WIFO ■ WORKING PAPERS
732/2026

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WIFO Working Papers 732/2026
August 2026

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2026/1/W/0

Media owner (publisher), producer: Austrian Institute of Economic Research
1030 Vienna, Arsenal, Objekt 20 | Tel. (43 1) 798 26 01 0 | https://www.wifo.ac.at
Place of publishing and production: Vienna

Free download: https://www.wifo.ac.at/publication/pid/72509616

The Macroeconomic and Biophysical Impacts of Decarbonization and Circular Economy Strategies. A Scenario Analysis for Austria

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Abstract

Growth in resource use is a key driver of climate change and environmental degradation. In recognition of this, a few governments have set targets to reduce their countries' per capita resource use while striving to achieve the goals set out in the Paris Agreement. In this context, the concept of the circular economy (CE) has attracted mounting interest as a means of mitigating climate change, reducing resource use and waste generation, while advancing economic performance. This paper uses a mass-balanced biophysical model (CeAT) linked to a macroeconomic model (DYNK) of the Austrian economy to analyse different stock-flow scenarios, combining a decarbonization scheme with CE strategies at varying levels of ambition. The analysis examines Austria's buildings, transport, and electricity sectors, evaluating economic impacts by employment, GDP, and disposable income results. The framework incorporates two stylized indirect rebounds effects arising from CE strategies of narrowing, i.e. reduced growth in infrastructure, buildings or car fleets. These rebound effects, driven by the reallocation of financial resources, manifest through two distinct consumption pathways: service-oriented and goods-oriented expenditure patterns. Findings indicate, the strong CE scenario can achieve substantial dematerialization. At the same time, it shows potentially the highest average growth rates in disposable income when combined with a service-oriented rebound. First order CE strategies (refuse, rethink, reduce) are therefore of key importance for the triple agenda of climate mitigation, resource use reductions and economic growth. Particularly, demand-side reductions can enhance economic performance if the rebound effects are constrained by reallocating the freed-up expenditure to low-material-intensity services.

Keywords: decarbonization, circular economy, economic impact analysis, resource consumption, indirect rebound effect, scenario analysis.

JEL Codes: Q39, Q43, Q54

Highlights

- Integrates a biophysical with a macroeconomic model of the Austrian economy.
- Develops a decarbonization scenario in combination with different circular economy strategies.
- Assesses biophysical constraints from reduced infrastructure growth in economic terms.
- Demonstrates potential economic gains from narrowing resource flows.
- Reveals service-oriented rebound drives circular economy effectiveness further.

1. Introduction

The increasing use of natural resources is the primary driver of the triple planetary crisis: climate change, environmental pollution, and biodiversity loss (UNEP IRP, 2024, Rockström et al. 2023, 2009; Richardson et al. 2023, Steffen et al. 2015). The current high levels of resource consumption in industrialized countries thus face clear limitations. Recognizing this, governments have formulated strategies and partly set targets to reduce per capita resource use while working toward the temperature goals of the Paris Agreement.

In this context, the concept of the circular economy (CE) has gained growing attention in academia, businesses, and policymaking as a means for achieving resource efficiency, climate mitigation and economic growth. However, the potential of different CE strategies to reduce resource consumption and carbon emissions to sustainable levels remains insufficiently studied (Cantzler et al., 2020, Wiedenhofer et al. 2025).

The CE seeks to transition from a linear "take-make-dispose" model to a circular one by decoupling resource use from economic activity and designing waste out of the system. It promises to enhance domestic economic performance while promoting climate change mitigation and reducing reliance on finite resources, including fossil fuels (Cantzler et al. 2020, Ellen MacArthur Foundation, 2013, European Commission 2015). The CE is understood here as a concept based on three groups of strategies: first, narrowing resource input (refuse, rethink, reduce), second, slowing down resource throughput by extended service life of products and infrastructure (reuse, repair, refurbish, remanufacture, repurpose), and third, closing resource loops through recycling and recovery (Potting et al. 2017, Morseletto 2020).

With two of its three groups of strategies, namely narrowing and slowing resource use, the CE prominently addresses demand-side reductions at a conceptual level. The argument is that mitigation measures are not sufficient to achieve the targets and that much more attention must be paid to avoid and shift strategies (Creutzig et al. 2024). While the scientific community highlights the importance of demand-side measures, suitable policy debate and relevant measures addressing such reductions are missing, as especially shown for Austria but also the EU (Brad et al. 2024; Creutzig et al. 2024; Grabow et al. 2026). One reason for this lies in the crucial dependence of states on both economic growth and its general perception as a means of improving the living conditions of their citizens. Decarbonization and the reduction of material consumption are jeopardising this relationship, as they interfere with the growth paradigm (Brand et al. 2025).

However, scientific investigations to explore different options of decarbonization and CE strategies and their effects on growth and disposable income[1] – the latter a veritable indicator of citizens' well-being (Stiglitz et al. 2009) – are rare (Cantzler et al. 2020; Wiedenhofer et al. 2025). Furthermore, such studies need to pay sufficient attention to rebound effects, as reductions in energy and material consumption from "refuse"-strategies free up financial means that might be spent with improved or diminished impacts on the environment. While there is growing

[1] Disposable income is the amount of money an individual or household has available for spending, saving, or investing after deducting all mandatory taxes from total income.

awareness of the circular economy rebound effects of material efficiency strategies such as reuse, repair, or recycling that threaten the environmental benefits (Zink – Geyer 2017, Lowe et al. 2025), our analysis goes one step further by including "refuse"-strategies. This addresses the indirect rebound effects of demand shifts, that have not yet been explicitly captured by the literature in the CE context.

Against this backdrop, this article strives for shading light on the economic impacts of combined decarbonization and CE strategies for achieving the set goals. In this context, the case of Austria is particularly interesting, as Austria is one of the few countries that has set clear targets for both climate neutrality and reducing material consumption. In 2020, the Austrian government set a goal to achieve carbon neutrality by 2040. Furthermore, it aims to reduce domestic material consumption (DMC) from 17 tons/cap/yr in 2022 to 14 tons/cap/yr by 2030 and lower the material footprint from 22 tons/cap/yr in 2020 to 7 tons/cap/yr by 2050 (BMK 2022).

Given these targets and the research gap, the authors analyzed these two strategies using an integrated biophysical and economic modeling approach by assessing:

- The impact of decarbonization (DC) on material consumption.
- The contribution of a circular economy (CE) to dematerialization.
- The economic impacts of these strategies.

To ensure a high-quality biophysical stock-flow scenario analysis, the study focused on selected sectors — buildings, transport (both passenger and freight), and electricity generation — due to their high material and carbon intensity, their interconnected nature, and their relevance to climate change mitigation and economic growth.

The paper is structured as follows: In Section 2, we describe the research approach and methodologies, section 3 outlines the scenarios, section 4 presents the results, and section 5 provides the conclusions.

2. Research Approach and Methodology

In a first step, possible realizations of decarbonization and circular economy (DC&CE) strategies were defined as scenarios and implemented in the biophysical model CeAT (Circular economy Austria, Haas et al. 2025, section 3). The strategies include transformation of existing stocks, i.e. slower growth in capital stocks (buildings, road networks, passenger car fleet) than in the counterfactual, and replacement of stocks (e.g. from fossil-powered to electric vehicles, electricity facilities based on renewable sources). These changes in stocks lead to reductions in physical flows and related embodied and operational energy demand. In a second step, the changes in physical flows were translated into altered monetary flows and fed into a macroeconomic model of the Austrian economy (DYNK, Dynamic New Keynesian, Kettner et al. 2024b).

The overall result was that the decrease in physical and monetary flows was mainly achieved with "narrowing" CE strategies. In economic terms, this would c.p. equate to a reduction in demand and an increase in the saving rates of private households. However, in this paper we assumed equal savings rates in all the scenarios. Reduced spending on housing, transport, and energy consumption due to DC&CE strategies, especially in "narrowing" strategies, will then be offset by increased consumption of other goods and services, which may lead to a smaller or larger indirect rebound effect[2], depending on the goods and services concerned (de Haan, 2008; Gonçalves Castro, et al., 2022). The type of commodity basket demanded thus determines the overall economic impact from freed up financial resources. We assessed two stylized expenditure shifts in economic terms: one directed toward material-intensive, mostly imported goods (e.g. smart phones, computers) and the other toward less material-intensive services (e.g. care, education, culture, and tourism). The related economic impact was modelled in terms of employment, GDP, and disposable income.

Methodologically we broke new ground by combining a strictly mass-balanced biophysical model (CeAT; Haas et al. 2025) with a macroeconomic model of the Austrian economy (DYNK, Kettner et al. 2024b). The macroeconomic model was used to simulate how the physical changes in stocks and demands resulting from the defined scenarios and implemented in the biophysical model may affect employment, value added and disposable income of private households.

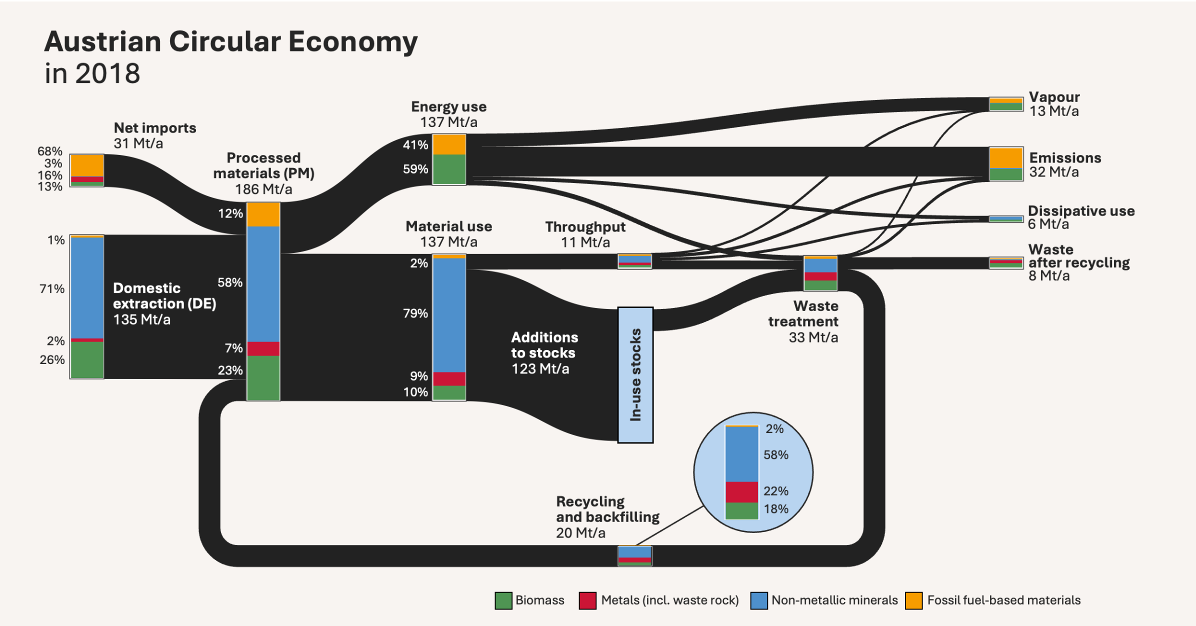
2.1 The Biophysical Model CeAT

The biophysical circular economy model for Austria, CeAT, follows economy-wide material flow accounting (MFA) conventions (Krausmann et al., 2017; Haberl et al., 2019). It tracks all flows of biomass, metals, non-metallic minerals, and fossil fuels from domestic extraction and imports through processing and transformation to capital stocks, exports, emissions, wastes, and recycling flows. The model has been applied to the global economy (Haas et al., 2015, 2020), the EU-27 (Mayer et al., 2019), Austria (Jacobi et al., 2018), and South Africa (Haas et al., 2023). For

[2] We use the term indirect rebound effect to refer to the impact of spending the financial resources freed up by reduced material and energy consumption as a result of DC&CE strategies, in particular "narrowing".

this analysis, the Austrian model has been expanded in several respects (Haas et al. 2025, Figure 1).

Figure 1: Material flows from inputs to outflows, additions to stocks, demolition, and discards of stocks for Austria, 2018



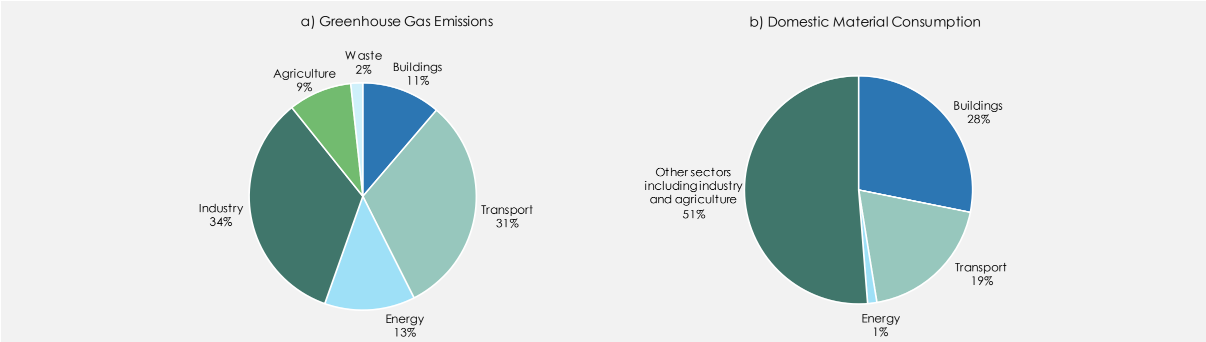
Source: Adapted from Haas et al. 2025

In a first step, the biophysical CE model CeAT was updated to the year 2018 and extended in a baseline scenario to 2040. To this end, we analysed the trend in material intensities for domestic extraction, import, and exports for the main material categories (biomass, metals, non-metallic minerals and fossil fuels in t/€) for the period from 1990 to 2018. Based on the declining trend in material intensities and GDP forecasts, we assumed that this trend would continue for the remainder of the modelling period.

We developed and applied two average GDP projections up to 2040 as reference scenarios. In R1 "smooth recovery", we assume that the economy will recover from a short dip in economic performance, growing at an average annual rate of 1.3%. This is slightly lower than the mid-term economic forecast (Baumgartner – Kaniovski 2021) and the GDP growth rate of the energy scenarios (Environment Agency Austria 2021) at the time. For a sensitivity analysis, we used the reference scenario R2 "slow recovery, zero growth". As we started our analysis during the first year of the COVID-19 pandemic, there was high uncertainty surrounding future economic development. A straightforward continuation of past GDP trends seemed somewhat unrealistic. GDP projections reflect developments in line with the principles of the 'With Existing Measures' (WEM) scenario methodology (Austrian Environment Agency 2023). This methodology accounts inter alia for planned and implemented climate mitigation measures by a certain deadline (Haas et al. 2025).

By multiplying average GDP growth rates (R1, R2) with material intensities, the annual material flows for both reference scenarios were calculated up to 2040 for the main material categories. The three sector modules (buildings, transport, and electricity generation), which represent the focus of the study, collectively covered 51% of emissions or 49% of domestic material consumption (DMC) in Austria in 2018 (for details see Haas et al. 2025, Figure 2).

Figure 2: Sector shares in greenhouse gas emissions and domestic material consumption (DMC), 2018



Source: a) Environment Agency Austria 2022, b) Haas et al. 2025.

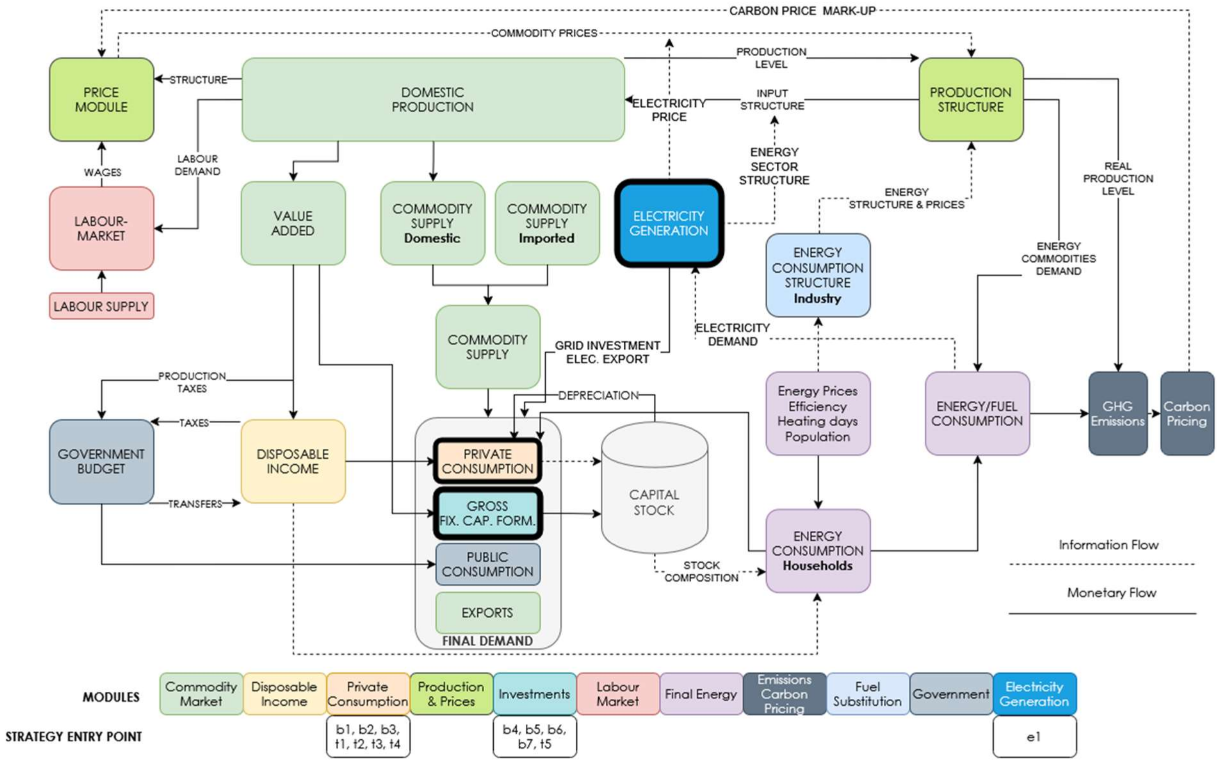
The CeAT model is a stock driven model. Consequently, scenarios were implemented by changing the future extent and composition of material stocks. In addition to the reference scenarios (R1, R2), three scenarios were implemented reflecting (A) full decarbonization in the three sectors of observation by 2040. In addition, scenario (B) implemented moderate, and scenario (C) strong CE strategies, or intensifications of the strategies of the previous scenarios (section 3). Each scenario changes future material stocks, and consequently material and energy demand and associated CO_2 emissions (for details see Haas et al. 2025).

2.2 The Macroeconomic Model DYNK

The Dynamic New Keynesian model DYNK is a macroeconomic model covering the economic activities of 74-90 NACE[3] sectors in a single region, see Figure 3 for a schematic diagram of the model.

[3] Nomenclature Statistique des Activités Économiques dans la Communauté Européenne (Statistical Classification of Economic Activities in the European Community)

Figure 3: Schematic diagram of the DYNK model



Source: WIFO representation

2.2.1 The DYNK Model in a Nutshell

DNYK is calibrated to the year 2018 and has an input-output-table in its core. It is a hybrid between an Input–Output (IO) model and a Computable General Equilibrium (CGE) model. It is an IO model in the sense that it is demand driven, as all that is demanded is produced.

On the supply side the capital market is not explicitly modelled and thereby not a limiting factor, unlike in CGE models. However, like in CGE models labor supply is a limiting factor to production in real terms through prices in the price system.

This labor market modelling approach bears some similarities with Dynamic Stochastic General Equilibrium (DSGE) models, as it explicitly describes an adjustment path towards a long-run equilibrium. The term 'New Keynesian' refers to the existence of a long-run full employment equilibrium, which will not be reached in the short run, due to institutional rigidities. These rigidities, as collective bargaining agreements, job market frictions or other regulations, for instance, slow down the adjustment of the wages to clear the labor market. This long-run equilibrium, or natural rate of unemployment, is calibrated by observed averages. However, the actual natural rate is not observable and can change over time due to demand shocks or institutional changes (Blanchard 2018, Shulman 1989).

The DYNK model provides an elaborated approach regarding consumption. Demand of private households is represented by at least 47 consumption categories (COICOP[4]) and is determined endogenously by consumer behavior[5]. The income of households is fed by wage income, self-employment income, profits and transfers. Commodity prices comprise producer prices and taxes/subsidies. Durable, non-durable and energy goods are treated separately. The representative private household is the sum of a subset of up to 250[6] household types which can each differ in income sources, consumption patterns and behavior[7].

In DYNK, the production structure of each sector is determined by a five-factor production function[8]. The applied own- and cross-substitution elasticities of those factors are determined by estimated coefficients using a translog specification[9]. This specification allows elasticities of substitution to vary with input levels (unlike Cobb–Douglas). They are used when the aim is a flexible specification that can approximate many underlying technologies without imposing constant shares or elasticities. However, due to the macroeconomic nature of the model, the estimations are based on sectoral accounting values rather than physical production relationships. Hence the link to physical dynamics can be criticized (Felipe - McCombie 2013).

A central feature of DYNK is that monetary flows of the IO structure are linked to physical satellite accounts data for energy and GHG emissions. The energy block of DYNK derives physical energy demand of industries based on their energy commodity demand (in constant prices), while energy consumption of private households is calculated directly in the form of econometrically estimated service energy demand equations.

A detailed description of the model can be found in recent applications (Kettner et al. 2024a, Kirchner et al. 2025) and in the supplementary data in Kettner et al. (2024b). See also Appendix C for additional information on the model.

2.2.2 Model extension

For this study the data and code structure of DYNK has been extended and modified in comparison to Kettner et al. (2024b). These changes are (i) the disaggregation of relevant sectors (sectoral extension), (ii) the link of specific households' consumption and investment categories to exogenous data, (iii) fixed savings rates, (iv) the explicit calculation of net disposable income and using it as the central parameter for non-durable/non-energy consumption.

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[4] Classification of Individual Consumption by Purpose

[5] Behavior is simulated via estimated elasticities of prices and demand.

[6] Depending on the research question, households can be allocated into groups based on region, income quantile, living situation (owner/tender) or similar. The disaggregation is based on the consumer survey of Statistik Austria.

[7] Behavior in the sense of consumption reaction to disposable income and commodity prices which are determined via elasticities.

[8] The five factors are: Capital, Labor, Energy, Intermediate Imported Goods, Intermediate Domestic Goods (KLEMD)

[9] Translog stands for transcendental logarithmic and approximates the Cobb–Douglas case of a Constant-Elasticity-of-Substitution function.

(i) Sector extension: The core of the DYNK model is based on the Austrian supply- and use tables (SUT) and contains interdependencies of 74 industries (NACE and CPA 2008). The number of sectors and commodities was expanded from 74 to 90 sectors and updated to the latest available IOT, which was 2018 at the start of the project. The focus was on the explicit representation of energy commodities and transport services to allow a direct link with CeAT inputs, such as fuels for road-bound transport services. The Appendix shows the details on the sectoral disaggregation (Table A1).

(ii) Consumption module: In transport (stock of vehicles) and housing (stock of buildings and heating systems), where the flow (energy demand) depends on the use and the energy efficiency of the stock, a stock-flow approach was already integrated in the DYNK model (Kirchner et al., 2019). For this project, the model code was modified to allow these endogenous developments to be set exogenously by implementing the results of CeAT as an input in the DYNK model. The biophysical results of CeAT are monetarized by using available costs and prices per physical unit (see next chapter). For example, the construction of new residential space (in m^2) is monetarized by multiplication with the average cost[10] calculated for 2018. The costs change over time in line with the respective commodity price level[11].

(iii) Fixed household saving rates are a central feature in this study and are new in DYNK. It became relevant because in the DC&CE scenarios the assumed stocks of housing and vehicle developments are lower relative to the reference scenarios. Consequently, operation costs of these stocks are lower as well. Even though some expenses (e.g. for electricity) increase, the total household expenditure would decline substantially. Ceteris paribus this would be equal to an increase in savings and results in a decrease of domestic economic performance. Since we wanted to analyze the economic effects of the DC&CE strategies, and not the impact of lower expenditure, we opted for the assumption of a fixed savings rate. Therefore, DYNK's code was attuned in a way that other expenditures adjust to the point that the yearly savings rate is equal to the savings rate in the reference case (R1). That is, the saved money is re-spent for other commodities and total consumption is roughly[12] similar. This shift in expenditure resembles an indirect rebound effect. From an economic perspective it is important for which bundle money is spent because commodities vary in their up-stream structure. In this project we define two stylized commodity sets for re-spending. One bundle of goods contains resource-intensive goods[13] which are typically purchased by households, and the other entails

[10] Costs in Euro per m^2 derived from i) sum of investments in dwellings based on the Input-Output-Table 2018 and ii) total new constructed dwelling area in 2018 provided by CeAT.

[11] Producer price levels in the reference scenario are calibrated to result in growth rates between 1 and 2 %.

[12] Total expenditure can change slightly if income changes due to macroeconomic feedback, i.e. if disposable income increases, the same savings rate allows higher expenditures.

[13] Categories CPA 01 to CPA 33, except for motor vehicles (CPA 29) and energy commodities (CPA 05, 06, 19, 35), as these are determined by the scenario inputs of CeAT.

services[14] only. This allows us to assess the impact of a structural change towards a more service-oriented economy, which uses less materials and energy inputs to produce a unit of GDP growth, in comparison to a conventional commodity mix. The results of these variations will feature in the form of sub-scenarios (M and S) in the results section (4).

(iv) Disposable income: In the DYNK model, household consumption includes three main categories: durable goods (housing, vehicles, heating systems), energy commodities (coal, oil, gas, biomass, electricity, and district heating) and non-durable goods such as food or health services. In our analysis, consumption of durables and energy commodities is determined by the results of the CeAT model and thus by scenario assumptions. Gross disposable income is the most relevant determinant in the DYNK model for the consumption of non-durable goods. But net disposable income gives a more accurate picture of a household's financial capacity. Thus, we used the net disposable income as a welfare indicator and a factor to drive non-durable consumption (Stiglitz et al. 2009, Botev et al. 2022). This is important because the scenarios simulate inter alia a situation of relatively lower growth of private capital stocks (e.g. housing). This, however, implies an increase in the net disposable income available for other consumption purposes than, e.g. maintenance costs, such as goods and services, as the calculation of the net disposable income excludes the (reduced) depreciation on dwellings. This is consistent with the official statistics on net disposable income, in which the relevant depreciation and investment predominantly relates to dwellings[15].

3. Scenarios and Implementation

3.1 Scenario Definitions

For the scenario analysis, we integrated the material stock changes and the resulting resource flows for the three sectors from the CeAT model via monetarization (3.2) in the DYNK model. Then we quantified theese impacts of the biophysical changes in the three sectors on value added, disposable income and employment along three scenarios:

- A: decarbonization in the three sectors buildings, transport, electricity generation,
- B: decarbonization plus additional moderate CE strategies, and
- C: decarbonization plus additional strong or intensified CE strategies.

To assess the potential effects of the DC&CE scenario strategies, we applied the two economic reference scenarios (R1, R2) up to 2040. The realization of the DC&CE strategies was then compared to these in biophysical terms (4.1). We use R1 as the business-as-usual scenario for the

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[14] Categories CPA 41 to 99, except for construction services (CPA 41 to 43) and rents (CPA 68), as these are determined by the scenario inputs of CeAT.

[15] "Household investment mainly consists of the purchase and renovation of dwellings. Consumer durables (which include passenger cars) are not considered as part of household investment" (Eurostat 2025).

economic impact assessment, and R2 for a sensitivity analysis focusing on material demand only.

The defined scenarios and their strategies are summarized in **Fehler! Verweisquelle konnte nicht gefunden werden.**1. Scenario A implements the relevant decarbonization strategies outlined in the Austrian National Energy and Climate Plan[16]. The sectoral strategies in scenario B and C reflect CE strategies typically discussed in the literature (see Appendix A for references). Only the strong CE strategies, e.g. 'no construction on unbuilt land' or 'no road expansion after 2030', are assumptions made specifically for this study; however, these are also firmly established in the literature (see Jandl et al. 2024).

The scenario names were selected as brief keywords that suggest a clear distinction between decarbonization and CE strategies, which is, however, not feasible, since most strategies typically contribute to both rather than being mutually exclusive. In literature, strategies are often labelled as CE strategies that contribute to decarbonization. For example, timber use in construction impacts C-emissions, yet timber construction is often referred to as a CE measure intending to replace construction minerals (Song et al. 2023, Pauliuk et al. 2021).

[16] https://commission.europa.eu/publications/austria-final-updated-necp-2021-2030-submitted-2024_en.

Table 1: Decarbonization and Circular Economy Scenarios until 2040

Sectors	No.	Strategies	A Decarboni-zation	B Decarboniza-tion plus weak CE strategies	C Decarbonization plus strong CE strategies	Nar-row-ing	Slo-wing	Loop Clo-sing
Buildings	b1	Heating/cooling systems decarbo-nization,100% phase out by 2040	•	•	•	•		
	b2	Increasing rate of thermal renovation: 1.3% in 2018 to 2.1% in 2030	•	•	•	•		
	b3	Increase in insulation of new buildings	•	•	•	•		
	b4	Reduction in newly built floor space per capita by 25%		•		•		
	b5	Lifetime extension of build-ings (25% fewer demolition)			•	•		
	b6	No construction on unbuilt land after 2030 (construction = demolition)			•		•	
	b7	Increase of timber construc-tion share to 50% by 2040			•	•		
Transport	t1	100% fleet electrification by 2040	•	•	•	•		
	t2	Modal split shift	–10% PPV (pkm) –10% road freight (tkm)	–20% PPV (pkm) –20% road freight (tkm)	–50% PPV (pkm) –40% road freight(tkm)	•		
	t3	Traffic volume reduction by 2040		–15% pkm –25% tkm	–30% pkm –50% tkm	•		
	t4	Car sharing: Two users share one car by 2040			•	•		
	t5	No road expansion after 2030			•	•		
Electricity	e1	Fossil fuel phase out by 2040 * Hydro capacity (in GW) con-stant in all scenarios * Biomass to power slowly de-clines in B and C from 2018 * Installed capacities for all scenarios account for change in electricity demand of build-ings and transport	Wind 23% PV 25% Hydro ROR 34% Hydro-stor-age 11% Biomass 5% Waste 1% Geothermal 0% Domestic electricity production: 358 PJ	Wind 21% PV 25% Hydro ROR 37% Hydro-stor-age 12% Biomass 5% Waste 1% Geothermal 0% Domestic electricity production: 335 PJ	Wind 18% PV 20% Hydro ROR 42% Hydro-storage 14% Biomass 4% Waste 1% Geothermal 0% Domestic elec-tricity production: 289 PJ	•		
Economy-wide	w1	Increasing recyclig quotas	Constr. Min-erals: 92% Iron and Steel: 79% Timber: 72% Plastics: 30%	Constr. Miner-als: 92% Iron and Steel: 79% Timber: 72% Plastics: 36%	Constr. Minerals: 95% Iron and Steel: 86% Timber: 81% Plastics: 57%			•

Source: Strategies based on a literature review, see Appendix A for data sources. Abbreviations: GW... gigawatt; pkm... person kilometer; tkm…ton kilometer; PPV... private passenger vehicles; PV... photovoltaic; ROR… run of river.

In scenario A, the changes in capital stocks required for complete decarbonization of the three sectors in focus were quantified. All other sectors of the economy are modelled in an unspecific category "other", where no change in relation to the reference scenarios is realized (Haas et al. 2025). The sector strategies outline the standard methods used in energy scenarios to achieve complete decarbonization (Environment Agency Austria 2023, for details: Haas et al. 2025). Strategies in scenario A include, for example, thermal renovation of buildings, and replacement of heating systems, vehicle fleets and power plants by CO2-neutral options. A dot indicates that the strategy was implemented as stated in the scenario in question.

Electricity generation is assumed to be completely decarbonized by 2030. This reflects the Austrian federal government's goal of achieving climate neutrality in this sector ten years earlier than required by EU regulations. The shares of individual electricity generation technologies to covering final electricity consumption[17] were taken from various studies (Austrian Energy Agency, 2017; Federal Ministry for Sustainability and Tourism, 2019; Austrian Environment Agency 2016, 2023).

Scenario B builds on scenario A but in addition implements moderate CE strategies for the building sector, i.e. a 25% reduction in newly constructed residential floor space per capita by 2025 (based on Kranzl et al. 2018), which is considered as a narrowing-strategy. This corresponds to a 19% reduction in net floor space in new buildings with respect to the reference scenario. In the biophysical model, the reduction was implemented gradually from 2018 onwards and kept constant after 2025. Further, a 20% shift in the modal split towards public transport and active mobility was implemented by 2040 in line with the transport policy strategy (Federal Environment Agency, 2023), and represent a reduce-strategy in the narrowing group. A reduction in traffic volumes of 15% (pkm) and 25% (tkm) was postulated. This is justified by the omission of fossil fuel transports and reduced construction activities.

The strong CE scenario C reflects CE strategies that go beyond what is currently planned by public institutions. As strong CE strategies of the narrowing group ("rethink, reduce, refuse") we assumed that no further construction would take place on previously undeveloped 'green' land, and that construction would only be permitted on sites where a building had previously been demolished. Furthermore, it was supposed that increased building maintenance would extend the service life of buildings and reduce demolitions by 25%.

Substitution of mineral construction materials (steel, concrete etc.) with wood is intensified and would account for 50% of the materials used in new buildings. The strategies implemented in the transport sector include an even more intense shift from private transport to public transport and active mobility (50%), and a 40% shift in freight transport from road to rail. The assumed 30% reduction in traffic volume (pkm) compared to the reference scenario relates to a halt to urban sprawl and new construction. For freight transport, a 50% reduction was implemented, considering that significantly less material will need to be transported due to strongly reduced construction activity and a phase-out of fossil fuels.

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[17] In 2019, electricity generation mix was as follows: Coal 6%, oil 2%, natural gas 14%, biomass 8%, waste 1%, wind power 9%, photovoltaics 2%, run-of-river hydropower 42%, storage hydropower 14%, net imports 16% (Statistics Austria, 2024).

Modelling of the buildings and transport sectors results in varying electricity demand depending on the scenario. As hydropower plants already exist but have reached their potential due to ecological limits, we assumed the same level of electricity generation by 2040. In scenario A, electricity demand was highest, resulting in hydropower (run-of-river and pumped-storage plants) accounting for 45% of the total. In scenario B, with a slight decline in total electricity demand, hydropower can cover 49%, and in scenario C, with even lower electricity demand, the hydropower share covers as much as 56%. These changes result in different shares for wind and PV.

Recycling rates in scenario A were kept unchanged from those in the reference scenario, as they were already relatively high, except for plastic recycling. Plastic recycling was kept at a low level. It should be noted that by 'recycling rate' we do not mean the collection rate. When calculating the recycling rate, we only consider whether a certain plastic product can be recycled into the same or a similar product, thus replacing primary raw materials. As studies indicate, this is very challenging (Klotz et al. 2023). For scenario B, recycling rates for all materials except plastics remained the same due to their high level. Plastic recycling was increased for the packaging waste share based on targets defined by EU legislation. For scenario C, we adopted a pragmatic approach by further increasing all rates by 30% of the recycling gap to 100%.

3.2 Scenario Implementation

We applied a one-way linking of the biophysical CeAT model and the economic DYNK model: The results of the biophysical model were used as input into the economic DYNK model to analyze the economic affiliations of the biophysical changes resulting from the defined scenarios and sectors. All other sectors were not directly altered. But production adjusts to shifts in demand, and its structure adjusts due to altered prices and price elasticities of substitution (c.p. modelling approach). Economic impacts were, however, not fed back into the CeAT model due to project constraints. But freed up money, which was not spent to increase capital stocks, according to the scenarios, were fed back into the economic cycle via two different indirect rebound effects: a service-oriented demand and a demand on material intensive goods. These two rebound-effects represent different material intensities of alternative spending.

While the reference scenario (R1) and its main economic variables, such as economic and population growth, is identical in both models, the output data sets from CeAT (biophysical flows as well as various stock-related parameters) were monetarized and used to exogenously determine specific variables in DYNK. For instance, the numbers and type of private vehicle purchases between 2018 and 2040 are provided by CeAT. The respective consumption category – in real terms - in DYNK[18] is forced to develop in analogy. I.e. if car purchases change year-on-year by a certain percent in CeAT, then real expenditure on this category in DYNK acts the same way (Table 2).

[18] COICOP category 07.2: Purchase of vehicles

The integration of the strategies (Table 1) into DYNK is realized via exogenously determining a set of variables that are in most cases endogenous (Table 2). The majority affects the final demand segment of DYNK (Figure 3). Nine out of the 14 strategies (b1-b3 and t1-t5) influence consumption decisions of private households in the respective module. Five strategies (b4-b7 and t5) define developments that affect the investment behavior in the module Gross Fixed Capital Formation. And one (e1) sets the structure in the electricity generation module. The strategy regarding recycling (w1) was not translated into the economic model.

Table 2 shows the monetarized results of the CeAT model as inputs to the DYNK model in relation to the scenario strategies displayed in Table 1. Two approaches have been applied. First, starting from 2018, the development of the respective consumption category (e.g. purchase of vehicles) in constant prices is identical to the physical outputs of CeAT (i.e. in real terms). To this value, the price index of the respective commodity is applied to represent inflation[19]. This price index is endogenous in DYNK and represents a producer price index. A nominal value (or value at current prices) is therefore calculated and applied. The second approach is relevant if the respective cost or expenses in 2018 are not known. Then only the cost differences with respect to the reference case are simulated. In those cases, the input value in scenario R1 is zero.

[19] DYNK operates with current prices (nominal terms). The price indexes in DYNK are commodity specific and endogenous. Price inflation is determined by import prices and wage negotiations. Inflation by money or capital markets are not addressed in DNYK.

Table 2: Input data for the macroeconomic modelling

Sectors		Strategies*	2018	2020	2025	2030	2035	2040
Buildings			**million Euros**					
Rent (households)	R1	(-): b4,b5,b6	29.910	30.869	33.587	36.786	40.516	44.845
	A		29.910	30.869	33.587	36.786	40.516	44.845
	B		29.910	30.767	32.849	35.151	37.910	41.180
	C		29.910	30.869	32.635	32.432	31.465	30.525
Investment in residential buildings (households and commercial housing)	R1	(-): b4,b5,b6 (0): b7	24.308	25.848	29.765	33.461	37.569	42.242
	A		24.308	25.848	29.765	33.461	37.569	42.242
	B		24.308	24.273	25.148	28.233	31.667	35.572
	C		24.308	25.848	19.268	8.590	8.377	7.755
Repair and maintenance of residential buildings (households)	R1	(-): b4,b5,b6 (0): b7	7.518	7.759	8.440	9.241	10.174	11.257
	A		7.518	7.759	8.440	9.241	10.174	11.257
	B		7.518	7.733	8.254	8.830	9.520	10.337
	C		7.518	7.759	8.201	8.147	7.900	7.660
Additional thermal refurbishment (households)	R1	(+): b2, b3	0	0	0	0	0	0
	A		0	366	1.080	2.037	1.420	1.004
	B		0	366	1.080	2.037	1.420	1.004
	C		0	366	1.080	2.037	1.420	1.004
Heating energy & electricity	R1	(+): t1 (-): b1	5.093	5.071	5.051	5.050	5.071	5.142
	A		5.093	5.030	4.632	4.082	3.458	2.730
	B		5.093	5.029	4.628	4.072	3.442	2.711
	C		5.093	5.030	4.628	4.057	3.403	2.653
Heating systems	R1	(+): b1	486	506	530	558	585	626
	A		486	533	699	827	1.099	1.536
	B		486	532	695	820	1.087	1.514
	C		486	533	693	803	1.049	1.438
Transport			**million Euros**					
Vehicle purchase (households)	R1	(+): t1 (-): t2,t3,t4,t5	6.644	6.092	9.987	9.598	11.036	12.918
	A		6.644	7.694	7.506	8.219	9.007	14.297
	B		6.644	5.796	5.429	5.945	6.515	10.357
	C		6.644	1.673	918	1.005	1.101	1.796
Vehicle energy (households)	R1	(-): t1,t2,t3, t4,t5	6.061	6.401	7.291	8.320	9.489	10.871
	A		6.061	6.186	6.297	6.219	5.840	2.888
	B		6.061	6.221	6.197	5.909	5.296	2.099
	C		6.061	6.302	6.092	5.523	4.631	766
Vehicle maintenance (households)	R1	(-): t2,t3,t4,t5 (o): t1	7.386	7.679	8.549	9.686	10.857	12.219
	A		7.386	7.701	8.283	8.942	9.690	10.539
	B		7.386	7.594	7.603	7.620	7.639	7.658
	C		7.386	7.362	6.127	4.746	3.182	1.397
Public transport (households)	R1	(+): t2 (-): t3,t4,t5	4.817	5.027	5.734	6.556	7.482	8.585
	A		4.817	5.035	5.931	7.056	8.358	9.929
	B		4.817	4.913	5.176	5.471	5.803	6.177
	C		4.817	5.062	6.492	8.281	10.136	12.090
Fossil fuels for domestic freight and bus transport (service sectors)	R1	(-): t1,t2	0	0	0	0	0	0
	A		0	-31	-193	-363	-537	-710
	B		0	-22	-139	-275	-439	-643
	C		0	-13	-83	-166	-292	-624

Electricity								
			million Euros					
Additional Investment in grid	R1	(+): b1, t1, e1, t4, t5 (-): t2, t3	0	0	0	0	0	0
	A		0	138	604	591	341	328
	B		0	104	470	452	225	201
	C		0	80	86	70	33	115
Additional Investment in power plants	R1	(+): b1, t1, e1 (-): t2,t3,t4,t5	0	0	0	0	0	0
	A		0	1.120	2.019	2.094	823	819
	B		0	976	1.767	1.825	584	557
	C		0	630	1.170	1.134	181	588
			in %					
Share of Natural Gas in electricity generation	R1	(-): e1	14	14	14	14	14	14
	A		14	14	6	0	0	0
	B		14	14	5	0	0	0
	C		14	14	5	0	0	0

Source: WIFO assumptions, *Strategies increase (+), decrease (-) or have neutral (0) impact on values. Source: WIFO assumptions

The consumption category on rent[20] belongs to private households. The expenditure for this category develops analogous to the physical stock of "living area" provided by CeAT and the price index for renting.

The expenditure for new dwellings is included in the IOT under the investment activities of the "real estate" sector (NACE L68). This category comprises private and commercial investments in dwellings. In the scenarios these investments[21] are linked to the "Inflow of new construction" in square meters provided in CeAT. Private expenditures related to the housing stock as O&M and miscellaneous services relating to the dwelling[22] are set to develop as the physical stock assuming that these costs change with the size of the dwelling.

As part of the decarbonization scenario A in CeAT, the housing stock partially undergoes thermal refurbishment. For these refurbished areas, average costs per square meter and investments were calculated. The difference to the reference cases has been set as exogenous additional expenditures[23].

Expenditures for heating fuels and electricity[24] are directly shown in the consumption structure of the IOT and develop as the physical CeAT variable "Fuel use". Costs of natural gas, heating oil, biomass and electricity were differentiated.

[20] COICOP 04.1 "Actual rentals for housing" and 04.2 "Imputed rentals for housing".

[21] I.e. assuming uniform costs per square meter.

[22] COICOP 04.3 "Maintenance and repair of the dwelling" and 04.4 "Water supply and miscellaneous services relating to the dwelling".

[23] Additional consumption of commodity CPA43 "Specialised construction works".

[24] COICOP 04.5 Electricity, gas and other fuels.

The investment in heating systems is a share of the expenditure category "Household applications"[25]. These investments develop with the change of the stock of heating systems in CeAT and an assumed depreciation rate of heating systems of 4%.

The purchase of vehicles resembles a single consumption category[26] in DYNK. Here its development is exogenously attached[27] to the physical purchase of cars as in CeAT. Analogous to heating energy, expenses for transport energy are linked to the physical inflow of "fuel use (vehicles, passenger)", and demand of electricity for transport is added separately to the expenses for electricity. The maintenance costs of vehicles are also a single category in the IOT[28] and are attached to the physical stock. CeAT delivers the use of public transport in form of person kilometers. The expenses on public transport in DNYK[29] are attached there.

In the scenario A it is assumed that passenger transport with busses and freight transport with trucks is electrified. The approach here was to decrease the consumption of fossil fuels in the input structure of the respective sectors[30] and therefore increase the expenditures for electricity[31].

The electricity generation in DYNK is represented in form of a distinct sector (NACE 35A). This sector comprises 11 sub-sectors which represent generation technologies by energy source as well as trade and distribution services. The shares of each generation technology can be determined exogenously. This detailed representation of electricity generation is the result of the works of a previous project[32] and allows the linkage to the development of physical electricity capacities of CeAT. In the DE scenario in CeAT the grid length and power plant capacities increase. Both are transferred to additional costs[33] and added to the investments of the sector.

3.3 Limitations

By making assumptions in the DC&CE scenarios many secondary or induced effects were not and could not be covered by our models, for instance the following:

By reducing housing costs analogous to living area, we imply that rent and maintenance costs are linearly correlated with physical living areas, which is, however, not with all cost categories the case, e.g. garbage fees would not decrease linearly with the size of the living area.

[25] COICOP 05.3 Household applications.

[26] COICOP 07.1 Purchase of vehicles.

[27] Assuming an average price for cars except battery electric vehicles (BEV) which are assumed to cost 20% more.

[28] COICOP 07.2 Operation of personal transport equipment.

[29] COICOP 07.3 Transport services.

[30] NACE 49B Passenger transport services, bus, tram, sub and NACE 49E Commodity transport services, road-bound.

[31] For simplicity the assumed factor was 1. I.e. a decrease by 1 euro in the consumption of diesel leads to an increase of 1 euro in the expenses for electricity.

[32] Project "START2030" at https://start2030.wifo.ac.at/.

[33] Assuming costs per MW power capacity and km grid.

Restricting the possibility of constructing new dwelling might lead to higher pressure on the housing market and might increase prices and rents. This could only be mitigated by counteracting policies.

With respect to the operation of electric cars we implied that the price of the consumed electricity is based on the private household's electricity price. However, cars that charge at public stations pay significantly higher prices since they finance the investment in charging infrastructure.

Impacts on the public households are not considered. This concerns especially the decline in mineral oil tax which might in practice be compensated by a tax on electricity which again would increase costs for electric vehicles. However, this drives a lowered traffic volume and a stronger shift towards active mobility forms as assumed in the different scenarios.

The above-mentioned points indicate that potential increases of expenditure for rents (housing) and electricity (transport) cannot be covered by the macroeconomic models. Hence the freed up financial resources from reduced capital stocks, and thereby the indirect rebound effects, might be smaller and lie within the range of the sensitivity results (see section 4).

In our impact analysis of the defined scenarios, we do not account for different energy and CO_2 price trajectories for R and A, B, C scenarios respectively because different price assumptions and market reactions are implicit in the biophysical results. Thus, we abstracted from price effects and focused on the macroeconomic rebound effects in terms of re-spending saved expenditures from reduced capital stocks and maintenance.

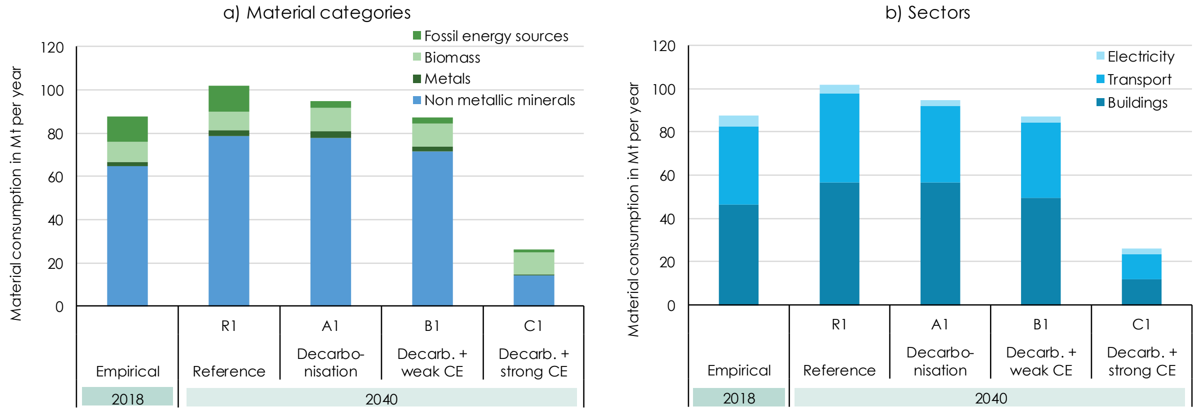
The economic impact of the calculated rebound effects should be interpreted as short-term effects because the long-term implications of human or physical capital build up on economic growth cannot be evaluated by our method. Since manufacturing sectors seem to contribute stronger to productivity growth (Hölzl, 2021) the gap between the scenarios with a service-oriented rebound and a material-intensive rebound effect might be smaller in the long term (see section 4.2).

4. Results

4.1 Material demand

The biophysical scenario results displayed in Figure 4 are based on the economic projection R1 (Haas et al. 2025). The reference scenario (R1) shows an increase of processed material (PM = DMC + Recycling) of 16% up to 102 Mt/yr for the three sectors (transport, buildings, electricity) until 2040. In contrast, the decarbonization scenario (A1) shows a slight reduction in PM due to the phasing out of fossil fuels. The scenario B1 following a moderate CE approach in addition to the decarbonization measures shows a decrease of 15% of PM and the strong CE scenario (C1) a reduction of 75% of PM. The strategies with the greatest impact on material savings are hence the phasing out of new construction of buildings and roads on undeveloped land and thus the narrowing strategies (Figure 4 a) and b)).

Figure 4: Processed Material including secondary raw materials, for R1, A, B and C, by a) material categories, and b) sector split.

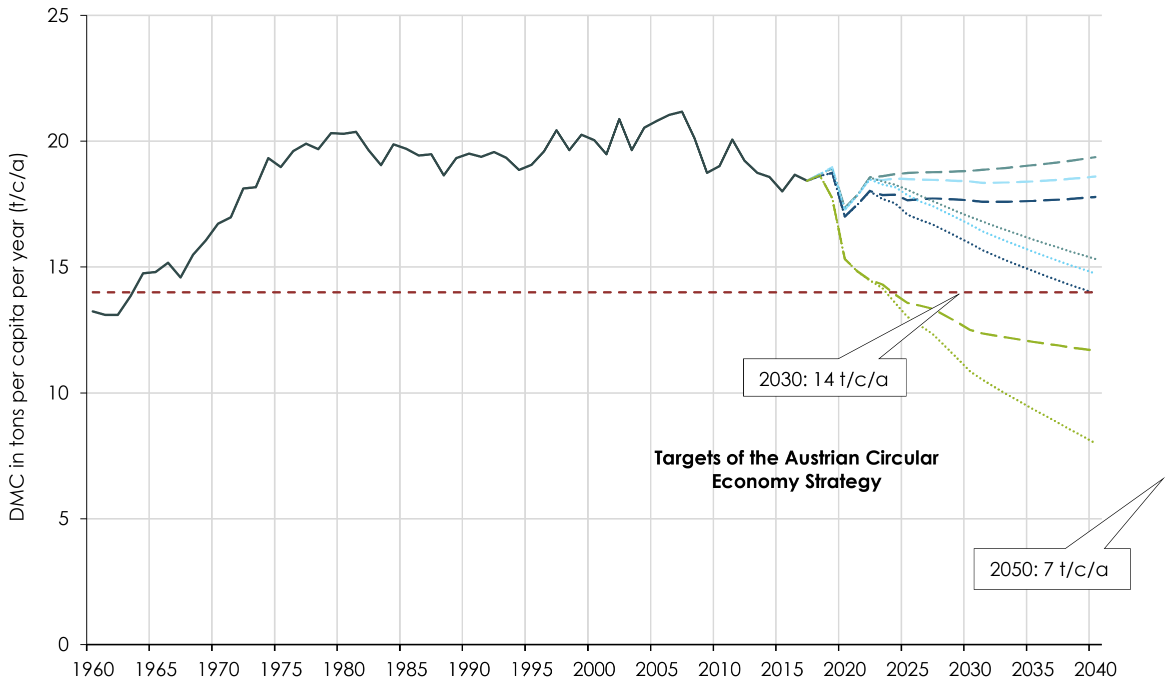


Source: Haas et al. 2025

A breakdown of the results by strategy reveals which strategy has the greatest impact on final energy and domestic material consumption. In all scenarios, reducing vehicle use (through a shift in modal split and a reduction in mileage) has the greatest impact on final energy consumption, at between 30% and 35%, depending on the scenario. This suggests that results are most sensitive to these transport-related assumptions. In stark contrast, domestic material consumption is most sensitive to the assumptions of no new roads (-22%) and no new buildings on unbuilt land (-43%). These results highlight the important role of the transport sector in terms of both final energy demand and domestic material consumption, as well as the important role of the buildings sector in terms of material consumption.

It was also found that, ceteris paribus, material demand is substantially impacted by economic growth. When the 'no growth' reference scenario R2 is applied as a sensitivity analysis, all decarbonization and circular economy scenarios demonstrate substantially greater material savings. Figure 5 displays the historical trend in domestic material consumption per capita, as well as the scenarios A, B, and C in relation to the two reference scenarios (R1, R2). Only the scenarios C1 and C2, which feature strong narrowing strategies in the buildings and road construction sectors, will achieve the 2030 target of 14 t/cap/yr of DMC (BMK 2022), and even exceed this target, particularly when economic growth is sluggish. The long-term goal of the Austrian CE strategy of a material footprint of 7 t/cap/yr in 2050 can therefore only be achieved with the C1 scenario.

Figure 5: Domestic Material Consumption Per Capita, 1960-2040

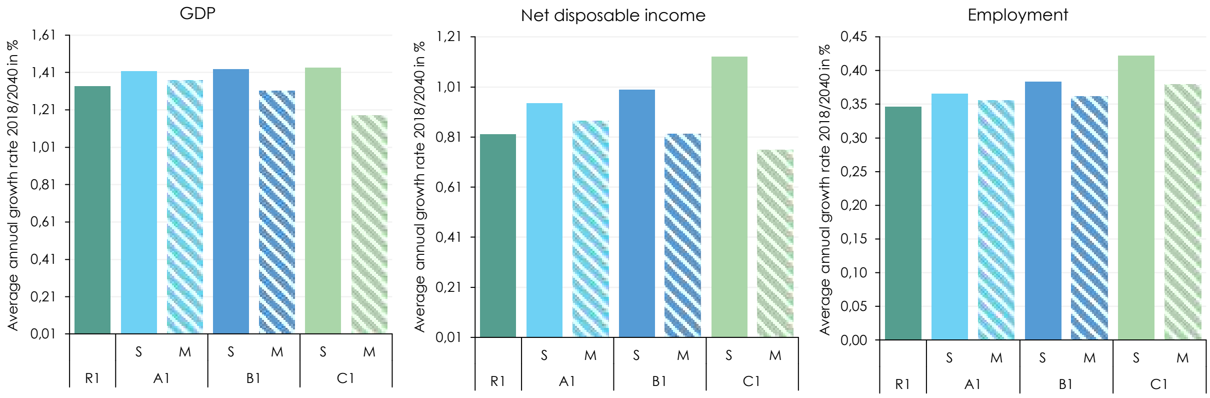


Source: Haas et al. 2025, MFA data 1960-2000: RENU 2015, sources for targets: Austrian circular economy strategy (BMK 2022), 2050 target refers to material footprint per capita.

4.2 Economic Impacts

The scenarios A, B, and C in the CeAT model represent shifts and alterations of investments and consumption to different extents. In an economic input-output model a ceteris paribus reduction of expenditures leads to an increase in savings rates and a decrease in domestic production and value-added. However, in this project it was assumed that, in each scenario, the savings rate of private households in each year is equal to the one in the reference scenarios (see methods section). This means, the expenditures for rent, dwelling debt payments or car operation in the reference scenarios are spent otherwise in the decarbonization and circular economy scenarios A, B, and C, which resembles a secondary rebound effect. We defined two stylized variants of this rebound. On the one hand, re-spending of the free monetary means is dedicated to material intensive commodities. This is equal to the 'M' scenarios. On the other hand, in the 'S' scenarios the re-spending is simulated for service demand. The former set of commodities is rather material and import intensive whilst the latter is rather labor intensive and has lower upstream imports. The two rebound variants in combination with the three main scenarios A, B, C result in six scenarios presented in Figure 4 along average growth rates between 2018 and 2040 regarding employment, GDP, and disposable income. The reference scenario is the moderate growth projection (R1).

Figure 6: Development of GDP, disposable household income and employment in the reference scenario (R1) and in model scenarios A, B and C



Source: WIFO calculations.

Figure 6 a) shows that GDP grows by slightly over 1.35% per year in the moderate growth projection (R1). Depending on the altered investments and expenditures in A, B, and C according to the biophysical scenarios, as well as the re-spending on commodities (M) or services (S), deviations from the reference growth are computed. In the A scenarios full decarbonization takes place, which is going along with a technology shift in investments. Consequently, fossil-based heating, electricity and mobility is replaced by alternative energy technologies over time. The isolated reduction in demand for fuels leads to a slight decrease in GDP growth by 0.01%-points over the whole period. The decrease is very moderate because in scenario A, imported fossil fuels are replaced with more domestically provided sources (as ambient heat). Overall operation costs are lower and the saved means can be re-spent until the savings rate is equal to the one in the reference scenario R1. We find a positive impact on GDP growth in both cases, i.e., under re-spending on commodities (A1.M, 1.37% p.a.) and services (A1.S, 1.42% p.a.). The latter has a more positive impact because services have a relative low import intensity and a high domestic wage intensity. Thereby a higher share of the re-spending generates domestic value-added. In general, the commodity mix (M) shows higher import rates than services (S)[34]. Importing commodities, on the other hand, implies that monetary means leave the domestic economy thereby reducing GDP.

In the B1 scenario, the expenditures and investments in dwellings and private mobility decrease more strongly. Without re-spending, the GDP growth would decrease by 0.14%-points to 1.20% per annum. However, the positive impact of re-spending is only slightly higher. The reason for that is, that in the A scenario mainly the demand for imported fossil fuels is replaced by expenditures on commodities or services which has a positive impact on GDP[35]. The B scenario extends the decline in fossil demand by a reduction in investments (construction services and

[34] Import shares vary slightly over time but are based on the Input-Output-Tables of Austria 2018.

[35] A reduction in Imports has a direct positive impact on GDP, since GDP = Consumption + Investment + Exports – Imports.

private car ownership including maintenance services). These reductions have a much larger domestic component. Car repair services and dwelling maintenance are domestically provided services. By reducing the demand for these items, the primary negative impact is higher than in the A scenario. Therefore, the re-spending in domestic services B1.S is only slightly higher than in the A1.S scenario. Re-spending on commodities even reduces the GDP growth by 0.03%-points. The reason is that – on average – the commodity mix has a higher import intensity than domestic construction and car repair services replaced. In the C scenario the changes of the B scenario are amplified and lead structurally to the same results. The isolated demand reduction in C would reduce the GDP growth to below 1% p.a. But the re-spending improves the growth again to positive values of 1.44% (C1.S) and 1.18% (C1.M).

The disposable income of households (Figure 6 b)) is an important indicator on how households would be affected by the different scenarios. One important driver of gross disposable income is the development of salaries and wages which is a component of GDP. In our analysis, net disposable income is equal to the gross disposable income subtracted by the depreciation of the private capital stock of dwellings. In other words: the difference between the two is the share of the income that is necessary to maintain the stock of dwellings. Hence, when the stock – that needs to be maintained – decreases, a larger share of the income is available for other consumption purposes. And this share is the net disposable income which is a more accurate indicator for the well-being of private households than gross income. Next to the GDP impacts described above, the net disposable income is, by definition, positively affected by a decrease in the dwelling stock. Consequently, the changes in growth rates structurally follow the GDP variants but show an additional positive impact, namely the lower necessary expenditures for maintaining dwellings. In all cases except C1.M, the net disposable income is affected positively. In the C scenario the magnitude of the rebound is larger than in scenario A and B, therefore the difference between the spending variants increases as well. The greater re-spending on import-intensive commodities leads to a negative growth in C1.M.

The impact on employment (Figure 6 c)) is positive in all scenarios. Disclosed on a sectoral level, three areas seem to be particularly positively affected by the re-spending on commodities (scenarios 'M'), thereby increasing the labor demand to the displayed values. The first area is food production and processing, the second is trade services (retail and wholesale) and the third is transport services. The reason for that lies in the structure of the re-spending. In the base years, households' commodity consumption shows large shares of agricultural and food products. Both are labor-intense. Furthermore, the consumption of these commodities is interlinked with transport and trade. All three areas profit from the re-spending primarily on commodities and are labor-intensive under low-wage conditions. In summary, in the B1.M and C1.M scenarios spending on construction and vehicles is replaced by expenditures on commodities. These commodities have a higher import share along their value chain and thereby reduce the GDP growth. But the labor intensity in the value chain of commodities is higher than in construction and vehicles. Hence, the employment effect of the re-spending is overall positive. Even though the wage rates in the sectors agriculture, food processing, trade and transport services are rather low, leading to a disposable income that is lower in C1.M than in R1 while employment is higher.

We have not fed back the service-oriented and material-intensive rebound effects in the biophysical model CeAT, but their impact is expected to be minor. Domestic material extraction is largely unaffected. The rebound excludes construction expenditures, resulting in a small effect in mining extraction. The same applies to wood biomass. Domestic ore mining is unlikely to increase significantly since most steel products are exported. Only the agricultural production is affected, but limitations on arable land restrict further extraction. However, the goods-oriented rebound involves largely imported commodities, meaning the material extraction occurs abroad. A multi-regional perspective is essential for a complete analysis.

5. Conclusions

The analysis shows that the 2030 CE goal of a DMC of 14 t/cap/yr is achievable with strong CE strategies only (scenario C, Fig. 5), particularly with narrowing resource flows. This strategy thus needs far higher attention in scientific analyses and policy debate than closing loops through recycling. This is especially relevant for the buildings and transport sectors, which are material-intensive sectors and where stock growth is also closely linked to energy consumption. The strong CE scenario (C1) simulates the realization of these priorities. With a cumulative material consumption reduction of two thirds compared to the reference case R1, the C1 scenario is the only scenario on a trajectory towards dematerialization. In addition to our calculations, both sectors are also tightly linked with patterns of land use, which have significant implications for climate resilience in terms of adaptation, biodiversity conservation and water resource management. Compact capital stocks and infrastructure development thus exhibit great potential for resource efficiency gains without obstructing economic growth.

In contrast, our analysis shows that GDP, employment, and disposable income in a strong CE scenario (C1), in which the freed-up financial resources are spent on services rather than on material-intensive, import-dependent goods, can potentially generate relatively higher growth rates than moderate CE strategies, or strong CE strategies with rebound effects towards material-intensive products (C1.M). This result challenges the conventional understanding that resource-intensive production and consumption activities are essential drivers of economic growth. However, it does not address the potential long-term economic impacts of such a structural shift toward compact capital stocks and reduced material demand, which requires further research.

Achieving Austria's climate and circular economy goals thus calls for a range of comprehensive policy measures, including regulation to avoid new construction on undeveloped land—both for buildings and roads—and a stronger emphasis on shifting demand towards service sectors such as education, culture, or care, rather than promoting material-intensive goods consumption. While recycling remains a necessary strategy, it is not sufficient on its own to meet ambitious environmental targets. However, the more effective efforts to reduce and slow down material flows become, the greater the contribution of recycling will be.

An important and promising finding of this study is that demand-side reductions can promote economic and disposable income growth if rebound effects are kept in check by redirecting freed expenditure towards services of low material intensity.

Acknowledgements:

Funding: The project was kindly supported by the Austrian Climate and Energy Fund (KR19AC0K17512). The paper is part of the ACeDC (Austrian Circular Economy and Decarbonization: Synergies and trade-offs) project. We would like to thank Susanne Markytan for research assistance.

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7. Appendices

7.1 Appendix A

Table A1: Decarbonization and Circular Economy Scenarios until 2040 with Data Sources

Sectors	Strategies	A Decarbonization	B Decarbonization and weak CE strategies	C Decarbonization and strong CE strategies	Sources
Buildings	Heating/cooling systems decarbonization, 100% phase out by 2040	•	•	•	oesterreich.gv.at (2024) Kranzl et al. (2018)
	Increasing rate of thermal renovation: 1.3% in 2018 to 2.1% in 2030	•	•	•	Kranzl et al. (2018)
	Increase in insulation of new buildings[a]	•	•	•	Calculation based on OIB (2019)
	Reduction in newly built floor space per capita by 25%		•		Kranzl et al. (2018)
	Lifetime extension of buildings (25% fewer demolition)			•	Own assumption
	No construction on unbuilt land after 2030 (construction = demolition)			•	Own assumption
	Increase of timber construction share to 50% by 2040			•	Own assumption
Transport	100% fleet electrification by 2040	•	•	•	BMK (2022; KW-Strategie)
	Modal split shift	–10% PPV (pkm) –10% road freight (tkm)	–20% PPV (pkm) –20% road freight (tkm)	–50% PPV (pkm) –40% road freight(tkm)	BMK (2021) for scenario A (Mobilitätsmasterplan); own assumptions for B and C.
	Traffic volume reduction by 2040		–15% pkm –25% tkm	–30% pkm –50% tkm	BMVIT (2016) for scenario C; own assumptions for B.
	Car sharing: Two users share one car by 2040			•	Own assumption
	No road expansion after 2030			•	Own assumption
Electricity	Fossil fuel phase out • Hydro capacity (in GW) constant in all scenarios • Biomass to power slowly declines in B and C from 2018 • Installed capacities for all scenarios account for change in electricity demand of buildings and transport	Wind 23% PV 25% Hydro ROR 34% Hydro-storage 11% Biomass 5%, Waste 1% Geothermal 0% domestic electricity production: 358 PJ	Wind 21% PV 25% Hydro ROR 37% Hydro-storage 12% Biomass 5%, Waste 1% Geothermal 0% domestic electricity production: 335 PJ	Wind 18% PV 20% Hydro ROR 42% Hydro-storage 14% Biomass 4%, Waste 1% Geothermal 0% domestic electricity production: 289 PJ	Assumptions derived from Austrian Energy Agency (2017), BMNT (2019), Umweltbundesamt (2016, 2023a)
Economy-wide	Increasing recyclig quotas	Constr. Minerals: 92% Iron and Steel: 79% Timber: 72% Plastics: 30%	Constr. Minerals: 92% Iron and Steel: 79% Timber: 72% Plastics: 36%	Constr. Minerals: 95% Iron and Steel: 86% Timber: 81% Plastics: 57%	

Source: Strategies based on a literature review. Abbreviations: GW... gigawatt; pkm... person kilometer; tkm…ton kilometer; PPV... private passenger vehicles; PV... photovoltaic; ROR… run of river. [a]: ~75% increase in insulation material thickness in new construction.

7.2 Appendix B

Table B1: Overview of sector disaggregation in DYNK

Basic IOT sectors (8 of 74)		DYNK IOT sectors (24 of 90)	
B05-07	Mining of coal a. lignite; crude petroleum and natural gas; metal ores	B05	Mining of coal a. lignite
		B06A	Mining of crude petroleum
		B06B	Mining of natural gas
		B07	Mining of metal ores
C19	Manufacture of coke and refined petroleum products	C19A	Manufacture of coke
		C19B	Manufacture refined petroleum products
C23	Manufacture of other non-metallic mineral products	C23A	Manufacture of glass and glass products
		C23C	Manufacturing of bricks, construction ceramics; products from concrete, cement and gypsum.
		C23X	Manufacturing of other glass, ceramic and china products
C24	Manufacture of basic metals	C24A	Manufacturing of ferrous metals and foundry products
		C24B	Manufacturing of other basic metals
D35	Electricity, gas, steam and air conditioning supply	D35A	Supply of Electricity
		D35B	Supply of gas,
		D35C	Supply of steam, air conditioning
H49	Land transport and transport via pipelines	H49A	Land transport of persons and products on rail
		H49B	Land transport of persons on road (other means)
		H49C	Land transport of persons on road (taxi)
		H49D	Land transport of persons by cable car
		H49E	Land transport of products on road
		H49F	Land transport via pipelines
L68	Real estate activities	L68A	Imputed rents
		L68B	Other services of real estate activities
I55_56	Accommodation; Food and Beverage Service Activities	I55	Accommodation;
		I56	Food and beverage serv. Activities

The following passages describe the general approach and/or source of the sectoral disaggregation in the central IO-Tables: supply and use-table. Sectoral supply (sectors column in the supply table), sectoral use/value added (sectors column in the use table) and product demand (commodity row in the use tables).

- B 05
    - **Sectoral Supply**: No mining of coal and lignite takes place in Austria; hence the domestic output structure is empty. However, coal is imported and therefore this sector represents only the imports of coal products. The monetary value of the imports is based on import value in the COMTRADE database for the year 2018.
    - **Sectoral Use/Value Added**: No domestic mining activity means no values in the use structure.
    - **Product demand**: The imported coal products are demanded by a small set of sectors. They are identified by the energy balance of Austria that identifies to which sector the physical coal is delivered.
- B 06 A, B 06 B, B 07
    - **Sectoral Supply**: Output value of oil, gas and ore has been estimated by the physical domestic production (energy balances, company website) and prices

for physical units based on export/import prices in COMTRADE database for 2018.

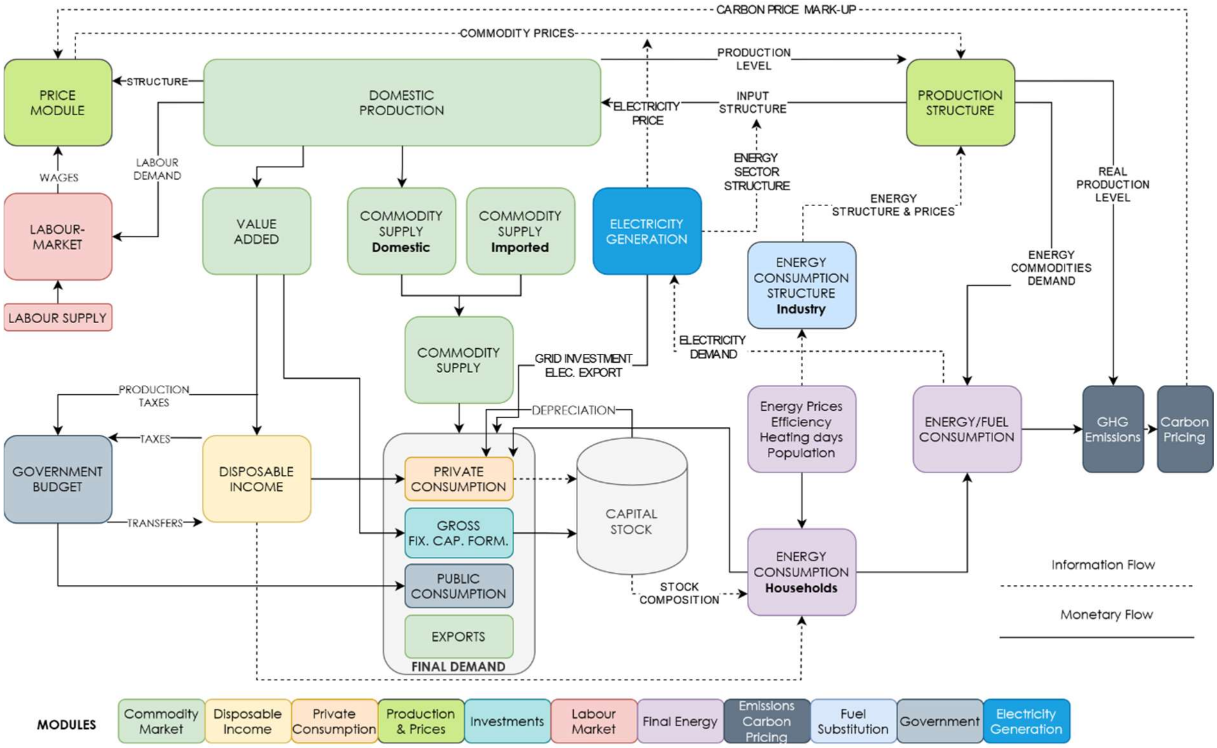
  - **Sectoral Use/Value Added**: Input and value-added structure has been allocated manually by the author.
  - **Product demand**: The allocation of the products is based on assumptions. Iron ore is used only in the manufacturing of basic metals (C24A) and crude oil is used by the refinery (C19B). The remaining gas resembles the residual demand.

- C19 A
  - **Sectoral Supply**: No company in Austria has coke as its main output. This means this sector has no supply and use values. The actual coke production is part of the manufacturing of basic metals (C24) since it is part of a larger company. This was not known at the beginning of the disaggregation process.
  - **Sectoral Use/Value Added**:
  - **Product demand**:
- C19 B
  - **Sectoral Supply**: Equal to C19
  - **Sectoral Use/Value Added**: Equal to C19
  - **Product demand**: Equal to C19
- C23 A, C, X
  - **Sectoral Supply**: The supply has been split manually based on the Structural Business Statistics (SBS) of these sub-sectors available at the Austrian Statistical Institute (Statistik Austria)
  - **Sectoral Use/Value Added**: The production value, value added, energy costs and intermediary demand for each sector was derived from the Structual Business Survey provided by Statistik Austria.
  - **Product demand:** The products of sector C23 have been disaggregated into glass products (C23 A), construction materials (C23 C) and the residual products (C23 X) by a special evaluation of the Statistik Austria.
- C 24 A, B
  - **Sectoral Supply**: Identical approach as C23 A, X
  - **Sectoral Use/Value Added**: Identical approach as C23 A, X
  - **Product demand**: Identical approach as C23 A, X
- D 35 A, B, C
  - **Sectoral Supply**: Provided by the Statistical Institute of Austria (Statistik Austria)
  - **Sectoral Use:** Provided by the Statistical Institute of Austria (Statistik Austria)
  - **Value Added**: manually based on the Structural Business Statistics (SBS) of these sub-sectors available at the Austrian Statistical Institute (Statistik Austria)
  - **Product demand**: Provided by the Statistical Institute of Austria (Statistik Austria)

- H 49 A, B, C, D, E, F
    - **Sectoral Supply**: Identical approach as D35 A, B, C.
    - **Sectoral Use/Value Added**: Identical approach as D35 A, B, C.
    - **Product demand**: Identical approach as D35 A, B, C.
- L 68 A, B
    - **Sectoral Supply**: Identical approach as D35 A, B, C.
    - **Sectoral Use/Value Added**: Identical approach as D35 A, B, C.
    - **Product demand**: Identical approach as D35 A, B, C.
- H 55, H 56
    - **Sectoral Supply**: Identical approach as D35 A, B, C.
    - **Sectoral Use/Value Added**: Identical approach as D35 A, B, C.
    - **Product demand**: Identical approach as D35A, B, C.

7.3 Appendix C

Figure C1: Schematic structure of the DYNK model



Source: WIFO representation

The DYNK model comprises several "modules". Modules are distinct blocs that receive inputs (exogenous or from other modules), process the information with intern parameters and provide a set of output variables. They represent specific blocs that have been added over time and contributed to the features of this approach. The module core is the **Commodity market** which provides the basic Input-Output-Tables and the transformation of demand into production. **Disposable income** is predominantly determined by the development of value added in the production and is itself the driving factor of **Private consumption**. Like private consumption, sectoral **Investment** is triggered by net surplus in value added. The **labor market** module simulates wage negotiations that result in tensions between labor supply and labor demand. Domestic production uses energy commodities from which physical **Final energy** consumption is derived. Some of the energy is provided by electricity. In the **Electricity generation** module, the technology mix can be determined exogenously, changing the input structure of the respective economic sector. By applying emission factors, CO_2 emissions can be calculated on which **carbon emission price** can be applied. This changes the prices of fuels via the **Price module** where sectoral unit costs are calculated. This affects the composition of energy carriers in each sector since this is driven by relative prices in the **Fuel substitution module**. The **Government** collects taxes and social contribution and spends these incomes on public consumption, subsidies, and transfers to households. In this module these expenditures can be restricted by following predefined budget paths.