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A Purpose-Based Energy Substitution Structure for CGE

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Abstract

We propose a novel method for modelling energy substitution in CGE models using energy processes defined according to the purposes of energy use. The purpose-based approach is superior for modelling the green transition because it closely mimics firms' decisions regarding switching energy sources and is more parsimonious, relying on fewer industry-specific elasticities in the production structure. Latvia's Computable General Equilibrium (CGE) model is an integral part of the joint CGE-EUROMOD modelling system used for policy simulations at Latvijas Banka. We improve this model by 1) incorporating endogenous substitution of energy resources by enterprises through the proposed purpose-based approach, 2) including the accounting of greenhouse gas (GHG) emissions generated by all public and private sector entities, and 3) introducing explicit modelling of expenses related to these emissions both due to state-level levies and participation in the EU Emissions Trading Scheme (EU ETS). To illustrate the advantages of the augmented model, we simulate a scenario in which Latvia follows a linear path to achieve GHG emissions reduction consistent with its European Green Deal objectives by 2030 achieved solely through carbon pricing. The analysis of this scenario suggests that over a three-year horizon ending in 2025, the resulting cumulative welfare losses would exceed 2% in the case of an uncompensated carbon tax (resulting in a budget balance improvement of 2.6% of GDP) or amount to 0.3% if government consumption is increased to keep the budget balance constant. If instead the size of the public sector is maintained and the higher carbon tax is compensated by a VAT rate cut, economic activity expands by 1% but GHG emissions fall by 40% less.

Keywords: CGE model, Latvia, GHG emissions, Emissions Trading Scheme, carbon tax, energy substitution, green transformation, energy transition, European Green Deal, EUROMOD

JEL codes: C68, Q58, Q48, Q54, Q41

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1 Introduction

The question of how to sustain economic growth while simultaneously reducing the greenhouse gas (GHG) emissions has become topical at least since the signing of the Kyoto Protocol almost three decades ago. To address this question, economists have employed various models to estimate the costs and welfare implications of the green transition. Computable General Equilibrium (CGE) models have a prominent role in this literature, as they allow for modelling prices and real volumes of different production resources and across a granular set of goods and economic sectors without losing the advantages of simulating the economy ensuring that a full equilibrium is maintained.[1]

The success of CGE models can be attributed to several key factors. First, they combine micro-founded behaviour of economic agents rooted in neoclassical economic theory with comprehensive sectoral and economy-wide coverage. This integration is achieved through the utilisation of input-output tables, which enables incorporating variations in the use of intermediate inputs, including energy commodities, across different sectors. Consequently, CGE models are well-suited to provide insights into the uneven effects of reducing the carbon intensity of output on different segments of the economy. Second, CGE models offer flexibility in scenario creation and transparent counterfactual analysis. This feature empowers policymakers to comprehend the direct and indirect consequences of proposed policy changes, evaluate the impact of entire policy packages, and assess the effects of individual policy measures. Some drawbacks of CGE models are over-reliance on a large number of elasticities of substitution between different inputs, which are difficult to calibrate and whose precision is difficult to verify, and the lack of dynamics – fundamentally, CGE is a static model. Although it is possible to create a dynamic model, assumptions about deviations from full adjustment need to be explicitly incorporated for every market with frictions. However, despite these limitations, CGE models are widely used to simulate effects of various policy questions because they can be tailored to specific purposes of analysis and can provide and extremely detailed comparison of effects of some policy to the counterfactual. Furthermore, CGE models can serve as a backbone to even more detailed analysis when linked with other models to simulate specific aspects of the economy, such as the use of resources, the energy sector, recycling, consumption, etc.

This paper focuses on the improvement of modelling energy substitution in CGE models. Several

[1] See, for example, Burniaux and Truong (2002), Truong et al. (2007), and Peters (2016) for the Global Trade Analysis Project (GTAP) model. Abrell (2010), Guo et al. (2014), Ojha et al. (2020), Thepkhun et al. (2013), and Yahoo and Othman (2017) represent a very incomplete list of CGE models used for the analysis of green transformation in the recent years.

factors have contributed to the increased importance of considering the energy mix around which firms organise their production: the recent substantial fluctuations of energy prices, the necessity for energy security, as well as the need to decarbonise our economies, which includes changing the energy mix in production, i.e. transitioning to less carbon-intensive energy goods and production processes. This requires researchers to take account of how absolute and relative quantities of energy goods used for production will change in different policy and macroeconomic scenarios, and to what changes in expenses on energy it will lead to.

Most traditional CGE models rely on an assumption that all intermediate inputs, including inputs of different energy commodities, remain proportional to output under any scenario, i.e. even if their relative prices change dramatically. In view of the described importance of the need to accommodate for adjusting the mix of energy inputs, this approach is ill-suited for reliable modelling. This becomes even more glaring if we consider carbon pricing. The whole point of designing a carbon taxation system is to make dirtier production processes and goods, including energy commodities, more expensive and thereby incentivise firms to move away from them by substituting them with cleaner alternatives.

Designers of CGE models often tackle this issue by revising the treatment of energy commodities within the production structure, departing from the traditional Leontief framework where they are considered perfect complements. Instead, they adopt a multi-level production structure that allows for dynamic substitution between energy commodities, capital, and labour. Typically the energy bundle substitutes the capital-labour bundle (see e.g. Ojha et al. 2020; Abrell 2010; Thepkhun et al. 2013; and Lin and Jia 2018), or the substitution occurs between capital and the energy bundle, but labour substitutes with the capital-energy bundle (see e.g. Shi et al. 2019; Duarte et al. 2018; Yahoo and Othman 2017; and Guo et al. 2014). Different types of energy products serve as imperfect substitutes within the energy bundle and most models assume equal elasticities of energy product substitution across multiple sectors, reducing the reliability of the policy simulations.

We propose a novel solution to the problem – one that allows for more precise modelling of substitution at the industry level while simultaneously eliminating the need to calibrate multiple elasticity coefficients. According to the modified production function, firms' utilisation of energy resources is determined by their demand for specific energy processes, with energy resource usage explicitly categorised by purpose. Primary inputs, intermediate inputs, and various energy processes (such as high-temperature process heat or lighting) are perfect complements, as in a canonical

CGE model. Energy commodities can only substitute each other within specific energy processes. Additionally, energy commodities may enter more than one energy process (e.g. gas can be used for both high and low-temperature processes), although the structures of how energy goods are combined to supply each energy process differ. The elasticities of energy product substitution within each energy process are assumed to equal across industries except for the exception of energy goods used for transportation. This modelling approach allows researchers to reduce the number of required elasticity estimations or calibrations, resulting in a more robust model. Nevertheless, the incorporation of energy processes enhances model flexibility and realism because of varying extent to which industries utilise each energy process in production. This closely mirrors the real-world decisions made by firms when considering a switch in power sources for their production processes.

We apply the novel approach based on energy processes to Latvia's CGE model. For the description of the previous versions of the model one can refer to Benkovskis et al. 2016; Benkovskis and Matvejevs 2023; and Benkovskis et al. 2023. We have enhanced this model to make it suitable for studying how carbon pricing and other policies can reduce GHG emissions in Latvia and kickstart the green transformation of the economy in the near term, i.e. with currently available technologies. To achieve this goal, apart from modifying the production structure according to the new principle of energy processes based on purposes of the use of energy goods, an accounting system of GHG emissions in CO2 equivalent generated by all public and private sector entities has been incorporated, as well as explicit modelling of expenses related to these emissions (carbon taxes) has been introduced, including both state-level levies and participation in the European Union Emissions Trading Scheme (EU ETS).

We employ the improved model to simulate the potential impact of GHG emissions reduction in Latvia achieved through the imposition of a high carbon price that would place the country on a linear trajectory toward meeting its European Green Deal objectives by 2030. By 2025, the resulting welfare losses would exceed 2% in the case of an uncompensated carbon tax but the additional carbon tax revenue would increase the budget surplus by 2.6 percentage points to GDP. The allocation of this supplementary budget revenue, whether it takes the form of a tax reduction, funding for a social safety net to shield vulnerable households from price increases, investments in green initiatives, or bolstering overall public investment, represents a political decision with the potential to yield different outcomes. If we assume that the budget balance is maintained and the government uses the additional revenue to increase fiscal spending, the reduction of GHG emissions is almost the same as for the uncompensated carbon tax, while the contraction of economic activity amounts to 0.3%. Keeping the size of the public sector constant and compensating the increased carbon tax by a cut of the value added tax rate in a fiscally neutral way leads to a 1% higher real GDP than in the baseline (versus a 2% lower GDP in the case of an uncompensated carbon tax increase), but GHG emissions decrease by 40% less than in the uncompensated carbon tax hike scenario.

The remainder of this paper is organised as follows. Section 2 provides an explanation of the new production structure, with specific insights into the substitution dynamics among energy commodities. In Section 3, we delve into the topic of carbon pricing, outlining the various forms it can take, describing the modifications made to our CGE model for its incorporation, and elucidating its impact on firms' cost-minimising decisions. Finally, Section 4 demonstrates the capabilities of the latest version of the model through a practical example, focusing on scenarios where Latvia aligns its GHG emissions reduction efforts with the European Fit for 55 pledge.

2 Production structure with energy substitution

2.1 The problem of modelling energy inputs and our solution

The most extensive and ambitious ongoing effort to develop a global CGE model capable of simulating substitution of energy commodities and incorporating various carbon taxation and cap-and-trade systems worldwide has been undertaken through the Global Trade Analysis Project (GTAP). The year 1999 marked the initial presentation of an energy-environmental CGE model (Burniaux and Truong 2002). Subsequently, Truong et al. (2007) successfully integrated emissions trading into this model, while Peters (2016) expanded the model further to account not only for the substitution of energy commodities by non-energy industries but also to illustrate how carbon pricing influences the energy sector's choice of primary power sources.

Traditional CGE models rely on a simple production structure: all intermediate inputs are assumed to be used in constant industry-specific shares that were proportional to the primary inputs – the mix of capital and labour. Capital and labour can substitute each other with industry-specific calibrated elasticities.

The described structure does not allow for the study of the green transition because it assumes that all production is extremely rigid in terms of how different intermediate inputs can be combined with the bundle of primary inputs to produce output. This implies that, even if the relative prices of energy goods change, the relative quantities in which energy inputs are used by each industry remain constant. This clearly contradicts the reality of the green transition, as for the greening of the economy to occur, dirtier fuels and production processes must be phased down in the near term and ultimately phased out.

Designers of CGE models typically address this issue by excluding energy commodities from the list of intermediate goods that enter the production structure in the Leontief form, where they are considered perfect complements. Instead, they create multi-level production structures in which energy commodities can substitute for capital and labour. A common approach is to assume that the substitution occurs between the energy bundle and the capital-labour bundle (see Ojha et al. 2020; Abrell 2010; Thepkhun et al. 2013; and Lin and Jia 2018). Other authors argue that reducing the intensity of energy and emissions in output often necessitates the introduction of more complex production technologies, which is associated with significant capital deepening. Therefore, a more realistic model of the production block is one in which, at the upper level, substitution occurs between the labour and capital-energy bundles, and at the next level, capital and the bundle of energy commodities act as substitutes (see Shi et al. 2019; Duarte et al. 2018; Yahoo and Othman 2017; and Guo et al. 2014).

In most of the aforementioned models, the elasticities of substitution between energy commodities within the energy bundle are assumed to be equal across multiple sectors. This is due to significant identification problems that arise when detailed price and quantity data are unavailable for extended periods at the industry level, as is typically the case. However, it is a general characteristic and limitation of CGE models, as demonstrated by Antimiani et al. (2015), that the estimation of welfare losses is only as accurate as the reliability of the elasticity estimates. Precisely estimating substitution elasticities for multi-level production structures is an exceedingly challenging task.

We propose a novel solution to the problem, one that allows for more precise substitution between energy commodities at the industry level while simultaneously avoiding the need to calibrate multiple elasticity coefficients in a complex multi-level substitution structure. Our approach is based on the observation that the use of energy commodities can be categorised into several purposes, and a transition to other fuels or types of energy can occur only if cost-competitive technologies are available for these purposes. Moreover, the elasticity of substitution can be expected to be more closely related to the costs and practical challenges of switching between specific technologies for particular types of energy supply rather than the sectors in question. For example, the elasticity of substitution between coal and gas is better represented by the difficulty of replacing a coal stove with a gas boiler rather than by the sector in which the enterprise considering this switch operates.

We refer to these purposes of energy use as "energy processes", and in accordance with the described concept, we can treat them like other intermediate inputs. We combine all purposes into five energy processes, which we will describe below. In the new structure, non-energy inputs directly enter the Leontief production function, while energy products are grouped under energy processes, which are then integrated into the production structure using the Leontief function as well. One energy input can be utilised for several energy processes; for instance, electricity may be used to power equipment, illuminate manufacturing premises, and operate electric vehicles within the firm. The production structure of each energy process differs, however.

2.2 The new approach to the production structure

The production structure we introduce can be described as follows. Once a representative firm from the non-energy industry i acknowledges the total output, it solves the following cost-minimisation problem:

$$\min_{Q_{ib},Q_{ip},Q_i^{PRIM}} \sum_{b\in NEC} P_{ib}^{PROD} Q_{ib} + \sum_{p\in PROC} P_{ip}^{PROC} Q_{ip} + P_i^{PRIM} Q_i^{PRIM} \tag{1}$$

$$s.t.\ \ Q_i^{TOT} = \min\left\{\frac{Q_{ib}}{A_{ib}}\forall b\in NEC; \frac{Q_{ip}}{A_{ip}}\forall p\in PROC; \frac{Q_i^{PRIM}}{A_i^{PRIM}}\right\}$$

where NEC and $PROC$ are the sets of non-energy commodities and energy processes respectively, P_{ib}^{PROD} and P_{ip}^{PROC} are their respective composite prices faced by the representative firm in industry i, index b denotes all non-energy commodities and index p – five energy processes. Q_i^{TOT} stands for the overall output of industry i, Q_{ib}, Q_{ip} and Q_i^{PRIM} – correspond to industry's i inputs of non-energy commodity b, inputs of energy process p and primary factor aggregates respectively, while P_{ib}, P_{ip} and P_i^{PRIM} denote the corresponding input prices. Finally, $A_{ib} > 0$, $A_{ip} > 0$ and $A_i^{PRIM} > 0$ are exogenously set industry-specific parameters that represent production technology.

As in conventional production structures, primary inputs, labour and capital, can substitute for each other with industry-specific elasticities. Firms determine their inputs by solving the following cost-minimisation problem, provided that the output and the total quantity of the primary inputs' bundle are already determined.

$$\min_{Q_i^{LAB}, Q_i^{CAP}} P_i^{LAB} Q_i^{LAB} + P_i^{CAP} Q_i^{CAP} \tag{2}$$

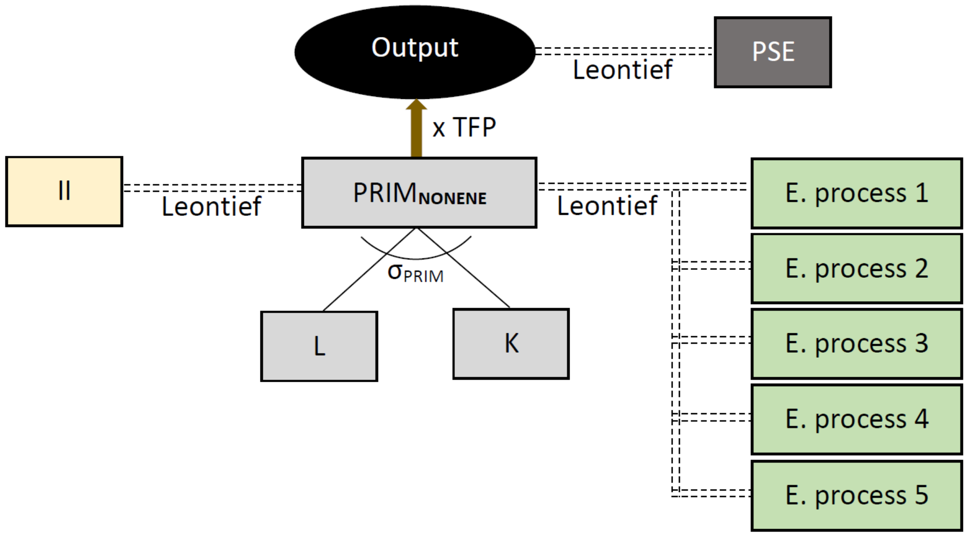
$$s.t. \; Q_i^{PRIM} = \left(B_i^{LAB} \cdot (Q_i^{LAB})^{\frac{\sigma_i^{PRIM}-1}{\sigma_i^{PRIM}}} + B_i^{CAP} \cdot (Q_i^{CAP})^{\frac{\sigma_i^{PRIM}-1}{\sigma_i^{PRIM}}} \right)^{\frac{\sigma_i^{PRIM}}{\sigma_i^{PRIM}-1}}$$

where P_i^{LAB} and P_i^{CAP} are labour and capital unit costs faced by industry i, Q_i^{LAB} and Q_i^{CAP} represent the industry's labour and capital inputs, σ_i^{PRIM} denotes industry-specific elasticity of substitution between capital and labour, while B_i^{LAB} and B_i^{CAP} are industry-specific exogenously set parameters that describe quality of labour and capital respectively.

Figure 1 presents the production structure in non-energy sectors, which includes all industries except for electricity generation, gas transformation, central heating, and cooling. The light-grey block in the centre shows the substitution between primary inputs as represented by Formula 2, while the bundle of primary inputs of non-energy industries ($PRIM_{NONENE}$), intermediate inputs (II), and energy processes (in green) act as complements as demonstrated in Formula 1. Note that the production structure also includes process-specific emissions (PSE) that are directly proportional to the total output of the industry. These are emissions not related to burning fossil fuels but to production-specific chemical and biological processes (e.g. methane emissions due to the digestion process in agriculture, or CO2 emissions as a product of chemical reaction in cement industry). These emissions are treated as a specific input due to the attached carbon pricing costs (see Section 3.2).

The mechanics of our approach for incorporating energy goods into the production structure are as follows. First, we compile a list of energy processes, specific enough to capture different technologies yet broad enough to encompass all energy resource consumption (including any fuel, electricity, heating, and hot water) by any firm. Next, for each industry, we specify the proportion of each energy commodity consumed for each purpose. Finally, for each energy process, a production structure is designed to reflect the options available to enterprises for adjusting the mix of consumed energy commodities while achieving the same energy process.

Figure 1: Production structure in non-energy industries



Source: Authors' drawing

2.3 Energy processes and substitution of energy commodities in non-energy industries

In literature on energy systems and decarbonisation of the industrial sector, energy use is often classified according to its end-use purposes, such as machine drive, process heat, building heat and hot water, and other processes, including cooling, lighting and ventilation. See, for example, Jaunzems et al. 2020 and Balyk et al. 2022.

We take inspiration from this approach centred around energy processes according to the purpose of energy use and classify main energy usage purposes in non-energy industries into seven categories but eventually arrive at five energy processes. Our reasoning is the following.

First, since only electricity is suitable for powering of equipment, lighting, ventilation, conditioning, and cooling, we combine them into the first energy process where no substitution is possible. Second, we divide industrial process heat into high-temperature and low-temperature because of different mixes of energy goods that are usually utilised to generate them. High-temperature process heat is utilised primarily by the mining industry and manufacturing of metallic and non-metallic products. The uniqueness of this production lies in the fact that while maintaining high temperatures is achievable with various energy sources, even waste and rubber, initiating the process is more challenging and can only be accomplished using coal or natural gas, depending on the installed technology. Therefore, we further divide high-temperature process heat into two processes: the initial heating phase to reach the required temperature, which typically exceeds 500 degrees Celsius, and the subsequent maintenance of this temperature. Only a small portion of natural gas and coal is used to initiate the high-temperature process, and as mentioned earlier, these energy resources are nearly irreplaceable. Consequently, we end up with the following energy processes:

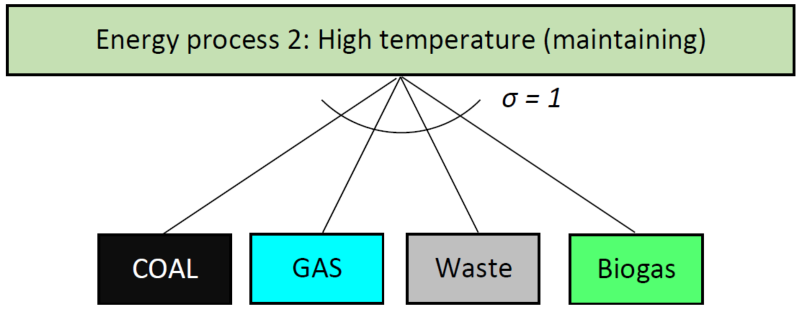
1. Energy Process 1:
    a. powering of equipment;
    b. lighting;
    c. ventilation, conditioning, and cooling;
    d. initiating high-temperature process heat;
2. Energy Process 2: maintaining high-temperature process heat;
3. Energy Process 3: low-temperature process heat;
4. Energy Process 4: hot water and heating;
5. Energy Process 5: transportation.

Within **Energy Process 1** we consolidate all energy resources that cannot be substituted by other energy goods under any scenario. These include consumption of electricity for powering of equipment, lighting, ventilation, conditioning, and cooling, as well as the initial phase of achieving high-temperature process heat. Substitution of resources is not feasible within this process; therefore, it is described by the Leontief function.

Energy Process 2 encompasses the consumption of energy commodities necessary for the maintenance of high-temperature process heat. Within this process, coal and natural gas can be substituted with waste, rubber, and biogas. While a different technology is required for these substitutions, there has been a significant increase in the proportion of energy generated from waste in the cement industry in the recent years. Therefore, assuming an elasticity of 1 and employing the constant elasticity of substitution (CES) function (implying constant cost shares) appears to be a reasonable assumption for modelling how the allocation of energy resources for maintaining high-temperature process heat will change based on their relative prices.

Once total output and hence the demand for Energy Process 2 are known, firms solve the following cost minimisation problem to determine the quantities of energy commodities used for

Figure 2: Substitution of energy commodities within Energy Process 2



Source: Authors' drawing

this process:

$$\min_{Q_i^{Coal},Q_i^{Gas},Q_i^{Waste},Q_i^{Biogas}} \sum_{R\in\{Coal;Gas;Waste;Biogas\}} P_i^R Q_i^R \tag{3}$$

$$s.t.\ \ Q_i^{EP2} = \left(\sum_{R\in\{Coal;Gas;Waste;Biogas\}} B_i^R \cdot (Q_i^R)^{\frac{\sigma^{EP2}-1}{\sigma^{EP2}}} \right)^{\frac{\sigma^{EP2}}{\sigma^{EP2}-1}}$$

where $R \in \{Coal; Gas; Waste; Biogas\}$, P_i^R and Q_i^R are respectively unit costs of these energy resources faced by industry i and input quantities, σ^{EP2} denotes the elasticity of substitution between these resources used for maintaining high-temperature process heat (Energy Process 2), while B_i^R stands for exogenously set parameters that describe the efficiency of using energy resource R for Energy Process 2 in industry i.

Energy Process 3 corresponds to the consumption of energy commodities for the generation of low-temperature process heat. Similar to high-temperature process heat, this process is exclusive to the manufacturing sector and is predominantly used by the following industries: food (10), textile (13–15), wood (16), chemicals (20), and pharmaceuticals (21). Various types of energy resources can be employed for this process, including coal, natural gas, biomass (biogas, wood, and wood products). Furthermore, firms also have the option to obtain the required heat from central heating facilities.

The ability to transition from one energy resource to another to obtain low-temperature process heat can vary significantly among different pairs of energy resources. For instance, if the price of coal increases to the point where its use is economically impractical, it may be quite challenging for a firm to connect to central heating or switch to natural gas or biogas. However, a coal-burning installation can often be retrofitted to use wood or wood pellets instead. Consequently, we have chosen a two-tier production structure for this process.

The lower level comprises hard fuels that can be burned interchangeably in the same furnace after a straightforward retrofitting process, without the need to change the entire furnace. These hard fuels include coal, wood, wood residues, and wood pellets, collectively referred to as the "hard fuels bundle" ("*H.bundle*"). Switching from one of these fuels to another requires a considerably lower capital investment, implying a higher elasticity of substitution between them. We have chosen a value of 2 for this elasticity, meaning that, all else being equal, a 10% increase in the price of coal would lead to a roughly 20% decrease in its usage, primarily in favour of wood, wood residues, and pellets.

Other energy commodities are placed on a higher level with a lower elasticity of substitution (0.4). This is because transitioning between gas boilers, hard fuel furnaces, central heating, or incorporating waste or biogas into the mix typically involves the adoption of new technologies. These changes are associated with substantial capital requirements and infrastructure investments that can take a significant amount of time.

Waste and wood chips, despite being hard fuels, are positioned on the upper level with a lower elasticity of substitution. This is because furnaces designed for burning wood and coal cannot be retrofitted to burn waste and wood chips, necessitating a substantial capital investment for the switch. Liquid fuels, such as diesel, gasoline and petroleum oil, are assumed not to be used in this process. To the best of our knowledge, diesel boilers are uncommon to be used in stationary combustion for the purpose of generating heat, and their share is so minuscule that it can be disregarded.

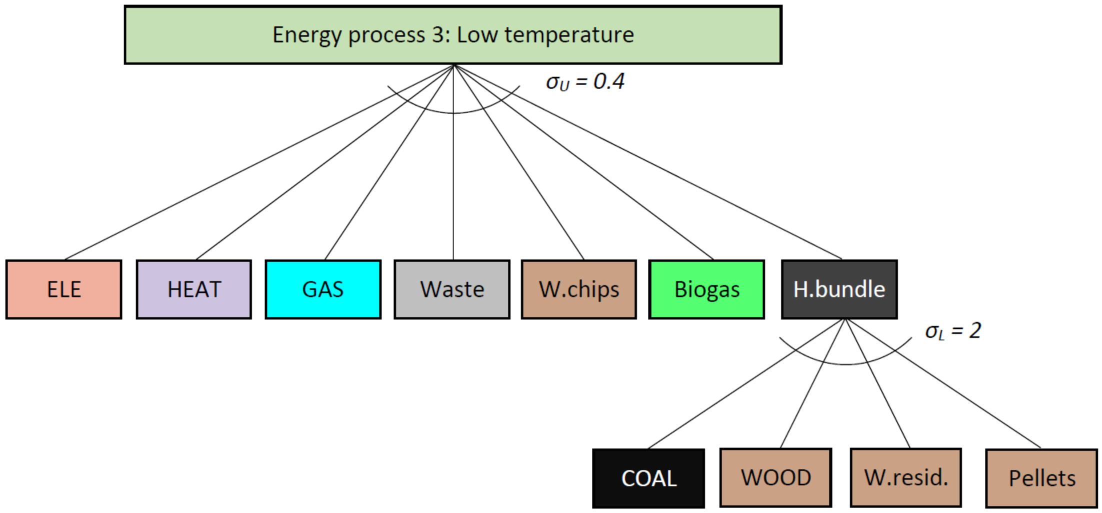
Once total output and hence the demand for Energy Process 3 are known, firms first solve a cost minimisation problem on the upper level to determine the quantities of energy commodities used for this process.

$$\min_{Q_i^{ELE},\ldots,Q_i^{Biogas},Q_i^{H.bundle}} \sum_{R\in\{RES\setminus H.bundle\cup\{H.bundle\}\}} P_i^R Q_i^R \tag{4}$$

$$s.t.\ \ Q_i^{EP2} = \left(\sum_{R\in\{RES\setminus H.bundle\cup\{H.bundle\}\}} B_i^R \cdot (Q_i^R)^{\frac{\sigma^{EP3u}-1}{\sigma^{EP3u}}} \right)^{\frac{\sigma^{EP3u}}{\sigma^{EP3u}-1}}$$

where R denotes all energy resources (RES) that do not constitute the hard fuels bundle and the hard fuels bundle per se, σ^{EP3u} denotes the upper-level elasticity of substitution between these

Figure 3: Substitution of energy commodities within Energy Process 3



Source: Authors' drawing

energy sources used for low-temperature process heat (Energy Process 3), while B_i^R stands for exogenously set parameters that describe the efficiency of using energy source R for Energy Process 3 in industry i. Afterwards, firms solve a cost minimisation problem on the lower level for the hard fuels bundle:

$$\min_{Q_i^{Coal}, Q_i^{Wood}, Q_i^{W.resid.}, Q_i^{Pellets}} \sum_{R \in H.bundle\}} P_i^R Q_i^R \tag{5}$$

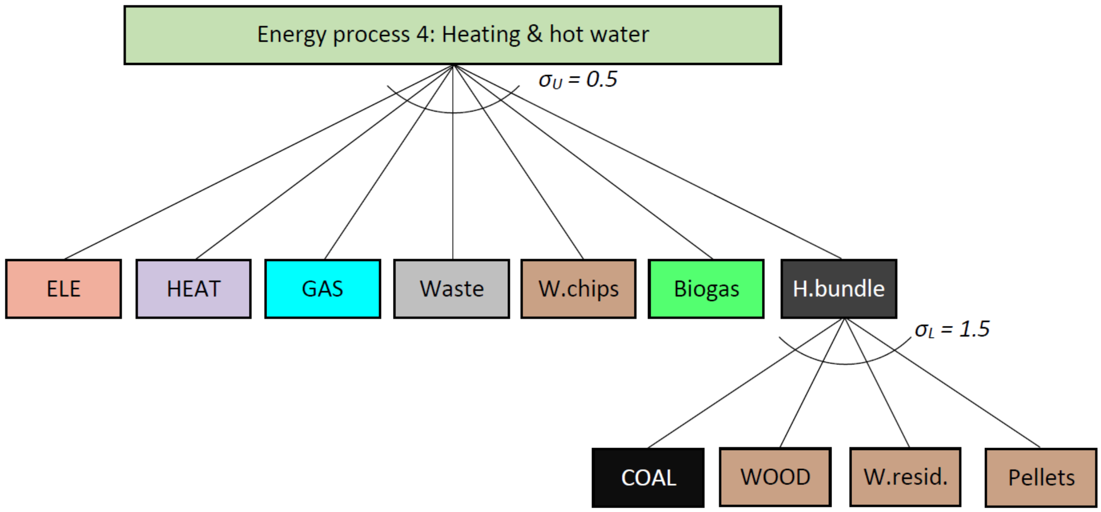
$$s.t.\ \ Q_i^{H.bundle} = \left(\sum_{R \in H.bundle} B_i^R \cdot (Q_i^R)^{\frac{\sigma^{EP3l}-1}{\sigma^{EP3l}}} \right)^{\frac{\sigma^{EP3l}}{\sigma^{EP3l}-1}}$$

where R denotes all energy resources that constitute the hard fuels bundle, σ^{EP3l} denotes the lower-level elasticity of substitution between these energy sources, while B_i^R stands for exogenously set parameters describing the efficiency of using energy source R in the hard fuels bundle in industry i.

Energy Process 4 corresponds to the utilisation of energy resources for hot water and heating. This process covers nearly all of the central heating systems employed by enterprises. Furthermore, in sectors outside of manufacturing, almost all usage of gas, coal, and biomass is categorised under this process.

In terms of the technologies employed, this process is akin to the previous one, with the exception that heat generation occurs on a smaller scale at the firm level. Typically, this involves a larger number of smaller enterprises, for which energy inputs constitute a smaller proportion of their total intermediate inputs. Consequently, we have chosen a lower elasticity value (1.5) for the bundle of hard fuels and a slightly higher one (0.5) for switching among other energy commodities. The

Figure 4: Substitution of energy commodities within Energy Process 4



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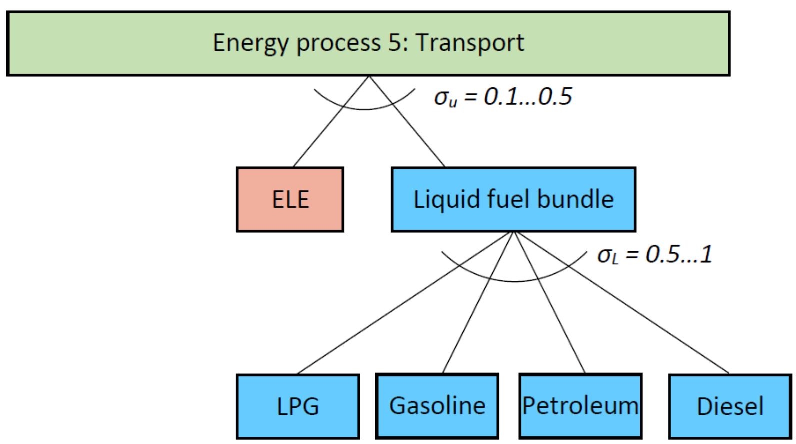
analytical form of firms' cost-minimisation problem for Energy Process 4 looks exactly the same as for Energy Process 3 with the exception that the substitution elasticities take different values: here, we have $\sigma^{EP4u} = 0.5$ and $\sigma^{EP4l} = 1.5$, whereas in the previous process $\sigma^{EP3u} = 0.4$ and $\sigma^{EP3l} = 2$.

Energy Process 5 includes all the use of energy commodities for transportation, which are primarily limited to liquid fuels and electricity. The electrification of the transportation sector necessitates a significant technological transformation that is already underway, although it is still in its early stages for certain types of transportation. For instance, as of now, heavy-duty vehicles and buses running on electricity are not widespread. We account for this in our choice of the substitution structure for this process by placing electricity at the higher level with a lower elasticity of substitution and grouping all liquid fuels into a "liquid fuels bundle". Substitution within this bundle occurs at the lower level with a higher elasticity.

This process also differs significantly from the others because the substitution elasticities vary across industries. This variation arises because in sectors such as manufacturing, construction, vehicle trade, wholesale trade, and agriculture, transportation primarily relies on heavy-duty vehicles or, in some instances, specialised transport, for which electrification options are limited in most cases. These vehicles cannot be easily transitioned from diesel to other fuels. Furthermore, even in cases where certain forms of transportation, such as within warehouses, are electrified, changes in technology typically require advanced planning spanning several years and are not influenced by short-term fluctuations in the relative prices of electricity and oil products from year to year.

In the services sector, a portion of transportation involves light vehicles, such as light vans, automobiles, or even scooters. These vehicles can be replaced by their electric alternatives more readily, which implies a higher elasticity between the liquid fuel bundle and electricity. Additionally, a lower proportion of heavy-duty and specialised vehicles means that firms can more easily transition to different oil products. However, this may not hold true for the commercial sector, as the prevalence of diesel vehicles is significantly higher. Furthermore, prices of various liquid oil products typically share the same trend, with their relative prices experiencing minimal change. Once the

Figure 5: Substitution of energy commodities within Energy Process 5



Source: Authors' drawing

output and, consequently, the demand for Energy Process 5 are known, firms begin by solving a cost minimisation problem at the upper level to determine the quantities of energy commodities used for this process.

$$\min_{Q_i^{ELE}, Q_i^{L.bundle}} P_i^{ELE} Q_i^{ELE} + P_i^{L.bundle} Q_i^{L.bundle} \tag{6}$$

$$s.t.\ \ Q_i^{EP5} = \left(B_i^{ELE} \cdot (Q_i^{ELE})^{\frac{\sigma_i^{EP5u}-1}{\sigma_i^{EP5u}}} + B_i^{L.bundle} \cdot (Q_i^{L.bundle})^{\frac{\sigma_i^{EP5u}-1}{\sigma_i^{EP5u}}} \right)^{\frac{\sigma_i^{EP5u}}{\sigma_i^{EP5u}-1}}$$

where σ^{EP3u} denotes the upper-level elasticity of substitution between these energy sources used for low-temperature process heat (Energy Process 5), while B_i^{ELE} and B_i^{ELE} stand for exogenously set parameters that describe the efficiency of using electricity and liquid fuels respectively for Energy Process 5 in industry i.

One should note that for Energy Process 5, the elasticity is subscripted with i because, as previously explained, electrification opportunities vary among industries, and we account for these differences through distinct substitution elasticities. Specifically, we set it at 0.5 for restaurants and accommodation services, 0.1 for manufacturing, construction, vehicle trade, wholesale trade, and agriculture, and 0.2 for all other sectors.

$$\min_{Q_i^{LPG}, Q_i^{Gasoline}, Q_i^{Petroleum}, Q_i^{Diesel}} \sum_{R \in L.bundle} P_i^R Q_i^R \tag{7}$$

$$s.t. \;\; Q_i^{L.bundle} = \left(\sum_{R \in L.bundle} B_i^R \cdot (Q_i^R)^{\frac{\sigma_i^{EP5l}-1}{\sigma_i^{EP5l}}} \right)^{\frac{\sigma_i^{EP5l}}{\sigma_i^{EP5l}-1}}$$

where R denotes all energy resources that constitute the liquid fuels bundle, σ^{EP5l} denotes the lower-level elasticity of substitution between these energy sources, while B_i^R stands for exogenously set parameters that describe the efficiency of using energy source R in the liquid fuels bundle in industry i.

2.4 Production structure in energy industries

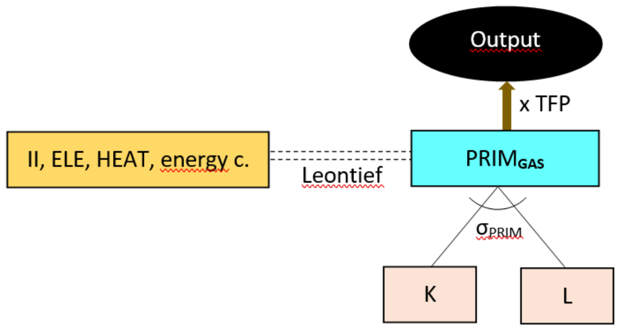
For energy industries, simpler production structures are chosen. **Gas industry** (35.2) primarily converts imported natural gas into a form available for domestic use. Therefore, we can assume limited opportunities for substitution among various intermediate inputs, including energy commodities. In the gas industry, it is assumed that all non-energy intermediate inputs and all energy commodities, including electricity, heat, and gas, are consumed in constant proportions regardless of their relative prices, just as in the previous versions of the CGE model (see Figure 6).

$$\min_{Q_{Gas}^{LAB}, Q_{Gas}^{CAP}} P_{Gas}^{LAB} Q_{Gas}^{LAB} + P_{Gas}^{CAP} Q_{Gas}^{CAP} \tag{8}$$

$$s.t. \;\; Q_{Gas}^{PRIM} = \left(B_{Gas}^{LAB} \cdot (Q_{Gas}^{LAB})^{\frac{\sigma_{Gas}^{PRIM}-1}{\sigma_{Gas}^{PRIM}}} + B_{Gas}^{CAP} \cdot (Q_{Gas}^{CAP})^{\frac{\sigma_{Gas}^{PRIM}-1}{\sigma_{Gas}^{PRIM}}} \right)^{\frac{\sigma_{Gas}^{PRIM}}{\sigma_{Gas}^{PRIM}-1}}$$

where P_{Gas}^{LAB} and P_{Gas}^{CAP} are labour and capital unit costs faced by the gas industry, Q_{Gas}^{LAB} and Q_{Gas}^{CAP} represent the labour and capital inputs, σ_{Gas}^{PRIM} denotes the elasticity of substitution between capital and labour, while B_{Gas}^{LAB} and B_{Gas}^{CAP} are the exogenously set parameters that describe quality of labour and capital respectively in the gas industry.

Figure 6: Production structure in industry 35.2 (Gas)



Source: Authors' drawing

Electricity and **central heating generation industries** differ because they have the capability to produce their output (energy goods themselves) using either dirty energy commodities or clean alternatives (green energy). Transitioning from the former to the latter requires substantial capital investment for the construction of solar and wind parks, as well as the installation of heat pumps. It also demands a significant labour force for the installation and maintenance of the green energy generation equipment. Consequently, capital and labour can be considered complementary factors, implying that the elasticity of substitution between them must be low.

Fossil fuel bundles and the value-added component are considered substitutes, hence their elasticity of substitution must be relatively high, especially in the context of green electricity generation, as the green transition is already underway in this sector. However, almost everywhere across the world heat generation still heavily relies on non-renewable energy resources, as heat pumps are more commonly installed by households and firms rather than on an industrial scale. Furthermore, all combustible energy commodities can easily replace each other when needed (see Figure 7).

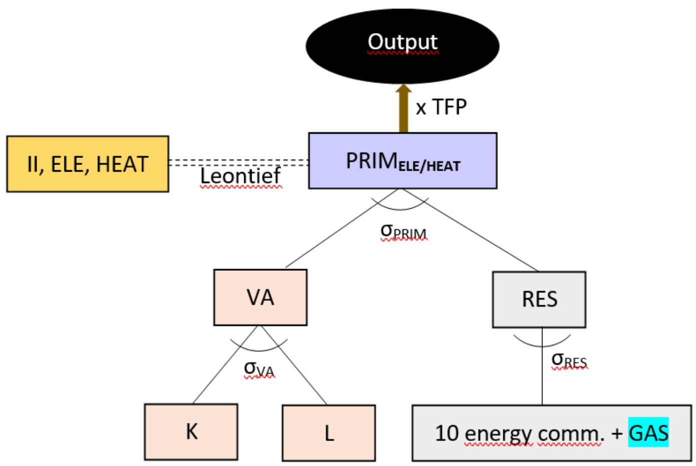
Analytically, the production structure in the electricity and heat generation industries can be described as follows. Once the industry's output is known, the quantity of intermediate non-energy goods inputs is selected in proportion to the output and, similar to other industries, adjusted by the productivity coefficient. To determine the quantities of other inputs, firms initially address a cost minimisation problem at the upper level, where they make decisions regarding the optimal quantities of the combustible energy resources bundle (RES) and the bundle comprising capital and labour (VA):

$$\min_{Q_j^{VA}, Q_j^{RES}} P_j^{VA} Q_j^{VA} + P_j^{RES} Q_j^{RES} \tag{9}$$

$$s.t.\ \ Q_j = \left(B_j^{VA} \cdot (Q_j^{VA})^{\frac{\sigma_j^{Eu}-1}{\sigma_j^{Eu}}} + B_j^{RES} \cdot (Q_j^{RES})^{\frac{\sigma_j^{Eu}-1}{\sigma_j^{Eu}}} \right)^{\frac{\sigma_j^{Eu}}{\sigma_j^{Eu}-1}}$$

where j is one of two energy industries ($j \in \{ELE; HEAT\}$), σ_j^{Eu} denotes the upper-level elasticity of substitution between the value added component and the bundle or combustible energy resources, while B_j^{VA} and B_j^{RES} stand for exogenously set parameters reflecting the quality of VA and RES in industry j such that their quantities are configured to match the initial inputs.

Figure 7: Production structure in industries 35.1 (Electricity) and 35.3 (Heating)



Source: Authors' drawing

After solving the cost-minimisation problem at the upper level and determining the quantities of the combustible energy goods bundle and the value-added bundle, firms optimise the composition of these bundles by addressing a cost-minimisation problem for each of them. This process allows them to select the optimal amounts of inputs for energy resources, labour, and capital.

$$\min_{Q_j^{Gas}, Q_j^{Coal}, \ldots, Q_j^{Biogas}} \sum_{R \in \{Gas, Coal, \ldots, Biogas\}} P_j^R Q_j^R \tag{10}$$

$$s.t.\ \ Q_j^{RES} = \left(\sum_{R \in \{Gas, Coal, \ldots, Biogas\}} B_j^R \cdot (Q_j^R)^{\frac{\sigma_j^{ElRES}-1}{\sigma_j^{ElRES}}} \right)^{\frac{\sigma_j^{ElRES}}{\sigma_j^{ElRES}-1}}$$

where P_j^R and Q_j^R represent respectively the unit costs and inputs of energy goods, σ_j^{ElRES} denotes the elasticity of substitution between different combustible energy resources (the lower level of the production structure in the energy industries), while B_j^R stands for exogenously set parameters that describe efficiency of different energy resources in industry j.

$$\min_{Q_j^{LAB}, Q_j^{CAP}} P_j^{LAB} Q_j^{LAB} + P_j^{CAP} Q_j^{CAP} \tag{11}$$

$$s.t.\ Q_j^{VA} = \left(B_j^{LAB} \cdot (Q_j^{LAB})^{\frac{\sigma_j^{ElVA}-1}{\sigma_j^{ElVA}}} + B_j^{CAP} \cdot (Q_j^{CAP})^{\frac{\sigma_j^{ElVA}-1}{\sigma_j^{ElVA}}} \right)^{\frac{\sigma_j^{ElVA}}{\sigma_j^{ElVA}-1}}$$

where P_j^{LAB} and P_j^{CAP} are labour and capital unit costs faced by the energy industry j, Q_j^{LAB} and Q_j^{CAP} represent the labour and capital inputs, σ_j^{ElVA} denotes the elasticity of substitution between capital and labour at the lower level of the production structure in the energy industries, while B_j^{LAB} and B_j^{CAP} are the exogenously set parameters that describe the quality of labour and capital respectively in electricity and heat industries. Table A.1 in Appendix contains details on what share of the use of each energy commodity is attributed to each energy process.

2.5 Industry unit costs

As in Benkovskis et al. (2016) and Benkovskis and Matvejevs (2023), we employ the zero-profit assumption to determine producer prices, which means we implicitly assume that producers do not possess market power. Consequently, basic prices are solely dependent on the costs of production resources and do not include any markups. These costs encompass expenses related to labour, capital, and the intermediate inputs essential for production:

$$P_i^{INPUT} \cdot Q_i^{TOT} = \sum_{c \in PROD} P_{ic}^{DOM} \cdot Q_{ic}^{DOM} + \sum_{c \in PROD} P_{ic}^{IMP} \cdot Q_{ic}^{IMP} + P_i^{LAB} \cdot Q_i^{LAB} + P_i^{CAP} \cdot Q_i^{CAP} \tag{12}$$

where i indexes over all industries, P_i^{INPUT} stands for the basic prices, and Q_i^{TOT} – the total output of industry i, Q_i^{LAB} and Q_i^{CAP} are quantities of respectively labour and capital inputs employed in the production, P_i^{LAB} and P_i^{CAP} are prices of these factors faced by producers, Q_{ic}^{DOM} and Q_{ic}^{IMP} are respectively domestic and imported quantities of intermediate goods c used by industry i, and P_{ic}^{DOM} and P_{ic}^{IMP} are prices of these goods faced by firms in industry i. Here, intermediate goods are both imported and domestically produced. Please refer to Benkovskis et al. (2016) on the Armington structure describing how firms source and substitute between domestically produced and imported intermediate inputs.

With the introduction of carbon pricing, certain industries must now acquire emissions allowances through EU ETS auctions to offset the greenhouse gas emissions they generate during the production process. In this context, we are specifically referring to the costs associated with allowances for PSE (Production and Special Uses), as the costs of allowances related to combustion emissions are already factored into the costs of the respective energy commodities. These allowances can be regarded as another essential resource required for production. Consequently, zero-profit firms adjust their basic prices to encompass all costs per output unit, including the expenses incurred for the surrendered, paid ETS allowances against PSE:

$$P_n^{BAS} \cdot Q_n^{TOT} = P_n^{INPUT} \cdot Q_n^{TOT} + Emis_n^{paidETS,PSE} \cdot EC_n^{ETS,PSE} + Emis_n^{paidCTAX,PSE} \cdot EC_n^{CTAX,PSE} \tag{13}$$

where n stands for each non-energy industry, $EC_n^{ETS,PSE}$ and $EC_n^{CTAX,PSE}$ are effective costs of one t CO2e of PSE paid by industry n, which equals the national carbon price / the price of one ETS emissions quota multiplied by the share of PSE emissions subject to the respective levy (see Section 3.3). Currently, the production process-specific emissions are not taxed by the national carbon tax, i.e. $EC_n^{CTAX,PSE}$ for $\forall n$. Therefore, for now, the last term equals zero in all cases, but can become positive depending on the simulated policy scenario.

In energy industries (indexed by e), all GHG emissions are combustion related and none are production process specific. Therefore, the basic price for these industries equals the cost of labour, capital and intermediate goods per unit of output:

$$P_e^{BAS} = P_e^{INPUT} \tag{14}$$

3 GHG emissions and carbon pricing

3.1 Types of carbon pricing

"Carbon should be given a price", declared UN Chief Antonio Guterres during the third annual Bloomberg New Economy Forum on 16 November 2020 (UN News 2020). This statement succinctly reflects the consensus among environmental scientists and climate researchers. It is grounded in straightforward economic reasoning: greenhouse gas (GHG) emissions represent a negative externality for all of humanity. Consequently, the socially optimal solution is to levy a price on such emissions that corresponds to the total marginal damages incurred by society for each emitted ton of greenhouse gases. As of 2023, approximately 23% of global GHG emissions are subject to some form of carbon pricing (World Bank 2023)

The most straightforward form of carbon pricing is a carbon tax, typically a tax imposed on the sale or combustion of fossil fuels in proportion to the greenhouse gases (GHG) emitted into the atmosphere as a result of their usage. As the carbon tax attaches a cost directly linked to GHG emissions for polluters, it effectively establishes a carbon price. Introducing such a tax provides "incentives for producers and consumers alike to reduce energy use and shift to lower-carbon fuels or renewable energy sources through investment or behavior" (Parry 2019).

A more sophisticated approach to carbon pricing is through a cap-and-trade system. In this system, a predefined total quantity of allowances required for each emitted tonne of CO2e is established, while their pricing is determined by the market. While the potential fluctuation in future carbon prices is a drawback of an emissions trading system, it is important to note that "by letting the market set a price on carbon, emissions can be reduced in the most cost-effective way" (Centre for Climate and Energy Solutions 2021).

Currently, both systems are similarly popular around the world but are applied somewhat differently. Emissions trading schemes are mostly located in subnational[2] jurisdictions, whereas carbon taxes are normally implemented at the national level (World Bank 2018). As noted by Parry (2019), carbon taxes are typically easy to administer since they can be integrated into existing fuel tax structures, which most countries already collect efficiently. Conversely, a cap-and-trade system may be the preferred policy approach when a jurisdiction has a specific emissions target in mind. In such a scheme, the total volume of emissions is predetermined, but this reduced amount is attained through processes that are economically less detrimental to achieve (Centre for Climate and Energy Solutions 2021).

Overall, both types represent distinct forms of direct carbon pricing, which, as indicated by World Bank (2023), is now being considered from a broader perspective. It is viewed not only as a pivotal mitigation policy but also as a mechanism for generating revenue, fostering innovation, and contributing to the achievement of more extensive sustainability and development objectives.

[2] A European reader might have heard most about the EU ETS, the European Union Emissions Trading Scheme, which is a supranational system. In fact, according to the World Bank (2018), the majority of emissions trading schemes around the world operate on the subnational level, the most prominent being those in Tokyo, California and several US cities.

3.2 Extended energy sector and GHG emissions accounting system in Latvia's CGE

GHG emissions are presumed to be proportionate to the consumption of energy goods, necessitating a high level of disaggregation in the model. This is because the quantity of emissions in CO2 equivalent generated by combusting energy commodities varies among different commodities. In all previous versions of Latvia's CGE model, only aggregated energy industries and energy commodities were included, and furthermore, all industries and commodities were modelled in a uniform manner (see Benkovskis et al. 2016; Benkovskis and Matvejevs 2023). We abandon this simplification by introducing more a sophisticated production structure (see Section 2). Additionally, we utilise Latvia's energy balance data (CSB 2022b) and the Supply and Use tables, both provided by Latvia's Central Statistical Bureau, to further disaggregate the energy sector (industry 35 under the NACE classification) into three sub-industries: electricity generation and supply (35.1), heating and cooling (35.3), and the transformation of imported gas for domestic use and its subsequent supply (35.2). Furthermore, we introduce 12 energy commodities, as outlined in Table 1, which include both biologically sourced (biomass) and fossil fuel-based commodities. Electricity and heating are treated as secondary energy commodities, but emissions are calculated and subject to carbon taxation only at the point of their production, not consumption. Table 1 also provides information on the industries that produce the above commodities. These energy commodities represent additional outputs of these industries, while the remainder of their production remains consistent with non-energy goods as previously defined.

For each of the fossil fuel energy commodities, there exists an emissions factor φ that reflects the amount of GHG emissions (in t CO2e) produced by burning one terajoule of the respective fossil fuel (as shown in the last column of Table 1). These coefficients are sourced from the Emissions Accounting Tables (LVĢMC 2021). By using the energy balance and energy prices for Latvian end users (CSB 2022a), we compute the quantity of emissions associated with the consumption of one nominal unit of each energy commodity. These coefficients exhibit slight variations by industry, but we present their averages in Table 1. By combining this information with the Supply and Use table, the calculation of combustion emissions becomes straightforward, as depicted in the top left of Figure 8.

Table 1: Energy commodities

Energy commodity	Producing industry	Emissions coefficient
Electricity	*(Separate industry: C35.1)*	*- (in energy inputs)*
Heating and cooling	*(Separate industry: C35.3)*	*- (in energy inputs)*
Gas (distribution)*	*(Separate industry: C35.2)*	54.63 t CO2e / TJ
Gas (imported)*	B Extraction	- (no combustion)*
Coal	B Extraction	101.83 t CO2e / TJ
LPG	C19 Manufacture of coke and refined petroleum	62.75 t CO2e / TJ
Gasoline	C19 Manufacture of coke and refined petroleum	71.18 t CO2e / TJ
Jet fuels	C19 Manufacture of coke and refined petroleum	71.50 t CO2e / TJ
Diesel	C19 Manufacture of coke and refined petroleum	74.75 t CO2e / TJ
Waste and rubber	C22 Manufacture of rubber and plastic products	87.10 t CO2e / TJ
Wood	A02 Forestry and logging	0 (biomass)
Wood residues	C16 Manufacture of products of wood and cork	0 (biomass)
Wood chips	C16 Manufacture of products of wood and cork	0 (biomass)
Wood pellets, briquettes	C16 Manufacture of products of wood and cork	0 (biomass)
Biogas, biofuels, charcoal	C20 Manufacture of chemical products	0 (biomass)

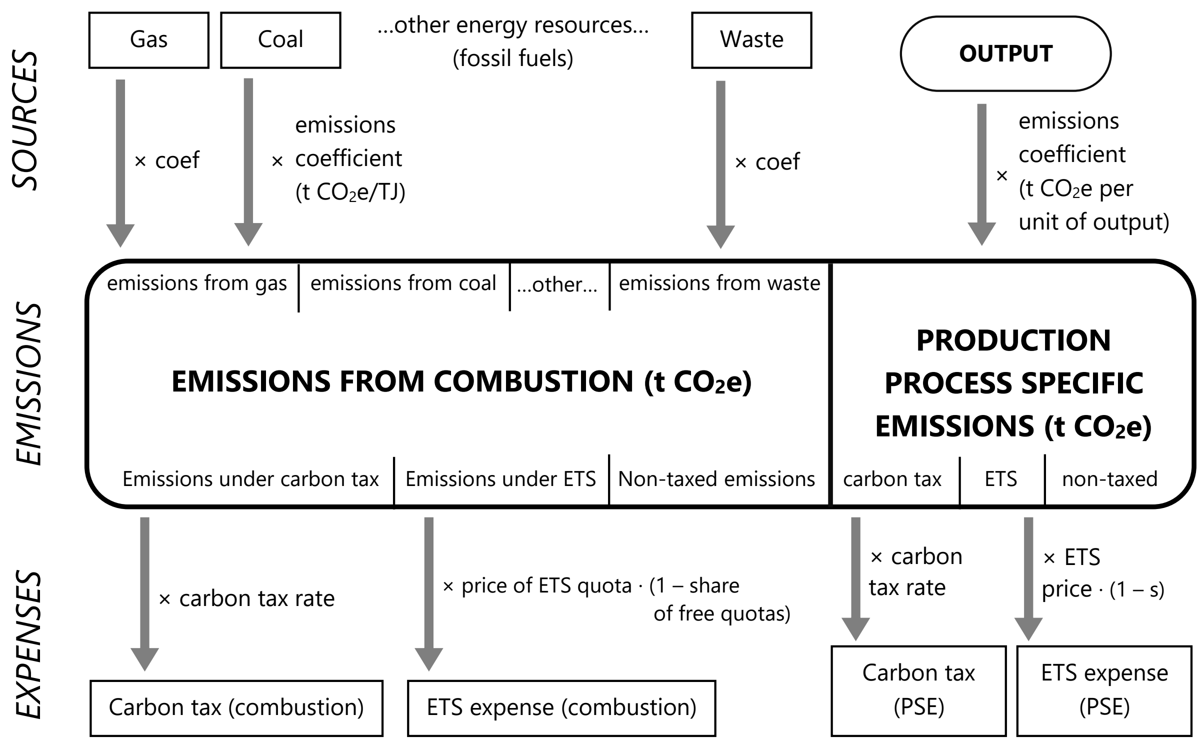
Notes. Column "Producing industry" shows which industry produces the respective energy commodity in addition to the rest of output, which is a non-energy good. Electricity, Heating and cooling, and Gas (distribution) each form a separate energy industry, whereas the rest 12 energy goods are those by which the list of commodities in the model exceeds the list of industries.
Column "Emissions coefficient" contains the number that shows how much GHG emissions in CO2 equivalent is produced as a result of burning one terajoule of the respective energy commodity. Emissions from consumption of Electricity, Heating and cooling, and Gas (distribution) are not counted because these emissions are already calculated when the respective energy commodities are produced from other energy resources.
The bottom five energy commodities are renewable resources, and emissions of their consumption are assumed to be zero by law (UN guidelines which the EU follows) – their emissions must be accounted for under Land Use, Land Use Change, and Forestry (LULUCF), which is beyond the scope of our model.
* Gas (distribution) represents the industry C35.2 in NACE Rev.2 – transformation and natural gas and its distribution as an energy commodity to other industries. Gas (imported) stands for the commodity produced by industry A06.2 "Extraction of natural gas". Natural gas is not extracted in Latvia, therefore all consumed amount of commodity A06.2 is imported and used only by industry C35.2. Natural gas is only transformed and distributed at this stage, hence the use of this good does not produce any emissions. When any other industry purchases gas as an energy commodity, it buys the output of industry C35.2. GHG emissions are attributed to the use of this natural gas that is delivered to firms that actually burn it for energy.

$$Emis_i^{Combustion} = \sum_r Q_{ri} \cdot \zeta_r \cdot \varphi_{ri} \tag{15}$$

where i indexes over all industries, r – all energy commodities, Q_{ri} stands for real intermediate inputs of energy commodities (in million real units), ζ is energy content (TJ per one million real units, such as kg of m^3), and φ is the emissions coefficient.

Total emissions at the industry level may encompass GHG emissions that do not originate from the combustion of fossil fuels but rather from chemical reactions occurring during the production process (as illustrated in the top right of Figure 8). These emissions are referred to as production

Figure 8: Sources of GHG emissions and related expenses



Source: Authors' drawing

process-specific emissions (PSE).

$$Emis_n^{Total} = PSE_n + Emis_n^{Combustion} \tag{16}$$

where n stands for non-energy industries and PSE_n.

Sectors where such emissions are most notable include agriculture (methane emissions resulting from the digestive processes of cows and sheep), the manufacturing of non-metallic products (CO2 produced as a result of chemical reactions to produce cement), and waste processing (methane and carbon dioxide emissions arising from the decomposition of organic matter). It is commonly assumed that these emissions are proportionate to the total output of these sectors (see also Figure 1). The respective coefficients for these emissions are obtained from LVĢMC (2021).

For energy industries, as their output consists of energy goods, all emissions are accounted for in the intermediate use of energy goods. Consequently, there is no need to distinguish between combustion and production process-specific emissions in their case.

$$Emis_e^{Total} = Emis_e^{Combustion} \tag{17}$$

where index e denotes energy industries.

3.3 Carbon pricing in Latvia and its modelling in CGE

3.3.1 Ways of paying for GHG emissions in Latvia

Currently, Latvian firms can be subject to charges for their GHG emissions through two mechanisms: the EU Emissions Trading System (EU ETS) and the natural resources tax[3] (*Dabas resursu nodoklis, DRN*) (as depicted in the bottom section of the central box in Figure 8). As a result, we can categorize all GHG emissions into three groups: those that fall within the purview of the EU ETS, those subject to the national natural resources tax, and those not subject to any taxation. It is important to note that this categorisation is made at the industry level, where the first group will have non-zero values only for industries included in the EU ETS.

$$Emis_i^{Total} = Emis_i^{paidETS} + Emis_i^{paidCTAX} + Emis_i^{Free} \tag{18}$$

We assume that in absence of any exogenous policy-driven shocks, ratios $\frac{Emis_i^{ETS}}{Emis_i^{Total}}$, $\frac{Emis_i^{CTAX}}{Emis_i^{Total}}$ and $\frac{Emis_i^{Free}}{Emis_i^{Total}}$ in all industries $i \in I$ remain constant at their 2022 level from 2023 onwards.

According to Equation (16), the total emissions consist of two components: emissions related to the combustion of fuels and production process-specific emissions (PSE). Furthermore, we assume that in the absence of policy-driven shocks, the three ratios mentioned in the previous paragraph will remain constant from 2023 onwards separately for combustion emissions and PSE. In other words, we establish the cost of carbon individually for combustion emissions and PSE, as well as for the carbon tax and ETS, under the assumption that there will be no changes to the ratios $\frac{Emis_{Combustion}^{paidETS}}{Emis_{Combustion}^{ETS}}$, $\frac{Emis_{Combustion}^{paidCTAX}}{Emis_{Combustion}^{CTAX}}$, $\frac{Emis_{PSE}^{paidETS}}{Emis_{PSE}^{ETS}}$, and $\frac{Emis_{PSE}^{paidCTAX}}{Emis_{PSE}^{CTAX}}$ at the industry level if the carbon pricing policy remains unaltered. We provide the values of these ratios in Table B.1 in Appendix, with the exception of the last ratio, which currently remains at zero for all industries because production process-specific emissions are not yet subject to taxation at the national level in Latvia.

[3] This is the tax law that determines the application of carbon tax in Latvia.

Furthermore, certain energy commodities, such as electricity, are subject to an excise tax. However, it is important to note that this excise tax is based on the actual quantity of consumed commodities rather than the emissions they generate. Consequently, we do not delve into discussions related to excise taxes in this paper. Nonetheless, we recognise that if there were intentions to revamp the existing carbon taxation system, excise taxes on energy commodities would need to be considered in conjunction with other levies on emissions.

3.3.2 EU ETS

The European Union Emissions Trading Scheme, known as the EU ETS, has been a pivotal component of the EU's climate policy for several years and has recently transitioned into its fourth generation (European Commission 2020). It applies exclusively to specific industries, including the manufacturing of food, metals, chemicals, pharmaceutical products, and various other goods. Within the EU, approximately 40% of emissions are subject to the EU ETS. However, due to the distinctive structure of Latvia's economy, it encompasses only 18% of the country's emissions (VARAM 2021).

Enterprises operating within industries covered by the EU ETS are obligated to monitor and validate their greenhouse gas (GHG) emissions. Subsequently, they must surrender allowances, or quotas, that match the quantity of their emissions in tonnes of CO2 equivalent. Some of these allowances are allocated to them at no cost, while they are required to procure the remainder through auctions.

$$A_i^{Paid} = Emis_i^{ETS} - A_i^{Free} \tag{19}$$

where A_i^{Free} stands for the number of allowances industry i buys or receives for free.

EUETS.info (2022) contains comprehensive historical records for each installation, detailing the number of allowances surrendered by each firm in each year and the quantity of allowances received by these firms at no cost. Furthermore, information regarding auction prices and volumes can be accessed publicly on the European Energy Exchange website.[4] For each year, we compute the weighted average price of allowances, denoted as P^{ETS}. Additionally, we make the assumption that all free quotas are redeemed in the same year they are received.[5] As a result, we precisely calculate the quantity of emissions for which EU ETS allowances needed to be procured for each Latvian firm

[4] https://www.eex.com/en/markets/environmental-markets/eu-ets-auctions

[5] Note that there is no available data regarding the stock of allowances held in reserve at the industry level.

subject to the EU ETS. By knowing the total emissions per industry (sourced from CSB 2022b and LVĢMC 2021), we then determine the effective cost of emissions payable through the Emissions Trading Scheme annually at the industry level, denoted as EC_i^{ETS}.

$$Expense_i^{ETS} = A_i^{Paid} \cdot P^{ETS} \tag{20}$$

$$EC_i^{ETS} = \frac{Expense_i^{ETS}}{Emis_i^{ETS}} \tag{21}$$

We assume that the effective carbon price resulting from participation in the EU ETS is closer to the average cost of emissions rather than the marginal cost associated with acquiring an additional quota. This is because when a firm emits an extra tonne of CO2e, it must purchase an additional quota at the full price (unless it possesses free allowances exceeding its emissions). Typically, such an emission increase is also accompanied by an increase in output. European regulations governing emissions and the allocation of free allowances are structured in a manner where the proportion of quotas a firm must purchase is approximately linked to its deviation in energy efficiency compared to firms at the energy efficiency frontier at the European level that produce the same goods. Consequently, as this firm raises its output and emissions concurrently, it should also receive more free quotas. Therefore, the average cost of emissions serves as a better approximation of the marginal cost compared to the full price of a single ETS allowance. Consequently, when simulating various scenarios, we assume that EC_i^{ETS} remains constant. In scenarios involving a change in the price of an ETS allowance, we adjust the effective ETS carbon price proportionally to reflect this change in the ETS mechanics.

Combining Equations (20) and (21), we can express the effective carbon price as

$$EC_i^{ETS} = P^{ETS} \cdot \frac{A_i^{Paid}}{Emis_i^{ETS}} \tag{22}$$

The effective cost of emissions can be computed individually for combustion-related emissions and production process-specific emissions (PSE). In the latter term, we only take into account the respective emissions and paid quotas surrendered specifically for them. As previously mentioned, we assume that this term remains constant in the absence of policy alterations. The values for combustion-related emissions and PSE at the industry level are provided in Table B.1.

3.3.3 Natural Resources Tax as a form of a carbon tax

The natural resources tax is the sole mechanism through which emissions can be taxed and is the only levy applicable to the remaining 82% of Latvia's GHG emissions. This tax encompasses various tax rates, assessing companies for emissions of pollutant substances, the utilisation of specific natural resources, and involvement in polluting activities. Several of these tax rates, detailed in Annex 4 of the Natural Resources Tax Law (refer to Likumi.lv 2006), are directly linked to the volume of GHG emissions. As of 2022, firms subject to this tax are charged 15 euro per tonne of CO2e emitted.

The above law specifies numerous conditions that determine whether the tax is applicable or not, making it challenging to estimate even an approximate effective tax rate at the industry level. To address this challenge, we utilise a dataset provided to us by the State Revenue Service, which allows us to compute the actual amounts of the natural resources tax payable for air pollution. Given that the price per tonne of CO2e is known and consistent across sectors, we can readily deduce the proportion of emissions subject to Latvia's version of the carbon tax.

For modelling purposes, we treat this tax on GHG emissions as a partial carbon tax. In doing so, we assume that the proportion of emissions subject to the tax remains constant. For instance, if the pharmaceutical sector generates 12.8 kilotonnes of CO2e emissions and incurs costs equivalent to covering 2.2 kt CO2e, we presume that this industry pays the full carbon price for 17% of its emissions under any scenario where this tax remains unaltered. However, if a comprehensive carbon tax were to be implemented, the carbon price would apply to all emissions, causing emissions-related expenses in the pharmaceutical sector to increase by a factor of 100/17.

4 Scenario analysis

To illustrate an application of the new approach, we embed the purpose-based energy substitution structure into Latvia's CGE model and examine taxes that would need to be implemented to reduce GHG emissions generated by Latvian firms in alignment with the European Green Deal objectives. As part of the European Union's Fit for 55 commitment, which aims to adapt the European Union to transition to a net-zero carbon economy by 2050, Latvia has pledged to decrease its GHG emissions by 17% by 2030. We simulate a scenario in which Latvia gradually reduces its GHG emissions along a linear trajectory commencing in 2023 and lasting until the end of 2030.[6] This objective implies

[6]We acknowledge that the green transition will involve the introduction of new green technologies and will likely be driven by them. However, we are interested in a scenario where the adoption of green technologies is limited to

that Latvia's emissions must decrease by slightly over 6% from 2023 to 2025 to put Latvia on a linear path toward achieving the pledged GHG emissions reduction goal.

A scenario for achieving such a reduction in emissions unfolds as follows. Firstly, as from 2023 onwards, the natural resources tax is revised to uniformly charge each firm in every industry for every tonne of CO2e emissions resulting from the combustion of fuels (excluding carbon-neutral fuels). This revision applies across all industries, including those currently not subject to taxation or participating in the EU ETS. In this scenario, we assume that the EU ETS remains unchanged, but the domestic tax is applied to all emissions, including those covered by ETS quotas.[7] Secondly, the price of emitting one tonne of CO2e GHGs will increase to 100 euro in 2023, 200 euro in 2024, and 300 euro in 2025.[8] Our model indicates that this scenario entails the minimum carbon price escalation required to reduce Latvia's carbon emissions by more than 6% within three years solely through carbon pricing, without relying on improvements in energy efficiency or the adoption of new technologies.

Table 2: Effects on macro variables and consumer prices in 2025

Economy		Welfare		Consumer prices	
Real GDP	-2.04%	Consumption (HH)	-2.07%	Groceries	0.41%
Investment	-1.97%	Gross wage (nom.)	-1.47%	Waste & water	0.98%
Exports	-1.98%	Gross wage (real)	-2.27%	Retail services	0.03%
Imports	-1.54%	Employment	-1.40%	Land transport	4.10%
Budget balance	2.65pp	Unemployment	0.72pp	Electricity	7.34%
GDP deflator	1.37pp	Inflation (CPI)	0.82pp	Heat	7.48%

Source: Authors' calculations

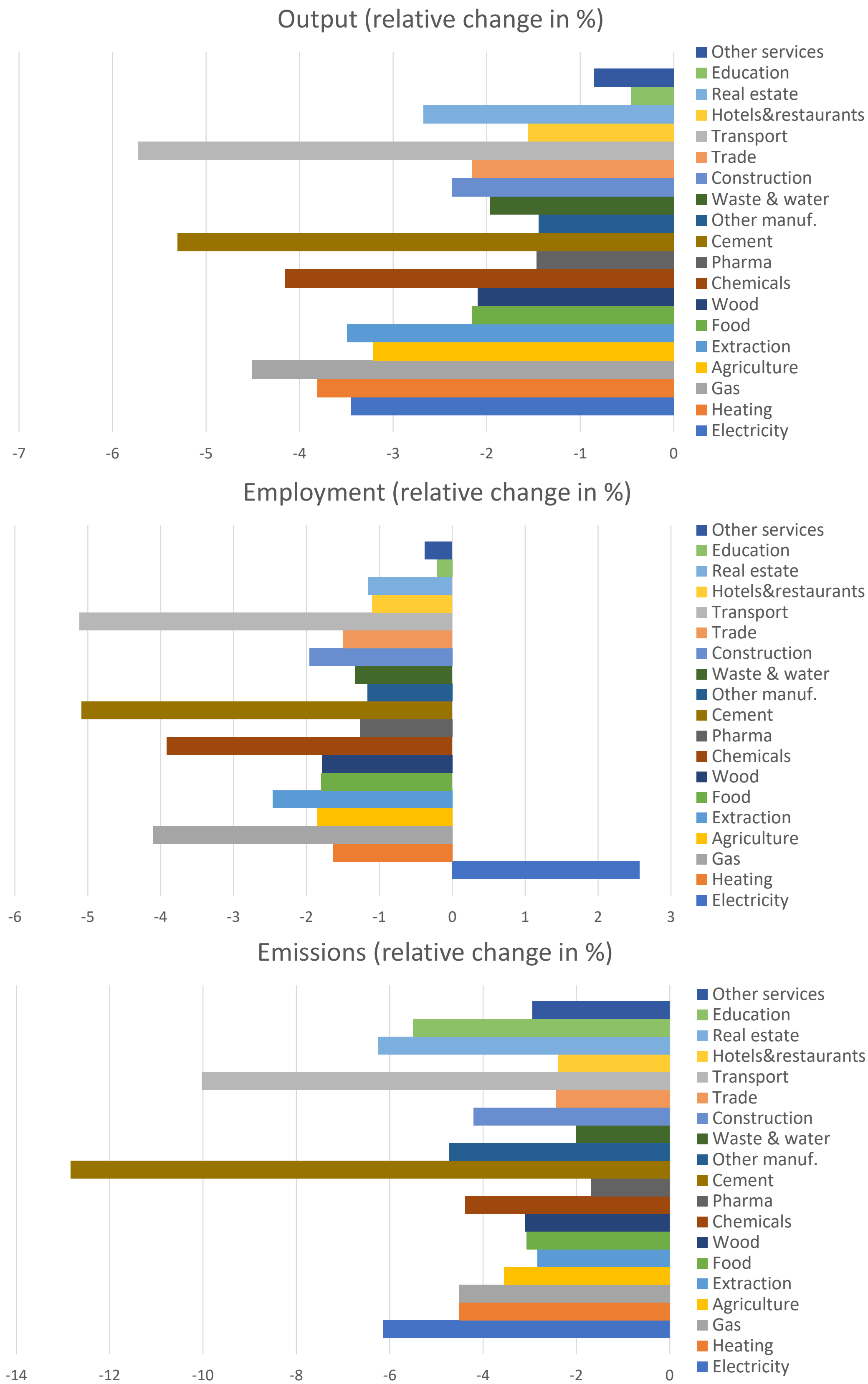
The impact of such a universal carbon tax on Latvia's economy is illustrated in Table 2. In this scenario, the economy would contract by approximately 2% with unemployment being 0.72 percentage points higher and consumers' purchasing power nearly 2.3% lower compared to a scenario

currently available options, such as electric vehicles and solar panels, and does not include fundamental technological change in the short term, e.g. fast adoption of less widespread technologies like green materials in manufacturing and industrial heat pumps.

[7]We further assume that production process-specific emissions (those proportional to output rather than the amount of burnt fuels) will remain untaxed in the scenario we are simulating. This assumption is based on the lack of feasible policy proposals to implement such a scenario in real life over the next several years. Currently, production process-specific emissions are estimated rather than verified as emitted. Imposing a flat tax on output would be akin to imposing a flat tax on certain industries, which is currently unfeasible without a well-established tool like the Carbon Border Adjustment Mechanism, which is not expected to be implemented until at least 2026. Calculating precise emissions directly from all produced output at all times is currently practically unattainable.

[8]Although such an increase seems unrealistically large, in reality it is dwarfed by price fluctuations during the energy crisis in 2022. For example, a carbon tax of 100 euro per tonne of CO2e will raise the final cost of natural gas by approximately 20 euro per MWh.

Figure 9: Relative changes in output, employment and emissions in 2025 by sectors



Source: Authors' calculations

where carbon taxes remain at their current level. While the prices of groceries would rise by less than half a percent, transportation, electricity, and central heating would become notably more expensive, increasing by 4.1%, 7.3%, and 7.5%, respectively. On average, consumer price inflation is expected to be 0.82 percentage points higher than in the baseline scenario. Here, we would like to remind the reader that one of the limiting assumptions of CGE models, including ours, is that prices fully adjust in a year's time, and goods markets return to equilibrium. As we have seen during the 2022 energy crisis, this might not be the case for energy goods markets, and prices can remain elevated during extended periods, even due to expectations rather than materialised shortage of supply. Hence, prices on some goods, especially energy commodities, can temporarily go up by more than indicated in Table 2. Therefore, this may constitute a minor threat to price stability.

Figure 9 provides insights into how the output and employment of the most significant industries are impacted, along with the change of the greenhouse gases in CO2e emitted annually by each industry. In Latvia, the industry with the highest carbon intensity is the manufacturing of cement and glass. Despite the fact that more than half of its emissions remain untaxed in the current scenario (these are production process-specific emissions, as noted in the footnote), it experiences the most substantial relative decline in emissions, nearly 13%, and makes the second largest absolute contribution to reducing Latvia's emissions, saving over 100 kilotonnes of CO2e emissions annually. However, its contribution to the economic decline is minuscule – this industry accounts for less than 2.3% of the total loss of economic activity. Another noteworthy industry is agriculture, where a significant reduction in emissions is associated with a relatively minor decrease in output. The contribution of electricity generation is the fourth largest in terms of emissions reduction. Interestingly, it is the only industry where more jobs are created than lost due to the shift towards renewable electricity. The installation of solar and wind farms leads to increased employment in this sector.

Notably, the described scenario does not impose a balanced government budget. In fact, the additional revenue generated from the carbon tax is substantial, resulting in an improved budget balance of more than 2.6 percentage points. This budget surplus can be employed to mitigate a significant portion of the hardship, especially among the most vulnerable households, provide strategic assistance to industries, and support green innovation. We understand that the decision how to spend carbon tax revenues is political, and we, CGE modellers, should not pretend as if we knew how these funds would be allocated. However, we can show how the ways the increased carbon tax revenues are spent lead to vastly different economic outcomes.

In Table 3, we compare the presented scenario (1) where the budget surplus is by 2.6 percentage points higher with two budget-neutral scenarios (i.e. the budget balance is the same as in the baseline). In Scenario 2, any incurring budget surplus is spent by the government so that the structure of public consumption stays the same. In 2025, this implies 20.5% higher government consumption. In Scenario 3, budget balance is maintained by lowering the value added tax rate. To fully compensate the additional carbon tax revenue (after considering the second round and further effects), the VAT rate cut reaches 9.2 percentage points in 2025. We have chosen these two scenarios of budget neutral carbon tax introduction because they represent two extreme cases in terms of macroeconomic outcomes among scenarios where subsidies or tax cuts do not target specific goods or households.

Table 3: Macroeconomic outcomes in 2025 depending on the use of carbon tax revenue

Scenario	**(1)**	**(2)**	**(3)**
Total GHG emissions	-6.1	-6.0	-3.6
Real GDP	-2.0	-0.3	1.0
Real private consumption	-2.1	-0.9	3.6
Real investments	-2.0	-0.7	1.2
Real exports	-2.0	-4.2	-1.7
Real imports	-1.5	-0.4	0.4
Deflator of GDP	1.4	4.6	-1.7
Deflator of private consumption	0.8	2.7	-3.6
Real gross wage	-2.3	0.9	2.5
Employment	-1.4	0.7	1.3
Unemployment rate	0.7	-0.4	-0.6

Source: Authors' calculations
Note. All figures show percent or percentage points deviation from the baseline scenario (everything remains unchanged, including carbon taxes, government spending and VAT rates) in 2025.

The results in Table 3 show that we cannot say whether the reduction of GHG emissions is driven by a budget surplus. If higher carbon tax revenues result in increased government consumption, almost the same emissions reduction is achieved, whereas if higher carbon taxes are compensated by a lower value added tax, the reduction of emissions is by almost 40% smaller.

However, the impact on the economy between scenarios 2 and 3 also differs substantially. If the government consumption is increased to maintain the budget balance constant in each of the three years of increasing carbon tax, real GDP falls by 0.3% instead of by 2.0% relative to the baseline. Compensating carbon taxes with lower VAT in a fiscally neutral way leads to higher economic activity – by 1% than in the baseline without any policy changes and by 3% relative to the case with just the uncompensated carbon tax and 2.6 percentage points improved budget balance. Other macroeconomic variables change as expected. Higher government consumption pushes up inflation even further, at the same time crowding out private investment and consumption. Conversely, a VAT cut leads to lower consumer prices and higher real private consumption.

Figures C.1 and C.2 in Appendix C presents the change in real output, employment and GHG emissions at the industry level. In all scenarios, cement production and transportation are the most affected, but also bring the largest reduction in emissions. For the case of higher government consumption in Scenario 2, only Education and 'other' services (excluding trade, transportation, accommodation, and real estate) show increased economic activity relative to the baseline. However, these services have low emissions intensity of output. A carbon tax compensated by a lower VAT rate in Scenario 3 leads to varying effects on employment and output across industries, but GHG emissions fall almost universally with the exception of only manufacturing of pharmaceutical products, waste and water management, and catering and accommodation.

5 Conclusions

This study focuses on developing the purpose-based energy substitution structure – a new approach to designing the production structure in CGE models allowing for flexibility of changing the shares of various energy inputs in the production of each industry in response to shifts in prices and taxes related to these inputs. Instead of adhering to the conventional nested production structure, we introduce energy processes as new composite intermediate inputs, each corresponding to specific industrial purposes of the use of energy goods. Within these processes, we model the substitution dynamics between various energy commodities. This approach offers several advantages, including a closer alignment with real-world substitution patterns and greater parsimony, as it relies on fewer elasticity parameters. However, this approach necessitates a deeper understanding of the energy sector and the specific energy usage by various industries, which goes beyond the information provided by a Supply and Use table. Given the highlighted advantages of the proposed energy process approach, we believe that other CGE models can benefit from adopting it and transitioning to a framework that models the substitution of energy goods based on the purposes of energy use.

To illustrate an application of the new approach, we incorporate the purpose-based energy substitution structure into Latvia's CGE model. To achieve more detailed modelling of the green transition in the short-to-medium term, we further enhance the model with an expanded Supply and Use table to provide a more detailed representation of energy industries and commodities, as well as an accounting system of GHG emissions and the local and European carbon pricing schemes. Using this extended version of Latvia's CGE model, we study the potential impact of reducing GHG emissions in Latvia by implementing a substantial carbon price – such that would place the country on a linear trajectory toward achieving its European Green Deal objectives by 2030. By 2025, the resulting welfare losses are projected to exceed 2%. However, the additional revenue generated from the carbon tax would increase the budget surplus by 2.6 percentage points. The allocation of this additional budget revenue – whether it is used for tax cuts, establishing a social fund to protect the most vulnerable households from price increases, funding green investments, or bolstering public investment – is a political decision that can lead to different outcomes. In two budget-neutral simulations, depending on whether the additional tax revenue is used to increase government consumption or cut the value added tax, with the same carbon tax the change in real output is respectively –0.3% and +1.0% instead of –2.0%. However, while changing government consumption has a negligible impact on the decrease in GHG emissions, the VAT cut makes the reduction by almost 40% smaller.

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Appendices

A Energy processes

Table A.1: Shares of energy commodity use by energy processes

	A	B	C10-12	C13-15
Electricity	EP1: 95%, EP5: 5%	EP1: 96%, EP3: 1%, EP5: 3%	EP1: 93%, EP3: 3.5%, EP4: 2.5%, EP5: 1%	EP1: 96%, EP4: 1%, EP5: 3%
Heating and cooling	EP4	EP4	EP3: 69%, EP4: 31%	EP4
Gas	EP4	EP4	EP3: 69%, EP4: 31%	EP3: 55%, EP4: 45%
Coal	EP4	EP4	EP3: 69%, EP4: 31%	EP3: 55%, EP4: 45%
LPG	EP5	EP5	EP5	EP5
Gasoline	EP5	EP5	EP5	EP5
Jet fuels	-	-	-	-
Diesel	EP5	EP5	EP5	EP5
Waste and rubber	-	-	-	-
Wood	EP4	EP4	EP3: 68%, EP4: 32%	EP3: 55%, EP4: 45%
Wood residues	EP4	EP4	EP3: 68%, EP4: 32%	EP3: 55%, EP4: 45%
Wood chips	EP4	EP4	EP3: 68%, EP4: 32%	EP3: 55%, EP4: 45%
Wood pellets, briquettes	EP4	EP4	EP3: 68%, EP4: 32%	EP3: 55%, EP4: 45%
Biogas, biofuels, charcoal	EP5	EP5	EP3: 68%, EP4: 32%	EP3: 55%, EP4: 45%

	C16	C17-18	C19	C20-21	C22
Electricity	EP1: 96%, EP5: 4%	EP1: 96%, EP5: 4%	EP1: 96%, EP5: 4%	EP1: 96%, EP4: 1%, EP5: 3%	EP1: 96%, EP4: 1%, EP5: 3%
Heating and cooling	EP3: 85%, EP4: 15%	EP4	EP4	EP4	EP3: 38%, EP4: 62%
Gas	EP3: 85%, EP4: 15%	EP3: 48%, EP4: 52%	-	EP3: 58%, EP4: 42%	EP3: 38%, EP4: 62%
Coal	EP3: 85%, EP4: 15%	EP3: 48%, EP4: 52%	-	EP3: 58%, EP4: 42%	EP3: 38%, EP4: 62%
LPG	EP5	EP5	EP5	EP5	EP5
Gasoline	EP5	EP5	EP5	EP5	EP5
Jet fuels	-	-	-	-	-
Diesel	EP5	EP5	EP5	EP5	EP5
Waste and rubber	-	-	-	-	-
Wood	EP3: 85%, EP4: 14%, EP5: 1%	EP3: 48%, EP4: 52%	EP4	EP3: 57%, EP4: 43%	EP3: 38%, EP4: 62%
Wood residues	EP3: 85%, EP4: 15%	EP3: 48%, EP4: 52%	EP4	EP3: 57%, EP4: 43%	EP3: 38%, EP4: 62%
Wood chips	EP3: 85%, EP4: 15%	EP3: 48%, EP4: 52%	EP4	EP3: 57%, EP4: 43%	EP3: 38%, EP4: 62%
Wood pellets, briquettes	EP3: 85%, EP4: 15%	EP3: 48%, EP4: 52%	EP4	EP3: 57%, EP4: 43%	EP3: 38%, EP4: 62%
Biogas, biofuels, charcoal	EP3: 85%, EP4: 15%	EP3: 48%, EP4: 52%	-	EP3: 57%, EP4: 43%	EP3: 38%, EP4: 62%

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	C23	**C24**	**C25**	**C26**
Electricity	EP1: 96%, EP4: 1%, EP5: 3%	EP1: 96%, EP4: 1%, EP5: 3%	EP1: 96%, EP4: 1%, EP5: 3%	EP1: 96%, EP4: 1%, EP5: 3%
Heating and cooling	EP4	EP4	EP4	EP4
Gas	EP1: 18%, EP2: 72%, EP3: 5%, EP4: 5%	EP1: 46%, EP2: 17%, EP3: 8%, EP4: 29%	EP3: 47%, EP4: 53%	EP3: 42%, EP4: 58%
Coal	EP1: 18%, EP2: 72%, EP3: 5%, EP4: 5%	EP1: 46%, EP2: 17%, EP3: 8%, EP4: 29%	EP3: 47%, EP4: 53%	EP3: 42%, EP4: 58%
LPG	EP5	EP5	EP5	EP5
Gasoline	EP5	EP5	EP5	EP5
Jet fuels	-	-	-	-
Diesel	EP5	EP5	EP5	EP5
Waste and rubber	EP2: 89%, EP3: 5%, EP4: 6%	-	-	-
Wood	EP3: 50%, EP4: 50%	EP1: 46%, EP2: 17%, EP3: 8%, EP4: 29%	EP3: 47%, EP4: 53%	EP3: 42%, EP4: 58%
Wood residues	EP2: 5%, EP3: 45%, EP4: 50%	EP1: 46%, EP2: 17%, EP3: 8%, EP4: 29%	EP3: 47%, EP4: 53%	EP3: 42%, EP4: 58%
Wood chips	EP2: 5%, EP3: 45%, EP4: 50%	EP1: 46%, EP2: 17%, EP3: 8%, EP4: 29%	EP3: 47%, EP4: 53%	EP3: 42%, EP4: 58%
Wood pellets, briquettes	EP3: 25%, EP4: 75%	EP1: 46%, EP2: 17%, EP3: 8%, EP4: 29%	EP3: 47%, EP4: 53%	EP3: 42%, EP4: 58%
Biogas, biofuels, charcoal	EP2: 33%, EP3: 33%, EP4: 32%, EP5: 2%	EP1: 46%, EP2: 17%, EP3: 8%, EP4: 29%	EP3: 47%, EP4: 53%	EP3: 42%, EP4: 58%

	C33	**E**	**F**	**G**	**H49**
Electricity	EP1: 96%, EP5: 4%	EP1: 96%, EP4: 4%	EP1: 96%, EP4: 4%	EP1: 96%, EP4: 4%	EP1: 95%, EP5: 5%
Heating and cooling	EP4	EP4	EP4	EP4	EP4
Gas	EP4	EP4	EP3: 42%, EP4: 58%	EP4	EP4
Coal	EP4	EP4	EP3: 42%, EP4: 58%	EP4	-
LPG	EP5	EP5	EP5	EP5	EP5
Gasoline	EP5	EP5	EP5	EP5	EP5
Jet fuels	-	-	-	-	-
Diesel	EP5	EP5	EP5	EP5	EP5
Waste and rubber	-	-	-	-	-
Wood	EP4	EP4	EP4: 95%, EP5: 5%	EP4	-
Wood residues	EP4	EP4	EP3: 42%, EP4: 58%	EP4	-
Wood chips	EP4	EP4	EP3: 42%, EP4: 58%	EP4	-
Wood pellets, briquettes	EP4	EP4	EP3: 42%, EP4: 58%	EP4	-
Biogas, biofuels, charcoal	EP4	EP4	EP3: 42%, EP4: 58%	EP4	EP5

	H50	**H51**	**H52-53**	**I-S**
Electricity	EP1: 95%, EP5: 5%	EP1: 95%, EP5: 5%	EP1: 95%, EP4: 1%, EP5:4%	EP1: 95%, EP4: 1%, EP5:4%
Heating and cooling	EP4	EP4	EP4	EP4
Gas	-	-	EP4	EP4
Coal	-	-	EP4	EP4
LPG	EP5	EP5	EP5	EP5
Gasoline	EP5	EP5	EP5	EP5
Jet fuels	-	-	-	-
Diesel	EP5	EP5	EP5	EP5
Waste and rubber	-	-	-	-
Wood	-	-	EP4	EP4
Wood residues	-	-	EP4	EP4
Wood chips	-	-	EP4	EP4
Wood pellets, briquettes	-	-	EP4	EP4
Biogas, biofuels, charcoal	-	-	-	EP4

B Carbon pricing

Table B.1: Shares of emissions taxed under the EU ETS and the national resources tax

Industry	$\frac{Emis^{paidCTAX}_{Combustion}}{Emis^{Total}_{Combustion}}$	$\frac{Emis^{paidETS}_{Combustion}}{Emis^{Total}_{Combustion}}$	$\frac{Emis^{paidETS}_{PSE}}{Emis^{Total}_{PSE}}$
A01 Crop and animal production	0.00%	0.00%	0.00%
A02 Forestry and logging	0.00%	0.00%	0.00%
A03 Fishery and acquaculture	0.00%	0.00%	0.00%
B Mining and quarrying	0.00%	**28.35%**	0.00%
C10-12 Food, beverages, tobacco	**35.18%**	**3.95%**	0.00%
C13-15 Textiles, apparel and leather	**57.02%**	0.00%	0.00%
C16 Wood, wood and cork products	**0.75%**	0.00%	**48.68%**
C17 Paper and paper products	**74.79%**	0.00%	0.00%
C18 Printing and media reproduction	**26.26%**	0.00%	0.00%
C19 Coke and refined petroleum	0.00%	0.00%	0.00%
C20 Chemical products	**46.18%**	**0.62%**	0.00%
C21 Pharmaceutical products	**85.23%**	**17.26%**	0.00%
C22 Rubber and plastic products	**59.72%**	0.00%	0.00%
C23 Non-metallic mineral products	**2.03%**	0.00%	**1.22%**
C24 Basic metals	**49.96%**	0.00%	0.00%
C25 Fabricated metal products	**29.90%**	0.00%	0.00%
C26 Computers, electronics, optics	**8.07%**	0.00%	0.00%
C27 Electrical equipment	**58.34%**	0.00%	0.00%
C28 Machinery and equipment n.e.c.	**34.71%**	0.00%	0.00%
C29 Motor vehicles and trailers	**33.35%**	0.00%	0.00%
C30 Other transport equipment	**0.05%**	0.00%	0.00%
C31-32 Furniture and other manuf.	**0.63%**	0.00%	0.00%
C33 Repair and installation	**100.00%**	0.00%	0.00%
E36 Water collection and supply	**100.00%**	0.00%	0.00%
E37-39 Sewerage and waste manag.	**11.71%**	0.00%	0.00%
F Construction	**35.11%**	0.00%	0.00%
G45 Trade & repair of motor vehicles	**28.63%**	0.00%	0.00%
G46 Wholesale trade	**12.34%**	0.00%	0.00%
G47 Retail trade	**5.06%**	0.00%	0.00%
H49 Transport by land & via pipelines	**0.10%**	0.00%	0.00%
H50 Water transport	0.00%	0.00%	0.00%
H51 Air transport	0.00%	0.00%	0.00%
H52 Warehousing, support activities	**8.11%**	**25.03%**	0.00%
H53 Postal and courier activities	0.00%	0.00%	0.00%
I Accommodation and catering	**18.09%**	0.00%	0.00%
J58 Publishing	0.00%	0.00%	0.00%
J59-60 Radio, TV, video and music	0.00%	0.00%	0.00%
J61 Telecommunication	**3.54%**	0.00%	0.00%

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Table B.1, cont'd.

Industry	$\frac{Emis^{paidCTAX}_{Combustion}}{Emis^{Total}_{Combustion}}$	$\frac{Emis^{paidETS}_{Combustion}}{Emis^{Total}_{Combustion}}$	$\frac{Emis^{paidETS}_{PSE}}{Emis^{Total}_{PSE}}$
J62-63 Programming, consultancy	0.00%	0.00%	0.00%
K64 Financial service activities	**32.68%**	0.00%	0.00%
K65 Insurance	0.00%	0.00%	0.00%
K66 Auxiliary financial services	0.00%	0.00%	0.00%
L68B Real estate activities	**70.19%**	0.00%	0.00%
L68A Imputed rent	0.00%	0.00%	0.00%
M69-70 Legal, accounting, HQ	**90.27%**	0.00%	0.00%
M71 Architecture and engineering	0.00%	0.00%	0.00%
M72 Scientific R&D	0.00%	0.00%	0.00%
M73 Advertising and market research	0.00%	0.00%	0.00%
M74-75 Other technical activities	**3.80%**	0.00%	0.00%
N77 Rental and leasing activities	**9.97%**	0.00%	0.00%
N78 Employment activities	0.00%	0.00%	0.00%
N79 Travel agencies	0.00%	0.00%	0.00%
N80-82 Security and office activities	**28.10%**	0.00%	0.00%
O Public administration and defence	**19.03%**	0.00%	0.00%
P Education	**7.38%**	0.00%	0.00%
Q86 Human health activities	**52.47%**	0.00%	0.00%
Q87-88 Social work and care	0.00%	0.00%	0.00%
R90-92 Art, culture and gambling	**3.47%**	0.00%	0.00%
R93 Sports and amusement	**8.70%**	0.00%	0.00%
S94 Membership organisations	**0.93%**	0.00%	0.00%
S95 Repair of personal goods	0.00%	0.00%	0.00%
S96 Other personal service activities	**7.92%**	0.00%	0.00%
D35.1 Electric power	**4.85%**	**52.55%**	
D35.3 Steam and air conditioning	**2.18%**	**5.21%**	
D35.2 Manufacture and distribution of gas	**31.88%**	0.00%	

Notes. At the moment, no production process-specific emissions are taxed under the national resources tax, so column $\frac{Emis^{paidCTAX}_{PSE}}{Emis^{Total}_{PSE}}$ is missing because it would contain only zero values.

C Budget neutral scenarios

Figure C.1: Relative changes of output, employment and emissions in 2025 in Scenario 2: government consumption is increased by 20.5% to keep the budget balance constant

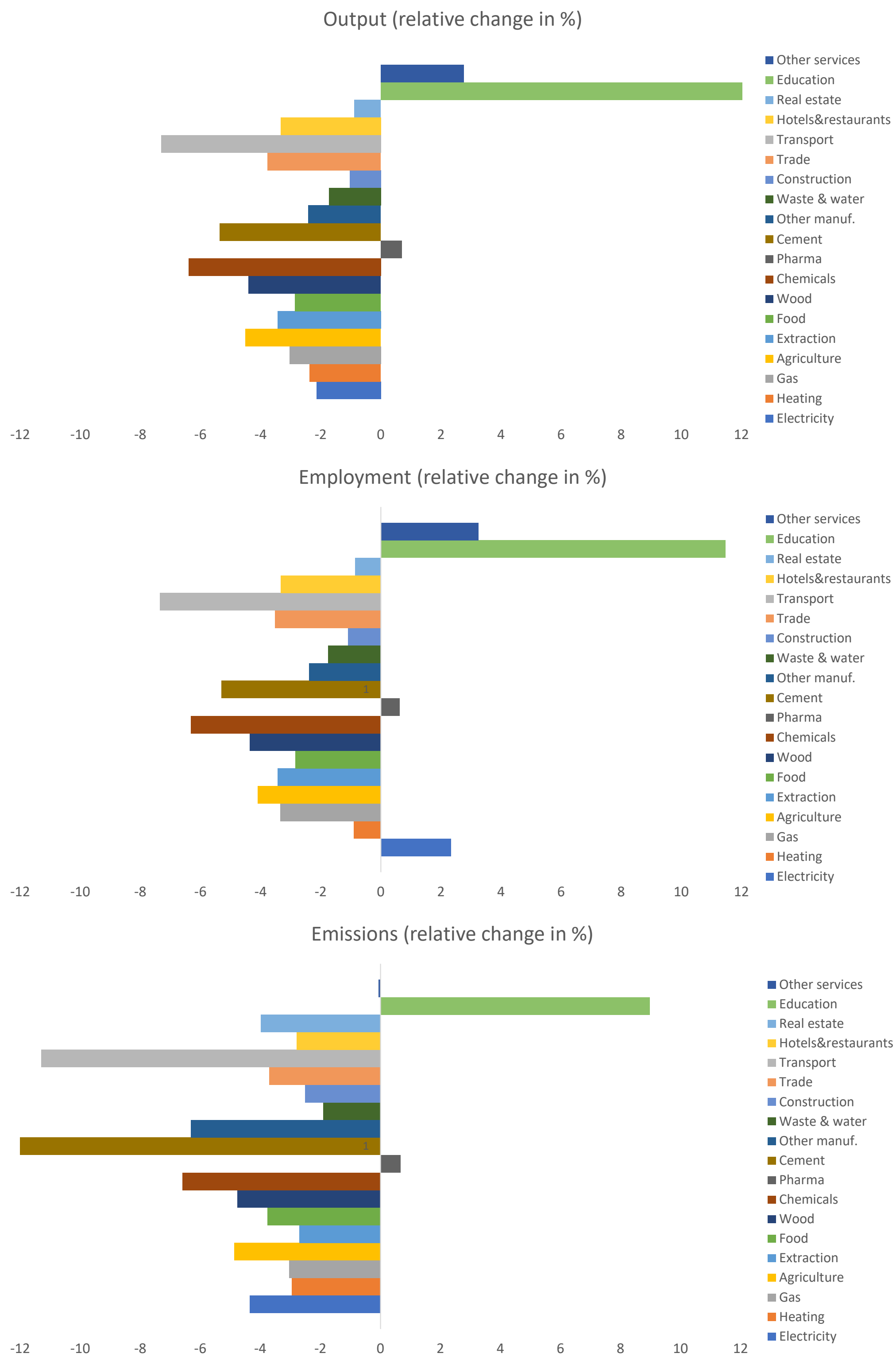

Figure C.2: Relative changes in output, employment and emissions in 2025 in Scenario 3: the value added tax rate is cut by 9.2 percentage points to keep the budget balance constant