Report

Scenario implementation and impact indicator calculation in dynamic input-output modeling

Two case studies in Circular Waste to Energy scenarios and Green Competitiveness indicators

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SUMMARY

Input-output modeling allows to study the possible impacts to environmental and socio-economic areas from decisions surrounding sustainability and business competitiveness. By way of two case studies, this report identifies challenges and presents methods for scenario implementation and indicator development. Data availability is a challenge for IOA, and must be considered in both indicator development and scenario modelling. Through the first case study on "Waste-to-Energy and Municipal Solid Waste management systems in Circular Economy," we discuss how to translate a general scenario description into an input-output model by determining the type and amount of monetary changes required within the tables. The second case study on "Veikart for grønn konkurransekraft i norske kommuner og regioner" demonstrates how impact indicators may be evaluated and formulas identified for calculation from input-output analysis.

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1 Introduction

Decision making in industry or local and national government can have impacts that may reach far beyond the directly intended effects. Decisions and strategies at system level, in particular, may affect many areas of society and environment. For example, industrial actors are tightly connected, using each others' resources and products through various value chains – both across sectors and geographic regions. This includes also raw materials and waste. Industrial activity, again, leads to local, regional and global ripple effects such as value creation, employment and demand for specific skills, various kinds of emissions, effects on biodiversity, land use, health and welfare.

Such highly complex systems call for holistic and prudent analyses to find robust policies that balance impacts across many areas and interests. Short-sighted decisions attempting to tackle specific challenges in isolation tend to backfire, and long-term perspectives must be considered. Positive effects and trends should be strengthened while negative ones need to be avoided or, at least, mitigated. Sustainability – environmental, social and economic – should be at the core of processes to develop policies and strategies. This is paramount today when the world must quickly find comprehensive and effective strategies to avoid a climate disaster and reach the Sustainable Development Goals promoted by the United Nations.[1] Therefore, a strong basis of knowledge is indispensable.

A means to strengthen decision-making and policy-finding processes is to acquire as much information as possible about potential outcomes and impacts under different situations and to analyse these insights thoroughly from various perspectives. This requires the development and application of methodology tailored to the context and goals of the analyses, combining well-established methods and models with customized approaches.

Scenario analyses (what-if analyses) help to expand the knowledge basis through developing a variety of scenarios and comparing them, e.g., by way of a set of impact indicators tailored to the case and analysis at hand. Scenarios describe a state of the considered system at a given time in the future, often with regard to several aspects. In general, they are developed as internally plausible storylines that define possible pathways, either to a given state from the current state (backcasting) or from the current state forwards to understand available outcomes (forecasting). These scenarios are not meant to show extremes and should not be offered as high-medium-low projections. Instead, they model the potential of different external factors to impact economy, environment, and other measures of sustainable development. Scenarios may also describe plausible future states, agreed upon through, e.g., expert discussions and estimations, without taking into account pathways to reach this state in the first line.

Impact indicators describe the state of the system along several dimensions such as environment, economics, social aspects in both quantitative and qualitative terms. They may specify the state at a given point of time but also describe development over time. For analyses, a set of indicators should be selected that is relevant to the situation, allows comparisons also in a wider context and can be derived from available information (e.g., public statistics) with suitable methodology. Comparing impacts across various scenarios can indicate which scenarios to avoid or to aim at, and

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[1] https://www.undrr.org/gar2022-our-world-risk

which strategies should be followed to arrive at preferable states and to prepare for (or mitigate) negative outcomes.

Figure 1. Scenario analysis process

In the context of this report, we are interested in the evaluation of (socio-) economic and environmental impacts at municipal, regional and national level, such that dynamic input-output modeling is an appropriate approach for quantitative impact indicator estimation. This is a macro-economic technique describing relations between all sectors in an economy and can be used, among others, to evaluate effects of changes in the economy such as the implementation of circular-economy concepts or a transition to more sustainable industry and business practices.

Moreover, the focus of our work is on approaches for scenario implementation in order to derive parameters that can serve as input to the dynamic input-output model and for calculation of relevant impact indicators. For this, we look at two cases are based on ongoing projects at SINTEF, CircWtE investigating effects of circular-economy concepts on management of municipal solid waste (MSW) and waste-to-energy (WtE) – and GKKiK on indicators to measure green competitiveness at municipal and regional level.[2] In each case we deal with one of the projects and look at different ends of the dynamic input-output modelling process: at one end we have scenario implementation (CircWte) and at the other end indicator calculation (GKKiK), as illustrated in Figure 2.

Section 2 explains the methods used more thoroughly, followed by sections 3 and 4 that present their application to the two case studies. Section 5 will give some final remarks and recommendations for further work.

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[2] Both projects are funded by the Research Council of Norway and other project partners from industry and public administration under project numbers 319795 (CircWtE) and 321114 (GKKiK).

2 Methods

2.1 Method for Dynamic Input-Output Scenario Analysis

The method, on which the report is based, involves three elements (see Figure 2). The method begins with some predefined scenarios which are desirable to examine. A dynamic input-output model is then utilized to forecast the scenarios' development forward in time. Finally, using this forecast to calculate predefined impact indicators enables the endpoints of different scenarios to be compared. This report is concerned with how the steps between these three elements can be executed, as illustrated by arrows in Figure 2. Section 3 deals with approaches to describe and implement scenarios such that they can be assessed by input-output analysis (IOA), while section 4 discusses how to connect various indicators to input-output (IO) models to evaluate the impact of the scenarios. The next sub-sections cover these steps in more detail.

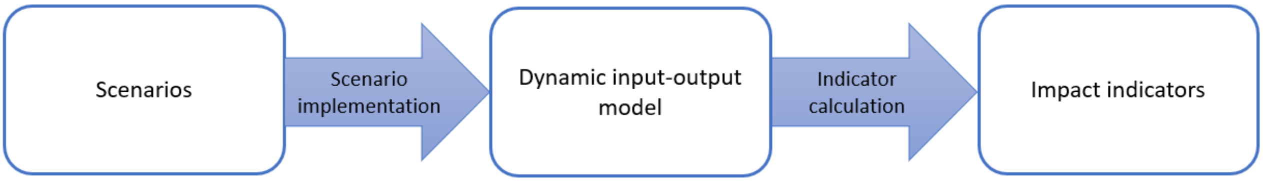


Figure 2. Main elements of dynamic input-output scenario analysis

2.2 Scenario Implementation

The first challenge to carry out a socio-economic analysis with dynamic input-output modeling is to implement the scenario. This entails understanding the scenario and what is of interest to model for the analysis as the scenario description has not necessarily been prepared with IOA in mind. In those cases, it will be necessary to interpret and adapt the description to suit the analysis. The model only takes monetary values as input, and it can be challenging to derive which changes to monetary flows a general scenario description entails. For this purpose, we have chosen a systematic approach that can be used on different scenario descriptions. The approach comprises some questions that may be helpful to investigate.

We use the following process for implementing scenarios to IOA.

1. Determine which parts of the scenario description will affect value chains and final demands in the economy:
    a. Does some novel technology alter value chains or demands?
    b. Do new laws and regulations alter value chains and demands?
2. Determine which changes these effects will entail
3. Get an overview of which sectors are involved in these changes
4. Determine how the relationships between these sectors will change:
    a. Will there be increases or decreases in sales and purchases?
    b. Will there be replacements of suppliers and customers?
5. Define estimates for the extent of the changes, either relative or absolute in relation to the monetary values in the input-output table (IOT)

2.3 Indicator Calculation

The impact indicators from any input-output table may be calculated as

$$D = cSLy$$

where D is the impact indicator matrix, c is the characterization matrix that defines how, e.g., absolute emissions link to impact indicators, S is the technology matrix expressing relative emissions of various stressors per monetary unit output, L is the Leontief inverse, and y is the final demand vector. It is important to note that characterization is not necessarily a multiplier; it is the function describing the relationship between the input-output economic model and the indicators. When calculating simple indicators, such as greenhouse gas emissions in carbon dioxide equivalents, the c matrix may be a matrix of multipliers. For a dynamic input-output model where indicators may depend on external, dynamic factors, characterization may require greater complexity than simple dot-product matrix multiplication.

Before calculating impact indicators, one must determine whether the input-output model is appropriate for the analysis. While some input-output models may express physical quantities or mixed units, most – including the SSB input-output tables for Norway – express monetary units; environmental or socioeconomic stressor extensions are then estimated per monetary unit. Dynamic input-output analysis (dIOA) may not be preferable for calculating indicators related to sectors where monetary values and technologies change unpredictably. Improved dynamic modeling of technological changes and unit price may mitigate such challenges. Additionally, for certain impact indicators, sufficient research is still lacking to characterize the impact of emissions (e.g., impacts of plastic pollution on species extinction rates is not yet well understood within lifecycle impact assessment). Further, indicators directly relating to public policy rather than the economic impact of public policy are not suitable for use with IOA, as also discussed in section 4.

We use the following process for selecting and calculating indicators from IOA:

1. Identify linkage between IO tables and desired indicators
2. Define formula for impact indicators
3. Identify external information required
4. Understand the uncertainty of external information:
    a. Does variable remain constant with respect to monetary value?
    b. If regionalizing the predictions, is the variable similar between region and aggregated average?
5. Determine availability of external information
6. Exclude indicators:
    a. Not related to IOA model outputs
    b. Requiring external information that is not available
    c. Requiring external information that cannot be deduced from monetary units
7. Consider whether indicators may be directionally predicted (not directly calculated) based on analysis of the IO model’s assumptions and projections

2.4 Norwegian Input-Output Table

The method utilizes the Norwegian input-output table, which is a part of the national accounts of Norway. It is based on Statistics Norway's standard for industrial grouping which again is based on the EU standard NACE (SSB, 2009). The table comprises a grouping into 64 sectors and shows the monetary flows from each sector to the others as well as to final uses (SSB, 2021a). Appendix A gives an overview of all 64 sectors and their associated codes.

2.5 MEIONorway

The dIOA is carried out using a model called MEIONorway. MEIONorway is a macroeconometric input-output model for Norway implemented and developed at SINTEF. It combines a macro-econometric program with the Norwegian input-output table. The model allows to project the development of the Norwegian economy under given scenarios and to estimate effects on various indicators such as value creation, greenhouse gas emissions, energy usage and employment by education level.

3 Case 1: CircWtE

3.1 Project Description

The full name of this project is "Waste-to-Energy and Municipal Solid Waste management systems in Circular Economy". The overall objective is to develop knowledge-based tools and methods to help answer the question: How will future municipal solid waste management systems look like in a Circular Economy, and which role will Waste-to-Energy have in our future renewable energy system? The work is set to be performed from 2021 to 2024, organized in five sub-projects and associated tasks. The project has been funded by the Research Council of Norway (project number 319795) under the SIRKULÆRØKONOMI program. Project partners are CIVAC, Franzefoss Gjenvinning, NOAH, NTNU, Oslo REG, SINTEF Industry, Tafjord Kraftvarme and Trøndelag county council, managed by SINTEF Energy.

The work presented in this report is within Task 4.3 Socio-economic analysis of existing and alternative waste treatment value chains. The ask assesses socio-economic impacts of policies and technologies in MSW management, for example on value creation, employment, long-term sustainability effects and ripple effects throughout the economy. For this, it is intended to utilize MEIONorway. The task builds on previous work in the project, especially the development of several scenarios for future MSW management. This report deals specifically with exploring how these scenarios can be implemented in the MEIONorway model.

3.2 Scenarios

The project addresses five MSW management scenarios. These are:

- Business as usual – *The Current Road* (baseline)
- Environmentally-conscious citizens – *The Frugal Road*
- Recycling economy – *The Circular Road*
- Fighting climate change – *The Carbon Road*
- System and citizens work together – *The Joint Efforts Road* (not included in this report).

The scenarios are described as different plausible development directions of MSW management. The descriptions include a concise narrative of what the scenarios involve and where the focus lies. Further, area, population development and timeframe of the scenario are specified. All scenarios considered in this project are based on population growth at the same level as last decade. In this report, all analyses have been carried out with the entire country of Norway as area. Next, the legal framework is specified, which revolves around the EU targets. Further, the scenario description indicates consumption behaviour, which includes both amount and composition of the waste. It also specifies waste sorting behaviour and sorting system. Finally, the description indicates which treatment technologies are expected to be used and additional comments.

From a macroeconomic modelling perspective, it is interesting to look at which aspects of the scenarios can be converted into monetary values and represented in the IOT. It is desirable to include as much information as possible in the model, but at the same time to make sure that this information is represented correctly to give the modelled results validity. The next sub-sections address each scenario in turn, resulting in proposed inputs to MEIONorway and descriptions of what remains to be done. The *Joint Efforts Road* scenario has been omitted from this report as its current description is deemed too vague for a thorough quantitative analysis.

3.2.1 Baseline Scenario

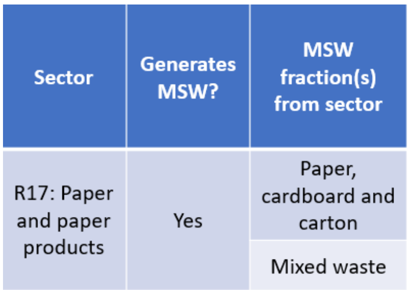
The baseline scenario is an unchanged run of the MEIONorway program, which retrieves IO tables and population projections from Statistics Norway and uses them to calculate a projection of the Norwegian economy if no changes from today's course are made. Hence, no further work is required to prepare input to MEIONorway.

3.2.2 Scenario 1: The Frugal Road

The frugal road scenario is concerned with reducing the amount of MSW produced. It includes a 50 % reduction in consumption in 2035 and a subsequent adjustment of the composition of the consumed products. With the goal of handling MSW, it is interesting to look at the effects on the economy if there is a 50 % reduction in MSW and thereby a reduction in the consumption of physical goods that generate MSW. Here we assumed a proportional relationship between the cut in consumption and the reduction in waste.

To use MEIONorway for this scenario, an overview of which sectors may be affected and by how much is necessary. For this, we used Microsoft Excel. The way this was done will be shown through a step-by-step illustrative example of sector R17 Paper and paper products. An overview of all sectors in the Norwegian input-output table with associated codes can be found in appendix A.

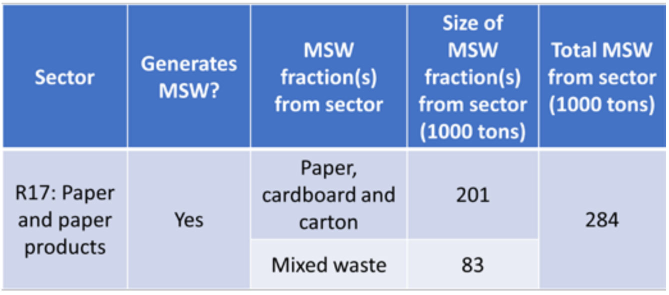
Step 1. We needed to know which sectors would be directly affected by the scenario. The Norwegian IOT table shows the monetary values of the final consumption expenditures by households for every sector. This gives information about which sectors are selling goods, and potentially MSW, to households. Disregarding service sectors, whose values in the IOT only represent the value of the service itself, we distinguish primary and secondary sectors that could produce MSW.



Sector	Generates MSW?	MSW fraction(s) from sector
R17: Paper and paper products	Yes	Paper, cardboard and carton
		Mixed waste

Next, sector definitions from SSB's Standard Industrial Classification (SSB, Standard for næringsgruppering (SN), 2009) were used to assess which MSW fractions, if any, were generated by the sectors. Through this, it became clear which sectors are likely to be affected, resulting in the three first columns in Excel as shown in the figure to the left.

Step 2. To approximate by how much the sectors would be affected, we looked at how much MSW they generated. This was done by studying SSB data for amount and composition of household waste in 2019 (SSB, Table 10514. Statistikkbanken, 2021b). The total amount of each waste fraction was distributed across all sectors assumed to produce it, based on market share. This means that sectors selling more to households would be assigned an accordingly larger part of the fraction. For mixed waste, additional data from SP1



Sector	Generates MSW?	MSW fraction(s) from sector	Size of MSW fraction(s) from sector (1000 tons)	Total MSW from sector (1000 tons)
R17: Paper and paper products	Yes	Paper, cardboard and carton	201	284
		Mixed waste	83	

(Cansu Birgen, personal communication, June 26, 2022) was used to distribute the amount across sectors based on its content. This step expands the overview.

Step 3. The overall decrease in consumption is assumed to be 50%, but it is unlikely that this is evenly distributed between the sectors. This is because some sectors offer more essential goods than others. For example, food consumption cannot be decreased by 50%. However, to be able to cut consumption of different sectors by different percentages, it must be ensured that the overall cut in MSW is 50 %. We achieved this by using the solver tool in Excel. First, we stated percentage cuts in sectors with enough data to make well-informed assumptions. Such assumptions could be that food consumption can only be cut by 30 %, while consumption of clothing can be cut by 70%. Then we summed up the total waste amount before and after the cuts. The remaining percentages were calculated by the solver with the constraint that the total waste amount after the cuts should be half the total amount before the cuts. This resulted in a complete outline of the cuts in weight for every sector, as represented in the figure to the left.

Sector	Generates MSW?	MSW fraction(s) from sector	Size of MSW fraction(s) from sector (1000 tons)	Total MSW from sector (1000 tons)	Proposed cut in volume	Total MSW from sector after cut (1000 tons)
R17: Paper and paper products	Yes	Paper, cardboard and carton	201	284	63%	105
		Mixed waste	83			

Step 4. The monetary expenditures of each sector cannot be cut with the same percentages as the consumption volumes. This is due to the assumption that the population will transition from buying many cheaper products with low durability to fewer more expensive products with higher durability within the same sector. This assumption is likely to be more fitting for some sectors than others. More specific data on buying habits and the composition of products from the sectors are needed to make individual assumptions on monetary reductions. Once these percentages are determined they give the final cuts in expenditures by households following from the cut in consumption. These are the first values needed for the dynamic input-output modeling. The final overview of the sectors for the example is shown below.

Sector	Generates MSW?	MSW fraction(s) from sector	Size of MSW fraction(s) from sector (1000 tons)	Total MSW from sector (1000 tons)	Proposed cut in volume	Total MSW from sector after cut (1000 tons)	Part of cut not replaced by higher value products	Proposed cut in expenditures
R17: Paper and paper products	Yes	Paper, cardboard and carton	201	284	63%	105	50%	32%
		Mixed waste	83					

Step 5. The excess money from these cuts is assumed to be split between savings and leisure activities, based on evaluations of buying habits made by SSB (SSB, Dette bruker nordmenn penger på, 2018). Several approaches can be taken to find the composition between these. We assumed a higher savings rate than during the covid-19 pandemic, which was 12.7 % (SSB, Sparingen i husholdningene økte markant, 2020). What does not go into savings is distributed between the six leisure activity sectors based on their market share, resulting in an equal percentage increase. These percentage increases would be the second and final input to the model. Both these and the percentage decreases in the primary and secondary sectors should be implemented

in MEIONorway as changes to final demand for households. This enables a run of the model and, if the assumptions are appropriate, gives an adequate forecast of the effects of the scenario.

Inputs to MEIONorway:

- A relative decrease in final consumption expenditures by households for every MSW producing sector towards 2035. The decrease can be set to happen linearly from the start year.
- A relative increase in final consumption expenditures by households for every leisure activity sector. The increase can be set to happen linearly from the start year.

What remains to be done:

- Find estimates for the extent to which households will shift from buying many cheaper products with low durability to fewer more expensive products with higher durability within the same sector.

3.2.3 Scenario 2: The Circular Road

The circular road scenario investigates the transition to a circular economy. The scenario description underlines that the focus does not lie on reducing consumption, but rather on introducing high-quality source sorting of MSW and highly efficient recycling of materials. This would allow more materials to be reused, leading to a lower consumption of raw materials. Moreover, this would lead to multiple changes to the value chains of household products. From a socio-economic analysis point of view, we have found it interesting to model how these changes in value chains will affect the Norwegian economy and, eventually, selected indicators.

Fully modelling circularity in the economy is particularly complex, as it requires assessing wide-reaching transformations of technology, supply chains, and economic structures. Because of the way the scenario is described and the scope of this report, we limit the model to only account for an increase in recycling. To reflect this transition, we focus on materials present in MSW and our report is limited to these materials:

- Plastic
- Paper, cardboard and carton
- Metal
- Glass

We focus on the sectors that evidently use these materials to produce products for households, and on the changes increased recycling would entail for these sectors.

3.2.3.1 Plastic

Today, the plastic that is collected as MSW is transported out of Norway for sorting and recycling (Grønt Punkt Norge, n.d.-a). However, as this scenario studies widespread introduction of circular-economy principles in Norway, it is interesting to look at a situation where a sorting and recycling industry was established domestically. We further assume that these recycling actors would be registered in sector R37_39 alongside other waste management companies. The change in the value chain of plastic products would include less consumption of raw materials, and rather consumption of recycled materials from sector R37_39, as shown in Figure 3. The figure is based on a swim-lane flowchart and utilizes horizontal lanes to show which sectors are involved at each step of the chain. The original value chain for plastic is part of the value chain for petrochemical products that, according to an assessment by the Norwegian government, includes domestically produced and imported refined oil and gas as raw-material input (Røtnes, Steen, Kordt, & Flatval, 2020). What remains to figure out is how much plastic can be recycled at most while industry is still able to meet final demand. An option is to additionally look at the increase in overall recycling under the assumption that chemical recycling is feasible.

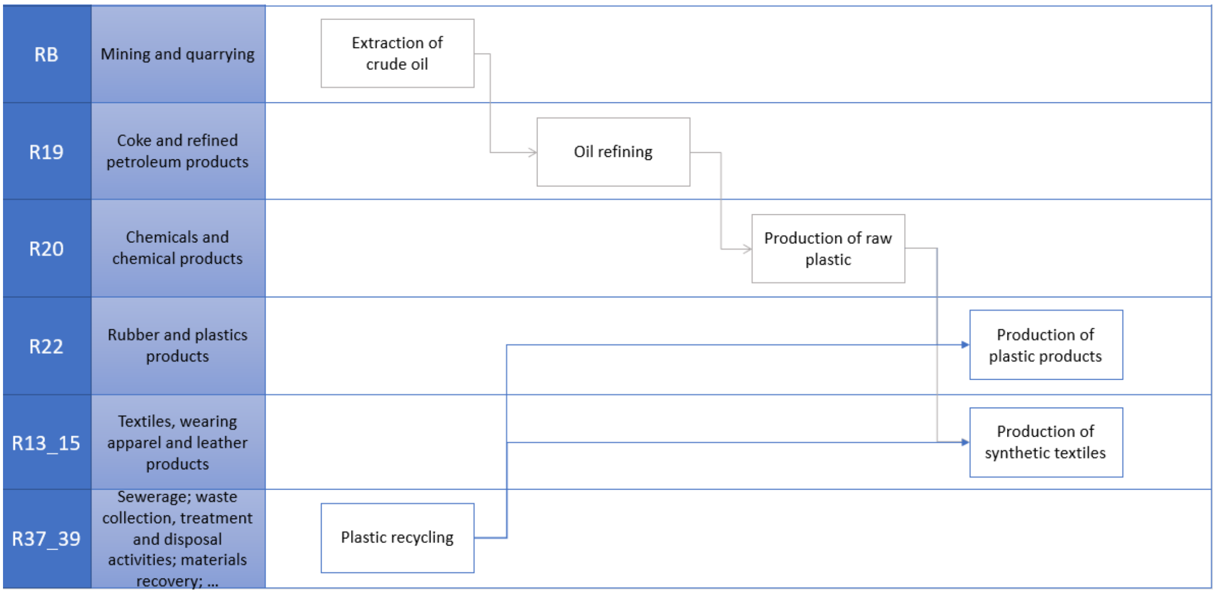


Figure 3. Changes in plastic value chain with use of recycled materials and establishment of domestic sorting and recycling industry

3.2.3.2 *Paper, cardboard and carton*

Norway has an established industry that produces paper, cardboard and carton, with the possibility of using recycled raw materials in production (Røtnes, Steen, Kordt, & Flatval, 2020). We assume that paper, cardboard and carton are collected and sorted by sector R37_39, before being sold to sector R17 Paper and paper products (Norsk Resy, 2018). The value chain is depicted in Figure 4. Assuming that collection and sorting will improve, it remains to find a monetary value representing how much more recycled material can be used in the production of new products in Norway.

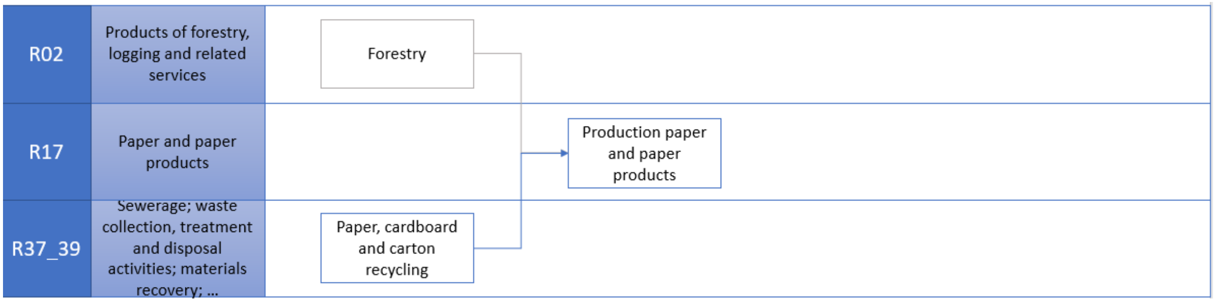


Figure 4. Changes in paper, cardboard and carton value chain with increased recycling

3.2.3.3 *Metal*

Both metal and metal packaging from households are collected as MSW. These materials are important to recycle as they are of limited supply worldwide. In Norway, several actors recycle metal, registered in sector R37_39.[3] They sell recycled material back to smelting plants producing metals in Norway (Grønt Punkt Norge, n.d.-b). This value chain is depicted in Figure 5. With higher-quality source sorting and more efficient material recycling, the share of recycled metal used in the production of basic metals is assumed to increase. Correspondingly, the share of virgin metals will go down. The size of this change remains to be approximated.

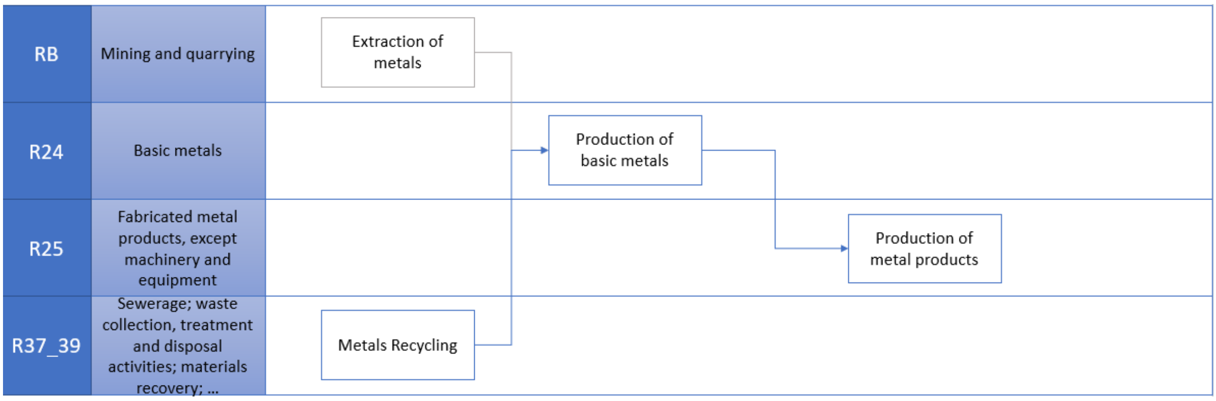


Figure 5. Metal value chain with transition to increased recycling

3.2.3.4 Glass

As a part of MSW, glass packaging is collected and sent to Sirkel Glass AS' facility where 100% is recycled (Grønt Punkt Norge, n.d.-c). As source sorting improves, the amount of glass recycled will increase simultaneously. Sirkel Glass AS is registered in sector R37_39, and we therefore assume a higher monetary flow from R23 to R37_39 as recycled glass is sold back to production companies. Correspondingly, we expect a decrease in the monetary flow from sector R23 to RB. The size of this change remains to be estimated based on how much more glass can be recycled.

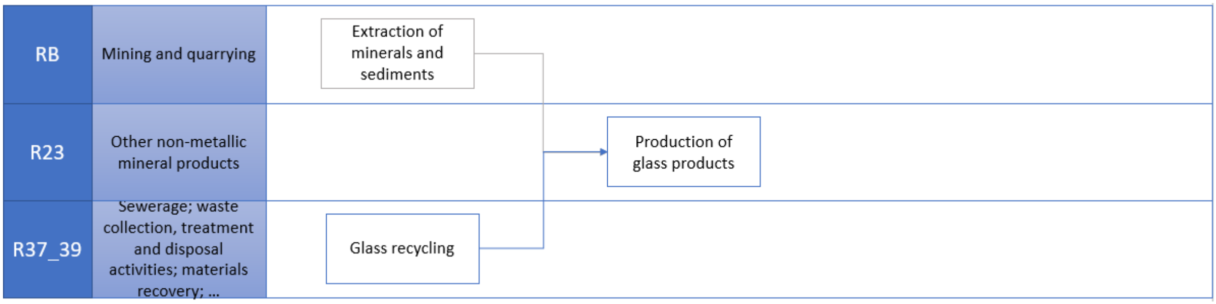


Figure 6. Glass value chain with increased recycling

Inputs to MEIONorway:

- A decrease in the inter-industry flows from R22 and R13_15 to RB, with a corresponding increase in the inter-industry flow from R22 and R13_15 to R37_39. This is due to more recycling of plastic.
- A decrease in the inter-industry flow from R17 to R02, with a corresponding increase in the inter-industry flow from R17 to R37_39. This is due to more recycling of paper, cardboard and carton.

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[3] The Brønnøysund Register Centre: https://www.brreg.no/en/?nocache=1659534565235 Checked for Norsk Gjenvinning AS, Metallco AS and Stena Recycling AS.

- A decrease in the inter-industry flow from R24 to RB, with a corresponding increase in the inter-industry flow from R24 to R37_39. This is due to more recycling of metal.
- A decrease in the inter-industry flow from R23 to RB, with a corresponding increase in the inter-industry flow from R23 to R37_39. This is due to more recycling of glass.

What remains to be done:

- Find an estimate of how much more plastic can be recycled and which monetary flows the increase would equate to.
- Find an estimate of how much more paper, cardboard and carton can be recycled and which monetary flows the increase would equate to.
- Find an estimate of how much more metal can be recycled and which monetary flows the increase would equate to.
- Find an estimate of how much more glass can be recycled and which monetary flows the increase would equate to.

3.2.4 Scenario 3: The Carbon Road

The carbon road scenario is concerned with climate change mitigation. The legal framework assumption stipulates that recovery targets are only indicative but negative CO_2 emissions and a ban on fossil carbon (C) in products must be attained by 2030. A ban on fossil C means that products are no longer allowed to be produced using carbonaceous raw materials from fossil sources. A main example here is plastic. The scenario also includes aims of using C to produce high-value products and preventing destruction of C-rich products. However, the two legal objectives have been deemed to be most relevant for the socio-economic analysis in this report.

3.2.4.1 Negative Emissions

The first objective is to attain negative CO_2 emissions by 2030. As the CircWtE project looks at waste to energy and MSW management, we will study the introduction of carbon capture and storage (CCS) to WtE plants. This technology is also mentioned in the scenario description. CCS in connection with WtE enables negative emissions as it withdraws CO_2 from nature's natural cycle. This is due to the organic waste fractions present in MSW (Haaf, Anantharaman, Roussanaly, Ströhle, & Epple, 2020). The WtE companies are included in sector R37_39 in the Norwegian IOT. For these companies to introduce carbon capture entails many new transactions across the Norwegian economy. It involves initial investment costs as well as continuous operating costs. Furthermore, the CCS process is not complete unless the carbon is safely stored. The storage is likely to be done offshore and is therefore assumed to be performed by the Mining and quarrying (RB) sector, which includes companies that operate on the Norwegian continental shelf. This assumption is in accordance with the ongoing full-scale CCS demonstration project Longship where companies from this sector are involved in developing infrastructure for transport and storage of carbon (Olje- og energidepartementet, 2021). This infrastructure development also entails investment and operating costs.

To model an introduction of CCS using MEIONorway, all these costs must be estimated. Moreover, it is not sufficient to only know the total costs. The composition of the total costs needs also to be estimated to know which sectors will be involved in both the investment phase and the operating phase, and how much they will be paid for their contributions. The payments for the investments will go from sector R37_39 and RB to the sectors offering their services and products, as illustrated in Figure 7. Further, after the CCS infrastructure is built, the operating costs are assumed to be paid by the companies producing the CO_2, in this case the WtE companies. This entails that the R37_39 sector now will pay the RB sector to carry out the storage for them, as depicted in Figure 8.

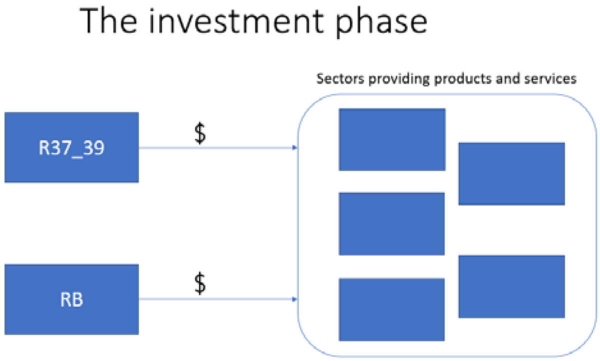


Figure 7. Monetary flows in the investment phase of introducing CCS in WtE

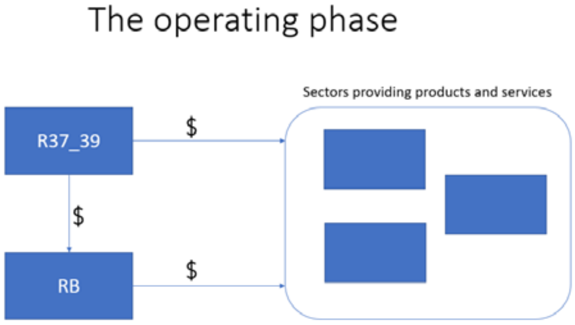


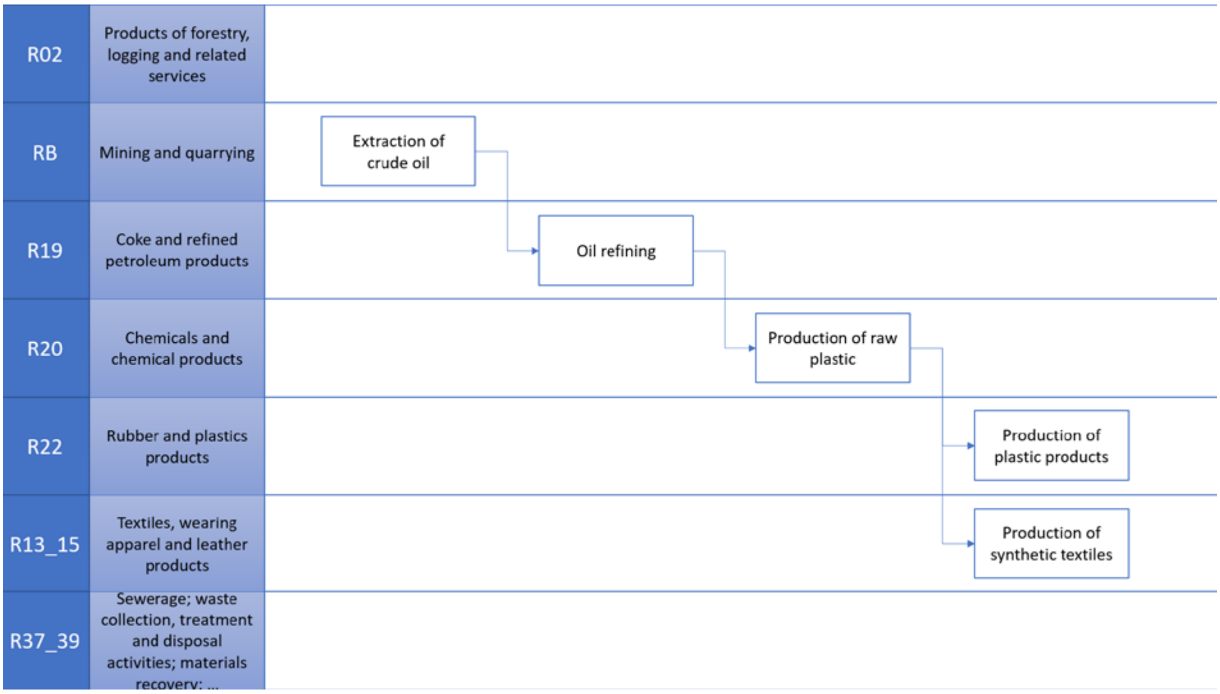
Figure 8. Monetary flows in the operating phase of CCS in WtE

The investment and operating costs can be estimated with various approaches. Ideally, this would be achieved through a dialogue with relevant industry partners. If such a dialogue is not feasible, a possible approach is to study reports such as from the CCS demonstration project Longship. This project includes a WtE plant and estimates for CCS investment and operating costs at that facility have been given (Gassnova, 2020). It was also estimated how much CO_2 the installation is supposed to capture. Furthermore, SSB has data on the amount of CO_2 emitted from all WtE plants in Norway (SSB, Table 08940. Statistikkbanken, 2022). These emissions data can be used to scale up investment and operating costs to approximate how much it would cost to install CCS at all WtE plants in Norway. The transport and storage project in Longship is about big enough to handle all CO_2 captured from WtE, and those cost estimates can therefore be used directly. Additionally, the state enterprise Gassnova has gathered experiences from the project so far, including a breakdown of investment costs for both the capture and the transport and storage infrastructures (Gassnova, 2020). This breakdown enables assumptions on which sectors are providing services, and which monetary values should be changed in MEIONorway. However, operating costs of the CCS process do not seem to be publicly available, and other methods for their estimation should be found.

The input to MEIONorway includes inter-industry monetary flows, from sectors R37_39 and RB to companies providing products and services during the investment phase. The duration of this phase must be estimated, together with its cost development. The Longship project has a planned investment phase of four years (Atkins Norge & Oslo Economics, 2020). After this investment phase, annual monetary flows will go from R37_39 to RB and other sectors that offer necessary products and services to keep the CCS process in operation.

3.2.4.2 Ban on fossil carbon

The second objective is to introduce a ban on fossil carbon in products by 2030. In this context, we model the removal of fossil C in all new plastic products, including synthetic textiles.[4] We assume that the industry gets an early warning, so that the change can be modelled to happen linearly from the start year on. Furthermore, we assume that the industry uses two approaches to adapt to the ban. The first approach is to increase the fraction of recycled plastic used in new products. The second one is that the remainder of the fossil C should be replaced by biocarbon. This entails a shift in the value chain of plastic products, that again entails a shift of which industrial sectors are included and in what way. The figure below shows the original value chain of plastic products.



As fossil C is banned, extraction of crude oil and refining is removed from this value chain. We assume that the raw material is going to be replaced by recycled plastic from sector R37_39 and biobased feedstock produced in sector R02. This is in line with the assumption that consumption stays unchanged in this scenario, and that recycling rates in Norway are assumed to rise with higher demand (SYSTEMIQ and Mepex, 2021). Additionally, the Norwegian Environment Agency reported that bioplastics can be produced by biobased feedstocks grown in Norway (Hann, Scholes, Briedis, & Kirkevaag, 2018). The biobased feedstock is further assumed to be turned into bioplastic in sector R20. This assumption is based on checking in which sector a known producer of bioplastics is registered in the Brønnøysund Register Centre[5]. The resulting changes to the value chain can be seen in the following figure.

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[4] The industry for synthetic textiles is negligible in Norway as of today, but the connection is worth to note if such an industry were to arise.

[5] https://www.brreg.no/en/ Checked for Borregaard AS.

These changes will be the basis for the input to MEIONorway. Several considerations still need to be clarified. Firstly, an approximation of the share of purchases for plastic production in the monetary flow from R20 to R19 must be found. This amount should then be subtracted and, instead, distributed to R02 and R37_39. Here, the proportion of the amount must be assessed that should be attributed to purchases of recycled plastic and bioplastic. This can be based on the potential recycling rate for plastic. Further, assumptions about the relative prices of recycled plastic and bioplastic should be derived to estimate their composition.

Concluding, modelling the carbon road scenario with dynamic input-output modeling entails several changes to the inter-industry matrix. Since the scenario does not include any changes to consumption, the final demand does not need to be modified. The changes ultimately include monetary flows in connection with the investment and operating costs of implementing CCS and a change in the value chain of plastic products as a result of the ban on fossil C.

Inputs to MEIONorway:

- Increases in the inter-industry flows from R37_39 to sectors contributing with products and services in the investment phase of establishing WtE carbon capture with sums according to their contribution.
- Increases in the inter-industry flows from RB to sectors contributing with products and services in the investment phase of establishing a carbon transport and storage infrastructure with sums according to their contribution.
- A decrease in the inter-industry flow from R20 to R19 corresponding to the amount that comes from plastic production.
- An increase in the inter-industry flow from R20 to R02 corresponding to the share of fossil plastic being replaced by bioplastics.
- Increases in the inter-industry flows from R22 and R13_15 to R37_39 corresponding to the share of fossil plastic being replaced by recycled plastic.

What remains to be done:

- Find an estimate for the breakdown of investment and operating costs for carbon capture at all WtE plants in Norway. Then, estimate which sectors are involved.
- Find an estimate for the breakdown of investment and operating costs for transport and storage of the carbon from all WtE plants in Norway. Then, estimate which sectors are involved.
- Find an estimate for how much of the monetary flow from R20 to R19 is associated with the production of plastic.
- Find an estimate for how the substitution of virgin plastic is divided between recycled plastic and bioplastic, in both plastic products and synthetic fibres.
- Find estimates for the prices of bioplastic and recycled plastic.

3.3 Discussion

This section describes approaches to implementing the scenarios in CircWtE for dynamic input-output modeling. Examining the scenario descriptions and investigating which changes to value chains and final demand they entail, made it possible to identify necessary changes between sectors. The approach describes which inputs should be given to the dIOA, but the sizes of the inputs still need to be estimated.

The chosen procedure was open-minded, looking at holistic approaches. However, as this can be intricate, it is interesting to study whether the process can be streamlined. The experience from this case shows that some parts of the procedure had to be adapted to the specific scenario. This is also likely for other potential scenarios. However, some parts of the scenario descriptions seem to be linked to a specific method of modelling. To summarize, the findings show:

- To model circularity: material recycling substitutes raw-material use
- To model changes to consumption, investment, imports: alter final demand
- To model taxes: alter value added
- To model changes in price of a material: alter the gross operating surplus price of the corresponding sector according to the Leontief price model to solve for the final demand price where the new price is (for example, change oil extraction operating surplus price, solving for the final demand oil price equal to the price increase)
- When household savings increase, this money is not reflected in the IO table and the economy shrinks

Note that these approaches are simplifications, and, depending on the scope of the work, further assessments are required. For example, analysis of scenarios involving circular economy could be approached by studying recycling rates. However, such scenarios are particularly complex, as circularity requires wide-reaching transformations of technology, supply chains, and economic structures. For simplicity, we altered the input-output table to reflect this transition on a material-by-material basis for large-volume materials. In reality, the size of the economy, the amount and type of raw material needed for outputs depend on the technology; a shift to large-scale recycling does not really lead to, for example, a perfect substitution of virgin plastic by recycled plastic. A circular economy should ideally be modelled on the waste hierarchy around reduce, reuse, and recycle such that a more complex scenario implementation may be done as outlined below.

Circular Economy Concept	IOT Implementation
Redesign	Increase R&D for circular design innovation
Reduce	This scenario avoids a reduction of the overall economy while assuming a reduction of totally new products.
Reuse	Cost savings are replaced by selection of more expensive but more durable products for negligible difference in final sales value
Repair	Reallocate sales within goods sectors (e.g., wholesale and retail) to repair categories
Refurbish	Assuming refurbished models replace sales of new products at the same rate, this only reduces raw material costs as long as refurbishment occurs within the same sector as the original producer
Recycle	Increase recycling rate. Reallocate incineration/landfill to recycling, which gives no change to R37_39. Raw material for other sectors reallocates, increasing R37_39.

Such assessments of the complexity to be included should be done for all scenarios. However, several challenges may limit the degree of complexity. The greatest obstacle to model scenarios is data availability. While an assumption may easily be reflected in the model by altering cells and balancing the model, and the balance functions are quite clear, the exact extent to which a sector needs to be altered to reflect the narrative of a scenario requires sufficiently detailed data or good assumptions. In addition, input-output modeling is rooted in material balances, not reflecting all economic theory. The interlinkages between supply and demand or other feedback loops affecting the size and structure of the economy are often not well understood or would require many changes throughout the supply chain. Thus, results are indicative, not predictive.

Limited data availability was particularly prominent with respect to cost estimates for introducing CCS and the technology's impacts. Hence, the scope of our research was limited to investigating which input parameters should be given to MEIONorway, but not specifying the size of these inputs. Furthermore, to carry out a dIOA, implications of the scenarios for the various involved sectors had to be explored. Studying the concerned value chains for the Norwegian economy, it was difficult to define which sectors were actually involved. One reason is that account reporting categories and actual activities are not always aligned. We used the Brønnøysund Register to determine the sectors where the largest industrial actors at the various value chain stages were registered in.

Another challenge concerned scenario descriptions. Such descriptions may serve several purposes and are, hence, often stated in rather general terms, involving several dimensions and leaving issues open to interpretation. Hence, they need to be narrowed down to the goal of the impact analyses to be carried out. This involves first choosing which aspects of the description to focus on. We found that this is best done by understanding the main points of the scenarios keeping in mind the overall goal of the project, to look at MSW management systems. For example, for the frugal-road scenario, the main point was a 50 % decrease in consumption, and we investigated how this could be done to obtain a 50 % decrease in MSW. The carbon-road scenario was concerned with achieving negative CO_2 emissions, and we chose to especially look at WtE CCS.

Secondly, after choosing the area of focus, the level of detail still has to be determined. Here, we were concerned primarily with changes in value chains. For this exploratory report, we worked with simplified value chains, showing only the processes from the most evident raw material to the most evident final product, without including input from other sectors along the way. Further work may expand on this.

A key takeaway from this section includes the usefulness of visualizing value chains and sectors together to get an overview of the necessary changes. We illustrated this connection in customized swim-lane diagrams. Obviously, this can also be done in other ways as long as it still translates changes in value chains into changes between sectors.

4 Case 2: GKKiK H3

4.1 Project Description

The project "Veikart for grønn konkurransekraft i norske kommuner og regioner” (GKKiK) has the main goal of defining a set of indicators and methodology to both measure and forecast green competitiveness of Norwegian municipalities, counties and regions. It is funded by the Research Council of Norway (project number 321114) under the IPOFFENTLIG20 program. Project partners are SINTEF, the county councils of Vestland and Trøndelag and the municipalities of Stjørdal, Bjørnafjorden and Bergen, managed by Trondheim municipality. The indicator set defined in the project shall provide an increased understanding of connections between business development and climate and sustainability goals. The project is divided in five work packages. Work package H1 described a set of indicators to quantify green competitiveness based on publicly available data. Secondly, H2 aims at testing and automating the calculation of these indicators. Then, H3 develops a tool to forecast the development of the indicators towards 2030. This activity is based on using the macroeconomic model MEIONorway. The model utilizes the Norwegian input-output table to forecast how policies and trends can affect the economy and thus green competitiveness in Norwegian municipalities and regions. Such what-if analyses are the topic of work package H4. The work done for this report contributes to H3, analysing how the indicators can be linked to the existing MEIONorway model.

4.2 Methods

Calculating green indicators for forecasting scenarios in work package H3 requires different formulas from the direct calculation in H2 due to the selected modelling approach. IOA is economically linked, making it ideal for linking economic policy to environmental indicators related to business competitiveness. However, not all green competitiveness indicators are compatible with input-output tables. For H3, the considerations described previously help to identify IO-compatible vs. incompatible indicators. We translate indicator definitions into formulas that use data from input-output tables and environmental extensions. Unit conversions from monetary units to the units defined for the indicators serve as the basis for these functions. In some cases, there is a need for relevant background information to modify dIOA predictions to the preferred units of the municipal green-competitiveness indicators. Additionally, we identify the need for data granularity or availability of sectoral or regional/ municipality-specific values to properly forecast changes in the indicators.

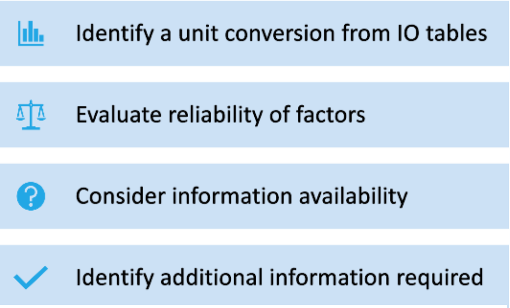

Figure 9. Indicator considerations

4.3 Indicators

Where indicators had clear linkages to economic values and fluctuations, and where external required data was available, we were able to define functions from the IOT and to recommend forecasting indicators related to energy, economic structure, environmental emissions, and water use. Indicator calculation may either be calibrated and verified with present calculations using functions defined in work package H2 or be used for forecasting in relative, rather than absolute, terms.

4.3.1 Recommended Indicators

Energy Consumption

The energy indicators depend on electricity use by industry and employees within the relevant industry, which both are clearly reflected in input-output tables in monetary terms. Additional information is needed to transform the monetary units into the proper units for better comparison: average employee salary for the relevant industries and the price of electricity to the industries. The function for energy indicators is given by

$$\frac{Z_{electricity,s}}{price_{electricity} \times V_{labor,s} \div \left(\frac{Salary}{employee}\right)_{s,avg}}$$

where

- $Z_{r,s}$ is the output of sector r used as input into sector(s) s, inter-industry matrix of the IOT For energy, r is electricity and $Z_{electricity,s}$ is the sum of electricity used in all sectors relevant to the GKKiK indicator (e.g., all service sectors for the service energy GKKiK indicator)
- $V_{labor,s}$ is the employment input to sector(s) s
- $price_{electricity}$ is the price per unit electricity sold to industry. This value may be found in SSB table 09364.
- $\left(\frac{Salary}{employee}\right)_{s,avg}$ is the average salary per employee for sector(s) s. This value is available in SSB table 11419 by sector but is not regionalized.

GKKiK indicator	NACE codes for sectors s
Total electricity consumption in primary industry, per employee / value creation	R1, R2, R3, RB
Total electricity consumption in industry, per employee / value creation	R10-33
Total electricity consumption in service industry, per employee / value creation	R37-R96, RT, RU

The salary per employee would preferably be given by sector and region, to account for pay differences between urban and rural jobs even in the same industry, but SSB table 11419 only offers values by region, a better predictor of NOK/capita pay for labor than municipality alone.

The energy indicators are interesting here because IOA enables useful ways of studying the split of energy consumption without looking at just electricity. Suitable sectors could be created to decouple electricity and renewables, and then only renewables vs. petroleum need to be compared rather than overall energy use.

Environmental Extensions

Emission-intensity and water indicators are calculated in terms of mass or volume through the environmental extensions of IOA. This makes the two categories of GKKiK indicators particularly straightforward to calculate, requiring only a normalization by number of employees, which comes from the value-added employment values of the IOA and the average employee salary.

	GKKiK indicator	**NACE codes for sectors s**
Emission intensity	Greenhouse gas emissions, per employee / value creation, directly	All
	Greenhouse gas emissions in agriculture and forestry, per employee / value creation, directly	R01 + R02
	Greenhouse gas emissions in aquaculture, per employee / value creation, directly	R03
	Greenhouse gas emissions in industry, oil and gas, per employee / value creation, directly	RB + R19 (split mining, pharmaceuticals)
Water	Municipal water for industry, primary industries and service industries, per employee / value creation	Sectors as defined for Energy indicators

$$\boldsymbol{E = SLy}$$

$$\frac{\boldsymbol{E_{stressor,s}}}{\boldsymbol{V_{labor,s}} \div \left(\frac{\boldsymbol{Salary}}{\boldsymbol{employee}}\right)_{\boldsymbol{s,avg}}}$$

where

- $\boldsymbol{E}$ is the environmental impact in terms of use or emission of a stressor
- $\boldsymbol{S}$ is the stressors, emissions, or technology matrix, including emissions of greenhouse gases by sector and water use by sector
- $\boldsymbol{L}$ is the Leontief inverse from the IO model
- $\boldsymbol{y}$ is the final demand for all sectors from the IO model
- $\boldsymbol{E_{stressor,s}}$ denotes the environmental impact of sector(s) $\boldsymbol{s}$ as a measure of use or emission of a stressor
  - For emission-intensity GKKiK indicators, the stressor is greenhouse gases
  - For water GKKiK indicators, the stressor is water use
- $V_{labor,s}$ is the employment input to sector(s) s
- $\left(\frac{Salary}{employee}\right)_{s,avg}$ is the average salary per employee for sector(s) s. This value is available in SSB table 11419 by sector but is not regionalized.

There is a difference between using aggregated values of emissions per sector and regionalizing those values. It makes sense to use the simpler emissions values when modeling many policies, but regionalized emissions/NOK provide greater clarity. Water-use values may be found in SSB tables 11787 or 04689, but these values are only by region or municipality and not by IOT sectors, so the forecasting of wastewater that can be provided through IOA is limited. To effectively predict water use, we must evaluate the variability of water use per monetary unit by sector, and, if appropriate (especially considering the regional scale), develop a sector-based approach to water use for the S matrix.

Economic Structure

Economic-structure indicators reflect a ratio of employment in a given sector to total employment, which can be found in monetary units in the employment portion of the value-added matrix within the IOT. Average employee salaries for specific industries of interest as well as the overall average employee salary transform this monetary ratio into the desired GKKiK indicator.

$$\frac{V_{labor,s} \div \left(\frac{Salary}{employee}\right)_{s,avg}}{V_{labor,total} \div \left(\frac{Salary}{employee}\right)_{avg}}$$

where

- $V_{labor,s}$ is the sum of employment within value added for sector(s) s for the region
- $V_{labor,total}$ is the sum of all employment within value added for the region
- $\left(\frac{Salary}{employee}\right)_{s,avg}$ is the average employee salary of the given sector(s)
- $\left(\frac{Salary}{employee}\right)_{avg}$ is the overall average employee salary.

GKKiK indicator	**NACE codes for sectors s**
Percentage of employment in oil and gas sector	RB + R19 (split mining, pharma)
Percentage of employment in sharing / reuse services	R77, R95 Could split R47 using goods retail
Percentage of employment in agriculture and forestry	R01, R02
Percentage of employment in aquaculture	R03*
Percentage of employment in building and construction	RF
Percentage of employment in industry	As defined for energy indicators
Percentage of employment in new green sectors	Create new sector

The proportion of jobs in new green sectors of total jobs requires some method of isolating these roles. We propose two ways to forecast how changes to local economies would affect GKKiK indicators in the future: (1) create a new "green industry/services" sector for this IOT, or (2) compare the changes in the IOT over time between green sector-focused scenarios and a baseline. Adding a new green sector requires building out the entire sector in the IOT with many assumptions: one must decide if and what sectors are substituted by the green sector, by how much, etc. This is the preferred method and will give outputs in absolute terms. However, absolute values in the IOA require calibration and validation before they are comparable to results from calculation methods using existing, collected data, e.g., as defined in work package H2 of the project. Relative values over time can be calculated within each forecast, so creating a new green sector is the best way to compare across forecasting and between scenarios. The comparative IOA approach neglects existing green jobs, but potential effects can be calculated in relative terms for a given scenario where green jobs are represented within each existing sector. Hence, it could be used as a shorthand approximation depending on the needs of the analysis.

Labor Market and Population

GKKiK indicator
Percentage over 16 skilled or higher education
Unemployment

From a unit conversion perspective, unemployment could be calculated as

$$1 - \frac{\sum_s \frac{V_{labor,s}}{\left(\frac{Salary}{employee}\right)_{s,avg}}}{\text{Working Population}}$$

This equation uses the variable-naming conventions previously defined. Unemployment may be estimated based on calculated labor costs within the value-added matrix from the dIOA, average annual salary per employee, and the number of employable workers within each region. However, this assumes that average employee salary is constant, making it difficult to reflect how pay of the labor force changes with restructured sustainable supply chains during scenario modeling. Regardless, this measure of unemployment can be useful in many types of scenarios.

The GKKiK indicator measuring the percentage of employees over 16 with skilled or higher education may be calculated based on the breakdown of skilled or higher education that currently exists by sector and adding this value to the S matrix. Then a similar calculation to that used for environmental extensions can be performed. The need for new, more sustainable and competitive technology could change the division of labor skills in a way that cannot be estimated based solely on total labor costs within the IOT. Analysing the assumptions and outcomes of the dIOA scenarios can help to better understand the need for skilled and unskilled labor for policies and economic transformations.

4.3.2 Indicators not Recommended for dIOA

Biodiversity and agriculture

GKKiK indicator
Net change in cultivated or arable land
Percentage of area for value creation of total area

Land use can be included in the S matrix as a stressor, and calculation would proceed as described for environmental extensions. A land-use environmental extension would be useful for scenarios exploring how changes to technology (S) result in land-use changes. However, considering that the goal is to measure at municipality or county level, agriculture in each region would use different amounts of land per NOK, depending on the types of farms, local geography, climate and demography, and farming technologies. At a larger scale, these factors might average out, but less so at the small sizes observed in Norwegian municipalities. Predicting land-use directly from scenario definitions may yield better results than using IOA as a proxy. Percentage of total area for value creation requires additional information on the total area of each municipality and area used per NOK for each sector to obtain a sufficient resolution for a what-if analysis through dIOA.

Indicators least relevant to dIOA

Category	GKKiK indicator
Technology and innovation	Percentage of environment-related projects with public support (% of total allocated projects)
Green strategies	Existence of a climate-adaptation plan

Both the technology and innovation and the green-strategies indicators are irrelevant to dIOA, as their units are not translatable to economic units. The percentage of environment-related projects with public support measures public support, which is not calculable from IOA.

Municipal green strategies are an important part of sustainability transition. Estimating how many municipalities have climate-adaptation plans in place may be useful for developing scenarios for dIOA. However, the green-strategies indicator measures political preparedness, and this is not predictable from economic outcomes. Without an indication of the quality and contents of the green strategies, this does not provide an indication of how economy would be affected. Thus, the climate-adaptation plan indicator may be related to green competitiveness but is not suitable for the type of modeling considered here.

4.4 Discussion

When designing and analyzing indicators from the IOA tools, we must consider the inherent uncertainty. Population growth at municipality level is quite uncertain. Impact of technology varies and is likely pronounced at the municipality scale (e.g., one factory can have a very different emissions matrix than the average). Many of the recommended calculations require an assumption of constant salary, at least by industry. However, salary is not constant when new green sectors transform demand for different education levels, service vs. industry type roles, etc. Salary may also vary by municipality for the same position in the same industry. More work is needed to ensure that the definitions align between indicators and IO tables, including industry, primary industry, services, “direct,” and value added. With all NACE codes, the sector level in the IOT may not reflect the exact, selected companies and industries used for direct calculation from existing municipal and regional data. For example, there may be good data for employment in aquaculture at the municipal level, but an IOT uses NACE code R03 “Fish and other fishing products; aquaculture products; support services to fishing”, which includes additional subsectors and companies that a municipality may need to split into separate values.

This work is designed to inform implementation in what-if analyses in project work packages H3 and H4. To perform such analyses on the various indicators, a dynamic input-output model, such as MEIONorway, could easily be adjusted with a package for the indicator calculations. Scenarios could then be implemented as described in section 2 (Methods) and demonstrated in section 3 (Case 1: CircWtE), with the model automatically calculating indicators for each scenario.

5 Final Remarks and Recommendations

Scenario analyses formed around macro-economic approaches such as dynamic input-output modeling help highlighting potential consequences of policies, strategies or development paths, in particular with respect to (socio-)economics and environment. In this relation, scenarios may express various framework conditions (external policies and regulations, demographic trends, technology development etc.) as well as decisions (strategies, political instruments etc.) Insights gained improve the understanding of complex linkages and strengthen municipal, regional and national decision-making and policy-finding processes.

This report has investigated approaches to operationalize such analyses, focusing on a) scenario implementation to transform descriptive scenario characterizations into information that can be utilized in dIO models and b) selection and calculation of impact indicators based on dIO model results. First, we established the approaches on a more general level before we exemplified their application by way of two project cases, outlining guidelines with fundamental questions and critical issues. A central point is that input-output models rely on monetary flows. Hence, scenario implementation must be concerned with deriving relevant changes to monetary flows in the economy while impact indicator calculations bring IOA results into a shape a decision maker may be more familiar with (e.g., employment, emissions).

We demonstrated the implementation of scenarios for IOA in the context of circular economy in municipal solid-waste management. Our work shows that it is indeed possible and beneficial to establish a general procedure. It starts with examining scenario characteristics closely to understand which aspects are most central and which aspects have greatest economic impact (e.g., changes in inter-industry flows, value added and final demand). Once this central meaning is clarified, the next step is to study and quantify ensuing changes in the IOT such as sectoral relations, magnitude of monetary flows. This process will be individual and tailored to each specific case and scenario, based on sector-specific information and expert knowledge. To ensure validity of analysis results, a balance must be struck between including as much information as possible and accurate presentation of this information.

We studied three scenarios of possible future framework conditions for MSW management. For each, we explored which characteristics can be dealt with in which way to convert them into monetary flows and present in IO tables. We described assumptions and detailed steps to derive input parameters to the MEIONorway dIO model and outlined further efforts needed to produce meaningful results. We reflected also on complex settings such as transitioning to a circular economy that have wide-spread effects and call for defining scope and limitations of impact analyses carefully.

Against the background of evaluating green competitiveness of Norwegian municipalities and county authorities, we showed how to calculate impact indicators based on dIO model results. We started with categorizing the set of indicators defined previously in the project according to their dIOA compatibility. Then, the indicator definitions were translated into mathematical expressions that use data from input-output tables and environmental extensions, converting from monetary units to the units defined for the indicators and, in some cases, relying on additional background information. In this connection, we indicated approaches to study the respective aspects further in the light of dIOA. We also pointed out needs for, e.g., better data granularity and sector-/region-specific values to improve reliability and accuracy. The inherent uncertainty of both the provided data and dIO results and the calculated indicators (e.g., due to data availability and granularity, assumptions, scaling issues, systematic uncertainty) should be kept in mind also for subsequent scenario analysis steps.

Summarizing, scenario implementation and impact indicator calculations are central elements of a scenario analysis (Figure 1). They can also be used as standalone approaches in a wide variety of assessments, helping to explore effects of decisions under various conditions and development paths comprehensively. With dIO approaches as evaluation method, the indicative results of scenario analyses can improve the knowledge base for evaluation and design of system-level decisions and strategies with sectoral, local, regional or national scope. Still, to improve efficiency and reliability of the analyses, some challenges should be addressed. Main issues concern data availability and variability (e.g., regionality, sensitivity to economic vs. other factors, access to expert knowledge beyond publicly available information), aspects of categorization of sectors and activities, efficient methods for calibration and validation. This may also facilitate the development of methods to quantify changes in monetary flows in various scenarios. Moreover, improved dynamic modeling of technological changes and unit prices may mitigate reliability challenges when analysing sectors and scenarios with quick or unpredictable shifts.

6 References

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APPENDICES

A Overview of the 64 sectors used in the Norwegian input-output model with associated codes

R01	Products of agriculture, hunting and related services
R02	Products of forestry, logging and related services
R03	Fish and other fishing products; aquaculture products; support services to fishing
RB	Mining and quarrying
R10_12	Food products, beverages and tobacco products
R13_15	Textiles, wearing apparel and leather products
R16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials
R17	Paper and paper products
R18	Printing and recording services
R19	Coke and refined petroleum products
R20	Chemicals and chemical products
R21	Basic pharmaceutical products and pharmaceutical preparations
R22	Rubber and plastics products
R23	Other non-metallic mineral products
R24	Basic metals
R25	Fabricated metal products, except machinery and equipment
R26	Computer, electronic and optical products
R27	Electrical equipment
R28	Machinery and equipment n.e.c.
R29	Motor vehicles, trailers and semi-trailers
R30	Other transport equipment
R31_32	Furniture; other manufactured goods
R33	Repair and installation services of machinery and equipment
RD	Electricity, gas, steam and air-conditioning
R36	Natural water; water treatment and supply services
R37_39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
RF	Constructions and construction works
R45	Wholesale and retail trade and repair services of motor vehicles and motorcycles
R46	Wholesale trade services, except of motor vehicles and motorcycles
R47	Retail trade services, except of motor vehicles and motorcycles
R49	Land transport services and transport services via pipelines
R50	Water transport services
R51	Air transport services
R52	Warehousing and support services for transportation
R53	Postal and courier services
RI	Accommodation and food services
R58	Publishing services

R59_60	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services
R61	Telecommunications services
R62_63	Computer programming, consultancy and related services; information services
R64	Financial services, except insurance and pension funding
R65	Insurance, reinsurance and pension funding services, except compulsory social security
R66	Services auxiliary to financial services and insurance services
R68B	Real estate services (excluding imputed rents)
R68A	Imputed rents of owner-occupied dwellings
R69_70	Legal and accounting services; services of head offices; management consulting services
R71	Architectural and engineering services; technical testing and analysis services
R72	Scientific research and development services
R73	Advertising and market research services
R74_75	Other professional, scientific and technical services; veterinary services
R77	Rental and leasing services
R78	Employment services
R79	Travel agency, tour operator and other reservation services and related services
R80_82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services
R84	Public administration and defence services; compulsory social security services
RP	Education services
R86	Human health services
R87_88	Social work services
R90_92	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services
R93	Sporting services and amusement and recreation services
R94	Services furnished by membership organisations
R95	Repair services of computers and personal and household goods
R96	Other personal services
RT	Services of households as employers; undifferentiated goods and services produced by households for own use
RU	Services provided by extraterritorial organisations and bodies

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