Transitioning to a climate-neutral electricity generation

Deliverable 4: Socioeconomic impact assessment of pathways for reaching climate-neutral electricity generation

Executive Summary

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Introduction

This executive summary outlines the core results of the modelling conducted for Deliverable 4 of the *Transitioning to a climate-neutral electricity generation* project. The objectives of Deliverable 4 were to assess the socioeconomic impacts of the pathways toward climate neutrality developed and analysed in Deliverable 3. Impacts were quantified for the Reference scenario (used as the baseline for comparisons), four technology-focused decarbonisation pathways (each exploring the impacts of investing in a particular low-carbon power technology in Estonia), and three decarbonisation pathways that allow for competition between technologies, given set constraints. The modelling focused on quantifying the impacts on energy sector investment, on GDP, on employment, and on disposable income associated with each pathway.

Model scope

To calculate the socio-economic implications of alternative configurations of the Estonian power generation mix, a two-stage methodology was deployed. The first stage involved a static analysis of the impact on investments on the Estonian economy where the first order impacts are identified and quantified. The key contribution of this stage to the analysis was to show how the demand stimulus effect varies across power mix options according to economic and employment multipliers. The second stage involved a full system analysis that included the feedback loops of the economy. At this stage, for each scenario examined, the impact of power choices on electricity prices, production costs, competitiveness, households' disposable income and employment were considered simultaneously in a consistent representation of multiple countries through a dynamic framework set up in the GEM-E3 model.

In this specific study, the policy scenarios were quantified using the inputs from the LEAP model developed in Deliverable 3. For each of the nine scenarios examined, the LEAP model generated a specific power mix for the years leading to 2050. The power generation mix considered in each scenario requires different levels of investments, addresses different capital goods & fuels, and requires different operational expenses. The GEM-E3 model received from LEAP the investments required for each power generation technology until 2050. Then the model decomposed these investments to demand for specific sectors. The financing of these investments was considered alternatively in GEM-E3 either through loans or out-of-pocket money. The GEM-E3 model was also calibrated to be consistent with the changes in electricity prices of the LEAP model for each scenario.

More details of the model are provided in the annex to this summary. More extensive further details on data used for modelling and on modelling methodology are included in the full Deliverable 4 report.

Scenario definition and key assumptions

This analysis quantified socioeconomic impacts for seven alternative climate-neutral pathways (developed during Deliverable 3), defined as follows:

- **RES_Storage** – The "Renewables + storage" pathway, evaluates a large deployment of offshore wind in Estonia (1 GW by 2030, 2 GW by 2035, 3 GW by 2040, and a total of 4 GW by 2050)
- **Nuclear –** The "Nuclear + renewables + storage" pathway, simulates climate-neutral electricity production in Estonia given an addition of 900 MW of Generation III+ small modular nuclear capacity by 2040
- **CCS –** The "CCUS + renewables + storage" pathway, explores the impacts of adding carbon capture to two large oil shale generators in Estonia
- **RES Gas** – The "Renewable gas + renewables + storage" pathway, assumes implementation of 1 GW of new biogas generation by 2030
- **All_technologies (AT)** – The least constrained climate-neutral pathway explored, allows for the model to endogenously invest in any electricity generation technology based on least-cost optimisation.
- **AT - No Net Imports (AT-NIMP)** – Supplements the All_technologies pathway by requiring that Estonia's electricity imports and exports should approximately offset each other

- **AT-1000** – Reassesses the All_technologies pathway by applying the constraint that Estonia have at least 1000 MW of readily dispatchable electricity production capacity at all times

Each of these pathways achieves carbon neutrality of the power generation system by 2050. Core investments in power generation for each scenario were collected as inputs from the Deliverable 3 LEAP modelling. Generally, investments peak in 2030 (except for the scenario that assumes increased storage for renewables), then slow in the decade between 2030 and 2040 before increasing in the last decade of the projection period. The time-profile of investment requirements depends on factors such as the electrification of transport and heating, the adoption of hydrogen which increases significantly in the last decade of the projection period, as well as on the assumptions regarding the lifetime of renewables. In terms of cumulative investments and compared to the reference, six scenarios require higher amounts for the energy system restructuring and one (CCS) requires less.

Each scenario has a different driver of energy system investments. Demand side management expenditures remain virtually at their reference levels across all scenarios, while oil shale remains an option (with CCS and/or with biomass) in the power generation system as new oil shale investments take place between 2020 and 2030. In 2050 there is a decrease in expenditures for storage systems in most of the scenarios considered. The cases where oil shale remains as an option in the PG mix are the: AT scenario, the AT-NIMP and mainly in the CCS scenario.

In the reference scenario, investment resources are mainly directed towards wind and solar PV and storage options, while no resources are directed towards fossil fuelled power and biomass generation. In the zero-emission pathways, wind investments are lower except for the Renewable storage variant where the expansion of offshore wind is foreseen. In general, the portfolio of power generation investments is more diversified in the carbon neutral scenarios compared to the reference scenario.

Further details on scenario definitions and assumptions carried over from the Deliverable 3 modelling are included in the full Deliverable 4 report.

Core findings

Impact on energy sector investment

Each pathway described above requires a different level of investments to decarbonise the Estonian electricity system. Additional investments in power generation and storage (compared to the reference scenario) are mapped out per technology in Table 1. The Renewables + Storage pathway requires significant additional investment in batteries and wind, given its assumed build-up of 4 GW of offshore wind by 2050. The Nuclear pathway requires additional investment in batteries, nuclear, and solar, as the 900 MW of built-up nuclear power acts as backup dispatchable capacity that enables expanded solar power output.

Further details on the dynamics driving investments in different technologies for each scenario are included in the Deliverable 3 Executive Summary and report.

Table 1 Additional investments in power generation technologies and storage (in million €)

	RES-STORAGE	RES-GAS	AT	AT-NIMP	AT-1000	CCS	NUCLEAR
Batteries	184	-187	-76	241	-167	-218	104
Shale oil fired*	0	0	725	327	219	-80	0
Gas fired	0	0	0	0	201	0	0
Nuclear	0	0	0	0	0	0	2329
Biomass	46	2635	0	0	0	-2	0
Hydro	0	0	0	0	184	0	0
Wind	5540	71	-85	551	-88	-1164	-1105
PV	-613	5	-270	-15	-144	-610	673
Other renewables	0	0	0	0	0	2	0
CCS Shale oil	0	0	0	0	0	1663	0

CCS Biomass	0	0	0	0	0	46	0
Total	**5157**	**2523**	**294**	**1104**	**205**	**-363**	**2001**

Source: LEAP model outputs, D3 "Development of pathways for reaching climate-neutral electricity generation"

**Note that for all pathways except the CCS pathway, investments in oil-fired shale refer to retrofitting former oil shale plants to use biomass; in the CCS pathway, the plants continue to burn oil shale.*

Impact on GDP

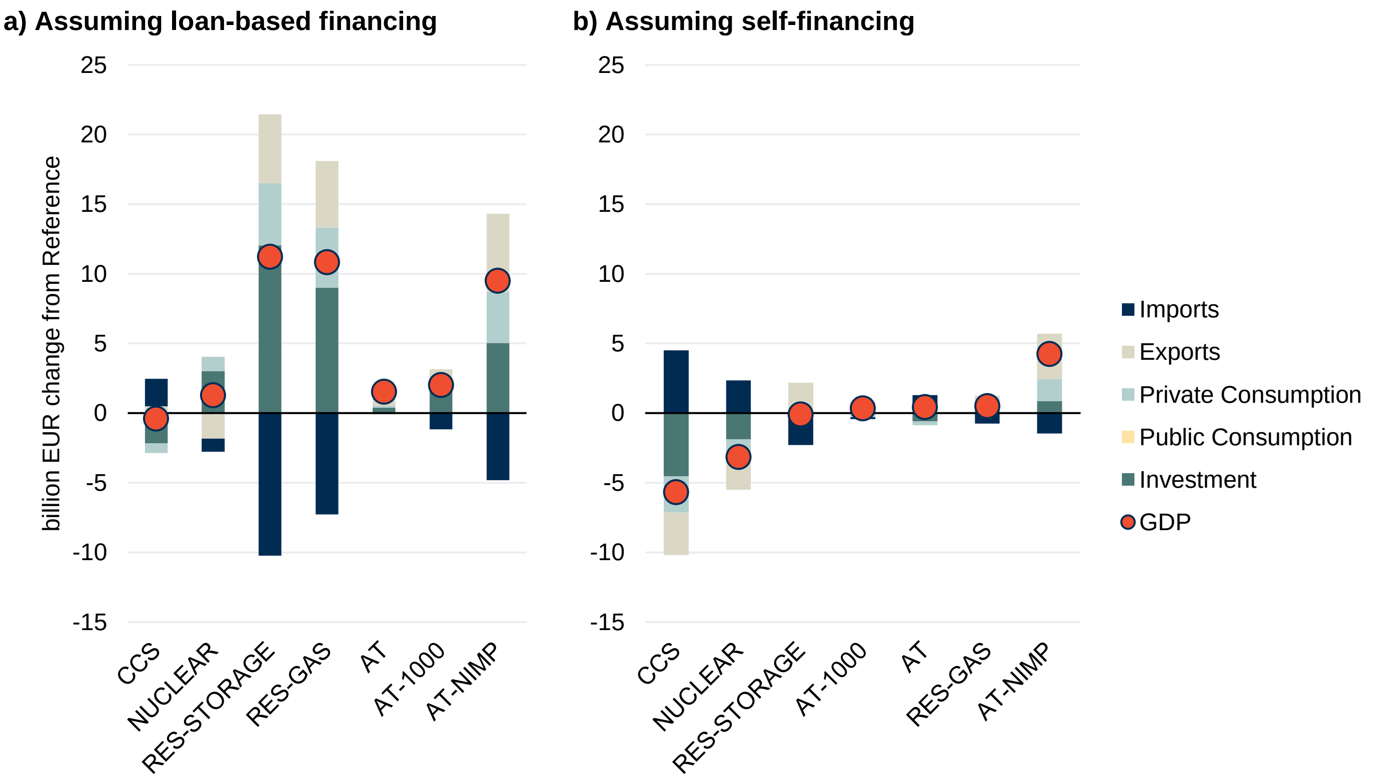
Building the power generation utilities requires the contribution of many economic activities. The extent to which investment in different power generation technologies will benefit the Estonian economy depends on i) the import dependence of the sectors providing the capital goods, ii) the output/employment multiplier of the sectors contributing to the investments, and iii) the cost of financing.

The Estonian economy imports a high share of the equipment goods that are necessary to deploy the different power generation technologies. However, there are potential GDP benefits from the transition when biomass or wind are deployed in larger shares. Biomass is sourced from largely domestic resources (as is shale oil in the CCS scenario, but with negative GDP outcomes), and the country's wind production potential is more favourable compared to other renewable options such as solar PV.

To assess the importance of the cost of financing, two options were considered corresponding to tight and favourable conditions in financial markets. The first option – self-financing – assumes that investments are fully financed by domestic/Estonian savings. This implies full crowding-out effects, i.e., financing power generation investments cancels out investments in other sectors of the economy. The second option – loan-based financing – assumes investments are financed through loans that have a 10-year repayment period and an interest rate equal to 5%. The scenarios result in higher net benefits assuming loan-based rather than self-financing, highlighting the importance of financial constraints in determining the macroeconomic performance of the alternative pathways.

The macroeconomic impacts of each scenario compared to the reference are depicted in Figure 1. Figure 1(a) shows calculated impacts assuming financing for investments in the power sector is loan-based, while Figure 1(b) shows impacts assuming investments are self-financed, crowding out investments in the rest of the Estonian economy.

Figure 1 Cumulative impacts on drivers of GDP and on GDP compared to the reference scenario (2025-2050)



Assuming financing is loan-based, investments in power generation capacities, changing electricity prices, and resulting changes in competitiveness drive impacts on GDP. Across all analysed scenarios, the Renewables + storage (RES-STORAGE) scenario yields the highest GDP gains compared to the reference case, while the CCS scenario records marginal GDP losses. In the RES-STORAGE scenario approximately 5 billion EUR of additional investments are required, while the CCS scenario requires 363 million EUR less investment than the reference scenario. At the regional level, Lääne-Eesti records the highest total output gains under the RES-STORAGE scenario, while the highest output losses are recorded in Lõuna-Eesti under the CCS scenario. Excluding changes in electricity output, the highest increase in the RES-STORAGE scenario is recorded in Põhja-Eesti (+0.77% compared to the reference case) and is driven by increased manufacturing and service output (these two sectors are responsible for approximately 76% of total regional output change). The region accounts for more than 50% of total national manufacturing output (and 57% of the manufacturing related to clean energy technologies) and approximately 47% of total national services output. Hence, it benefits from the increased demand for goods and services related to power generation investments at a larger extent compared to other regions.

Assuming investments are self-financed, the Estonian economy records the highest GDP gains (compared to reference scenario) under the No Net Imports (AT-NIMP) scenario, while the lowest performance is recorded in the CCS scenario. In the AT-NIMP pathway, wind power generation is backed up by dispatchable fossil fuel-based electricity. The latter has a significant positive multiplier effect in the economy and leads to GDP gains. The CCS pathway, although it assumes that fossil fuel plants are not phased out, leads to small GDP losses due to higher electricity costs which are propagated to other the sectors implying increases in production costs and competitiveness losses. At the regional level, Lõuna-Eesti records the highest absolute cumulative output gains in the AT-NIMP scenario, and the same region records the highest absolute cumulative losses in the CCS scenario. Output changes in both cases are driven by the energy related sectors, by services, and by construction. Table 2 summarises the cumulative impact of each pathway on GDP in Estonia given different financing assumptions, as also depicted in Figure 1.

Table 2 Cumulative GDP changes compared to the reference scenario (in billion EUR)

	Loan-based financing	Self-financing
AT	1.52	0.42
AT-NIMP	9.49	4.23
AT-1000	2.00	0.49
RES-STORAGE	11.20	-0.12
RES-GAS	10.83	0.33
NUCLEAR	1.27	-3.16
CCS	-0.41	-5.69

Source: GEM-E3

Impact on employment

In terms of employment, the highest numbers of additional jobs are generated in the Renewable Gas (RES-GAS) pathway (assuming loan-based financing) and in the No Net Imports (AT-NIMP) pathway (assuming self-financing). The CCS pathway leads to job losses under both financing options. On average in the RES-GAS scenario assuming loan-based financing, 1125 additional jobs are created between 2020-2050, most of which are associated with investments in the power generation and the manufacturing sectors. Assuming self-financing, the AT-NIMP pathway creates 434 additional jobs by 2050. Country-level impacts on employment given different financing assumptions are summarised in Table 3 and depicted inFigure 2.

At a regional level, Lõuna-Eesti (in the RES-GAS scenario) and Põhja-Eesti (AT-NIMP) record the highest employment gains, while the highest employment losses in the CCS scenario are recorded in Kirde-Eesti (loan-based) and Lõuna-Eesti (assuming self-financing).

Table 3 Average additional net jobs compared to the reference scenario

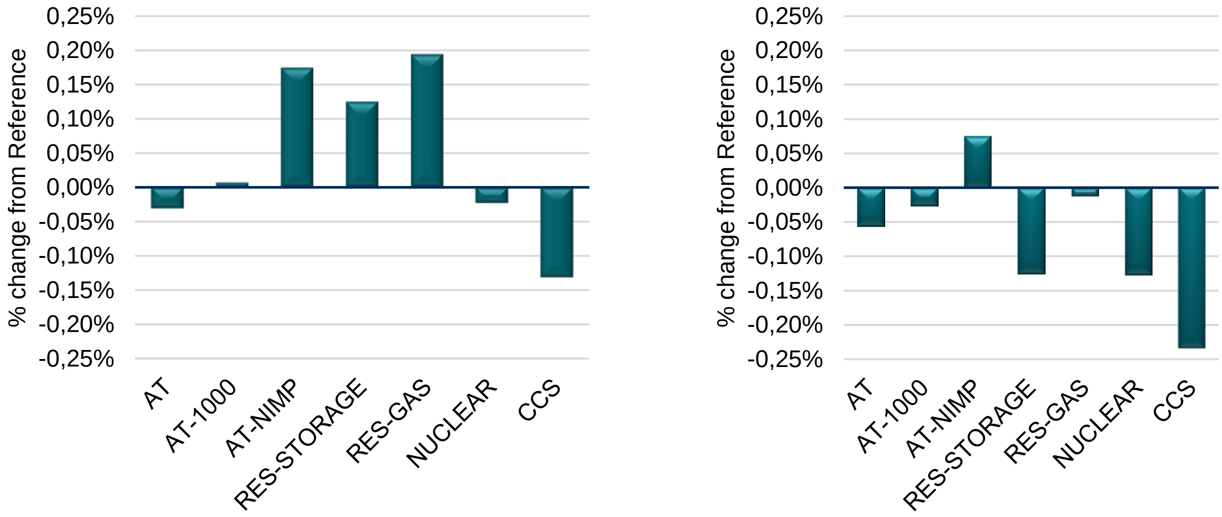
	Loan-based financing	Self-financing
AT	-183	-324

AT-NIMP	1010	434
AT-1000	38	-150
RES-STORAGE	723	-724
RES-GAS	1125	-66
NUCLEAR	-135	-732
CCS	-764	-1352

Source: GEM-E3

Figure 2 Impacts on aggregate employment compared to the reference scenario

a) Assuming loan-based financing [fig 16] b) Assuming self-financing



Impact on electricity prices

Changes in power generation systems leads to changes in electricity prices with respect to the reference scenario, as depicted in Table 4. Electricity prices in 2050 are lower than in the reference scenario for the No Net Imports, Renewables + storage, and All technologies pathways, but higher than the reference for all others.

Table 4 Average electricity prices (% change from the reference scenario, Estonia, 2050)

	Average price change over the simulation period
AT-NIMP	-2.26%
RES-STORAGE	-0.87%
AT	-0.64%
RES-GAS	0.40%
AT-1000	0.78%
NUC	2.03%
CCS	2.05%

Source: LEAP model D3 "Development of pathways for reaching climate-neutral electricity generation"

Impact on disposable income

Changes in disposable income correspond to aggregate-level GDP changes. Under loan-based financing, the Renewables + Storage (RES-STORAGE) scenario yields the highest impact, with cumulative disposable income increasing by 2.5 billion EUR compared to the reference case. Contrastingly, the CCS scenario leads to a marginal decrease of cumulative income. Under self-financing, the No Net Imports (AT-NIMP) pathway leads to a disposable income gain of 0.8 billion EUR, while the CCS pathway results in cumulative losses of 1.4 billion EUR over the projected period.

Table 5: Cumulative disposable income changes compared to the reference scenario

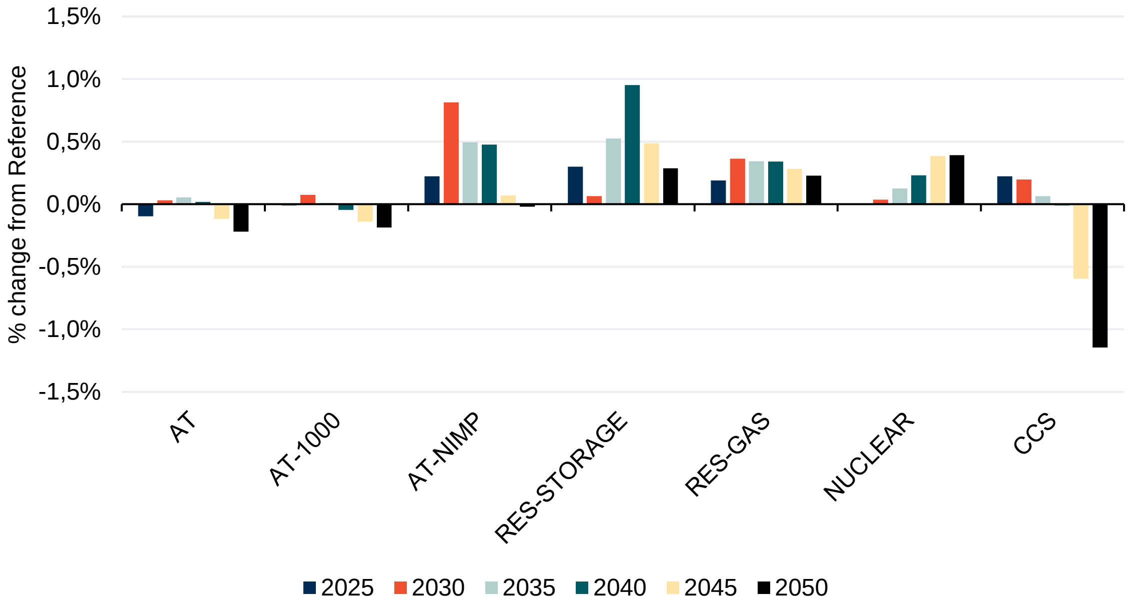
	Loan-based financing	Self-financing

	Billion EUR	%	Billion EUR	%
AT	0.1	0.0%	-0.2	0.0%
AT-NIMP	1.9	0.4%	0.8	0.2%
AT-1000	0.0	0.0%	-0.3	-0.1%
RES-STORAGE	2.5	0.5%	-0.5	-0.1%
RES-GAS	2.2	0.5%	0.1	0.0%
NUCLEAR	1.0	0.2%	-0.2	0.0%
CCS	-0.7	-0.1%	-1.4	-0.3%

Source: GEM-E3

Impacts on disposable income over time (assuming loan-based financing) are depicted per scenario in Figure 3. While impacts on income are small across all scenarios, they are consistently positive in the No Net Imports scenario (AT-NIMP), the Renewables + Storage scenario (RES-STORAGE), and in the Renewable Gas scenario (RES-GAS). Under the Nuclear scenario, disposable income initially decreases compared to the reference scenario before rising at each five-year interval between 2030-2050. Under the CCS scenario, disposable income increases between 2025-2035 before dropping at each five-year interval between 2040-2050, driven by increasing electricity & production costs and an overall deceleration in long-term economic growth.

Figure 3 Distributed net impacts on disposable income at five-year intervals (loan-based financing, 2025-2050)



Summary conclusions

Across these different energy system pathways, using different modelling techniques and different assumptions on financing the following conclusions can be drawn on the socio-economic impacts of different choices.

- The financing assumption plays a crucial role in determining the socio-economic impact. In the case of closed (self-) financing the potential socio-economic benefits are much lower, and the risk of negatives much higher. To support socio-economic benefits, it is recommended to remain open to loan-based (external) financing.
- In a case where financing is open, then the RES-STORAGE, RES-GAS and AT-NIMP scenarios would deliver the most positive socio-economic impacts. The latter has the lowest positive GDP impact of the three, but a significantly more positive price impact. AT-NIMP is the least beneficial for disposable income. The RES-STORAGE pathway could offer the most positive overall balance across the socio-impacts.
- In the case of closed (self-) financing, then the RES-STORAGE and RES-GAS scenarios have little impact, but of the two the RES-GAS a marginally more positive impact, as RES-STORAGE may

have negative employment impacts. The most positive overall impacts are found in the AT-NIMP pathway which could deliver small benefits to GDP, employment, and disposable income.

- The AT and AT-1000 scenarios have relatively minor social impacts under all assumptions.
- The NUCLEAR scenario has relatively negative socio-economic impacts, especially on prices. In a self-financing scenario it may have small positives for GDP and disposable income but underperforms compared to most other scenarios in this setting.
- The CCS scenario has negative impacts under all indicators and in all circumstances, its only positive is providing a small boost to disposable income up to 2040, but which is lost by 2050.
- Based on these conclusions either of the RES-STORAGE, RES-GAS or AT-NIMP pathways could be recommended from a socio-economic impact perspective. A final decision between them would need to be based on the broader considerations and also the likely financing means. In the case of significant self-financing being desirable then the AT-NIMP pathway would likely emerge as the recommendation from a socio-economic perspective.

Annex – model characteristics and scope

The GEM-E3 model[1] is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model which provides details on the macro-economy and its interaction with the environment and the energy system. The version used for this study represents Estonia as a separate economy fully linked with the external sector (the European and global economy) through endogenous bilateral trade transactions. The GEM-E3 model incorporates micro-economic mechanisms and institutional features within a consistent macro-economic framework and avoids the representation of behaviour in reduced form. The model features perfect competition market regimes, discrete representation of power producing technologies, semi-endogenous learning by doing effects, equilibrium unemployment, options to introduce energy efficiency standards, and it formulates emission permits for GHG and atmospheric pollutants.

The GEM-E3 model was calibrated to the base years 2015 and 2020, after which a reference case scenario was defined, corresponding to the reference scenario developed in Deliverable 3. The key drivers of economic growth in the model are the labour force, total factor productivity and the expectations on sectoral growth. “Counterfactual” equilibria were computed by running the model under assumptions that diverge from those of the reference scenario (assumptions underlying the climate-neutral pathways developed in Deliverable 3). This corresponded to scenario building. In the analysis, scenarios were defined as a set of changes of exogenous variables. Changes of institutional regimes that are expected to occur in the future, were reflected by changing values of the appropriate elasticities and other model parameters that allow structural shifts (e.g., market regimes). These changes were imposed on top of the assumptions of the reference scenario, thereby modifying it. To perform a counterfactual simulation, it was not necessary to re-calibrate the model.

Counterfactual simulations were characterised by their impact on consumers’ welfare, or through the equivalent variation of their welfare function. The equivalent variations could be, under reasonable assumptions, directly mapped to some of the endogenous variables of the model such as consumption, employment, and price levels. The direction of the change of the equivalent variation then gives a measure of the policy’s impact and burden-sharing implications.

More extensive further details on data used for modelling and on modelling methodology are included in the full Deliverable 4 report.

[1] Full model documentation is available at https://e3modelling.com/modelling-tools/gem-e3/.