicators were called the Economy-Wide Material Flow Indicators (EW-MFA), visually represented in Figure 1.

The first material indicator is **Domestic Extraction (Used)**, abbreviated to **DE** or often **DEU**. The DEU is the amount of materials that are domestically extracted through e.g., mining, agriculture, or forestry. Next, materials can be imported instead of mined domestically. The imports and the DEU together form the **Direct Material Input** or **DMI**, which reflects the amount of materials that are processed domestically, independent of where they will be consumed. If we want to look at **Domestic Material Consumption (DMC)**, we need to subtract the exports from the DMI. The DMC gives us the amount of materials that are processed domestically minus those that are consumed elsewhere.

We have now discussed all the yellow boxes from Figure 1 and the relation between these indicators can also be expressed in the following formulas:

$$DMI = DEU + IMPORTS$$

$$DMC = DMI - EXPORTS = DEU + IMPORTS - EXPORTS$$

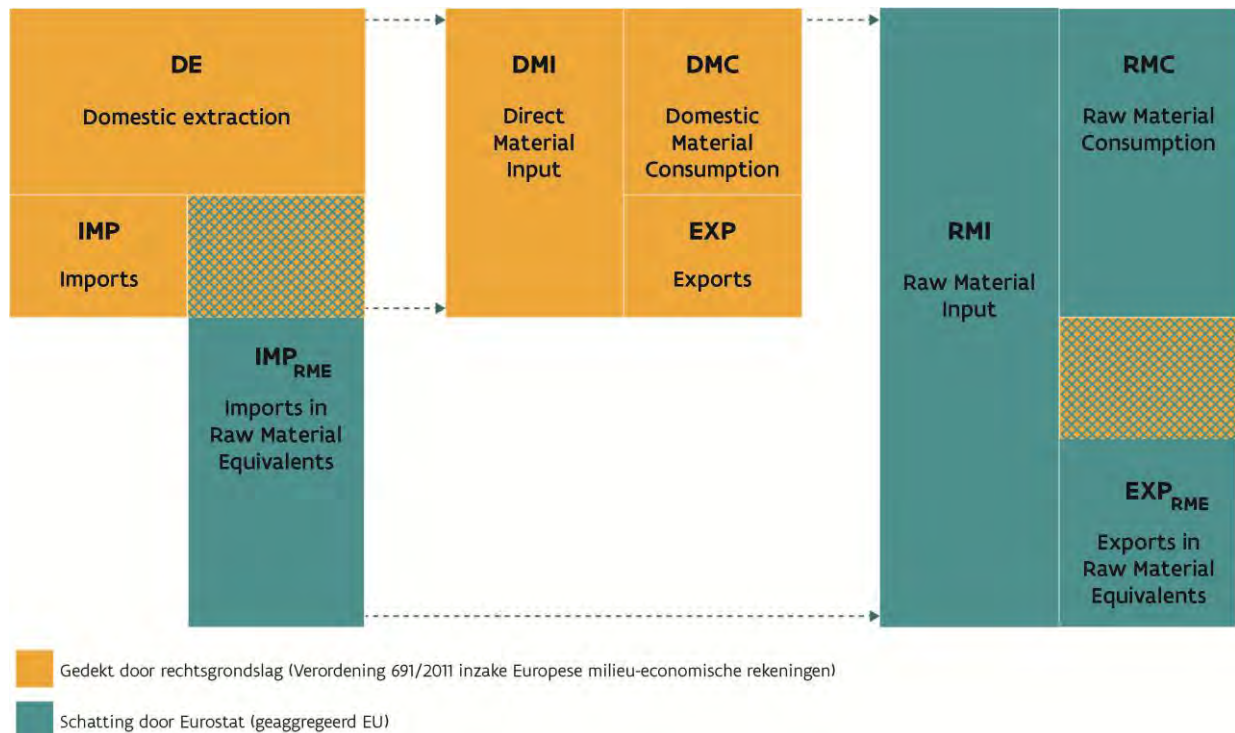


Figure 1: Visual representation of the EW-MFA. Source: OVAM based on Eurostat (2018).

Next, we discuss the blue indicators. These are footprint indicators and take into account the full chain. For example, the material import counts all the meat that crosses the Belgian border.

However, meat has a large footprint because of the large quantities of materials needed to produce one unit of meat, such as wheat, soy, water, and materials to build sheds, etc. These additional materials can be calculated using “**raw material equivalents**” (**RME**). These RMEs are published every year by Eurostat and are coefficients that reflect the extra material needed in the calculation. The results for material imports can thus be expressed in imports in raw material equivalents, and the exports can be expressed in exports in raw material equivalents.

The DEU and the imports in RME together form the **Raw Material Input (RMI)** that reflects all the raw materials needed for the production processes in Belgium, independent of where they are consumed. Subtracting the exports from the RMI gives us the **Raw Material Consumption** or **RMC**, or the material footprint of Belgian consumption. Next, you find their respective formulas:

$$RMI = DEU + IMPORTS_{RME}$$

$$RMC = RMI - EXPORTS_{RME} = DEU + IMPORTS_{RME}$$

Lastly, the four main indicators (DMI, DMC, RMI, and RMC) can all be used to calculate material productivity: GDP/DMI, GDP/DMC, GDP/RMI or GDP/RMC. This reflects the amount of euros generated in Belgium per kilogram of materials in direct material input, domestic material consumption, raw material input, or raw material consumption. For this report, the GDP/DMI indicator was chosen as the objective of interest for our research.

The reason for choosing the GDP/DMI indicator as our object of interest is multifold. First, currently the Material Footprint indicator is researched as a possible Flemish CE target. However, this target only considers consumption in Flanders. In a previous study from CE Center (No. 25: *Overview of existing targets for the circular economy in Flanders*) it was argued that an additional target would be needed with a complementary focus on the production side of the Flemish economy. More recently, Material Productivity has been recently installed as a prestatation indicator for the Flemish economy and might become amenable to evolve into a policy target later on. Second, in international literature and reports, the GDP/DMC indicator is used more often, however, using the DMI gives a more complete overview as the whole territorial economy and production is included, in contrast to the DMC where only the territorial consumption is considered. The footprint of this production or consumption is excluded in both indicators. Third, the advantage of a target on the DMI or DMC is the national scope, which allows policies to have a more direct impact on them, as can be read in the CE Center report nr. 25: *Overview of the existing targets for the circular economy in Flanders*. Lastly, there are countries which use GDP/DMI as a target indicator such as in Japan (Ministry of the Environment Japan, 2013). This gives us some references and previous work for inspiration.

Below, in Figure 2, you will find the evolution of the indicator between 2010 and 2023 for Belgium, in current prices or chain-linked volumes to account for inflation. The indicator increases in any case, reflecting either an increase in GDP or a decrease in DMI.

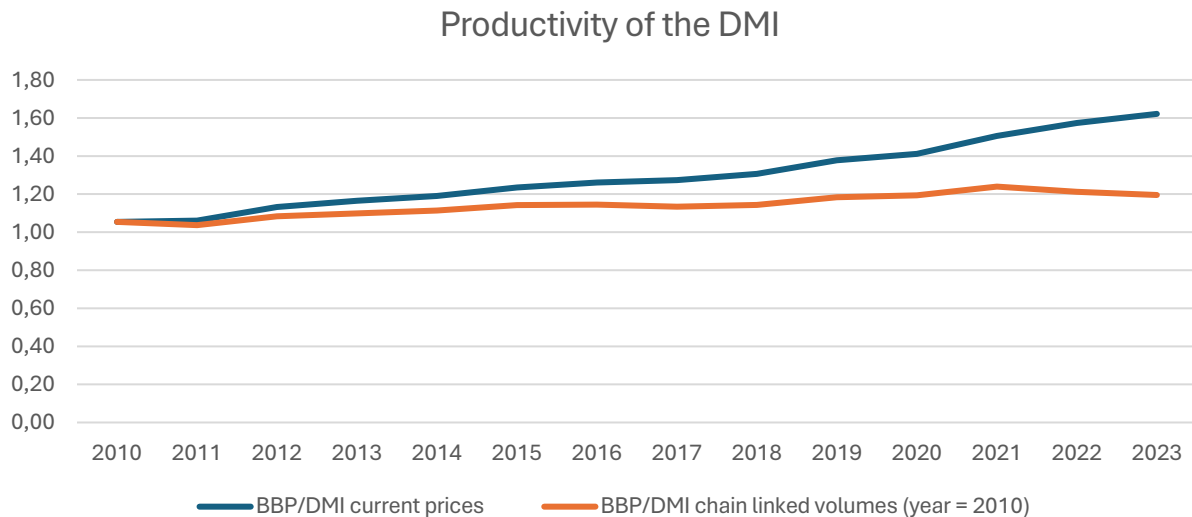


Figure 2: Evolution of the productivity of the DMI of Belgium between 2010 and 2023. Source: Eurostat (2024a) and Eurostat (2024b)

Currently, there is a lack of insights into the different indicators and possibilities for targets. The unclarity in the choice for the material footprint, or the GDP/DMC or GDP/DMI indicators is the main motivation for this report. In this report, we will use **CGE modelling** to gain an understanding of material productivity and the impact of policy measures on the indicator GDP/DMI and other underlying macroeconomic indicators. The goal is to understand how the indicator works and how it reacts to different macroeconomic changes, such as policy measures. This research is important for policymakers to understand the impact of their actions and measures. The Belgian CGE model is an adept model for capturing macroeconomic indirect and rebound effects.

The modelled scenarios are identical to those modelled in a previously published CE Center report (No. 24: *Socio-economic effects for the circular economy*). This report serves as an extension: the first report discusses the macroeconomic results of three policy measures from the Circular Economy Action Plan, modelled in the CGE model, whereas this report adds insights into material productivity. Furthermore, this report introduces a novel methodology for incorporating material flows into CGE models.

2. Methodology

2.1 Integrating material coefficients into the CGE model

2.1.1. The Computable General Equilibrium (CGE) model

For a full literature study of CGE models and the extension of our Belgian CGE model to accommodate the W&R sector, we refer to the previously published report (No. 24: *Socio-economic effects for the circular economy*). Here, we provide a summary of the general mechanisms.

The Belgian CGE model is calibrated using data from 2018 and originally consists of 13 sectors (classified according to NACE codes) and 13 goods/services (classified according to CPA codes), as shown in Table 1. Goods can be imported from and exported to the EU or the rest of the world (RoW). Belgium is a small, open economy and is therefore a price taker on international markets. The different agents in the model make decisions to optimise their utility. These agents include producers, consumers, the labour market, investments, the government, firms, Europe, and the RoW. CGE models account for indirect and spillover effects, making them a suitable tool for studying the impact of policy measures in a given region. A limitation of this study is that the CGE model used is developed at the Belgian national level and does not represent the Flemish economy specifically.

Good	Sector	Activity
G1	S1	Agriculture, fishery, forestry
G2	S2	Mining
G3	S3	Manufacturing
G4	S4	Energy
G5	S5	Construction
G6	S6	Trade
G7	S7	Land transport
G8	S8	Water transport
G9	S9	Air transport
G10	S10	Logistics & post
G11	S11	Commercial services
G12	S12	Non-commercial services
G13	S13	Waste & recycling

Table 1: Classification of goods and sectors in the CGE model

2.1.2. Material coefficients as an exogenous input variable

We identified two possible methodological approaches to incorporate the GDP/DMI indicator into the CGE model to get a better understanding of the indicator. That is, to understand how

the indicator responds to different policy measures and how the two components (GDP and DMI) interact with each other:

- I. **To set a target for GDP/DMI** and analyse the effects on macroeconomic indicators
- II. **To simulate a policy measure** (e.g. tax on exports of waste, mandatory use of secondary materials, etc.) and analyse what happens to both macroeconomic indicators and the GDP/DMI indicator

The first approach, setting a target for GDP/DMI, proved not to be feasible in this study, seeing as the GDP/DMI indicator is not yet endogenously modelled in our Belgian CGE model. Hence, we opted for the second methodological approach and first simulated several policy measures, which will be later discussed in this report, to then assess how these measures influence macroeconomic indicators and how these impact the GDP/DMI indicator.

To move forward, we first had to exogenously add the DMI into our model. This could be done by calculating material coefficients for domestic production (linked to domestic extraction) and for the import of goods. These coefficients represent how many kilograms of materials are used or imported per unit of economic output.

Domestic production coefficients

The production coefficient is based on the domestic extraction of materials in Belgium, which can be found in the Eurostat database by the European Commission. Given that the only sectors in the CGE model that extract materials in Belgium are the agricultural and mining sectors (S1 and S2), we assigned the extraction of biomass to the agricultural sector and all other extracted materials, which in reality are only minerals in Belgium, to mining. We calculated the coefficients by dividing the total domestic extraction of every sector by the total economic output of the agricultural and mining sectors. The total economic output of the sectors can be found in our CGE model, which is based on the Belgian supply and use tables by the National Bank of Belgium (NBB).

Import coefficients

Import coefficients represent the kilograms of materials associated with each unit of imported goods. These were calculated using Belgian trade data from the NBB, classified according to CN codes (the standard international classification for traded goods). The data is expressed in different units: in euros or in quantities, which can be kilograms but also litres, pieces, m³,...

To calculate how many kilograms of materials are imported for each unit of good imported, we used material conversion coefficients developed by the European Commission, which can be found in their Annexes to the Economy-Wide Material Flow Accounts (EW-MFA), in Annex 6. That way, we can express all the data in a uniform unit, namely, in kilograms. Next, we had to translate these CN codes to CPA codes, which are used in the CGE model to classify goods. CPA codes classify goods and services based on the economic activity (expressed in NACE codes) that produces them. This translation was done using conversion tables from the European Commission's ShowVoc¹ platform, which links CN-classified products to their CPA counterparts.

¹ [ShowVoc](#)

By doing so, we could match kilograms of material in CN codes to the import in units in CPA codes used in the CGE model. These coefficients were then inserted into the CGE model as exogenous inputs. This allowed us to analyse the changes in kg materials used or imported in response to simulated policy measures.

2.2 From Material coefficients to Material productivity

2.2.1. Initial approach: direct mapping via CPA codes

Our first approach to understanding the material productivity indicator was to exogenously integrate the material coefficients directly into the CGE model and evaluate how total material imports per group of goods changed across policy scenarios. While this approach seemed promising, it proved to give rather meaningless insights into the workings of the indicator. Although we could calculate the material import associated with each imported good (based on CPA codes), the CGE model uses a highly aggregated classification. Most of the goods that represent actual physical products and have any material relevance, like the manufacturing, agriculture, mining, waste, and energy sectors, are bundled into these few categories, while the remaining groups of goods largely represent services.

This aggregation implies that although the combination of the NBB trade data with the conversion tables offers a detailed overview of imported materials based on CN codes, once converted to CPA codes and aggregated to CGE model categories, much of the nuance is lost. For example, sectors like construction or transportation play a major role in both material use and GDP, but this approach did not allow us to capture their real material impact under different policy measures.

To summarise, tracking material imports per group of goods as classified in the CGE model was not enough to analyse changes in the DMI or understand what drives the GDP/DMI indicator. The goods in the model are too broadly defined, and sectors such as construction or transport are not properly captured through a goods-based approach, even though these sectors play an important role in both material use and economic output. That is why a sector-based approach was needed, this would allow us to see how each sector's import of materials per good changes due to the different policy measures.

2.2.2. Alternative approach: Indirect sectoral mapping via I/O

To better link material imports to the economic sectors, we used an indirect approach. Instead of focusing solely on goods, we wanted to know which sectors import which goods, and thus, how material imports could be linked back to sectoral output.

This required three steps:

1. Run CGE policy measures

We first simulated each policy measure in the CGE model to observe how sectoral output and total goods imports changed. Based on this, we could calculate the total material imports per good using the previously calculated material coefficients.

2. Determine the sectoral use of imported goods

To find out how much of each imported good was used by each sector, we used the 2015 FIGARO-e3 input-output tables² (Cazcarro et al., 2025). More specifically, the use table, which shows how much each Belgian sector (classified by NACE codes) imports in monetary value of the CPA-classified goods.

3. Aggregate to the CGE model structure

Since the CGE model only uses 13 sectors and 13 goods, we aggregated the FIGARO data to match this simplified structure. We then calculated the share of each good imported by each sector as a percentage of total imports for that good.

By applying these percentages to the CGE import data (expressed in kg via material coefficients), we estimated the material imports per sector. Since the FIGARO-e3 use table is expressed in monetary values, while the output in our CGE model is expressed in physical units (quantities of goods), we applied the monetary shares from FIGARO-e3 to divide material imports across sectors. This introduces a limitation, as the relationship between price and quantity is not always one-to-one, but the approach still provides a reasonable proxy for estimating the distribution of material flows per sector.

We then added domestic extraction (DEU), attributed to the agricultural and mining sector based on domestic production coefficients, to get the total DMI per sector. This methodology allowed us to calculate the DMI at the sectoral level, providing more meaningful insights into how policy measures affect the material productivity indicator and which sectors are most impacted.

2.3 Policy measures

As mentioned earlier, the modelled policy measures and scenarios are identical to the ones from the previous report and follow from the EU Circular Economy Action Plan. This has the advantage that we can focus on the interaction between the indicator for material productivity and the already published macroeconomic results. For a detailed description of the methodology and macroeconomic results, we refer to the other report.

2.3.1. Increased share of waste and recycled material as input

For the first policy measure, we increased the share of waste and recycled materials as input by altering the production function of the manufacturing sector, a material-intensive and large sector in the Belgian economy. By increasing this share of W&R materials in the manufacturing industry, we stimulate the manufacturing industry to use fewer other inputs, preferably primary inputs, by substituting these primary inputs for secondary materials. In total, the share was increased nine times, resulting in nine scenarios for this policy measure.

² FIGARO-e3 input-output tables have been created by disaggregating the official FIGARO database (Eurostat) based on the monetary structures of EXIOBASE (exiobase.eu).

2.3.2. Enabling high-quality recycling

The second policy measure is aimed at increasing the quality of recycling instead of the quantity. This could be done by, among others, creating Digital Product Passports, extending the Ecodesign Directive, via effective separate collection of waste, or by technological advancements. We propose that targeted measures could increase the efficiency of the recycling process and, therefore, also the quality of recycling. In the CGE model, the efficiency parameter is increased nine times to again create nine scenarios within this policy measure. This means that more recycling activity can be achieved with the same materials.

2.3.3. Addressing waste export to third countries

The last policy measure has the goal of restricting European waste from being exported to third countries (non-EU). In CGE, this is modelled through ‘ad valorem equivalents’, which increase the difference between world and domestic prices. We model this so that the share of the price that producers of waste receive for their exports decreases nine times, until this share eventually becomes zero, and the tax makes up 100% of the price.

3. Results

This chapter describes the macroeconomic effects of the previously mentioned policy measures from the EU Circular Economy Action Plan: (i) increasing the share of waste and recycled materials, (ii) enabling high-quality recycling, and (iii) restricting waste exports. Furthermore, we add material indicators to these results to study the effects of circular policies on the main BBP/DMI indicator.

The policy measures in this report are the same as discussed in the previous report of CE center “Socio-economic effects of the circular economy, modelling the recycling and waste sectors using CGE”. Therefore, in this report, we focus on the results for GDP, DEU, import of materials (together DMI), and the ratio GDP/DMI. To understand the results, a brief summary will be given of the interactions and dynamics of the model, the output of sectors, the prices, and so on. However, for further information on the macroeconomic effects, we refer to the previously published report for a full description.

3.1. Increased share of waste and recycled materials as input

3.1.1. GDP

As can be seen in Figure 3, the increase in the share of W&R materials as inputs leads to an increase in the output of the W&R sector from 8.8 billion units to 29.0 billion units of production or 229.03%. The manufacturing industry is forced to use more of these materials, and therefore, the W&R sector will increase its production of W&R goods. At the same time, however, the total output of the manufacturing sector decreases by 65.56% from 210.4 billion units to 72.5 billion units of production. This can be explained by the fact that their new optimum leads to a lower

output, considering the higher cost of production due to a forced shift from primary to secondary materials, seeing as the model does not allow for a change in production methods.

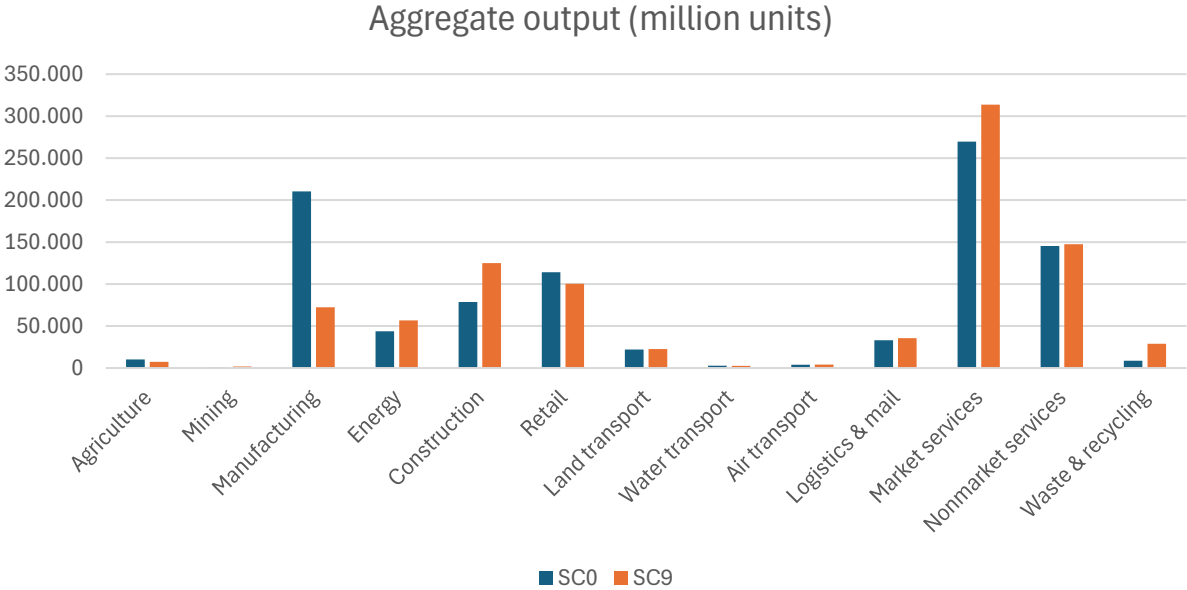


Figure 3: Aggregate output per sector (in million units) in scenario 0 and scenario 9

We note that the structure of the production function remains unchanged, and therefore, the shift feels forced for the manufacturing sector. In reality, however, we expect that the manufacturing sector would adapt its production method to the new regulation to obtain additional capacity, for example, by innovation.

The impact on the W&R and manufacturing sectors causes chain reactions to other sectors: there is a higher activity for logistics and transport due to the increased activity of the W&R sector, which requires more transport and logistics from end of life to separation facilities, to recycling facilities, and finally back to the producer. Also, the energy and mining sector increase their activities due to a decrease in their prices, so it becomes more beneficial to produce energy domestically, export more energy, and import less energy. The mining sector increases its production to deliver the necessary materials for the increased demand in energy output.

Finally, GDP decreases due to the decreased output of the manufacturing sector, the largest sector, and decreased consumption due to higher prices. This lower GDP will lead to a higher investment demand to stimulate the economy, and therefore a higher output of typical investment goods such as construction and market services. This can also be seen as an increase in investment for recycling facilities to be built in Belgium as we become more competitive with lower prices of W&R goods.

3.1.2. DMI

Fout! Verwijzingsbron niet gevonden. shows the evolution of the total DMI per scenario; each scenario shows a tightening of the policy measure. In scenario 9, where the increased share of W&R goods as inputs is the highest, the DMI increased with 31.51% compared to the basescenario, from 352.9 Mt to 464.1 Mt. The results for the DMI will henceforth be discussed

in two steps: first, we will discuss the results of the DEU and next the results of the import of materials. Together, they make up the DMI.

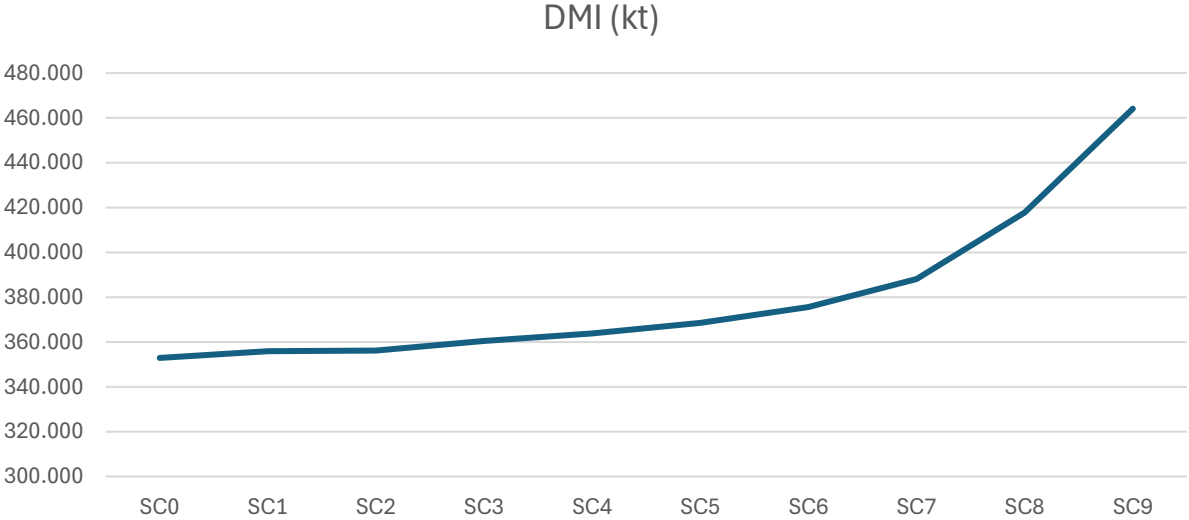


Figure 4: Evolution of DMI per scenario (in kt)

Domestic extraction

As a consequence of the increase in the share of W&R materials, the DEU decreases in the agricultural sector (S1) from 33.5 Mt to 24.4 Mt, but increases significantly in the mining sector (S2) from 62.4 Mt to 150.5 Mt, as illustrated in Figure 5. The decrease in the DEU in agriculture results from a decline in agricultural production. The substantial increase in the DEU in the mining sector stems from heightened mining activity to meet the increased demand for energy output. However, we recognise a limitation of the model: the higher mining output will not increase as much in reality, given the limited availability of materials to be mined in Belgium. Instead, it is possible that material imports could increase once mining is no longer possible within Belgium. Furthermore, the production of the mining sector constitutes only a small percentage of total production, meaning that a share increase in this sector will have a limited effect on GDP.

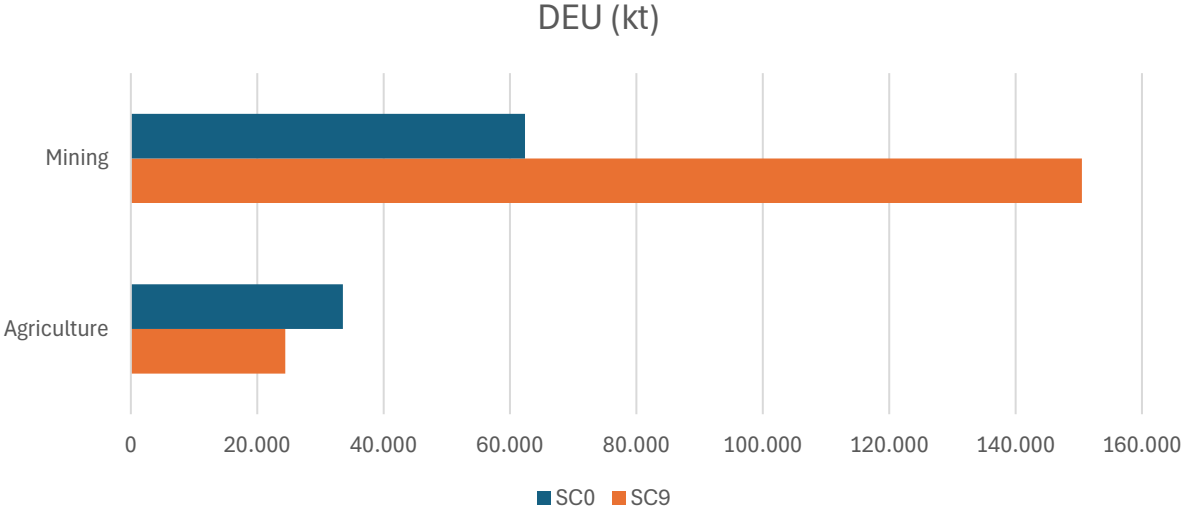


Figure 5: DEU in scenarios 0 and 9 (in kt)

Material import

The total domestic import of materials rises by 12.52% in total, from 257.0 Mt to 289.2 Mt. More particular, the domestic import of materials in the W&R sector steeply increases by 111.75%. This surge is driven by the sector’s insufficient domestic production capacity and therefore imports more secondary materials to meet the increased domestic demand. However, these imported goods also come with additional materials. The import of the sector almost doubles in the most extreme scenario, scenario 9, to compensate for the increase in demand for W&R goods. The manufacturing industry, on the other hand, has the largest absolute increase in imports, mostly due to an increase in imports of W&R goods that they need. The model shows that the domestic output of W&R goods is not enough for the manufacturing sector to fulfil its new need for W&R input. The change in the material import of each sector in scenario 9 can be seen in Figure 6.

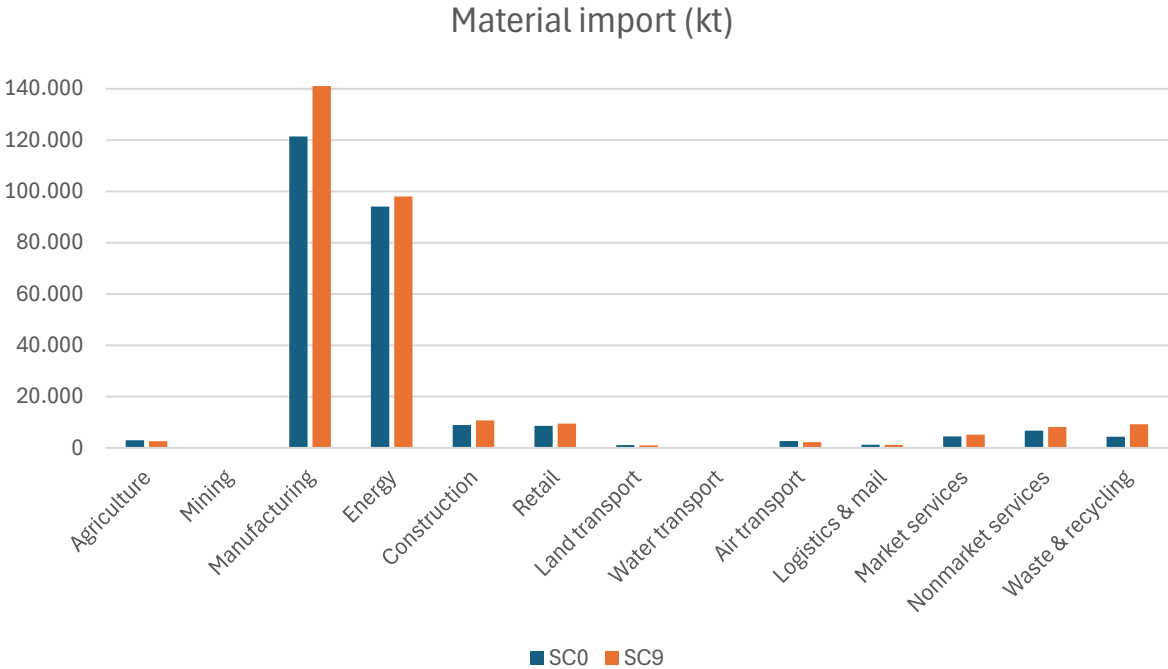


Figure 6: Material import per sector in scenarios 0 and 9 (in kt)

3.1.3. Conclusions GDP/DMI

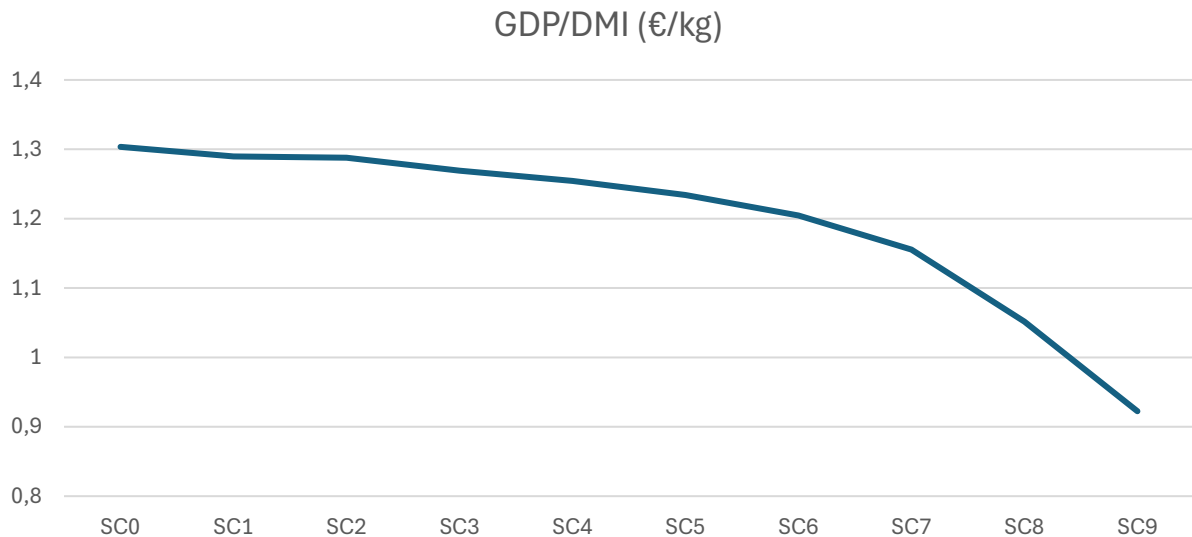


Figure 7: The evolution of GDP/DMI (€/kg) in each scenario

The first policy measure, increasing the share of waste and recycled materials as input, shows some interesting effects. On the one hand, the manufacturing sector is now forced to use more secondary materials as inputs, but seeing as the production methods stay the same, their production cost goes up, and they are forced to produce less to reach a new optimum. This decline in production causes GDP to drop. At the same time, DMI increases, mainly due to higher imports of materials to satisfy the increased demand for W&R goods. In this scenario, we would end up using more materials even though the GDP shrinks, as can be seen in Figure 7. The indicator GDP/DMI decreases with -29.24% from 1.30 euros per kg to 0.92 euros per kg in the most extreme scenario. It is important to note that in reality, production methods would most likely be adapted to meet these requirements more cost-effectively. It highlights the importance of adjusting production systems to the new type of raw materials, and of combining these policy measures with the necessary support for innovation and appropriate infrastructure to satisfy the increase in domestic production of W&R goods and put less pressure on the production costs of other sectors.

3.2. Enabling high-quality recycling

3.2.1. GDP

Enabling high-quality recycling leads to lower costs of the W&R commodities as the sector becomes more efficient. Therefore, as can be seen in Figure 8, the output of the sector will go up by 114.78% from 8.8 billion units to 18.9 billion units of production. At the same time, there will be a decrease in the output of other sectors: W&R goods have become cheaper and therefore they are being used more as input material at the expense of other sectors' inputs. In total, the output will increase by 0.27% from 943.3 billion units to 945.8 billion units of production.

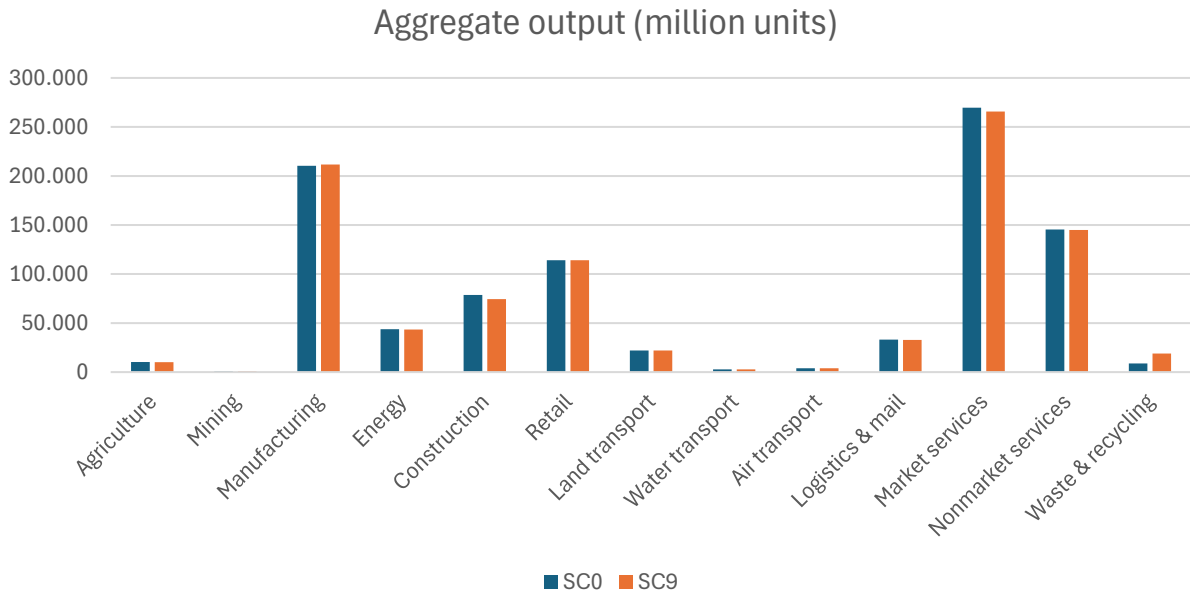


Figure 8: Aggregate output per sector in scenarios 0 and scenario 9 (in million units)

Next, the investment demand decreased due to a shifting trade balance (fewer imports, more exports) as a result of our increased competitiveness of W&R commodities. Less will be saved for future consumption, and the outflow of money leads to a decreased demand for typical investment goods: construction and market services. Finally, GDP is positively impacted due to an increase in Belgian economic activities and will increase by 0.51% from €460.0 billion to €462.4 billion.

3.2.2. DMI

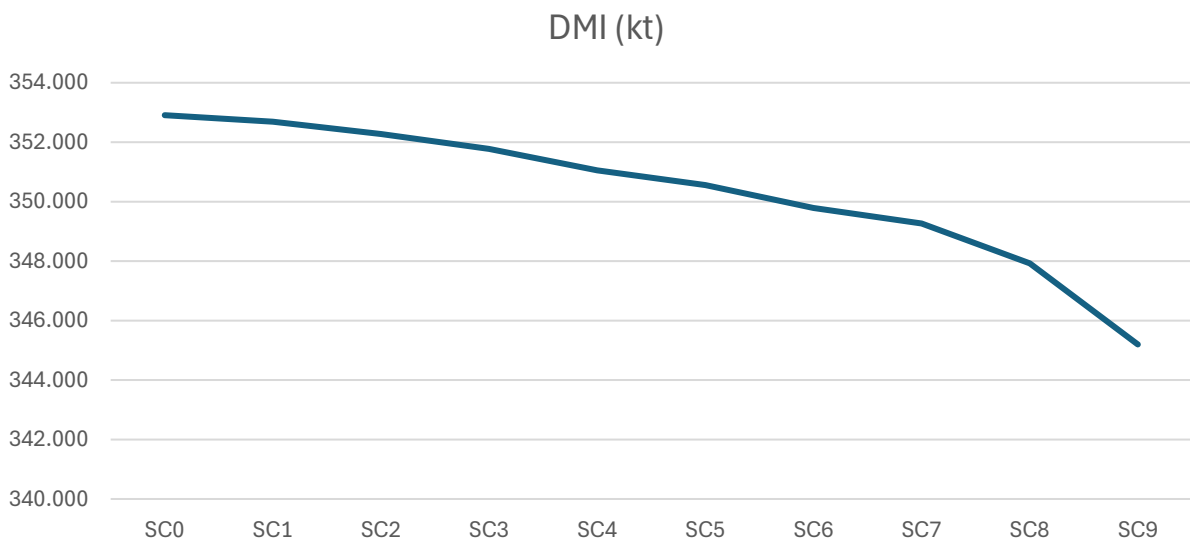


Figure 9: Evolution of DMI per scenario (in kt).

Figure 9 shows the evolution of the DMI in each scenario. The total DMI decreases in each scenario and decreases by a total of -2.19% in the most extreme scenario from 352.9 Mt to 345.2 Mt. The reason for this is again twofold.

Domestic extraction

First, the DEU decreases slightly in the mining sector from 62.4 Mt to 61.3 Mt, responsible for 13% of the total decrease in DMI. This is caused by a reduction in the output of the energy sector. The DEU of the agricultural sector also has a minor decrease because of a slight decline in the output of this sector. Figure 10 shows the difference in DEU in scenarios 0 and 9. We conclude that we do not see an increase in mining activities due to higher domestic economic activity, instead, we import more goods from abroad.

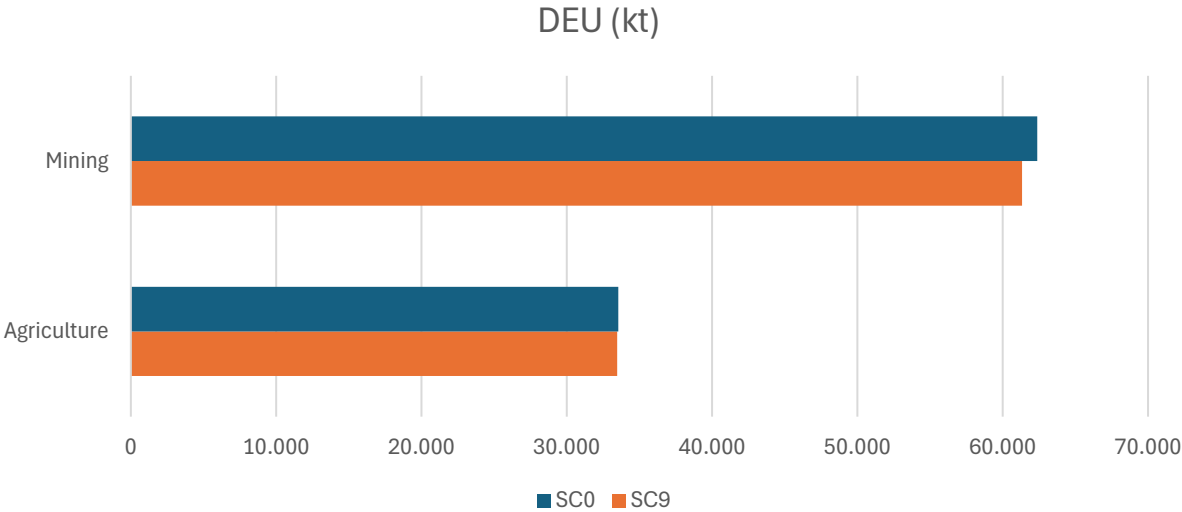


Figure 10: DEU in scenarios 0 and 9 (in kt)

Material import

Concerning the material import, we see that the import of W&R goods decreases by 53.71% from 4.4 Mt to 2.0 Mt due to the competitiveness of W&R commodities. The W&R goods will be produced more domestically and used in the production of manufacturing products. So, although the manufacturing industry’s imports remain more or less the same for all other goods, as shown in Figure 11, they import 57.14% less of W&R inputs. This partly explains the decrease in DMI of the manufacturing industry.

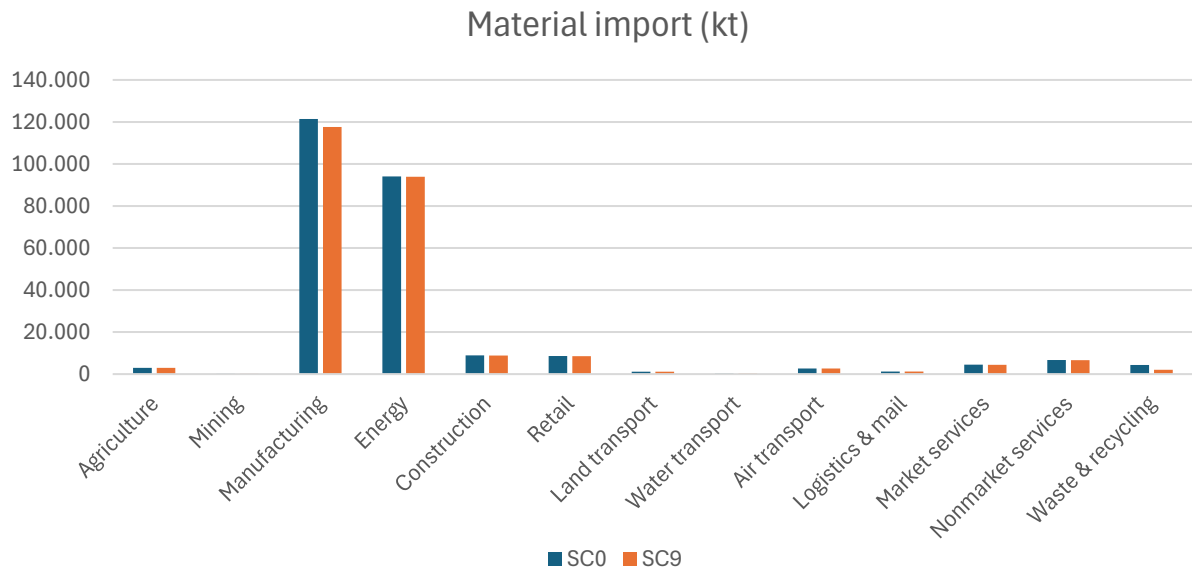


Figure 11: Material import per sector in scenarios 0 and 9 (in kt)

Further decrease in the DMI can be explained by the decrease in material imports from the W&R sector. The material imports from the other sectors also slightly decrease due to less import of W&R materials and more domestic production, with the exception of an increased material import in the transportation and logistics sector.

3.2.3. Conclusions GDP/DMI

The second policy measure, which aims at improving the quality of recycling instead of the quantity, has shown to have a minor positive influence on the material productivity indicator, as can be seen in Figure 12. By increasing efficiency in the recycling process, W&R goods become cheaper. This leads to more domestic production in the W&R sector, which slightly boosts GDP. At the same time, material imports drop in almost every sector, given the increased use of domestically produced W&R goods in each sector. The decrease in DMI and slight increase in GDP result in an increased material productivity of 2.75% from 1.30 euros per kg to 1.34 euros per kg.

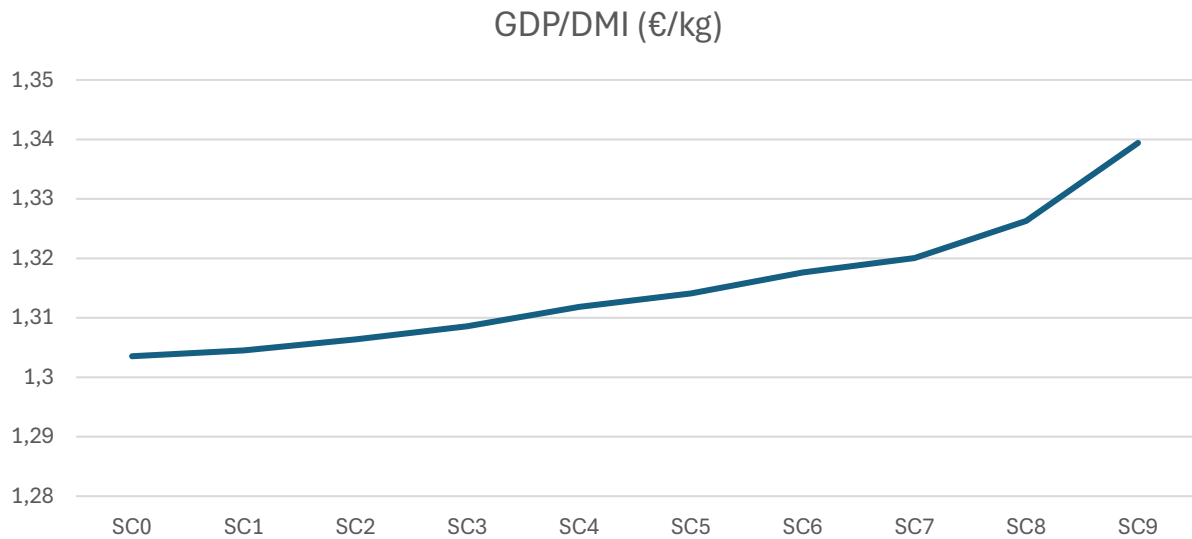


Figure 12: Evolution of GDP/DMI (€/kg) in each scenario

3.3. Restricting waste exports

3.3.1. GDP

In the most extreme scenario, the policy measure that enforces a restriction on waste exports results in a complete halt in the export of W&R goods. At the same time, the total production only slightly decreases. This indicates a domestic infrastructure capable of handling the volumes that were previously exported and processed abroad. There is an increased demand for investment due to the need for this new waste management infrastructure. As Figure 13 illustrates, the impact on other sectors remains minimal, and the effect on GDP is an increase of only 0.01%.

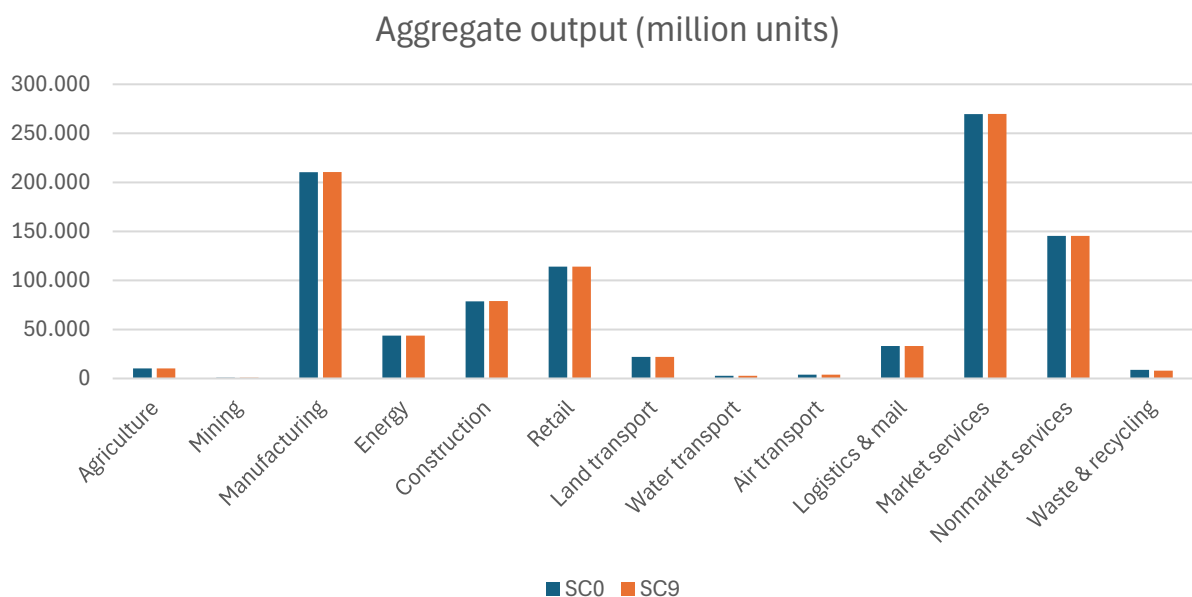


Figure 13: Aggregate output per sector in scenarios 0 and 9 (in million units)

3.3.2. DMI

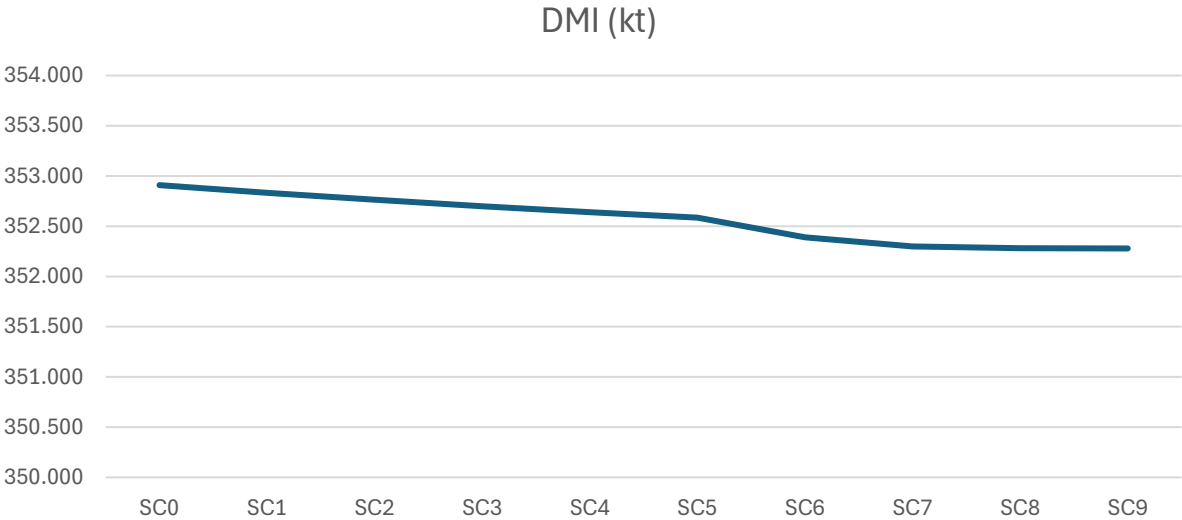


Figure 14: Evolution of the DMI in each scenario

Figure 14 shows that the DMI in the most extreme scenario decreases very slightly by only 0.2%. The explanation for this can again be explained by two factors.

DEU

As shown in Figure 15, the DEU remains more or less the same in both sectors: there is a slight decrease in the material sector, compensated by a slight increase in the agricultural sector. This is the direct consequence of a respective decrease and increase in economic output. The total DEU decreases by 0.01%.

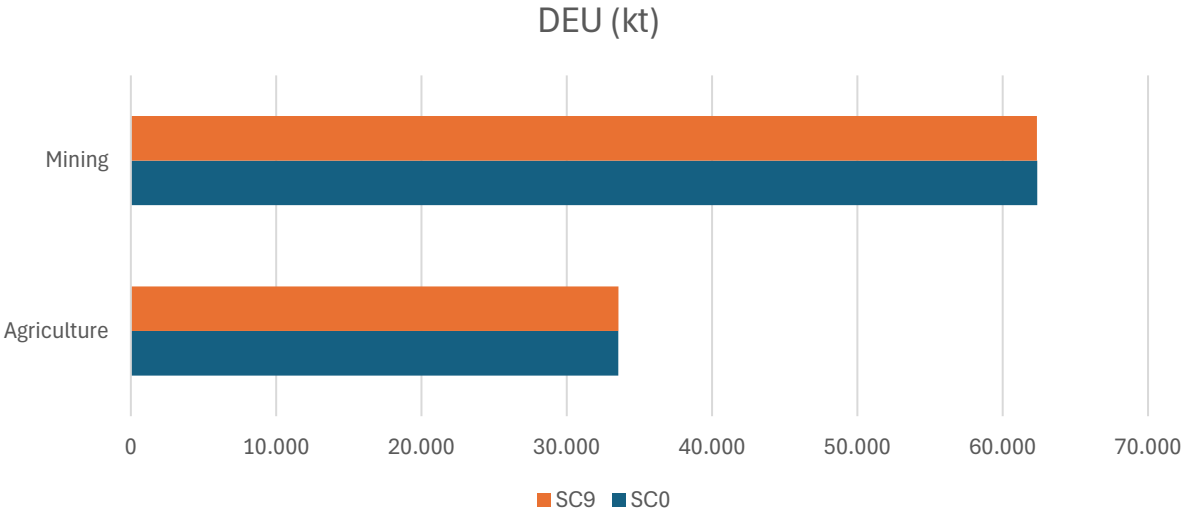


Figure 15: DEU in scenarios 0 and 9 (in kt)

Material import

The material import, on the other hand, decreases in all sectors, as can be seen in Figure 16, except for energy and construction, which have a very slight increase of less than 1%. The decrease in the other sectors is due to a lower material import from W&R goods.

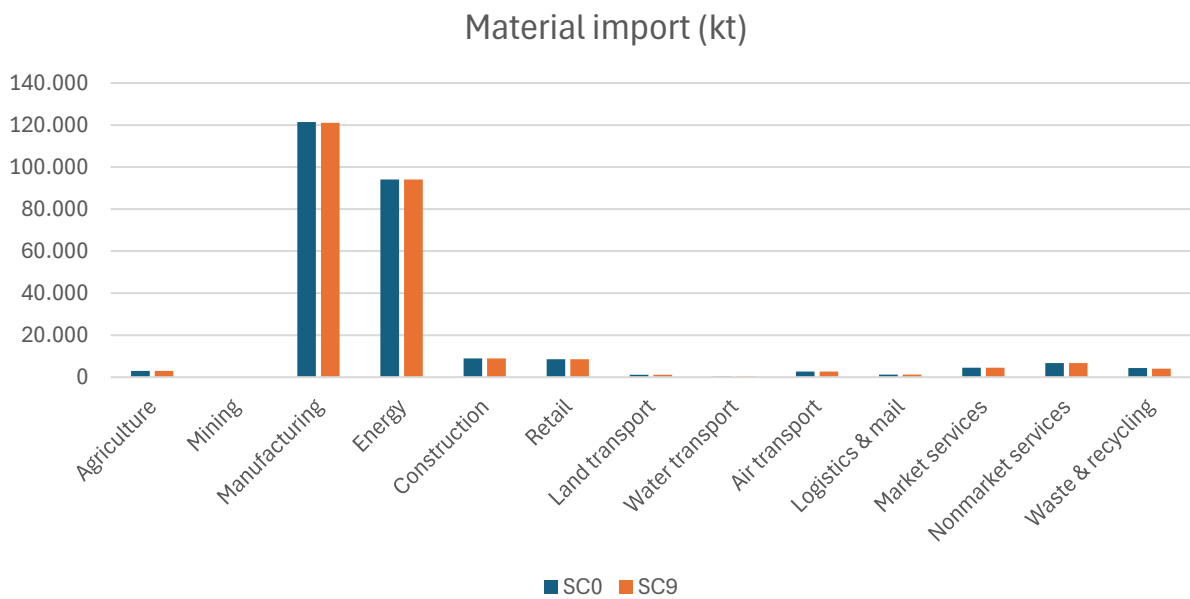


Figure 16: Material import per sector in scenarios 0 and 9 (in kt)

3.3.3. Conclusions GDP/DMI

The third policy measure, restricting waste exports, has only a small effect on the material productivity indicator, as shown in Figure 17. In the most extreme scenario, all W&R goods that used to be exported are now processed domestically. This leads to a slight increase in investment demand for new recycling infrastructure, but overall GDP remains nearly unchanged. The DMI also stays relatively stable, with only a minor decrease in material imports. This makes for the indicator to only increase slightly by 0.19%.

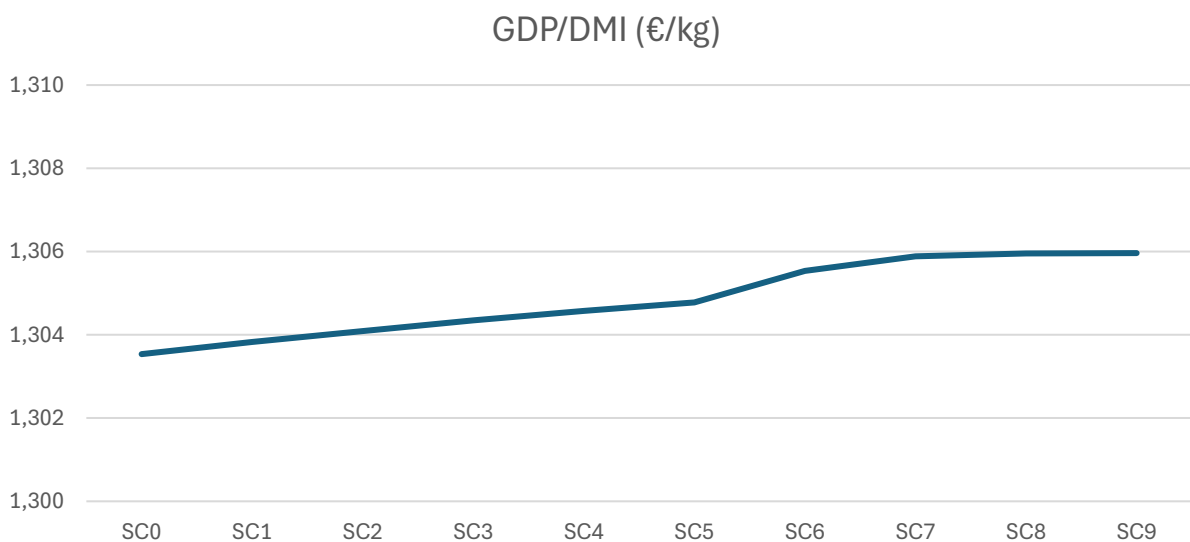


Figure 17: Evolution of GDP/DMI (€/kg) in each scenario

Conclusions

This report builds further on the previously published CE Center report (n° 24: Socio-economic effects for the circular economy), where three CE policy measures from the Circular Economy Action Plan were modelled in the CGE model and their macroeconomic effects on Belgium analysed. In this follow-up report, we introduce material productivity in the CGE model using the GDP/DMI indicator. The aim was to study how the indicator responds to different macroeconomic changes, such as the CE policy measures discussed in the previous report, and how the two components (GDP and DMI) interact with each other.

To achieve this, we developed a methodological approach to incorporate the GDP/DMI indicator in the CGE model. First, we exogenously added material coefficients in the model. Two types of coefficients were introduced: (1) domestic production coefficients, based on domestic extraction data and assigned to the relevant sectors (agriculture and mining), and (2) import coefficients, derived from Belgian trade data and material equivalent conversion tables, and mapped to CGE sectors via the FIGARO-e3 use tables. These coefficients allowed for the estimation of the direct material input (DMI) per sector and the analysis of how the DMI changed under different CE policy measures.

The three policy measures modelled in the previous report were used in this analysis to study their effect on GDP, DMI and GDP/DMI ratio:

1. **Increasing the share of waste and recycled materials as input** results in a higher DMI and a lower GDP. The increase in the DMI is mainly driven by a rise in imports of materials to meet the increased demand for waste and recycled (W&R) goods, seeing as the W&R sector is not yet equipped to produce as much as before. Manufacturing output declines due to higher production costs, given that their production methods remain the same. As a result, material productivity decreases, highlighting the importance of combining this policy measure with support for innovation and proper infrastructure to meet the increased demand for W&R goods.
2. **Enabling high-quality recycling** leads to a lower DMI and a slight increase in GDP. By increasing efficiency in the W&R sector, secondary materials become more cost-effective, resulting in higher domestic production and an overall increase in GDP/DMI.
3. **Restricting waste exports to third countries** only has a limited effect on both GDP and DMI. The decrease in export of W&R goods is partially compensated by an increase in domestic production, resulting in a small increase in investment demand and GDP. The DMI also stays relatively stable, which leads to an overall stable GDP/DMI indicator.

This study showed how CGE modelling, extended with material coefficients, offers a useful framework for understanding the effects of different policy measures on macroeconomic indicators and material productivity as an extension. This method is especially useful for understanding indirect and rebound effects. For example, in the first policy measure, the intention was to decrease material use, but the result was an increase in material input and a drop in GDP. This outcome can be explained by the fact that producers in the model do not adjust their production processes when new policy requirements are introduced. As a result,

they move away from their optimal input mix, which increases production costs and reduces output. At the same time, the waste and recycling sector cannot scale up quickly enough to meet the higher demand. Therefore the results show that changes in material productivity are not caused by a single factor. One policy measure can trigger rebound effects across the economy by affecting production choices, demand, and material flows in multiple sectors. This illustrates that GDP/DMI is shaped by the interaction between sectors and economic actors, and not just by direct shifts in input use. This suggests that policy measures should be introduced gradually and supported by innovation and infrastructure investments to allow sectors to adapt effectively. These types of rebound effects are important to understand when evaluating CE policies, and CGE modelling offers a useful tool to do this.

As always with CGE modelling, these findings should be interpreted in light of the model's assumptions and limitations. One limitation is that material flows were introduced exogenously into the model, meaning they do not respond to changes in economic behaviour. Making these flows endogenous would allow the CGE model to incorporate feedback mechanisms between production, prices, imports, and material demand, leading to more accurate evaluations of material productivity. It would also enable more precise modelling of policy scenarios, allowing us to set targets on material imports, for example. Additionally, we currently do not distinguish between different types of material imports, such as biomass or metal ores. Introducing material flows by category could yield more insights into the effects of policy measures. Furthermore, the model is currently static and cannot capture delayed or long-term economic impacts; a dynamic CGE model would facilitate this type of analysis. Lastly, coupling the CGE model with environmentally extended input-output (EEIO) models would enable the introduction of more targeted CE policy measures, such as reducing the imports of a specific material, while still gaining insight into potential rebound or indirect economic effects.

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