Report

Scenario definition and indicator selection for dynamic supply-use modelling

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SUMMARY

Input-output modeling provides a means to assess socioeconomic and environmental impacts of policies and instruments and, thus, support public and private decision makers. This report discusses aspects of scenario definition and indicator set development in the context of such modeling. A first case study is concerned with green transition and regional competitiveness. We outline how scenarios may be modelled for input-output analyses on topics such as carbon taxation, energy and mobility, public procurement, and employment and skills transformation. The scenarios highlight also how national and supranational political decisions may affect local authorities. A second case study is centred on municipal solid waste management. There, we investigate how to develop an indicator set that effectively supports policymaking but is applicable within the possibilities and limitations of the underlying analysis framework.

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List of abbreviations

ETS	Emissions trading system
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
GPP	Green public procurements
IAEA	International Atomic Energy Agency
IO	Input output
IOT	Input-output table
IRA	Inflation Reduction Act
MSW	Municipal solid waste
SDGs	Sustainable Development Goals
SSB	Statistics Norway ("Statistisk sentralbyrå")
SUT	Supply and use table
TBL	Triple bottom line
UN	United Nations
WEF	World Economic Forum
WtE	Waste to Energy

1 Introduction

The pressing need to restrain global warming has put climate change at the top of the political agenda. In light of the prevailing scientific consensus on the link between CO_2 emissions and global warming, efforts must be increased on all fronts to transition away from carbon-based economies in the most sustainable way, not only with respect to the environment but also socially and economically. There is no lack of suggested policies, measures and solutions – but their realisation is not fast enough, not powerful enough, not comprehensive enough. Uncertainty, both about potential impacts and about the future development of the environment where actions are to be implemented, represents a large barrier for going forward. The search for truly optimal solutions that perform best in all regards with little negative impact leads to hesitance and transition inertia, keeping the status quo. Finding good practicable solutions to go forward with – and overseeing their realisation – is challenging for decision makers, both public authorities at all administrative levels and private/industry actors. There is an urgent need for assistance in this task.

A systems perspective takes a broad view, emphasizing that climate change is a result of intricate issues, such as social norms and economic growth (patterns). In contrast, a single-actor perspective focuses on individual entities, such as governments and international organizations, to address climate change via policies. The emergence of new industrial activities may affect the potential of other industries. Given the scarcity of resources in terms of labor and investment capital, their efficient usage becomes instrumental. Public policy can contribute to reallocating resources where they yield the largest return for society as a whole. Therefore, it is advantageous to have an approach suited to evaluate both intended and potentially unintended effects caused by a policy.

Major transformations must take place if we are to achieve the goals set in the Paris Agreement, in terms of both national and global emission reductions. This alters conditions for businesses and organizations. However, in today’s complex and interconnected society, nothing happens in a vacuum without impacting other parts of the economy. The Inflation Reduction Act (IRA) is considered the largest climate policy in the history of the USA and will certainly have an impact on Norway (Menon Economics, 2023). This can unfold by, for example, hydrogen and battery production that otherwise would be built in Norway now being relocated to the US. IRA can potentially trigger a chain reaction where other countries implement similar policy measures. The European Green Deal is a cross-sectoral plan to make Europe carbon-neutral and has gained increased attention in policy making (European Commission, 2019). Through the EEA agreement, Norway is part of this strategy, along with the associated opportunities and challenges. Another example is the “Fit for 55” law newly adopted by the European Union (EU), requiring, among others, fast chargers to be installed along the European roads (European Union, 2023). These examples show how strategies and decisions on supranational level (e.g., EU and United Nations (UN)) affect the scope of action for national and regional authorities. The effectiveness of such policies in local contexts depends largely on how they are translated and implemented at regional level. Local governments often play a critical role in mediating impacts of these policies, adapting them to their conditions and involving local stakeholders in decision-making processes. In addition to the policies imposed, local authorities must utilize their local expertise to explore the opportunities created by the green transition.

The Sustainable Development Goals (SDGs) promoted by the UN are basis for much of today's policy making to eliminate poverty, combat inequality and halt climate change by 2030 (UNDP, 2023). To achieve a truly sustainable future, the holistic connection between the single goals must be acknowledged. The implementation of strong climate-policy measures may not necessarily be justified if it leads to a dramatic increase in inequality and poverty. The 2030 Agenda for Sustainable Development has also strengthened the focus on a circular economy (United Nations, n.d.) with opportunities for greater value creation through improved resource efficiency (Nørstebø, et al., 2020). Nevertheless, there exist obstacles for a successful implementation that must be addressed, e.g., through stronger alignment between rules and regulations and industrial opportunities. But goals such as minimizing waste in production can only go so far if consumer behaviour remains unchanged and a throwaway culture persists. In that context, authorities can promote circular-economy principles and encourage better reuse of resources through, e.g., effective municipal waste management.

On the one hand, long-term strategies are necessary to create lasting and sustainable solutions. At the same time, there is a risk that long-term thinking makes it easier to postpone tough but necessary measures. On the other hand, immediate threats require short-term strategies, with the downside that they can cause a loss of overall perspective. The challenge lies in striking a reasonable balance between the two perspectives. A strong policy should integrate both views to effectively address the complexities of climate change and its impacts on environment and society. This requires development and application of sound analysis methods adjusted to the specific context and goals, combining established approaches and customized models to provide useful insight.

Understanding the complex relationships between multinational and local policies is important to design sustainable and inclusive governance frameworks. Policymakers must be attentive to the diverse needs and challenges local areas face and strive to balance the need for global action and regional differences to foster socially equitable solutions. In this process, multi-faceted analyses help to gauge potential effects of instruments, policies and strategies for steering the transition in a desirable direction. They allow different options and variants to be tested before an implementation as real-world policies. This finds suggestions that would perform well according to the intentions without incurring overly negative consequences. The analyses may also help identifying actions to mitigate unwanted development (states) and to increase the robustness to meet such conditions. That is, they can both guide the transition to a more sustainable world (finding good actions and strategies) and help actors to follow the transition in a good way (finding ways to adapt to external developments or others' actions).

The transition towards a low-carbon and circular economy is accompanied by substantial uncertainty in many dimensions. Scenario (what-if) analyses contribute to better understanding such uncertainties and strengthen, hence, the basis for policy formulation at all levels. In general, scenarios are formulated as plausible storylines to showcase possible pathways forward or possible states at a time in the future. With suitable analysis methods, various formulations can be simulated and tested in a controlled environment. For a broad comparison of different scenarios, a well-suited set of indicators must be developed, aiming at a holistic view on the aspects that are desirable to be captured. Carefully selected indicators facilitate more insightful and meaningful assessments. Hence, the set should be comprehensive in scope, although some indicators may prove more relevant for certain scenarios or analyses.

The complete process of a scenario analysis is illustrated in Figure 1. First, the scenarios are defined and described with respect to certain analysis interests. Then, they are translated and evaluated by a suitable model to assess their impact. This impact is measured by a selection of indicators whose values, finally, are interpreted in the context of the analysis.

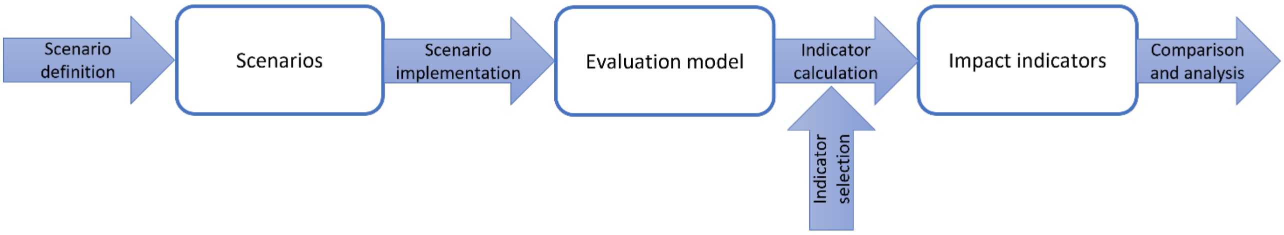

Figure 1. Scenario analysis process

The report “Scenario implementation and impact indicator calculation in dynamic input-output modeling” (Geldermann, Lindgren, Perez-Valdes, & Werner, 2022) looked specifically at the stages of implementing scenarios for dynamic input-output (IO) modelling and calculating indicators from the model’s output. The present report, on the other hand, takes a step back. It examines how scenario definition and indicator selection can be done with the prerequisite that they should be compatible with an evaluation by dynamic input-output modelling, based on Norwegian Supply and Use tables (SUT).

For this, two case studies are explored. The first case study addresses scenario definition, which involves all steps within the Scenario Definition Boundary, illustrated in Figure 2. This is demonstrated for three scenarios in the context of municipal and regional policies to stimulate green competitiveness. More specifically, one scenario addresses energy transition and mobility. Another scenario focuses on public procurements. Finally, a third scenario looks at needs for cooperation and human resource development. Additionally, an overarching scenario studies carbon taxation, highlighting the interplay between national and local policies. The second case study is concerned with indicator set development, factoring in all aspects within the Indicator Set Development Boundary. Against the background of circular economy concepts in municipal solid waste (MSW) management, it focuses on how to efficiently select a set of indicators for specific scenarios and analyses. This requires that the indicators should be computable from the evaluation method. The indicators should also be transparent and easily to understand, particularly in a project involving rather diverse project partners. Adhering to these guidelines ensures that the indicators chosen are relevant, measurable and simple.

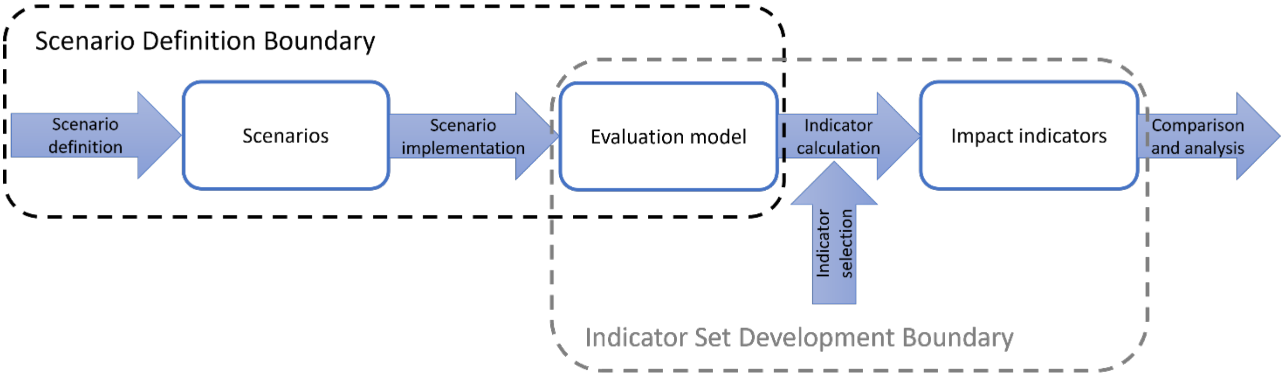

Figure 2. Scenario definition and indicator set development boundaries

The remainder of this report is structured in the following way: Section 2 provides a thorough description of the methodology used, followed by Sections 3 and 4 that present and investigate the two case studies. Section 5 concludes the report with discussions and some final remarks.

2 Methodology: input-output modelling and the SUMSNorway model

In an economic framework, each transaction is seen as a monetary outflow of a firm or household, resulting in a monetary inflow to another firm or household. Wassily Leontief formalized this concept in the article "Quantitative Input and Output Relations in the Economic Systems of the United States" (Leontief, 1936). Originally, the framework was built on the assumption that each industry produced one single commodity. Since then, more detailed *Supply and Use tables (SUT) and Input-Output tables (IOT)* have been developed from this approach. They are part of the central framework of the System of National Accounts (United Nations Statistics Division, 2009), and many countries produce SUTs and IOTs within their national accounts (UN Department of Economic and Social Affairs, 2018). Furthermore, they are used as foundation for policymaking, analysis and research purposes.

Supply and use tables comprise two interconnected matrices of statistical data, the supply table and the use table (UN Department of Economic and Social Affairs, 2018). The supply table presents data on the total supply of all goods and services by all economic sectors categorized by product and industry type, distinguishing between domestic industry and imports. The use table provides data on the utilization of all goods and services by all sectors and households, categorized according to product type and type of use, such as intermediate consumption by industries, final consumption, gross capital formation, or exports. Additionally, the use table lists various components of gross value added generated by the industry, including employee compensation, other taxes (less subsidies) on production, consumption of fixed capital, and net operating surplus. Figure 3 summarizes the structure of the tables.

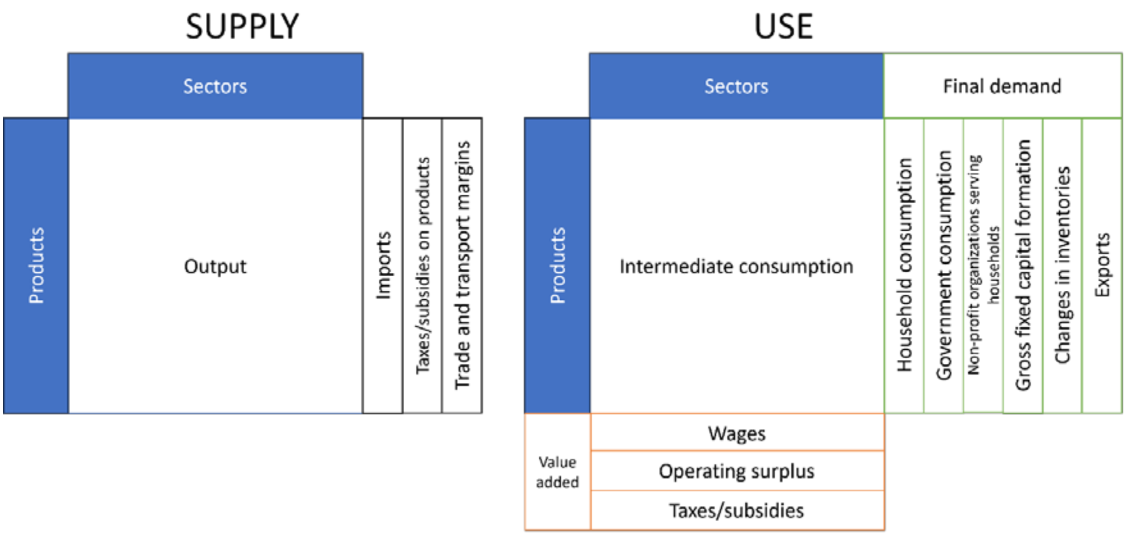

Figure 3. Structure of Supply and Use Tables

In contemporary research, *input-output data driven economic models* stand at the forefront of macro-economic value-chain analyses (Wiebe, et al., 2022). By utilizing information from IOTs or SUTs, consumer and producer actions can be effectively captured in a framework at industry-sector level. This makes it possible to examine changes in consumption and production and to observe effects on the respective value chains. The models are primarily demand-driven and may include extensions for environmental and social impacts. Moreover, models that consider dynamic aspects help to obtain more comprehensive results, as they can cover transitions in the economy over a longer time frame (Wiebe, et al., 2022).

The projects at the core of the cases discussed here utilize a model developed by SINTEF, SUMSNorway, that belongs to this family of dynamic input-output approaches. It is based on the SUTs or IOTs for an economy, combined with macro-econometric regressions to project future development. Extensions on labor and emissions help to assess impacts on the social and environmental dimensions. An earlier variant based on the same approach is described in Wiebe et al. (2020). The model is exogenously driven by population growth and global economic development and closed with regard to household consumption. The latter, together with investments, is endogenous in the model. This setup allows the model to project the development of an economy year by year.

In the cases considered here, SUMSNorway is used for scenario-based what-if analyses to project and measure effects of potential policy measures on the Norwegian economy. The according sector division follows SSB's standard for industrial classification (Statistics Norway, 2009), with potential adjustments such as sector aggregation or creation of sub-sectors for specific analyses. SUTs from Statistics Norway (SSB) (Statistics Norway, 2022) are used as a starting point for the projections.

Regionalization includes splitting sector production, demands for goods and services, and employment figures for each sector into regional levels. This reflects the heterogeneity of municipalities and counties with respect to, e.g., natural conditions, environmental challenges or economic and demographic structure and helps to explore regional impacts in more detail. Scenario analyses can be customized better to specific challenges and the scope of actions for local authorities, helping them to adapt to and benefit from national and global developments in a way that is well-suited for their region. The scenarios discussed in Case 1 (green competitiveness) are good examples of where a regionalized approach can provide additional insights, improving both the knowledge base and future decision-making processes.

A *scenario analysis* begins with a model run on a benchmark scenario, resulting in a reference set of indicator values projected over a certain time horizon. Then, the model is run on a given scenario, which has been translated to IO modelling. Typically, this implies changes to certain SUT elements or other model parameters such as production intensities, emissions or employment coefficients, consumption by households or government – but also structural changes like the introduction of new products or services or of industrial activities (Geldermann, Lindgren, Perez-Valdes, & Werner, 2022). With dynamic analyses, these changes may occur over time. Any such changes will create an imbalance in the SUT. A model run recalculates the table, establishing a new equilibrium from which the corresponding new indicator values are determined. These values are then compared against the reference values to deduce impacts of the measures or developments described in the scenario. To effectively deduce such implications, the studied scenarios should be simplified sufficiently but still capture the most relevant traits. When only a few changes are implemented at a time, effects can be traced easier through the model, from implementation to results (Wiebe, Bjelle, Többen, & Wood, 2018). Such considerations are an important part of scenario definition and subsequent translation to IO concepts, as also discussed in the following section.

Obviously, scenario analyses with dynamic IO models like SUMSNorway face limitations – beyond the invariable challenge of access to data in sufficient detail and quality. Based on supply and use tables, i.e., monetary values, the models cannot directly assess, e.g., environmental aspects such as effects of land-use changes or biodiversity impacts. Social aspects can also be addressed only to a certain degree. Additionally, the current implementation of SUMSNorway does not allow for deeper investigation of financial aspects such as income tax effects, which would require a dedicated module. Section 3.3.2 mentions further characteristics to be considered in this context. Some effects can be captured through proxy data and indicators and through background information, extending the scope of the model. Section 4 investigates some indicators that can be measured using SUMSNorway. In general, though, the methodology should be complemented by other approaches to address all dimensions of sustainability adequately.

3 Case 1: Scenario definition – green competitiveness (GKKiK)

3.1 Introduction

Stricter global climate policies and rapid technological development are changing the framework for regional Norwegian authorities. A long-term development of green competitive strength depends on the identification of opportunities and challenges inherent in this transition. The project "Veikart for grønn konkurransekraft i norske kommuner og regioner» (GKKiK – "Roadmap for green competitiveness in Norwegian municipalities and regions") is concerned with approaches to measure and forecast green competitiveness of Norwegian municipalities, counties and regions. Funded by the Research Council of Norway (project number 321114) under the IPOFFENTLIG20 program, the project partners are SINTEF, the county councils of Vestland and Trøndelag and the municipalities of Stjørdal, Bjørnafjorden and Bergen. The project is managed by Trondheim municipality and comprises four main activities. Firstly, a set of indicators was selected and described to quantify green competitiveness based on publicly available data. Subsequently, calculation of these indicators is tested and automated using existing data for all project partners. This gives insights into their current green competitiveness. It can also provide timelines of the development hitherto. In parallel, a macroeconomic approach is developed using SUMSNorway to project potential future development of the indicators. Finally, the capabilities of the approach are demonstrated by way of several scenarios, to explore impacts of policy instruments on green competitiveness and to find suitable strategies. The work conducted for this report contributes to that activity.

The concept of green competitiveness is concerned with achieving, among others, emission reduction goals while stimulating economic growth and creating jobs (Regjeringen, 2021). In the context of the GKKiK project, green competitiveness is thus composed of two main components: being competitive and moving towards a more environmentally friendly (green) direction with reduced greenhouse gas emissions. A more comprehensive discussion of this concept is provided in Delic et al. (2022).

Municipalities and counties exhibit considerable heterogeneity in their business structure, demography and geography. They have also different needs, interests and focus areas with respect to green competitiveness. For example, Trøndelag county council highlights bioeconomy, technology, experiences, and the public sector as areas where the county has advantages and opportunities (Trøndelag fylkeskommune, 2022). Moreover, different administrative levels, but also different sizes in terms of both population and local industry and business, mean different latitude and capability to find and implement appropriate policies and measures. The Klimakur report (Miljødirektoratet, 2020) describes the varied decision space of counties and municipalities and potential barriers for facilitating a sharp reduction of emissions by 2030. It points out opportunities for actions that can be realized through strategic use of public procurements, comprehensive social and spatial planning, energy planning, and the municipalities' role as community developers. These opportunities depend very much on regional specifics. Obviously, a one-size-fits-all analysis approach cannot capture all distinctive regional attributes. Hence, to adequately address this heterogeneity when demonstrating capabilities of the macroeconomic approach in the GKKiK project, the considered scenarios should vary accordingly – and they should be defined in close collaboration with the project partners to ensure relevance and applicability.

In this report, we discuss three main scenarios, focusing on responsibilities and capabilities of county councils, large/town municipalities and smaller municipalities, respectively. They cover aspects within *energy and mobility* (Scenario 1), *public procurement* (Scenario 2), and *employment, skills development and industry structure* (Scenario 3). The context of the first two scenarios makes them well-suited to demonstrate how to directly model specific policy instruments under the control of county councils and municipalities. The latter scenario, in contrast, illustrates how the framework can be used to assess impacts of policies and developments on, e.g., required labour skills in the region. This can build a basis to find (or to call for) measures to maintain or increase green competitiveness. To a degree, Scenario 1 serves a similar purpose, outlining how policies at various levels may affect the energy demand/supply situation in a region and pointing out potential areas for effective intervention.

In addition, we discuss how to use the approach to explore impacts of *carbon taxation* in a simple way. This is a highly topical instrument that may be expected to affect the single regions in different ways. The effectiveness of policies and measures at regional decision level may also change under the taxation. It can, therefore, serve as a framework for the scenarios to illustrate how the interplay between national and local policies can unfold. Hence, it is worthwhile to explore potential development of the indicator set in the main scenarios with and without carbon tax, and we consider this an overarching Scenario 0. Figure 4 illustrates the scope of the single scenarios in an analysis process utilizing the SUMSNorway model.

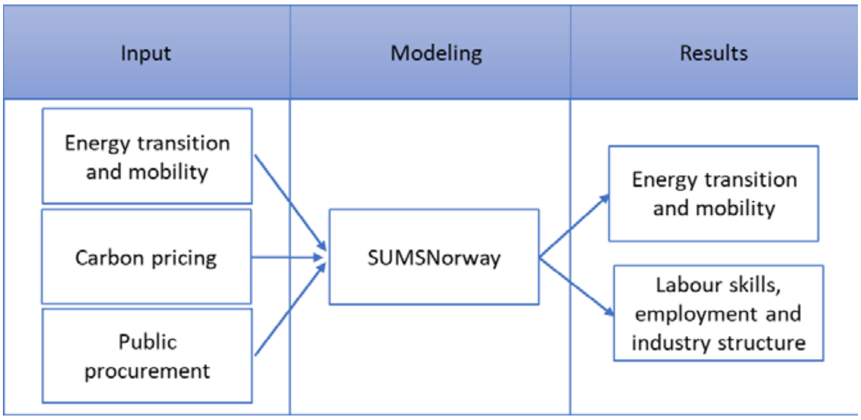

Figure 4. Scope of the scenarios to analyse policy impacts on regional green competitiveness

In the following, we first provide some theoretical background before we outline how carbon taxation can be modelled in the context of GKKiK scenario analyses. Then, we discuss the three main scenarios and suggest modelling approaches as examples for how dynamic IO models such as SUMSNorway can be utilized to evaluate policy measures towards improved green competitiveness.

3.2 Theory background

Market failures occur when unregulated markets do not provide the most efficient allocation of resources (Bator, 1958). Economists often use emissions as schoolbook example of negative externalities, where the economic decision making will not fully incorporate third-party costs. This allows for public intervention to correct market inefficiencies through various policy tools, such as regulation, subsidization, and taxation (Helbling, 2010). In *The Economics of Welfare,* economist Arthur Pigou (1920) suggested that governments should tax polluters equivalent to the cost of the harm caused to third parties. Conversely, governments should subsidise those creating positive effects for others. The former is considered more efficient because of, among others, neutrality in selecting the industry to lead the way.

Climate change is inherently global by nature. This requires collaborative efforts among intergovernmental actors such as the UN and the EU. However, recent decades have witnessed an ongoing discussion about the close relationship between decentralization and effectiveness of environmental policies (Mao, 2018). Within the field of fiscal federalism[1], one key question is how the administrative, fiscal and political responsibilities should be distributed between different levels of authority (Oates, 1999). In accordance

[1] In economics, the term “federalism” refers to different levels of government that provide public services and have some scope of decision-making authority. In a Norwegian context, this includes municipalities, county councils and the state.

with the decentralization theorem[2] initially introduced by Oates (1972), it is logical to argue that public goods should be supplied by local authorities, which are the ones closest to their residents, businesses, and organizations. This theory suggests that decentralization can lead to better environmental policy outcomes by allowing for tailored approaches that consider local contexts, preferences, and knowledge. However, it must be noted that application and effectiveness of decentralization in environmental policy may vary with specific contexts and governance structures. For example, Kim and Yoon (2018) find that the positive effects of decentralization and environmental policies are significantly strengthened by the quality of government capacity.

3.3 Carbon pricing

Combating climate change requires transitioning away from a fossil fuel-based economy. One approach is to subsidize goods with low or no emissions. It is conceivable that the USA, with the Inflation Reduction Act (IRA), signal that they are betting on this by providing tax reductions and subsidies for environmentally friendly solutions (White House, 2022). The EU has taken similar measures, and further actions in response to the IRA may be expected. All of this may affect competitiveness of Norwegian industry and businesses. Alternatively, carbon taxation and emission trading systems are two essential policy tools to achieve a reduction of emissions. Their implementation will expectantly accelerate a transition towards a greener economy but may have undesirable consequences for the economy.

For this overarching scenario, we use a stipulated increase in carbon taxes as a framework to investigate how it may affect Norwegian regional economy. It should be noted that, rather than being a forecasting tool, SUMSNorway explores how the tax may impact production chains and sector composition. It offers, hence, a valuable method to identify sectors that may experience significant disruptions due to carbon taxation. In a next step, we can examine how the findings in the three main scenarios may change with the taxation and, this way, assess, potential complementarities between national (e.g., carbon taxation) and local instruments (e.g., procurements). Such analyses are crucial for devising targeted policy measures such as transitional support, effective public procurements, or sector-specific adjustments to mitigate potential adverse regional effects. All this may affect green competitiveness of municipalities and counties.

3.3.1 Background

Both a carbon tax and an emission trading system are approaches that utilize price mechanisms to increase the cost of emitting. Levying a carbon tax would directly increase the price, while a cap-and-trade policy limits the amount of emissions allowed, resulting in market forces driving the price (Elkins & Baker, 2001). Carbon pricing may increase the price of fossil fuels, making renewable energy more attractive and incentivizing more efficient energy usage. Furthermore, it will lead to changes in sector-level prices, thereby changing relative commodity prices and the relative demand from all sectors (Choi, Bakshi, & Haab, 2010). It has been shown to have regressive impacts, inflicting significant burdens on lower-income households (Känzig, 2023). For China, Zhang et al. (2019) demonstrated that the tax may also adversely affect rural areas. Two main measures have been proposed to address this issue: first, recycling the tax revenue as a lump-sum transfer back to households and, second, decreasing the taxation on labour (Kaushal & Yonezawa, 2022). We will use the former in our modelling.

In the short run, emissions per unit of product/service are expected to remain relatively unchanged due to inertia associated with transitioning. However, over time, it is expected that businesses will be able to improve production technologies and decrease their emissions per unit. In general, an increased CO_2 tax will lead to a substitution of high-emission goods/services by less emission-intensive ones. In an ideal world, carbon taxation would, hence, give a smooth shift in economic activity towards less emission-intensive sectors (e.g., the service sector). However, this may be costly depending on sector composition

[2] Also referred to as Oates Theorem.

and the existing businesses' adaptability – some sectors will be able to reduce emissions effectively, while others may not. Using an IO model, Kay and Jolley (2023) find that a $200/ton tax on CO_{2e} emissions increased prices in the range of 10-30 percent for highly carbon-intensive sectors such as agriculture, mining, transportation, utilities, and chemical industries. This poses a significant competitive risk for municipalities and counties where high-emission industries constitute a large proportion of the economic structure. In this regard, the public sector plays a crucial role in easing the transition.

It is expected that carbon taxes will increase and allowances through emission trading systems decrease, leading to higher emissions prices. Around half of Norway's emissions are covered by the European emissions trading system (ETS) and are, thus, regulated by European directives. Not covered by the ETS are emissions related, for example, to transportation, agriculture, heating, waste, fluorinated gases, and certain emissions from industry and petroleum production. Norway's Climate plan aims to reduce these emissions by 40% by 2030 compared to 2005 levels (Miljødirektoratet, 2020), using a a carbon tax (Miljødirektoratet, 2023). For non-ETS sectors, the government intends a steep increase of the tax to NOK 2000 per ton CO_{2e} in 2030 (2020 prices). The ambition is that this level will facilitate Norway to reach the intended emissions reduction (Klima- og Miljødepartement). A report by SSB finds that a NOK 2000/ton CO_{2e} tax for the non-ETS sectors in 2030 will have a modest macroeconomic impact, while emissions can be reduced by about 9 percent compared with the current tax level (Kaushal & Yonezawa, 2022).

3.3.2 Scenario modeling

In the following, we discuss some aspects related to modeling this scenario for an analysis with a dynamic IO model such as SUMSNorway. This concerns modeling choices and limitations inherent to SUMSNorway as well as scenario-specific assumptions.

The model assumes *constant emission intensities* for all sectors, which are exogenously given. Hence, technology adjustments leading to reduced CO_2 intensity per unit of a product or the emergence of new lower-emission industries/sectors incentivized by a higher carbon tax cannot be reflected directly by the model. However, such *technological change* can be incorporated externally through scenario-specific modelling such as econometric estimation of diffusion curves for new technologies (Aponte, Wiebe, & Luttikhuis, 2023) and explicit characterization of new industries/sectors, such as the split-and-aggregate approach outlined in section 4.3.6.

For the production functions, *constant return to scale* is assumed, i.e., quantity changes for intermediate inputs are directly proportional to output changes. This means that the composition of products within each sector remains constant, resulting in linear production functions with fixed technical coefficients.

SUMSNorway assumes a *perfectly elastic labor* supply. For example, if the carbon tax would lead to an increase in activity of a new labor-intensive sector, it is assumed that sufficient workforce is available to cover the new demand. Additionally, this is assumed to not have any impact on wages, which it probably would have in practice.

To model the scenario, we implement a *uniform carbon tax* for all non-ETS sectors, with no exceptions. This is contrary to the existing scheme where certain sectors are not covered by the tax or get compensated through a decrease of other taxes/fees.

Depending on the sectors' ability to reduce emissions, the tax may potentially be a great source of revenue for the government. We assume that this additional revenue is *recycled* from the government to the households as a *lump sum transfer* to relax the burden on low-income households, amongst other reasons.

Furthermore, we assume that *producers pass on the tax increase completely to consumers*. In reality, the tax burden would likely be shared between producers (lower profit and/or wages) and consumers (higher prices). Whether businesses can shift the tax burden onto consumers in the form of higher prices depends on the price elasticity of demand. Products with inelastic demand, such as food and electricity, are examples where businesses can usually raise prices without significantly reducing consumer demand. Redistribution is often a matter of policy preferences, and the model's flexibility makes it possible to handle multiple ways to redistribute. To account for undesirable distributional effects, one could for example, run an analysis without implementing the tax on products with inelastic demand (e.g., utilities, food, prescription drugs).

Higher prices on high-emission consumption goods may lead to lower demand and, thus, an increase in the utility of leisure. However, we do not incorporate such a potential *distortion between work/leisure decisions*. Additionally, an increase in domestic carbon prices could lead to a reallocation of production to other countries, often referred to as *carbon leakage*. Simplifying, we assume there will be ways to address this potential concern (e.g., through consumption-based accounting).

3.3.3 Implementing a carbon tax for analyses with SUMSNorway

To account for uncertainty concerning the level of the carbon tax imposed on non-ETS sectors, we suggest running a series of sensitivity analyses with different start levels. All these pathways are based on values stipulated by the Norwegian government (Regjeringen, 2022). The lowest level pathway continues with the current tax of NOK 600/ton CO_{2e}. It can be viewed as a business-as-usual perspective and will function as reference. The second level is the one planned by the Norwegian government, a gradual increase to NOK 2230/ton CO_{2e} in 2030. The third and fourth pathways denote lower and upper bounds, at NOK 757/ton CO_{2e} and NOK 2990/ton CO_{2e}, respectively. The lower-bound pathway is set at 75 percent of the emission allowance price in the ETS in the first year and increases thereafter at the discount rate used for socio-economic analyses. The upper bound is related to the estimate by the Intergovernmental Panel on Climate Change (IPCC) to achieve the 1.5-degree Celsius temperature limit (median estimate). Table 1 shows these pathways of gradually increasing emissions prices for non-ETS (three levels), ETS, petroleum, and aviation sectors and for CO_2 absorption and emissions in forestry and land use.

Table 1. Suggested pathways for emission prices. (All prices in NOK/ton CO_{2e}, price level 2023, exchange rate 10.25 NOK/€ (Regjeringen, 2022))

Year	Non-ETS sectors			ETS sectors (except for aviation and petroleum)	Petroleum	Aviation	CO_2 absorption and emissions in forestry and land use
	Government	Lower bound	Upper bound				
2023	952	598	1470	798	1559	1447	798
2024	1135	627	1679	836	1724	1611	836
2025	1317	654	1918	872	1907	1796	872
2026	1500	686	2096	915	2121	2016	915
2027	1682	703	2291	937	2230	2230	937
2028	1865	721	2504	961	2230	2230	961
2029	2047	739	2736	985	2230	2230	985
2030	2230	757	2990	1010	2230	2230	1010

We suggest a method to implement carbon taxation that is in accordance with literature (Kay & Jolley, 2023), using expected emission prices and information about product and industry emissions to calculate an efficient tax rate. Statistics Norway provides data for national CO_{2e} emissions for all industry sectors in the SUT (Statistics Norway, 2022b). We multiply these values by the according carbon-tax levels to obtain the tax revenue gained, shown in column "Tax revenue" in Table 2. As input parameter to SUMSNorway, the tax will be part of the *net taxes on production* entry in the value-added section of the SUT. Lastly, to obtain an effective tax rate for each sector, the tax-revenue estimate is divided by the sector's output. This gives us an understanding of which sectors are more exposed to transition risk. The final column in Table 2 shows the effective carbon tax rate for the ten sectors with highest CO_{2e} emissions relative to their output. Due to the interdependencies among sectors, increased production costs for high-emission sectors will potentially raise prices across the whole economy. SUMSNorway quantifies such effects, which makes it possible to study and interpret specific results of interest for each scenario, e.g., via indicators for green competitiveness.

Table 2. Efficient carbon tax rate for sectors with highest emissions relative to their output. (Note: Some sectors are covered by ETS, while some sectors are covered by both ETS and non-ETS.)

NACE code	Sector name	CO_{2e} (1000 ton)	Total industry output (MNOK)	Tax revenue (MNOK)	Effective carbon tax rate
R01	Agriculture	5 049	41 408	10 098	24%
R24	Manufacture of basic metals	4 279	57 509	8 538	15%
R51	Air transport	1 416	22 841	2 832	12%
R23	Manufacture of other non-metallic mineral products	1 728	33 745	3 456	10%
R19	Coke and refined petroleum products	4 731	113 017	9 462	8%
R06	Extraction of crude oil and natural gas	14 741	402 933	29 482	7%
R03	Fishing and aquaculture	863	23 506	1 726	7%
R37_39	Sewerage[3]	1 426	54 236	2 852	5%
R35	Utilities	1 681	71 698	3 362	5%
R49	Transportation on land	1 948	92 631	3 896	4%

3.4 Main scenarios

3.4.1 Scenario 1: Energy and mobility

There is a large amount of industry projects and activities that can contribute to a green transition, and a robust infrastructure for supply and distribution of clean energy is paramount for their successful realisation. New green industry may be energy demanding, e.g., battery production, but may also replace less energy-efficient industry. Consequently, changes in industry activities and structure will most likely also imply changes in both spatial and supply/demand balances for energy. The same holds for endeavours towards zero-emission transportation and mobility. The energy balance changes may, in turn, affect the potential for further transition activities and future green competitiveness. Policy and strategy processes should, hence, also consider these effects, identifying the "right" projects to stimulate in the right way.

This scenario explores how the transition towards a greener economy may affect a region's energy situation. In particular, we investigate effects of policy measures with respect to industry and business infrastructure and transport/mobility, with Vestland county as an example.

Background

Through the project Grøn Region Vestland ("Green Region Vestland"), Innovation Norge and Vestland county council aim to stimulate collaboration between public and private actors such that green transition in the region can be done faster, better and easier (Vestland Fylkeskommune, n.d.). Under the umbrella of that project, 16 "Hubs for green transition/Green hubs" are established based on industrial symbiosis in

[3] Includes waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services.

areas with particularly beneficial conditions. These hubs shall facilitate a large number of green transition projects, with a potential of, in total, 17.000 new jobs, increased export and lower emissions.

Transport and mobility are important to facilitate these activities, both for transportation of the products used and produced but also for public transportation. In coastal regions such as Vestland, maritime transport and mobility form a crucial part of the infrastructure. Overseeing public transport – as both purchasers and providers – county councils contribute to transportation solutions closely connected with comprehensive spatial planning, and, thus, regional industry and demographic development (Miljødirektoratet, 2020). Procurements can be utilized to stimulate innovation and implementation of zero-emission solutions, e.g., for buses, ferries, and high-speed boats, and to establish the necessary infrastructure effectively. (Section 3.4.2 outlines how to model public procurement in the context of SUMSNorway.) At the same time, sufficient government funding is essential to meet national expectations on regional tender processes (Vestland fylkeskommune, 2022). As an example, the Klimasats scheme shall support specific climate measures of municipalities and county councils, such as through a dedicated high-speed boat programme (Miljødirektoratet, n.d.).

Obviously, the green transition in transport affects the region's energy balances, increases demand for renewable energy at different places and requires the establishment of a robust supply/distribution infrastructure, charging facilities, etc. Vestland county's energy balance for 2018 indicated about 30 TWh fossil energy (mostly used by industry and transport) to be replaced by renewable energy sources (Viken Fylkeskommune, 2023). This requires efforts in three areas: more renewable energy, more distribution infrastructure and capacity, more energy-efficiency improvements. The public sector plays a vital role to facilitate these efforts. County councils are well-positioned to challenge and stimulate markets for environmentally friendly solutions. A strong energy infrastructure helps to reduce emissions in existing industry and transportation and to provide energy for new industrial symbioses/clusters and development of new industry with low climate footprint.

The Regional plan for climate 2022-2035 is the first climate plan to be implemented in Vestland county (Vestland Fylkeskommune, 2023) and sets the strategic direction for climate action in the region. The plan and the associated yearly action plan point out needs for collaboration across technologies and interests to create an energy situation benefiting households and industrial development. Subthemes concern topics such as sustainable regional business development (e.g., reduce industry emissions to reach net zero GHG emissions, exploit regional advantages to develop green businesses and green clusters/hubs, strengthen circular business models through industrial symbiosis and sustainable resource use, stimulate innovation and climate-friendly business development, use public procurement to reduce climate risks) and transport (e.g., facilitate a transition to low- and zero-emission solutions for all means of transport, establish the needed infrastructure). More concretely, the action plan sets guidelines for municipal and regional planning, e.g., to stimulate a reduction of transport needs, to encourage fossil-free means of transport, and to facilitate the establishment of charging infrastructure for zero-emission vehicles and of shore power and charging stations for vessels at harbours and docking facilities. With respect to energy, goals are to generate a surplus of energy from renewable sources and to establish a robust supply and distribution infrastructure that facilitates green value creation in the whole region. This implies ensuring sufficient access to clean energy for the 16 Green hubs comprised by the Grøn Region Vestland project.

Vestland faces the additional challenge that it is part of three electricity price areas, which may experience different pathways. Hence, policy measures may have different effects in different regions of the county.

Practical implementation

For this scenario, impacts on resource and carbon productivity are deemed particularly interesting, a category comprising ten indicators in the set defined in the GKKiK project. Suitable policy measures may then be investigated also with respect to how they can be used to control and direct these indicators in a desired direction. It may also be worthwhile to assess whether changes in value creation show a relation to changes in emissions. A regionalised modeling approach is well-suited for this scenario to provide valuable detailed insights taking into account specific regional challenges. To ensure timeliness and practical relevance of the analyses, detailed formulations, but also potentially alternative measures, must be discussed further with the respective project partners.

As a first analysis step, model results for the different carbon taxation pathways in Scenario 0 (section 3.3) should be investigated against the background described here. That means, focus should be on interpreting energy-related indicators in the context of Vestlandet county's challenges and the authorities' decision space. This may point out sectors and topics where certain instruments or measures would be especially efficient or are urgently needed. The insights can, hence, complement and strengthen previous analyses, but also point out directions for strategies in the future.

Then, selected measures may be modelled to analyse impacts, in particular on energy-related aspects discussed above such as changes in energy demands and balances. Together with expert knowledge on spatial industry distribution, sector-level indicator values can give insights on green industry and business development. One may also discuss how the findings align with previous analyses of such or similar measures.

Finally, the two steps may be combined to a common analysis investigating robustness and effectiveness of the measures under different CO_2 taxation pathways.

Examples for measures suitable for analyses with SUMSNorway are as follows:

Measures to facilitate the *establishment of hubs for green transition and similar industrial cluster activities* can take various forms. Analyses may test the impacts of different variants of supporting measures – but also the effects of supporting different types of activities and projects. This helps to stimulate the right projects in the right way to ensure green competitiveness in the region. Modeling these instruments may concern changes due to emerging new technologies (leading to changes in the technology matrix, product or emission intensities) or changes in demand for products. It may be relevant to consider an introduction of subsectors as discussed in section 4.3.6. If the measures involve financial support, changes in monetary flows between the concerned sectors and the Government sector must also be modelled. A discussion of model results should not only focus on energy-related impacts in the region but also set a connection with potential impacts on demand for labour skills and employment as outlined for Scenario 3 in section 3.4.3.

Policy decisions on *zero-emission maritime transport* such as public procurement of high-speed boats, support and incitaments for ferries and high-speed boats and facilitating charging infrastructure are also well-suited for such analyses. Modeling such instruments for SUMSNorway may follow the approach outlined for Scenario 2 Public procurement. Here, it is important to consider how fossil fuels are replaced by electricity and hydrogen in maritime transport. Furthermore, detailed emission data for this sector are needed. For discussing the model results, energy-related indicators and their interpretation are central.

Another analysis of this scenario may assess potential distortive effects on green competitiveness due to framework conditions such as *different electricity price areas in the region*. Price volatility may hamper the predictability required, e.g., by new energy-demanding industry when choosing a location. It may also affect the effectiveness of policy measures. Such an analysis requires input data with a sufficiently detailed regionalisation. Then, similarly to Scenario 0, model runs may use differentiated electricity prices and development pathways reflecting the single price areas to assess regional effects on energy demand, sector composition, etc.

3.4.2 Scenario 2: Public procurement

This scenario investigates impacts of stronger environmental requirements in public procurement on green competitiveness, using the construction sector as an example. In 2021, the public sector purchased goods and services for 650 billion NOK, equivalent to about 16% of Norway's gross domestic product (GDP) (DFØ, 2023). Public procurement accounts also for 16% of Norwegian emissions, with the construction sector as the most significant contributor. Many Norwegian municipalities have set ambitious emission-reduction goals (Miljødirektoratet, 2020, p. 313), which they aim to reach by, for example, utilizing procurement to incite low- and zero-emission solutions (Bergen kommune, 2023; Oslo kommune, 2020; Trondheim kommune, 2017). Just recently, the Norwegian government intensified legislation on public procurements (Regjeringen, 2023), requiring environmental aspects to be weighed stronger, with at least 30%, from 2024 on (Nærings- og fiskeridepartementet, 2023). This shows how policy instruments controlled by local authorities can be affected by legislation on national level.

Background

A central goal of public procurement is to effectively meet the public's needs by using market mechanisms (competition) to achieve the lowest price. Nevertheless, lately there has been a policy shift towards prioritizing other concerns, such as societal and environmental aspects (Cheng, Appolloni, D'Amato, & Zhu, 2018). In this way, the public sector can contribute to the transition to a greener economy through its bargaining power. This can be achieved in multiple ways, for instance, through mandatory environmental requirements among the selection criteria in a procurement process. Green public procurements (GGP) may yield sustainability benefits such as reduced emissions and enhanced positive externalities. However, it is unclear whether potentially higher investment costs due to stricter environmental requirements may be balanced over the life cycle by lower operating costs. According to the Auditor General of Norway, currently only 40% of public procurements use environmental selection criteria, and only 21% weigh them by the above-mentioned 30% (Riksrevisjonen, 2022). Overall, the report indicates that the public sector does not utilize its bargaining power sufficiently, promoting climate policy only to a limited degree.

Criticism claims that the policy behind GPP potentially displaces private purchasing (Cheng, Appolloni, D'Amato, & Zhu, 2018). It is therefore of great importance to analyze impacts of GGP compared to other environmental policy tools such as tradable permits, taxes and fees. In addition, welfare effects of a trade-off between gained environmental benefits and losses due to fewer qualified bids should be considered. It is natural to assume that the latter is especially valid for smaller regions. Including specific environmental criteria may also hamper innovation as requiring mandated standards may distort incentives away from developing even greener technology. Economists tend to prefer technology-neutral procurements valuing outcome rather than process, which fosters innovative solutions. On the other hand, technology neutrality may be weighed according to different criteria, leading to less efficient procurement processes (Arvidsson & Stage, 2012). Hence, it is not obvious which approach is most effective. In this section, we exogenously implement specific environmental requirements, then assess their impacts on the concerning value chains and, hence, intersectoral relations as prerequisite to input-output model analyses.

A report from the World Economic Forum (WEF) (2022) states that public procurements emphasizing environmental aspects will likely cost more, at least in the short run. According to this analysis, GGP may increase procurement costs by between 3% and 6%; but, depending on the sector, about 40% of all related emissions can be abated for less than 15$ per ton CO_2. For municipalities to fully leverage their purchasing power, they need to have the additional costs covered. Otherwise, other concerns may take precedence in budget decisions, such as health and education. However, the whole picture must be seen to evaluate the impact of procurements on green competitiveness and to acknowledge ripple effects throughout the economy. For instance, higher expenses for local authorities may manifest in more competitive industry in the region with an according increase in employment and tax income.

In 2021, Norwegian municipalities and counties purchased from the construction sector for 61 billion NOK. With this, the sector was the largest contributor to procurement expenses – at a substantial climate emission footprint (DFØ, 2023). In other words, there is a large potential to reduce emissions by the sector through stronger emphasis on environmental aspects in procurements. The Norwegian Agency for Public and Financial Management offers guidance on selecting suitable procurement requirements related to the construction sector (DFØ, n.d.), such as to reduce waste by 10%, to collect twice the amount of plastic that is used in the project, and improved waste management.

Practical implementation for scenario analysis

SUMSNorway helps to assess impacts of stronger environmental focus in public procurements. In the following, we outline how the scenario can be interpreted for IO modeling, using the building and construction sector as an example. Specifically, we study two potential requirements, a) more recycling, reuse and repurposing of materials and components in the sector and b) zero-emission building sites, and show how they may lead to changes in the SUTS used as input to the model. In line with the WEF report mentioned above, we assume that the requirements would increase procurement costs by 3-6%. This translates to an accordingly increased monetary flow from the Government sector in the SUT for the product group "Construction and construction works", based on the share of procurements in this flow.

Recycling, reuse and repurposing of materials and components from building and construction gained more attention in recent years, with research projects like REBUS[4] or BAMB[5], and clearer regulatory guidance (Direktoratet for byggkvalitet, 2018). Arenas to share knowledge and experiences (Sirkulær Ressurssentral, 2023) have been established as well as marketplaces for exchange of materials and components, e.g., Loopfront[6], Rehub[7], OMBYGG[8]. Trøndelag county council, with Trondheim municipality among the partners, initiated the DIPLOM project to develop a digital platform facilitating reuse and repurposing of building materials (Trøndelag fylkeskommune, 2023). In practice, projects have been carried out successfully (Futurebuilt, 2022).

With respect to macroeconomic modelling, more reuse and repurposing of building components and materials entails fewer purchases by the construction sector of product groups such as Wood products, Fabricated metal products, Rubber and plastic products, or Other nonmetallic mineral products. Instead, demand for recycled and reused products increases accordingly. Likely, most materials and components are not reused directly within the construction sector, but may first require, e.g., collection, sorting and registration, cleaning, repair and upgrading, storage and re-sale. We assume that such activities happen within sector R37_39 "Waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services". Higher demand for reused/repurposed materials is, hence, reflected by increased purchases of such goods from the R37_39 sector by the construction sector. This shift is illustrated in Figure 5, based on supply and use data for 2019 (Statistics Norway, 2022). Demand for services from R37_39 would also increase, leading to higher activity levels in the sector.

The next modeling step is to estimate how much of the various material and component fractions can be replaced by recycled and reused resources, how much additional sectoral activity this entails and how that would translate to monetary flows. Furthermore, it should be explored how the remaining waste and resources streams and related industrial activity will be affected.

[4] https://www.sintef.no/prosjekter/2020/rebus-reuse-of-building-materials-a-user-perspective
[5] https://www.bamb2020.eu
[6] https://www.loopfront.com
[7] https://www.rehub.no
[8] https://www.ombygg.no

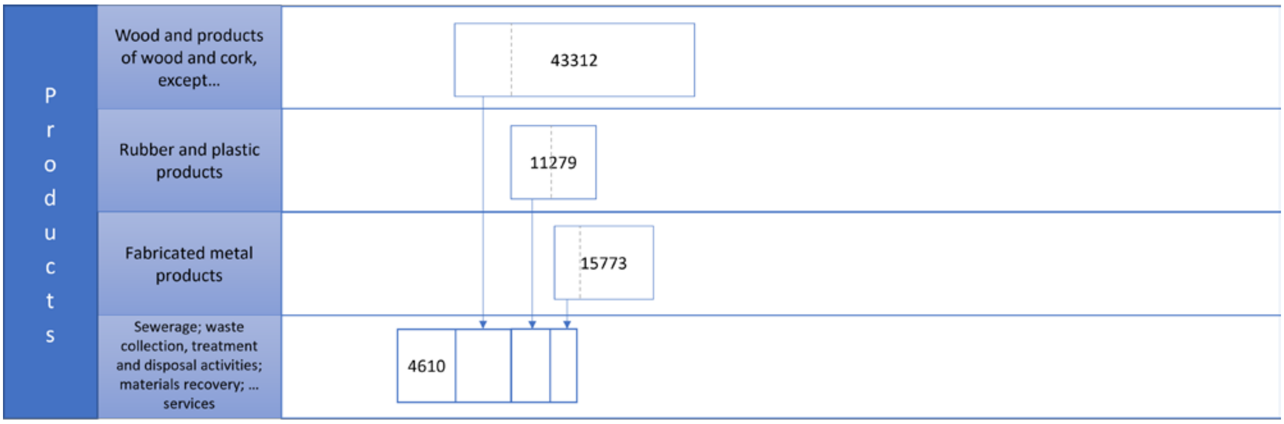

Figure 5. Shift in purchases by the building and construction sector from new to recycled and reused goods

The focus on *zero-emission building and construction sites* increased also in recent years (SINTEF, 2022). Guidelines have been developed (DFØ, 2022) (Miljødirektoratet, 2022), and work on a new Norwegian standard is underway (Standard Norge, n.d.). Oslo municipality set the goal that, by 2025, all building and construction work procured by them shall be have no emissions (Oslo kommune, 2020), while Trondheim municipality aims at completely zero-emission machinery in all municipal building and construction projects by 2023 (Trondheim kommune, 2021). Demonstration projects such as Torget (Miljødirektoratet, 2020) and Marinen (Miljødirektoratet, 2023) in Trondheim show that these goals can be in reach indeed.

In terms of IO modelling, the requirement leads to fewer purchases of refined petroleum products and refined gas by the building and construction sector and, instead, higher demand for power from renewable sources (see Figure 6 based on SUT for 2019 (Statistics Norway, 2022)). Here, not only the share of purchases shifting from fossil to renewable energy sources must be estimated but also potential changes in energy efficiency. Both may affect the ensuing change in monetary flows in the SUT for the scenario.

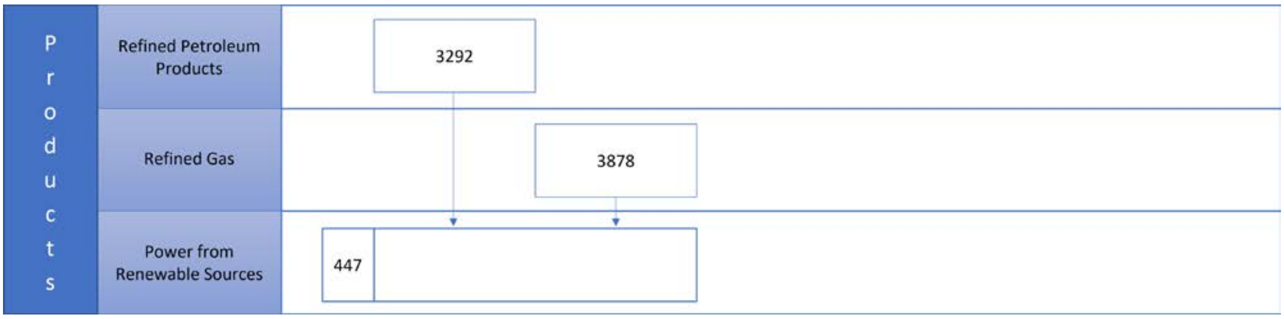

Figure 6. Shift in energy purchases by building and construction sector with low-/zero-emission building sites

3.4.3 Scenario 3: Labour skills, employment, and industry structure

Access to labour with a sufficiently broad skill set, combined with a diversified industry and business structure, is an important prerequisite for (green) competitiveness, strengthening a region's robustness and capability to adapt to changes. It is the responsibility of public authorities at various levels, in cooperation with other actors, to define and implement tailored measures for education and training such that these requirements are met also in the future. However, (direct) impacts of such measures on a region's green competitiveness are challenging to estimate in a macro-economic framework. This scenario will, instead, outline how results of models like SUMSNorway can provide more insight into which areas may require targeted measures, within which time frame and, hence, at which administrative level. For example, selected indicators provide information about which industries may need more or fewer workers, which skills may be demanded, and – with sufficient regionalization – where these industries are located.

Background

The transition towards a low-carbon economy entails structural changes in the economy. Some sectors will face less demand and higher costs, losing competitiveness, while others will become more attractive. This also concerns demand for various labour skills and, vice versa, opportunities for employment as industries that are phased out may have required an entirely different set of skills and competencies than emerging industries. For example, stronger CO_2 taxation may result in higher product prices, and consumer demand may shift from goods to services. In turn, services sector demand for low-skilled labour may increase. In contrast, strengthening circular-economy concepts may stimulate research, innovation and technology development, e.g., within resource recovery and waste treatment, increasing demand for high-skilled labour. Such shifts may create challenges for the labour force, requiring an adaptation to new job demands and acquisition of necessary expertise to participate in the emerging sectors. Lamo et al. (2011) find that highly specialized workers experience more difficulties when facing sectoral demand shifts, resulting in longer unemployment spells. Hence, such structural changes may be accompanied by higher and more persistent unemployment. In turn, a lack of sufficiently skilled workforce may impede transition towards a greener economy as critical sectors cannot tap their full potential.

To ensure a sufficiently strong and broad labour skill base, both short-term (retraining) and long-term/ proactive (education) measures are needed, where responsibilities lie with different actors. For example, municipalities are in control of primary schools, county councils are responsible for upper secondary education while public higher education is under the responsibility of the state. In addition, private actors and institutions such as labour unions, industry associations and businesses may be involved. Efficient cooperation between public authorities and these other actors is crucial to ease the transition and maximize the potential of job creation (Wiebe, et al., 2022).

A regional economy relying on only a few industries will be more vulnerable to economic distortions. In contrast, diversified economies with a large variety of industries provide different sources of revenue and employment opportunities. This diversification acts as a buffer during economic downturns or transitions, as a negative impact on one sector may be offset by the stability or growth of others. It entails that the region can retain a workforce with broader expertise, also reducing needs for lengthy retraining. Emerging industries can easier find sufficiently skilled labour, and workers have more suitable employment options in the region. Consequently, a region with a diverse economic base can better withstand shocks and adapt more effectively to changes.

Practical implementation

SUMSNorway allows us to assess how a green transition may affect demand for labour in a region over time, not only in total numbers, but also categorized according to skills, gender or age groups, and by which sectors. An extension of the model provides a more detailed evaluation of impacts on the population composition, such as age, gender, and education level. These estimates can then be set up against each other to evaluate whether the expected (development of) labour skill demands in the region can be matched by the available workforce. The dynamic nature of the model provides insights about when the respective skills and expertise may be needed.

Industry or sector concentration can provide a measure for how diversified – and, thus, how robust – an economy is. It can be assessed using Herfindahl's index (HHI),

$$HHI = \sum_{i=1}^{N} (\mathrm{MS_i})^2$$

where $\mathrm{MS_i}$ denotes the market share of sector i and N the total number of sectors. The index ranges between 0 (perfect competition) and 10,000 (monopoly). This assessment should be extended taking into account diversification with respect to which sectors emerge or vanish in a green transition and their typical skills and expertise requirements. In addition, skill-based commonalities between environmentally friendly (green) and non-green occupations and sectors should be identified.

Such evaluations give insights towards defining suitable and effective retraining and education measures, their timing and scope and, consequently, which institution or authority may bear responsibility. They may also point out which industries should be stimulated in which way to efficiently utilize the existing skill base. Different regions have different economic and demographic conditions, and transition processes may affect industry structure and labor skill demands differently. More detailed analyses with a regionalized approach can provide a bigger picture and help to coordinate measures between regions.

3.5 Discussion

This first case study outlined how a dynamic input-output approach such as SUMSNorway can be utilized for scenario analyses to better evaluate implications of measures facilitating a green transition. Comparing results of dedicated what-if scenarios with a reference provides a basis to understand how exogenous and endogenous measures can affect municipalities and counties with respect to green competitiveness. With such a flexible framework, modelers can easily adapt parameters (e.g., CO_2 tax level, emission intensities) according to their experience and the specifics of the scenario to be analyzed. This facilitates a systematic investigation of alternatives and variations of policy measures to find the most suitable formulation.

We discussed several scenarios, showing how the analyses can be used in different ways. Scenario 0 is concerned with exploring the impact of supranational and national policies (here, various carbon-taxation pathways) on regional characteristics, also without specific regional policy measures under consideration. Scenarios 1 and 2 focus on measures under control of county councils and municipalities, respectively. While Scenario 1 is concerned with identifying suitable activities to facilitate green industry activities and zero-emission maritime transport, focusing on their impact on a region's energy situation, Scenario 2 demonstrates how a specific public procurement requirement may be modelled to explore effects on a region's green competitiveness. Using expected changes in demand for labour and skills as an example, Scenario 3, on the other hand, shows how results of a model run can be used to identify suitable areas for targeted measures and how to sketch out such measures. Combining Scenario 0 with, in particular, Scenarios 1 and 2 demonstrates the interplay of policy measures at several administrative levels. Likely, it will change the results of the analyses, indicating that the considered measures have different impacts and effectiveness. In turn, this means that different formulations of the measures may be more suitable then.

In today's complex society, estimating a future state of the economy is, naturally, subject to significant uncertainty. It is therefore important to keep in mind that approaches such as SUMSNorway do not directly predict a potential development but can be used to understand how value chains and, hence, regional economies adapt to exogenous impacts such as carbon pricing and stronger environmental procurement requirements. Data availability and quality may limit both scope of analyses and applicability of results, and complementary evaluations are important. Demographic and economic developments are highly uncertain, especially at municipal scale, and may vary from region to region. For example, will current urbanization trends continue? Could carbon taxation (and other climate policies) direct household consumption preferences more toward services and leisure/nature activities, potentially slowing, even reversing the emission-reduction effect of the policies? This should be considered when setting insights from the macroeconomic analyses in a larger picture.

4 Case 2: Indicator selection – circular economy and waste management (CircWtE)

4.1 Introduction

The project "Waste-to-Energy and Municipal Solid Waste management systems in Circular Economy" (CircWtE) has been used as a case to explore methodology for developing an indicator set for dynamic supply-use modelling. The project is funded by the Research Council of Norway (project number 319795) under the SIRKULÆRØKONOMI program. Project partners include CIVAC, Franzefoss Gjenvinning, NOAH, NTNU, Oslo REG, SINTEF Industry, Tafjord Kraftvarme and Trøndelag county council, managed by SINTEF Energy AS. The scope of the CircWtE project is to develop knowledge-based tools and methods to explore how future MSW management systems may look like in a circular economy and which role Waste-to-Energy (WtE) may have.

Previous work in the project has defined five scenarios describing plausible future outcomes of policy and technology development for municipal solid waste (MSW) management:

- Business as usual – *The Current Road* (baseline/benchmark)
- 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.*

The context of each scenario is outlined through a concise narrative, that also includes assumptions on geographical scope, demographic trends, timeframe, legal framework and technologies that are to be considered. These scenarios, with appropriate interpretations, are the basis for various analyses, such as projecting how volumes and composition of MSW streams may develop at municipal and national level, impacts on the composition of WtE residuals (e.g., ash components) and on greenhouse gas (GHG) emissions at larger scale, and impacts on recycling rates.

Task 4.3 "Socio-economic analysis of existing and alternative waste treatment value chains" assesses socio-economic impacts such as effects on value creation and employment. It will also identify long-term sustainability effects as measured by the UN SDGs. The work takes a holistic view, identifying potential interlinkages and trade-offs – making dynamic supply-use models such as SUMSNorway a well-suited approach. Geldermann and Lindgren (2022) described how the scenarios may be modelled for analyses in this context, outlining according changes to the model input. The impacts of each scenario are to be captured through indicators that can be measured based on model outputs and then compared to the Current Road benchmark. Hence, possibilities and limitations of dynamic supply-use methods should be taken into account when developing a suitable indicator set. How this can be done effectively, is the focus area in the following part of this report. Finally, a draft set is presented, together with explanations of why some of the initially studied indicators are included and why others have been left out.

4.2 Theory background

4.2.1 Measuring sustainable development

In 2015, the United Nations adopted the SDGs as a call to action towards ensuring a sustainable future for all (UNDP, 2023). Alongside 17 goals, 231 indicators were developed to effectively measure and monitor sustainable development (United Nations Statistics Division, 2023). To ensure alignment of policies and actions, this monitoring of progress towards the SDGs is anticipated to happen at sub-national, national, regional, and global levels (Fraisl, et al., 2020). The response from various statistical communities has shown remarkable dedication to meet this challenge of measuring and monitoring the SDGs (UNECE, 2020). However, all countries face challenges in this endeavour. This may involve identifying appropriate methodologies, ensuring good data quality, managing and sharing information, and reporting indicators with an appropriate level of disaggregation (UNECE, 2020).

4.2.2 The Triple Bottom Line framework

In 1987, the report Our Common Future presented by the World Commission on Environment pointed out that the term sustainable development must consider environmental, economic and social aspects (World Commission on Environment and Development, 1987). This has also come to be known as the three pillars of sustainability (Wiebe et al., 2022). Inspired by this, John Elkington introduced in the mid-1990s a new framework for performance measurement in corporate America, called the Triple Bottom Line (TBL) (Slaper & Hall, 2011). The framework had the intention to go beyond the traditional economic measures of success, to include environmental and social performance. Alhaddi (2015) explains that the economic line of the framework refers to the economy's capability to evolve into the future and to support future generations. Further, the social line entails conducting beneficial and fair business practices considering the welfare of labour, human capital, and the community. Finally, the environmental line refers to adopting practices that safeguard environmental resources for future generations (Alhaddi, 2015). The UN's understanding of sustainable development has been built on a similar perspective. First, with specifying the reconciliation of lasting economic growth and protection of the environment in 1992, and then adding the assurance of social development in 2002 (Hák, Janousková, & Moldan, 2016).

Even though the TBL framework was initially created as a framework for performance measurement in corporations, both non-profit organizations and governments are increasingly adopting it (Slaper & Hall, 2011). Such sustainability assessment frameworks are used by policymakers to guide decisions about which projects and policies should or should not be implemented to make society more sustainable.

4.3 Indicator selection

The next step of WP4.3 is to develop indicators to measure the socio-economic impacts of the various scenarios that are assessed using SUMSNorway. The model is based on a supply-use methodology, which in essence only involves monetary flows between sectors and final demand. Therefore, it provides a relatively limited basis for calculating indicators. In the following, we outline a process to develop an indicator set with the prerequisite that the indicators can be utilized within such a methodology.

The process starts by establishing a thorough understanding of scope and requirements of the considered case (here, the CircWtE project). Figure 7 illustrates the subsequent steps. We begin with examining relevant known indicator sets that can be used as inspiration. This creates a foundational pool of indicator candidates. Further indicators not mentioned in these sets may also be included if deemed especially relevant. Then, the indicators in the pool are assessed individually. In this step, it is helpful to create suitable categories, stating which types of indicators are interesting to the project. This ensures sufficient variation in the covered aspects such that a holistic analysis approach is guaranteed. The resulting draft indicator set should be discussed with the project team, to decide if the indicators are approved or if more work needs to be done in gathering and assessing indicators. This takes the form of an iterative process until the project team is satisfied, represented by the turning arrow in Figure 7. Then, the draft set can be finalized and prepared to be further discussed with the project partners.

Figure 7. Indicator selection process

4.3.1 Case requirements

When assessing case requirements to select suitable indicators, several considerations must be made. The aim of the case studied here is to investigate socioeconomic effects such as value creation and employment, but also to analyze long-term sustainability impacts aligned with the UN SDGs. In more detail, the work examines socioeconomic impacts of circular economy practices on value chains in the MSW management system, considering political, regulatory, technological, and social factors. It is set to explore linkages between these impacts and the SDGs. With this, it is natural to see sustainability indicators at system level as the basic means of measurement.

Furthermore, it is important to consider the broader task at hand. The indicator set should be applicable to all scenarios but also address the specifics of each scenario. Although all indicators will be important, some will be more relevant than others for a given scenario. For example, indicators on emissions are highly relevant for the Carbon Road scenario. Indicators measuring MSW amounts are particularly interesting for the Frugal Road scenario, while indicators measuring recycling rates are extra interesting for the Circular Road scenario.

Finally, close dialogue must be maintained with all project partners to ensure practical relevance of the analyses. Keep in mind that the case description is essentially only a guiding instrument. At any point, the partners can give the most up-to-date project requirements, and a consideration of these is vital to achieve the societal goal of the project. Thus, this report will only conclude on a draft set of indicators that should be further discussed with the partners before the final indicator set is determined.

4.3.2 Established indicator sets

To identify indicators relevant for our case, several internationally established sets on sustainable development and circular economy have been analysed. These sets have been carefully developed over time and are internationally acknowledged in research and politics. Such indicators can therefore be related more easily to reporting requirements and used as inputs to policy making.

As a starting point, we chose another ongoing project within the research group that includes indicator development, the GKKiK project (Delic, et al., 2022) as well as its preliminary project (Bysveen, Wiebe, Støa, & Johansen, 2020), see also Case 1 in this report and the report by Geldermann and Lindgren (2022). However, while this work is concerned with indicators measuring green competitiveness at a regional level, the CircWtE project investigates socio-economic effects at national and sector level. In addition, we reviewed several established indicator sets developed by intergovernmental organizations and research foundations together with industry experts:

- UN SDG Indicators
- OECD Green Growth indicators
- EU's Circular Economy Monitoring Framework
- IAEA Energy indicators for sustainable development
- Green Growth Index (GGI), Global Green Growth Institute
- Ellen MacArthur Foundation Material Circularity Indicator.

Each set was selected with the intention that it should help cover a part of the case description and follow the theme of the overall project.

UN SDG indicators

This set is essential to include as the case description directly asks to examine effects measured by the SDGs. The UN SDG indicators were developed by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) and are to be refined annually (United Nations Statistics Division, 2023). The set includes 231 unique indicators to measure the world's progress towards the goals. For our case, the indicators are considered in a national perspective.

OECD Green Growth indicators

The OECD describes green growth as “fostering growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies”. The indicator set has been established to measure the progress towards green growth in OECD and G20 countries (OECD, 2017). This entails monitoring progress towards four main objectives:

- Establishing a low-carbon, resource-efficient economy
- Maintaining the natural asset base
- Improving people’s quality of life
- Implementing appropriate policies to realise the economic opportunities of green growth.

The set was developed with the intend that countries can adapt it to their context.

EU’s Circular Economy Monitoring Framework

This framework is designed to monitor the progress of the EU and its member countries on circular economy (Eurostat, 2023). The indicator set is deemed especially interesting as the project’s main theme revolves around circular economy. It is based on the priorities found in the European Green Deal, the 8th Environment action programme, the 2030 Agenda for sustainable development as well as the EU’s security of supply and resilience objectives. The set is supposed to cover the circular economy focus areas together with interlinkages relating to circularity, climate neutrality and the 'zero pollution' ambition. The framework consists of five thematic sections with a total of eleven indicators (Eurostat, 2023):

- Material consumption
- Waste generation
- Waste management
- Secondary raw materials competitiveness and innovation
- Global sustainability and resilience.

IAEA Energy indicators for sustainable development

This indicator set is part of an analytical tool for tracking countries’ progress on energy for sustainable development (IAEA, 2005). It was developed by the International Atomic Energy Agency (IAEA), the UN Department of Economic and Social Affairs, the International Energy Agency, Eurostat and the European Environment Agency. The set includes 30 indicators divided into social, economic, and environmental dimensions. As our case also investigates the role of WtE technology in a circular economy, these energy indicators are considered highly relevant for our draft set.

Green Growth Index

The Green Growth Index has been developed by the Global Green Growth Institute, an inter-governmental organization supporting sustainable economic growth in developing countries and emerging economies (GGGI, 2023). It aims to measure a country’s performance in achieving targets included in the SDGs, the Paris Climate Agreement, and the Aichi Biodiversity Targets (GGGI, 2022). The set contains indicators in the four green growth dimensions on efficient and sustainable resource use, natural-capital protection, green economic opportunities, and social inclusion.

Ellen MacArthur Foundation Material Circularity Indicator

The Ellen MacArthur Foundation Material Circularity Indicator results from a project to address the gap when companies are transitioning from a “linear” to a “circular” business (Ellen MacArthur Foundation and Granta Design, 2015). Intrinsically, it is not an indicator set, but rather only one indicator. However, since it has been developed to measure something that other indicators are not capable of, it is interesting for us to investigate an adaptation to a national/economy level for use in the case analyses.

4.3.3 Indicator categories

The process of gathering and assessing indicators starts by defining certain indicator categories to ensure that the resulting set is sufficiently broad to cover the scope of the analysis. Most of the established sets investigated for our case follow such a set-up and inspired our development of suitable categories. The TBL framework was also used as inspiration. Finally, two fundamental questions have been asked:

- What are the areas that are *interesting* to look at?
- What are the areas that are *possible* to look at?

This resulted in the following categories:

- Economic growth and structure
- Energy and Environment
- Circular economy
- Social impact.

Economic growth and structure includes indicators to measure the direct impact on the performance of the economy in traditional economic measures. It includes not only growth of the economy, but also its structure, i.e., which industries thrive and which shrink and also connections between the industries' production and consumption of various products. Economic structure is particularly well-suited to be measured from supply and use modelling.

Energy and environment includes indicators to assess energy production and consumption, together with indicators measuring emissions. These two concepts are grouped together as they are related and can give a more holistic picture of an economy's dependency on energy- and carbon-intensive industries.

The *Circular economy* category includes indicators on material consumption and waste handling. They cover the economy’s degree of circularity, which is part of the focus area of the studied case.

As recognized by the UN, it is essential to include *social impacts* in monitoring sustainability effects. The social area most accessible for analysis with the modelling method is employment, which has therefore been the focus for this category.

This thematic categorization should also be further discussed with the project partners before the final indicator set is established.

4.3.4 Selection criteria

After collecting a pool of indicators from well-established sets and identifying suitable categories to investigate, it is time to filter out the indicators to be included in the specific draft set. The considerations for their selection indicators can be summarized into three criteria.

1. Relevance. The indicators should fit into one of the defined categories and measure what the scenario analyses are set to examine. This ensures that they are aligned with the project scope and the project partners’ interests.
2. Measurability. It should be possible to calculate the indicators considering the limitations of the modelling method.
3. Simplicity. The indicators should be simple and understandable to maintain a high level of transparency towards, e.g., project partners from industry and public administration.

4.3.5 Indicator assessment process

For each category, the indicator pool is evaluated to identify candidates that may meet the three selection criteria. Each indicator is assessed as shown in Figure 8. Indicators satisfying the criteria are then gathered in a preliminary indicator set. This set may contain indicators at different levels of completion. Therefore, the next step in the process helps to refine and finalize the draft set.

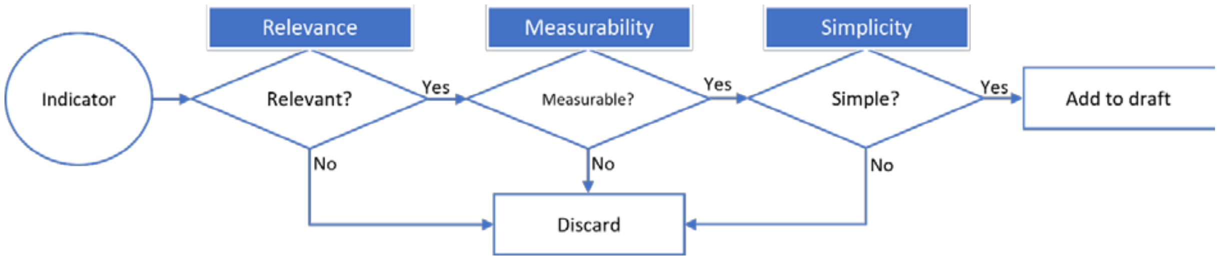

Figure 8. Indicator assessment process

Once such a preliminary draft set is prepared, it should be discussed with the project team, following a similar process. The team should go through all indicators at all levels of completion to assess whether they fulfil each team member's perception of relevance, measurability, and simplicity. The team will then decide which indicators to go forward with, which ones to improve, if any should be discarded and if further indicators may be required to cover the project requirements.

4.3.6 The measurability criterion

As relevance and simplicity are, to some extent, subjective terms, they are recommended to be discussed further with the project partners. Measurability, on the other hand, is an objective term given by the limitations and opportunities of the evaluation method. It will therefore be discussed in more detail here.

As mentioned, this report investigates indicators for supply-use modelling. The methodology is based on projecting monetary flows, which constrains the freedom of movement when selecting suitable indicators. Therefore, a clear picture of the basis for indicator calculation is important.

An ongoing SINTEF project, eaSi-system, develops a framework for systematic SDG impacts assessment (SINTEF, 2021). The approach differentiates between SDG indicators that are directly available from macroeconomic models and indicators that are used to approximate impacts. A similar approach has been used here, distinguishing between two areas that form a basis for calculation.

1. Direct output from the model
2. Background data that can be linked to model output.

Direct output from the model

Dynamic supply and use modelling results in a recalibrated equilibrium in the form of an updated supply and use table, and all parameters in this updated table (illustrated in Figure 3) can be utilized to calculate indicators. These parameters constitute the main calculation basis for indicators in this category. Keep in mind that the supply and use tables are given in monetary values. Therefore, additional background data should be used to link monetary values with other information.

Background data

It is also possible to measure indicators that are not directly computable from the model output by utilizing background information about the sectors and products in the supply and use table. This approach assumes a proportional relationship between various background data and the sizes of sectors and the supply of products given in monetary values. For example, the current emissions of each sector and the current total industry outputs of each sector are known. When the total industry outputs of the sectors are projected to change in the future, each sector's emissions can be assumed to change in proportion, supposed everything else is equal. This assumption greatly increases the freedom of movement when choosing indicators to project. For our case, the following background information has been considered:

- Emissions
- Employment
- Waste generation
- Recycling rates
- Material consumption.

The first two aspects are already implemented in the SUMSNorway model. Data about emissions and employment in each sector at the start of the projection is retrieved from statistical databases such as Statistics Norway's tables 07984 and 13932 (Statistics Norway, 2022b, 2022c). Then, the model gives emissions and employment in the projected future state, based on changes of the sectors' activity levels. This enables the calculation of indicators such as emissions per sector and employment per sector.

However, finding suitable background data can be challenging, specifically since it needs to be segmented into each sector or product category. Databases like the ones by Statistics Norway have large amounts of data that is valuable for such analyses but not always categorized by sectors, and rarely by product groups. Even then, data and model categorizations do not necessarily harmonize. In some cases, adaptations can be made, for instance, when the data is segmented into primary, secondary, and tertiary sectors. For the case studied here, background information on waste generation relies on data generated in another task in the CircWtE project. This work mapped and projected current and future MSW streams and composition in Norway using both existing data and estimations. For background information on material consumption, no suitable data were found.

The approach assumes proportional changes in background information relative to shifts in sector sizes or total production and does not allow for variations in production intensities. That is, SUMSNorway cannot reflect endogenous intensity changes as a response to, e.g., policies leading to technology shifts. For example, reductions in carbon or labour intensity resulting from technological advances must be provided exogenously to the model. This can be achieved by directly modifying the intensities at a specific time point or by introducing new sectors with different starting intensities. The latter points to a way to circumvent this limitation.

Split and aggregate

In addition to utilizing direct output and background data, there exists a method to study indicators that are originally exogenous to the model but may be expected to change (such as the intensities discussed above). It relies on the fact that the model projects the sizes (activity levels) of the sectors in terms of value added, and that we can assume proportional changes in background information.

Intensities can be explained as how much of a product or service much a sector uses or creates related to value added. Initially, there would be no point in measuring an intensity by way of an indicator based on model output, as it would remain the same when sector sizes change. However, to investigate effects related to intensity changes, one may split a sector into subsectors with different pre-defined intensities. Running the model will then give a projected change in activity levels of the subsectors. Aggregating these results to sector level again, gives a new, changed intensity for the whole sector. For example, to model transition to a new, less emission-intensive technology, the concerned sector is split into a "green" (new) and a "brown" (traditional) part with different exogenous emission intensities. After running the model, the new emission intensity for the entire sector can be determined based on each sub-sector’s share of value added. This approach is referred to further on as *split and aggregate method*, illustrated in Figure 9.

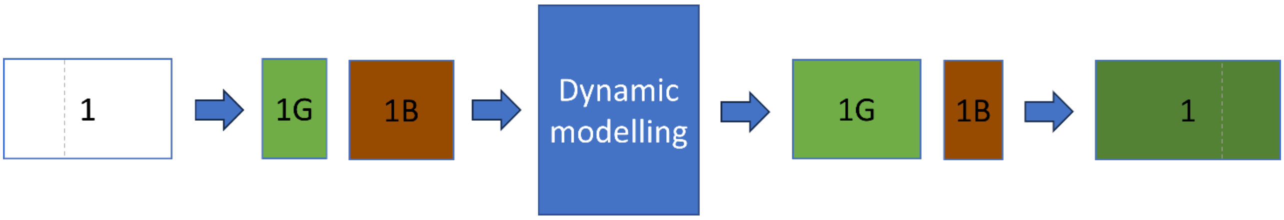

Figure 9. Split and aggregate method

4.4 Indicator set draft

Table 3. Indicator set draft (* Indicator makes only sense to measure when using split and aggregate method, otherwise measures an exogenous value.)

Category	Indicator	Purpose	Especially relevant scenarios	Inspiration indicator set
Energy and Environment	**Energy use per unit of GDP**	Measure overall productivity	Carbon road	IAEA, ECO2
	Energy use per sector	Compare energy demand	Carbon road Circular road Frugal road	OECD
	Energy use per sector, per value added*	Measure sector-specific productivity	Carbon road	IAEA, ECO6-ECO10
	GHG emissions per unit of GDP	Measure overall productivity	Carbon road Frugal road	SDGs, 9.4.1
	GHG emissions per sector	Compare emissions	Carbon road Frugal road	IAEA, ENV1 EU Circular Economy
	GHG emissions per sector, per value added*	Measure sector-specific productivity	Carbon road	OECD
Economic Growth and Structure	**GDP per capita**	Measure economy performance	All	OECD
	Value added per sector	Measure sector performance	All	OECD
	Intersectoral relations	Measure sector interdependencies	All	
	Imports per sector	Measure import-dependency	All	IAEA, ECO15 EU Circular Economy
	Net taxes per sector	Compare taxation	All	
Circular Economy	*Material circularity*	Measure economy's state of circularity	Circular road	Ellen MacArthur Found.
	Domestic material consumption per capita	Measure material consumption	Frugal road	SDGs, 12.2.2 GGI, ME1
	MSW generated per capita	Measure MSW generation	Frugal road	EU Circular Economy GGI, EQ3 OECD
	National MSW recycling rate	Measure circularity of MSW value chains	Circular road	EU Circular Economy SDGs, 12.5.1
Social Impact	**Employment per sector**	Measure labor demand	All	SDGs, 9.2.2
	Employment per sector by skill level	Measure skills demand	All	SDGs, 4.4.1, 4.6.1
	Unemployment rate	Measure social impact	All	SDGs, 8.5.2

The draft set shown in Table 3 results from the selection process described in section 4.3. It requires further development, including discussion with the project partners, before it can be finalized. Indicators that are stated as measured per sector, are vectors with measurements for all sectors. From this, one can select the values for the sectors that are most relevant for the analysed scenario. Some indicators can be measured either as total values per sector or as intensities (e.g., related to value-added). The former allows to assess the total contribution of the sector, in relation to other sectors or to the whole economy. The latter helps, e.g., to investigate if carbon-intensive sectors also are tax intensive (indicator "Net taxes") and to explore a sector's dependency on imports in more detail (indicator "Imports").

The three selection criteria explained in section 4.3.4 are crucial for determining which indicators to include in the draft. We discuss some of the included indicators in the following, outlining our reasoning for each criterion. Additionally, certain indicators in the draft, marked in italics, require further refinement to meet the criteria. The subsequent section describes these. Finally, we exemplify indicators that were not included in the draft set, explaining the criterion they failed to fulfil.

4.4.1 Approved indicators

The following are examples of indicators that were approved on relevance, measurability, and simplicity.

GHG emissions per sector

This indicator measures total tons of CO_2 equivalents emitted per sector, as inspired by the IAEA and EU Circular Economy indicator sets. In other words, it will give one value for emissions for each sector. It is placed in the Energy and environment category as it measures environmental impact and is especially relevant for the Carbon Road and Frugal Road scenarios. Both scenarios expect changes to emissions and to sector composition.

The indicator is measurable by utilizing the direct output of value added per sector in the new equilibrium in the supply and use tables, together with background information about emission intensities of the technologies used in the sectors. A challenge here would be to gather this background data by sector. However, this is already achieved in the SUMSNorway model.

Using CO_2 equivalents to measure emissions has become a widely recognized method, extensively utilized to support policy making. The indicator is thus considered to fulfil the simplicity criterium.

National MSW recycling rate

This indicator measures the MSW recycling rate at national level. It has a tight connection to the focus on recycling in the Circular Road scenario. The indicator captures if the model's output implies changes to the overall recycling rate. It can therefore be considered relevant according to the definition of the criterion.

The indicator is measurable by assuming proportional changes as discussed in section 4.3.6. The model estimates changes to sector sizes, measured by changes in value added. The first step would therefore be to map the amounts of the different MSW fractions produced in each sector. Next, background data about potential recycling rates for each fraction can be used to calculate a weighted total recycling rate for each sector. Furthermore, we can assume that projected total MSW amount from each sector is proportional to the change in sector size. Now, a weighted sum for the national recycling rate can be obtained, aggregating the recycling rates of each sector weighted by projected total MSW amount generated by the sector. This is illustrated in Figure 10.

Sector	Generates MSW?	MSW fraction(s) from sector	Amount of MSW fraction(s) from sector (1000 tons)	Recycling rate of MSW fraction	Recycling rate of sector (weighted by fraction)	Total MSW from sector before model run (1000 tons)	Change in sector size from SUMSNorway	Total MSW from sector after model run (1000 tons)
R01: Products of agriculture, hunting and related avivities	Yes	Park/garden waste	161	88%	68%	210	15%	242
		Mixed waste	49	0%				
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
				Indicator	Weighted sum of recycling rates, where each rate is weighted by the total MSW from sector after model run			

Figure 10. Calculation of national MSW recycling rate

The indicator describes how much of the MSW produced in the economy is recycled. The term recycling rate is widely known and commonly used in policymaking. Therefore, the indicator is considered to meet the requirement of simplicity.

Note that, depending on the quality of the background data, it may be necessary to distinguish MSW from domestically produced goods and MSW from imports, see also the discussion in section 4.4.2.

Unemployment rate

For all scenarios, it is important to examine the social impacts they entail. Unemployment rate is a relevant indicator as it gives an indication on the state of the economy and the wellbeing of its citizens. It represents a consideration that policy makers often keep in mind when formulating strategies.

The indicator is measured by utilizing background data on demographic projections, including the expected size of the workforce. In addition, background data about labour intensities of each sector is used together with direct output from the model on value added per sector to calculate labour demand for each sector. Then, the unemployment rate can be calculated with the following formula.

$$\frac{WF - L}{WF}$$

WF – expected size of the work force
L – expected labour demand.

Unemployment rate is a widely used indicator in socioeconomics and policy making, which needs no further explanation. Thus, it contributes to the transparency of the indicator set and fulfils the final criterion of simplicity.

4.4.2 Indicators requiring further development

The following indicators need more research before they can satisfy the criterion of measurability.

Material circularity

The material circularity indicator is set to measure the economy's state of circularity as a value between zero and one. Zero indicates no circularity and a completely linear flow of materials, while one indicates full circularity and a completely restorative flow. The indicator is heavily inspired by the Ellen MacArthur Foundation's Material Circularity Indicator and can be seen as a simplified version suitable at national or sector level. The formula is as follows:

$$MC = (0, MC^*), MC^* = \frac{V + W}{2M}$$

V – amount of virgin material used
W – amount of unrecoverable waste
M – mass of all products.

Remaining work involves defining clearly in the context of the analyses what constitutes virgin material input as well as finding estimates for this, the amount of unrecoverable waste produced, and the total mass of all products produced.

MSW generation per capita

This indicator is intended to measure the total production of MSW per capita but is not fully developed yet in terms of measurability. To project the indicator, we assume that, for each sector, changes in value-added are proportional to changes in the production of goods that entail MSW. Therefore, data is needed on how much MSW each sector produces. Construction of such data has been initiated (Geldermann, Lindgren, Perez-Valdes, & Werner, 2022) but the generated information did not discern the significant share of MSW from products imported from abroad. Therefore, a remaining task is to estimate this proportion of MSW and the distribution of the remainder across the domestic production sectors. Consequently, there are two possibilities for how this indicator can be utilized further.

1. Interpret it as "Domestic MSW generated per capita" and do not include the imported MSW in the calculation.
2. Keep it as it is and use changes in imports, from the model, to estimate proportional changes to the amount of imported MSW.

The estimation, along with a decision about which method is suitable for a scenario, remains to be done before the indicator fulfils the criteria.

Intersectoral relations

This indicator aims to point out interdependencies between sectors in the economy. It takes the form of a matrix showing how much each sector purchases from and sells to other sectors. Essentially, it is an input-output table to be derived from the supply and use table. The indicator can help to uncover weaknesses in supply chains where certain sectors rely highly on others, making them vulnerable to changes in these sectors. Remaining work includes figuring out how to calculate this indicator from the supply and use tables and how it can be used in a meaningful way to guide policies.

4.4.3 Rejected indicators

The following are examples of indicators that have not been approved on relevance, measurability, or simplicity, respectively.

Energy production, total

This indicator measures total energy production across all energy-producing sectors. It is an indicator that, on a general basis, can be interesting. However, the dynamic modelling approach in SUMSNorway assumes that production is demand driven. None of the specified scenarios are expected to yield changes in energy demand. Consequently, this indicator does not measure anything relevant for the analyses, and it does not meet the criterion of relevance.

Net disposable income

In addition to measuring how various measures may affect employment, it may be interesting to assess effects on the disposable income of an average employee. The indicator is calculated by subtracting income taxes from wages. The supply and use tables give wages in the value-added section. However, the SUMSNorway model currently lacks a detailed financial extension module such that, e.g., effects on income tax cannot be projected. Thus, this indicator fails to fulfil the criterion of measurability.

Hazardous waste generated per capita

This indicator is set to measure the amount of hazardous waste produced per capita. Basically, it can be interesting to monitor when studying MSW value chains. However, determining the indicator involves several unresolved issues. Firstly, there may be questions about what is defined as hazardous waste. Different partners may have varying perceptions. Furthermore, all different types of hazardous waste are aggregated into one sum. Disagreements may arise regarding whether all types should be weighed equally or if some are more hazardous than others. The aggregation obscures also which types of waste, if any, constitute the majority. Furthermore, sources of the waste must be clarified, which sectors contribute to its production, and whether certain activities within the sectors are more significant in this context. With this lack of transparency, the indicator fails to meet the criterion of simplicity.

4.5 Discussion

While the focus of this section has been on developing a set of indicators based on their measurability from a specific dynamic supply-use model, it is essential to maintain an open mind throughout the process. Limitations of the underlying model lead to the exclusion of several types of indicators. As a consequence, certain indicators crucial for supporting policymaking might not be included, which must be addressed during further comparison and analysis. An option is to incorporate complementary methodologies or additional indicators that may offer a more comprehensive understanding of the scenarios.

Furthermore, collaboration with project partners plays a fundamental role to refine the indicator set and to ensure its relevance for real-world policymaking processes. Acknowledging the potential constraints of the model and actively seeking diverse perspectives can enhance the robustness and applicability of the proposed approach. This will lead to a better understanding of the complexities of industrial changes, ultimately promoting sustainable development.

5 Discussion and final remarks

Scenario analyses used together with macroeconomic models are well-suited to shed light on expected consequences of policies, strategies, and development plans, in particular related to environmental and economic impacts. This includes both how local authorities are affected by decisions outside their scope of action and which impacts the policies of local authorities may have. While our work demonstrates certain aspects, it does not encompass all parts of the complex and interconnected systems in play. Moreover, it is necessary to complement the analysis with other methods to obtain a sufficiently good knowledge base to make well-informed decisions.

This report has investigated methods to put these analyses into practice, with a focus on two key aspects: a) implementing scenarios into actionable information for application of dynamic supply and use models, and b) developing a set of indicators for impact measurement and comparison. Initially, we discussed these approaches at a broader level, and subsequently, we provided practical demonstrations using two project cases. We outlined guidelines that include fundamental questions and critical considerations to aid in the application of these approaches.

There are nearly unlimited factors that can influence regional green competitiveness. The first case study, GKKiK, investigated how policy on a national level (Scenario 0: carbon tax) can interplay with local policies (Scenarios 1 and 2) and affect regional industry activities (Scenarios 1 and 3). It outlined also how this can be translated into input to dynamic supply-use models. On this basis, we can evaluate more concretely how, e.g., emissions and demand for clean energy or various types of labour (skills) may be affected. In summary, the first case addressed several aspects that impact competitiveness, including supranational (EU laws, ETS), national (carbon tax), and local (public procurements) measures.

Subsidies are often seen as more politically feasible than taxes. A badly designed carbon tax may face opposition from low- and middle-income populations (e.g., yellow vest protests in France, coal miners in the USA). Looking ahead, it is unclear which measure will become the preferred one for efficiently reducing emissions. Therefore, it is important to have a flexible setup that can be easily adjusted according to the circumstances. In a model such as SUMSNorway, the according parameters can be tailored as needed, making it well-suited to investigate various such measures.

The second case study demonstrated considerations that should be taken when developing an indicator framework for dynamic supply-use modelling. The study reveals two main types of data sources that can be utilized: direct outputs from the model and background data linked to those outputs. By combining these, a comprehensive set of indicators can be derived, which, when projected forward, can provide valuable input to policymaking processes. Additionally, a methodology was discussed to measure changes in intensities that are essentially exogenously given in the model. Further such approaches to expand the foundation for measuring indicators could be explored in future studies.

While the methodology offers promising opportunities to project several critical indicators, it also has its limitations. Data availability poses a constraining factor for generating indicators from background data. Moreover, certain types of background data cannot be easily linked to model outputs, such as biodiversity and land use. To address this, a detailed categorization of activities and their positive or negative contributions to these topics would be required. Splitting sectors based on activities and estimating intensities for each subsector may facilitate an analysis that encompasses several more sustainability aspects. Such an approach would demand substantial effort, but progress is already evident. For instance, the EU's taxonomy classifies sustainable activities, opening for potential indicators related to green employment and green innovation. These advancements indicate that the approach discussed in this report can be expanded and further improved, providing an even stronger basis for policymaking, and helping the world to achieve the sustainable development goals.

To conclude, this report has examined how an input-output based model can be used to provide essential information for policy makers. It has also highlighted the complex interplay between regional, national and supranational policies. The methodology allows to assess potential effects of policies and strategies before their implementation. By utilizing indicators, different formulations can be compared, and the most suitable solutions under the current knowledge base can be found. However, the approach does have its limitations as it cannot account for all factors, and further research may focus on enhancing the methodology in light of the continuously evolving landscape of sustainable development.

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