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# Fit-for-55 impact assessment

## E3ME model results

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# 1 Introduction

The following report has been produced as part of the Air Quality Research Assessment and Monitoring Integrated System (ARAMIS) project and has been supported by the Technology Agency of the Czech Republic. The project aims to develop and apply model assessment of impacts of measures aiming to reduce pollution by solid particles and greenhouse gases on the economy, distribution, energy consumption and the environment.

Following these aims, the current report aims to provide insights into the implications of certain elements of the European Commission's (Commission) Fit-for-55 agenda for the Czech Republic. The report builds on the modelling exercise carried out by Cambridge Econometrics, working together with the Charles University Environment Centre. The exercise has employed the E3ME macroeconometric, economy-energy-environment model developed and maintained by Cambridge Econometrics in order to estimate and quantify the impacts of the analysed policies.

This report is divided into three main sections: the first part briefly introduces the E3ME macroeconometric model used for this analysis, the second part describes the simulated scenarios and details the assumptions made, while the final, third part presents and discusses the results.

# 2 The E3ME model

E3ME is a macroeconomic model built on Post-Keynesian economic theory and on econometric estimations of macroeconomic relationships. The model was originally developed by an international team, operating under European Commission research programs (Cambridge Econometrics 2019). The model is maintained by Cambridge Econometrics and has regularly been used in high-profile scenario-based policy analyses, including assessing the EU's 2030 environmental targets (European Commission, 2020) or the EU's skills projections (CEDEFOP – Eurofund 2018).

E3ME simulates 70 world regions in total, 27 of them representing individual EU member states. In each EU country the model works with 69 industrial sectors (mostly corresponding to NACE Rev. 2 sectoral classification). Household consumption, which is divided to 43 categories, corresponding to COICOP classification, is linked to sectoral production in the model. Sectoral supply and demand are linked together through the use of input-output tables, while regions are linked through bilateral trade tables (Cambridge Econometrics 2019). The model is demand driven, assuming an adjustment on the supply side to fit demand, subject to constraints.

The input-output linkages provide channels between producing sectors and final demand. This means that as the model is demand driven, firms in the economy assumed to adjust their production (supply) to fulfil product demand. This process is subject to constraints, such as capacity constraints in labour and product markets, that feed back to prices and investment decisions (Pollitt et al. 2017), it is assumed that there is usually spare capacity in the economy (unlike in CGE models). Policies that draw upon this spare capacity may lead to increases in output and employment (Cambridge Econometrics 2019; Mercure et al. 2019).

The model's behaviour is different from that of computable general equilibrium (CGE) models (e.g. GTAP, GEM-E3) which are often used for macroeconomic modelling. To highlight some important differences: E3ME adopts a 'bounded rationality' approach, represented through behavioural parameters estimated on historical data and the money supply is assumed to be fully endogenous (Pollitt – Mercure 2018). The model builds on economic relationships estimated on historical data. A full list of equations used to define these relationships can be found in Mercure et al. (2018). Historical data was collected from various sources such as Eurostat, OECD, and the UN. Model parameters were estimated on this data using the concepts of cointegration and error-correction, based on Engle and Granger (1987) and Hendry, Pagan, and Sargan (1984). To avoid issues with shorter time-periods and possible volatilities related to the economic transition of the 1990s, the model uses a shrinkage technique for estimating parameters of long-term equations in all EU member states who joined the Union in and after 2004 (Spicer – Reade 2005). Ščasný et al. (2009: 468) describes this as "essentially adopting a western-European average", with the estimation basically assuming that on the long-run member states will converge to long-run behaviour of Western economies.

This modelling also takes advantage of 'Future Technology Transformations' (FTT), a suite of bottom-up technology models integrated with E3ME. The

FTT:Power and FTT:Transport submodels are used in the modelling exercise. These technology models assume technology diffusion and learning effects within individual technologies and employ discrete choice modelling to forecast path-dependent choices made by agents in the system (Mercure et al. 2014). FTT:Power is a bottom-up technology model following these principles (Mercure et al. 2014), while FTT:Transport uses a similar approach with heterogenous agents to simulate private passenger transport (Mercure et al. 2018).

**Appendix B** presents a more detailed description of the model. The E3ME model manual, which is a detailed description of data used, underlying mechanisms and equations, which form the model, is available at www.e3me.com.

# 3 Scenario design

As it was stated in the introduction the goal of this modelling exercise is to assess the impacts – including socio-economic, energy system and emission – of several major parts of the proposed Fit-for-55 (FF55) policy package. This section describes the scenarios constructed and simulated using E3ME for this assessment. A thorough description of the cornerstone assumptions of the scenarios simulated are followed by descriptions of carbon pricing / emission trading scheme (ETS) scenarios as well as details on how the revenues collected from these measures are used within the model. It is important to note that much of the assumptions used in the scenarios are defined on the EU27 level, rather than on the level of the Czech Republic. Nevertheless, multiple assumptions are exceptions to this, for example energy-mix developments.

## 3.1 Energy-mix assumptions

Thus, we start the discussion of the scenarios simulated with a discussion of the energy-mix assumptions of the simulations. We do this as both in the use of fossil fuels (coal and natural gas) and in the use of nuclear power there are major local policies that drive our simulation results. We consider two of these: coal phase-out from power generation and nuclear power capacity developments.

**Coal phase-out**

As of today fossil fuels play an important role in the Czech energy sector. With regards to coal, the scenarios assume that the Czech Coal Commission's recommendation[1] about the phasing out of coal and lignite in the power sector is implemented as early as 2033. This means that in the modelling (unless otherwise noted) we assume that this phase-out is happening, therefore no new coal-based power generation capacity is deployed in the Czech Republic from 2033.

**Nuclear pathways**

The Czech Republic has two major nuclear power plants, one in Dukovany with four reactors and another one in Temelin with two reactors. The former got connected to the electrical grid between 1985 and 1987 and has been in operation ever since, it was planned to be decommissioned in the 2030s, but recent reports have suggested that extending its lifecycle is the better decision both in terms of the country's energy security, as well as achieving its emission reduction targets. The latter was constructed quite recently and got connected to the grid between 2000 and 2002, thus its decommissioning is not on the agenda.

The four Dukovany reactors are capable of producing around 430 MWe each, while the newer Temelin ones, of which there are two, are much more powerful, they produce around 1030 MWe each. Accordingly, the closing down of the Dukovany reactors would result in the loss in electric capacities of around 1700 MWe. There are multiple plans for building new reactors which are at different stages of the approval/planning process.

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[1] https://beyond-coal.eu/2022/01/07/czech-republic-commits-to-2033-coal-exit-which-will-need-to-be-sped-up/

The scenarios implemented in the modelling process all assume that the Dukovany power plant's lifecycle is extended until 2045[2], at which point a new reactor, capable of providing 1200 MWe, is deployed and connected to the grid.

## 3.2 Emission trading scheme (ETS) assumptions

**ETS scenarios**

For the modelling of ETS pricing the modelling employs both endogenous and exogenous options. If the endogenous option is used the model is calibrated to reach certain emission targets, increasing ETS prices until the target is reached. If the exogenous options are chosen, then exogenously defined ETS price assumptions are used and the model, from a practical point of view, applies the defined ETS price to emissions as a carbon tax.

*Exogenous prices*

In the exogenous case therefore, we have used the recommended price trajectories drafted by the EC: *"Recommended parameters for reporting on GHG projections in 2023"*. This recommendation contains two sets of prices for emission allowances. The first is called 'WEM', *with existing measures*, which represents the development of carbon pricing if policy measures that are supposed to mitigate climate change remain largely the same. The second one 'WAM', *with additional measures*, it is important to note that this price trajectory goes beyond being an "explicit ETS carbon price", rather it serves as a "shadow price" for carbon pricing *and* other measures that would be necessary to maintain an FF55 compatible emission pathway. As Table 3.1 shows, the differences between these prices only become apparent after 2035.

**Table 3.1: ETS carbon pricing recommendations by the EC (EUR 2020 / tCO2)**

| | WEM | WAM | WEO NZE |
|---|---|---|---|
| 2020 | 24 | 24 | 24 |
| 2025 | 55 | 55 | 79 |
| 2030 | 55 | 55 | 114 |
| 2035 | 55 | 120 | 145 |
| 2040 | 85 | 250 | 180 |
| 2045 | 130 | 360 | 202 |
| 2050 | 160 | 410 | 220 |

Source(s): European Commission, International Energy Agency

The modelling also employs an ETS price pathway defined by the International Energy Agency (IEA). The International Energy Agency (IEA) releases a yearly report, titled World Energy Outlook (WEO), which "*provides critical analysis and insights on trends in energy demand and supply, and what they mean for energy security, environmental protection and economic development*" (IEA, 2022). Different environmental scenarios are modelled as part of the WEO, one of which is referred to as the Net Zero Emission by 2050 Scenario (NZE). In this report prices based on this scenario are also employed for the more ambitious scenarios with exogenously defined ETS prices. As we can see these represent somewhat

[2] In line with expected decommissioning in or around 2045. https://www.neimagazine.com/news/newstemelin-2-receives-permit-for-extended-operation-9737994

higher prices before 2035, compared to the EC's recommendations, but after that they become somewhat of a middle ground between the WEM and the WAM.

The baseline scenario that we use as a point of comparison for all subsequent scenarios uses the exogenously defined WEM prices.

*Endogenous prices*

Nevertheless, as we impose other policies in the modelling (energy policies, CBAM, revenue recycling, etc.) it is also valuable to let the model endogenously determine the ETS carbon prices *necessary* for meeting the set emission reduction targets[3]. In this case the target that we consider is a 62% reduction by 2030 compared to 2005 $CO_2$ emission levels in ETS-covered sectors on EU27 level, which corresponds to the higher economy-wide target of 55% reduction by 2030 compared to 1990 levels on EU27 level (Burger, Gibis, Knoche, Lünenbürger, & Weiß, 2020). In this case, we start with the WEM ETS prices, and calibrate these prices in the model to reach the 62% target by 2030. After 2030 we assume a linear extrapolation of the price using the initial WEM pathway.

In the modelling exercise a total of four scenarios use the exogenous price assumptions and four scenarios (initially) use the endogenous price assumption, as it was discussed before the baseline uses an exogenous price assumption as well.

## ETS2 scenarios

The scenarios, in line with a major proposal in the FF55 package, also envision an extension of the current emission trading scheme. More precisely, they apply a so-called 'ETS2' scheme in parallel to the existing ETS scheme, which covers building (residential and commercial) and transport sectors. The scheme is implemented from 2026 onwards, i.e. from 2026 it have larger than zero prices.

Similarly, to the ETS carbon prices, in this case we also have scenarios with exogenous and with endogenously defined carbon prices. In the exogenous case WEO NZE prices were used as shown in Table 3.2. Meanwhile, in the endogenous case we employ an EU27 wide, 43% $CO_2$ emission reduction target, which should be reached by 2030. The target is defined compared to 2005 emission levels and cover the sectors that are included in the ETS2 scheme – buildings and transport. (Stenning, et al., 2022)

**Table 3.2: ETS2 carbon pricing base on the WEO's NZE scenario (EUR 2020 / tCO2)**

| | WEO NZE |
|---|---|
| 2020 | |
| 2025 | |
| 2030 | 48 |
| 2035 | 91 |
| 2040 | 134 |
| 2045 | 177 |
| 2050 | 220 |

Source(s): International Energy Agency

[3] Note that within the framework of the model exogenously defined ETS carbon prices can result both in lower and higher emission reductions than the proposed targets.

### 3.3 Carbon Border Adjustment Mechanism

The Carbon Border Adjustment Mechanism (CBAM) is also part of the Commission's Fit-for-55 agenda. Its main aim is to limit carbon leakage, while creating a level playing field, within the EU, for products that are covered under the ETS system. (Markkanen et al., 2021).

Thus, the goal of CBAM is to ensure that EU producers do not move production outside of the EU, but at the same time foreign actors do not have a price advantage over said EU internal producers. As such, it equalises costs of carbon for the aforementioned actors, much like a tariff (Markkanen et al., 2021).

Current plans establish that a transitional phase is supposed to start in 2023 and the system should become fully operational in 2026, consequently this is the stage where financial adjustments will be introduced. There are a number of questions as to how feasible these initial plans are, as both experts and legislators expect considerable pushback from the WTO, and it is unclear how long those legal challenges will take to smooth out or how watered down the proposal will have to get to pass those challenges (Markkanen et al., 2021; European Commission, 2021).

**Modelling CBAM**

The modelling approach adopted here is a simplified version of the proposed CBAM regulation[4]. In the simulation it covers energy intensive NACE sectors, that are at risk of carbon leakage: basic metals (iron & steel), non-metallic mineral products (cement) and chemicals (incl. fertilizers and some plastics). Note that the scenario, contrary to the EC proposal, does not consider the coverage of electricity imports, which, nevertheless, will not cause major disruptions in the case of Czechia. This approach was chosen because modelling electricity imports and electricity market dynamics would be beyond the scope of this exercise. The modelling considers the introduction of a CBAM system from 2026 onwards.

Technically, the CBAM is modelled as a tax on import prices for EU countries, with exceptions for announced third-party countries and with decreased rates for those countries who have adopted a net-zero carbon pledge. If a country exporting to the EU belongs to none of those categories, then a tax, equivalent with the ETS price, is applied onto its products. The total amount of the tax is calculated from the estimated carbon intensity of the exporting sector in its home country and the EU ETS price.

It needs to be noted that in reality CBAM coverage will likely be specified on the CN product code level[5] and it will likely be levied on certain products. NACE sectors (and their E3ME equivalents) are broader categories that necessarily include more than the selected products (*Table 3.3* shows the correspondence). In the modelling we apply the CBAM to these broader categories. This leads to over- and underestimation at the same time, with these two effects balancing out much of each other. On one hand, due to applying the CBAM to a larger sector, we might

[4] The overall method for simulating the CBAM in the E3ME model, as well as results from some global simulations and a discussion of legal and political issues with the CBAM proposal can be found in *Markkanen, S., Viñuales, J., Pollitt, H., Lee-Makiyama, H., Kiss-Dobronyi, B., Vaishnav, A. et al. (2021). On the Borderline: the EU CBAM and its place in the world of trade. Cambridge, UK: Cambridge Institute for Sustainability Leadership, University of Cambridge.* https://www.cisl.cam.ac.uk/files/cbam_report.pdf

[5] The Combined Nomenclature (CN) is a tool for classifying goods, set up to meet the requirements both of the Common Customs Tariff and of the EU's external trade statistics

overestimate its effects, but on the other hand, we apply the CBAM to a carbon intensity that is calculated based on the whole sector, therefore likely to be much lower than if we took the product level emission intensity. Thus, these two effects act in opposite directions and might cancel each other out, leading to less biased estimation.

**Table 3.3 – CBAM coverage (CN codes) and E3ME/NACE sectors**

| Products | Relevant E3ME sector / NACE sector | EU imports of products covered by CBAM (€bn 2020 prices) | EU imports of products in E3ME sector (€bn 2020 prices) | Share of CBAM product trade in the broader E3ME sector |
|---|---|---|---|---|
| • Iron and steel<br>• Iron and steel articles<br>• Aluminium | Basic metals | 89.2 | 114.9 | 77.6% |
| • Fertilizers<br>• Inorganic chemicals | Other chemicals | 17.9 | 152.1 | 11.8% |
| • Cement | Non-metallic mineral products | 0.2 | 21.8 | 1.1% |

**Free allocations**

Concerning the introduction of CBAM, free ETS allocations also need to be considered. It has been suggested that the introduction of a CBAM system will be followed by the complete phasing-out of free allocations from the ETS system. Crucially, in the modelling we assume that firms take an "opportunity cost" approach to the costs of the ETS system.[6] Meaning that regardless of them getting the necessary permits through auctioning or through free allocations from the government they factor in permit costs to their prices. The underlying assumption is the opportunity cost treatment of the free allocations on the firms' side: as they are able to trade with permits they should be able to sell free allocations if there was overallocation in the system, hence by emitting and then surrendering the permits for their own emissions carries opportunity costs – forfeited revenues from the sale of the permits.

Nevertheless, the share of free allocations determine government revenues collected from the ETS system. Therefore, in order to take into effect how a change in free allocations impact government budgets we define two cases of free allocation ratios for the scenarios. In the case where CBAM is introduced free allocations are gradually phased-out by 2030 from the ETS sectors. While in simulations where CBAM is not introduced free allocations follow a linear (decreasing) trend from their current levels, but do not have a strict phase-out date. In both cases, the level of free allocations impact government revenues collected from carbon pricing and therefore revenue recycling, which we discuss in the next section.

Revenues from CBAM are currently not recycled in the modelling. Given current policy developments these revenues are expected to be allocated towards administrative spending and measures supporting third-countries (EU-external).

[6] See *Verde, S.F., Teixidó, J., Marcantonini, C., Labandeira, X., 2019. Free allocation rules in the EU emissions trading system: what does the empirical literature show? Climate Policy 19, 439–452. https://doi.org/10.1080/14693062.2018.1549969* for a discussion on ETS costs as opportunity cost.

## 3.4 Revenue recycling

The scenarios are intentionally aim to be 'budget neutral' on the EU27 level. Meaning that all ETS revenues collected are 'recycled' in towards other measures. The composition of these measures and the share of spending on certain measures differs scenario by scenario.

**Revenues collected**

Technically, the distribution of the revenues mimics the institutional and legal environment that the EU provides, in the sense that the collected revenues can be accessed through the Innovation Fund (IF), the Modernisation Fund (MF) and the state budget, when it comes to the ETS, and the Social Climate Fund (SCF) and the state budget, when it comes to ETS2. Both ETS and ETS2 revenues are collected on EU27 level and then redistributed according to pre-defined schemes.

The Innovation Fund collects 2% of total EU27 ETS revenues, just as the Modernisation Fund uses 2% of total EU27 ETS revenues. The IF's 2% is then allocated according to ETS revenues collected on Member State (MS) level, therefore it corresponds to 2% of revenues collected on MS level. The MF, however, has a redistribution factor across the member states. *Table 3.4* shows the expected share received by the Czech Republic, the table also shows that there is an extra national contribution (from collected ETS revenues) in the country. This amounts to 47.97% of auctioned ETS revenues on MS level. All revenue remaining from the national auction envelope are then used for purposes defined on the MS level.

In a similar fashion, ETS2 revenues are collected and allocated to the Social Climate Fund (SCF, 25% of revenues as fund contribution, 25% as national contribution – the SCF is 'matching' fund) and to other MS level purposes. Notably, this setup implicitly assumes that member states will use SCF funds allocated to them to their full extent and are willing to pay the necessary national contribution for SCF eligible purposes. The rest of ETS2 revenues are used for government purposes as defined in the revenue recycling (details below).

**Table 3.4: MF core funding and national contribution and SCF allocation in CZ**

| | MF core | MF national contribution | SCF allocation |
|---|---|---|---|
| Czech Republic | 15.59% | 47.97% | 2.2% |

Source(s): MoE and own calculations

**Revenues spent**

After the amount of collected revenues (across EU) and redistributions (on MS level) are calculated the modelling uses three pre-defined cases to allocate the revenues to certain actions. In the scenarios we have (1) a low 'green' ambition recycling case, which is used in the baseline as well and (2) high 'green' ambition' recycling case, which assigns more of the collected revenues to 'green' measures. We also have an 'environmental tax reform' scenario, in which case all revenues (both ETS and ETS2) are used for decreasing taxes (income, labour and sales taxes in equal proportions).

*ETS revenues*

In the 'low ambition' pathway ETS revenues from the IF and the MF are spent on some green initiatives, like introducing green hydrogen, energy efficiency in industry, electronic vehicles, heat pumps or solar and wind power. Assumed intensity of support is 60% for IF and 35% for MF. While remaining ETS auction revenues are spent as general government expenditures. Importantly, not all subsidies are necessarily 'taken-up' to their full extent in the modelling. Especially in the case of subsidies that are modelled using FTT submodules (power generation, heating and transport) there is no assumption on how much of the provided subsidies are actually taken up by the economy. Due to the nature of these models (i.e. bounded rationality assumption) increasing the level of subsidies provided do not linearly increase adaptation of the subsidized technology.

The 'high ambition' recycling is similar in most of its spending. Nevertheless, rather than using the remaining ETS auctions for increasing general government expenditures it uses that part of the revenues for 'green' measures as well. Energy efficiency measures (50% support intensity) and power generation, electric vehicle subsidies are considered here, in addition to measures detailed previously.

*ETS2 revenues*

When it comes to the SCF revenues of the ETS2, 40% are used for lump-sum transfers towards the two deciles with the lowest incomes, while the rest is spent on similar green subsidies as before. Here, the 'high ambition' pathway once more differs from the 'low ambition' in how it handles remaining auction revenues.

In the 'low ambition' pathway 50% of remaining auction revenues is spent on lump sum transfers to the lowest two deciles, while 50% is considered general government spending. In the 'high ambition' scenario this changes: 40% is still spent on lump sum transfers, but the other 60% is spent on 'green' subsidies: EE for households, subsidies for EVs and subsidized heating modernisation (heat pumps).

## 3.5 $CO_2$ emission standard assumption in transport

Another important measure considered in the modelling is the expected strong $CO_2$ emission standard regulation for passenger cars. The scenarios (other than the baseline) therefore assume that regulation, as part of FF55, is implemented, which allows only the sale of zero emission passenger vehicles from 2035 onwards.

## 3.6 Natural gas price

To respond to recent geopolitical and energy market developments the modelling also considered higher global natural gas prices, in line with the EC's recommended price trajectories (*"Recommended parameters for reporting on GHG projections in 2023"*). In these cases, we are exogenously defining global natural gas prices, which are otherwise (and in the other scenarios) are calculated endogenosuly based on global demand. We treat these scenarios as 'sensitivities' in order to show how main results change given these shocks are stay with us in the long-term.

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**Table 3.5 – Overview of the defined scenarios**

| Scenario name | Coal phase-out | ETS price | ETS2 price | CBAM | Revenue recycling | NG price | Net-zero cars |
|---|---|---|---|---|---|---|---|
| BAU | No | WEM | No | No | Low ambition | Endo | No |
| S8 | 2033 PG | Endo (F55 target) | Endo (43% target) | Yes | Low ambition | Endo | From 2035 |
| S9 | 2033 PG | Endo (F55 target) | Endo (43% target) | Yes | High ambition | Endo | From 2035 |
| S10 | 2033 PG | Endo (F55 target) | Endo (43% target) | Yes | ETR | Endo | From 2035 |
| S11 | 2033 PG | Endo (F55 target) | No | No | Low ambition | Endo | From 2035 |
| S12 | 2033 PG | WEO NZE | WEO NZE | Yes | Low ambition | Endo | From 2035 |
| S13 | 2033 PG | WEO NZE | WEO NZE | Yes | High ambition | Endo | From 2035 |
| S14 | 2033 PG | WEO NZE | WEO NZE | Yes | ETR | Endo | From 2035 |
| S15 | 2033 PG | WEO NZE | No | No | Low ambition | Endo | From 2035 |
| BAUH | No | WEM | No | No | Low ambition | Exog HT | No |
| S12H | 2033 PG | WEO NZE | WEO NZE | Yes | Low ambition | Exog HT | From 2035 |
| S13H | 2033 PG | WEO NZE | WEO NZE | Yes | High ambition | Exog HT | From 2035 |
| S15H | 2033 PG | WEO NZE | No | No | Low ambition | Exog HT | From 2035 |

## 3.7 Overview of defined scenarios

*Table 3.5* shows an overview of the defined scenarios, bringing together many aspects that has been discussed in this section. All, but the baseline scenario(s) include coal phase-out in power generation. There are four scenarios with endogenously defined ETS and ETS2 prices and four scenarios with exogenously defined prices. Altogether nine scenarios employ endogenous global natural gas price calculation and four scenarios (which we consider sensitivities) consider an exogenously defined global gas price. CBAM is applied in all scenarios where ETS2 is implemented (both phased in from 2026) and the scenarios choose between three different type of revenue recycling (RR) setups (as indicated in the RR column).

# 4 Results

This chapter discusses the results of our scenarios, specifically in terms of emission reductions, changes in the power generation mix, the development of the GDP and certain socioeconomic considerations.

The discussion will focus on relevant and interesting results and try to explain certain mechanisms rather than try to give a comprehensive set of all scenario results.

## 4.1 Emission reductions

As it was previously discussed, emission reductions are a focal point of the FF55 package and as such, interpreting the results of the models needs to begin with an overview of whether emission targets and aims are reached within the scenarios, both in the EU27 and specifically in Czechia.

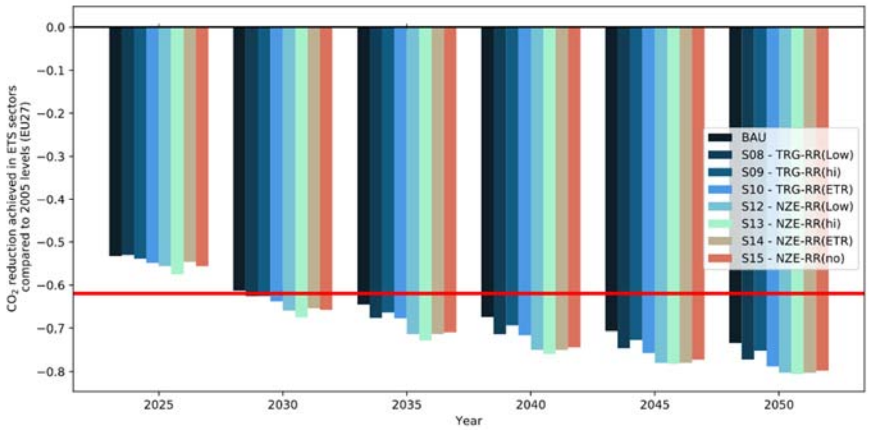
As such, overall emissions are expected to decrease by 55% compared to 1990 levels, ETS sector emissions by around 61-62% and ETS2 emissions about 43% by 2030, both compared to 2005. Obviously, these figures are only valid for the EU27, and are not explicitly defined for the Czech Republic.

**EU27 - ETS**

ETS targets in 2030 are reached in all scenarios in EU27. The reduction by 2030 is smallest in the case of the baseline (61%) and the largest in the case of S13 – NZE-RR(hi) (about 68%). Notably, scenarios with exogenously defined ETS prices all overachieve the reduction goal.

This is mostly explained by the difference in ETS carbon prices assumed: the exogenous WEO NZE price is much higher than the endogenously produced prices. Therefore, emission reduction is notably higher in the scenarios S12 and S13, between 66% and 68%, compared to S8 and S9, where it is only slightly higher than the target.

**Figure 4.1 Emission reduction in the ETS sectors in the EU27**




Source(s): E3ME modelling results.
Note: Red line indicates the ~62% reduction target

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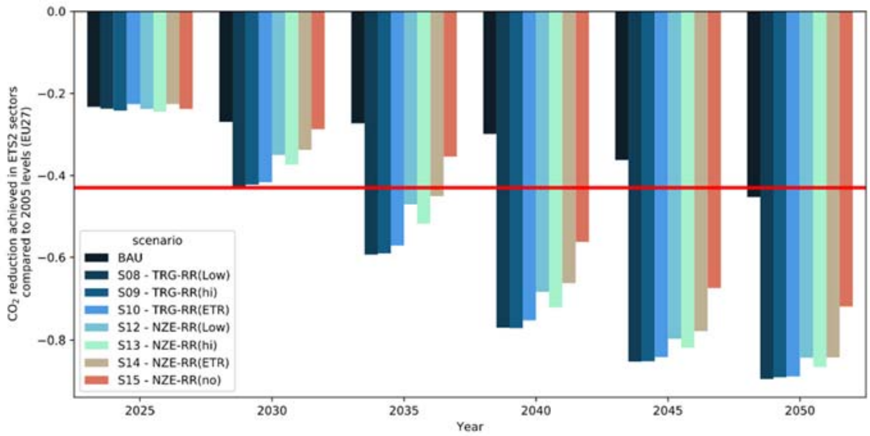
While these scenarios were not calibrated for any emission reduction goals in 2050 they reach a reduction of 73-81% in ETS sectors. With the WEO NZE scenarios reaching significantly higher reductions than the rest of the scenarios.

**EU27 – ETS2**

At the same time the results in the ETS2 sectors show somewhat different dynamics. The endogenous scenarios are successful in achieving the targets, but no other scenario does so. This shows, that given the muted reactions to price signals by consumers ETS2 prices are likely need to be much stronger to have the needed effect than ETS prices. Consumers react less to price signals in the model than industry does, therefore the price is not enough to shift demand towards more carbon friendly consumption.

**Figure 4.2 Emission reduction in the ETS2 sectors in the EU27**




Source(s): E3ME modelling results.
Note: Red line indicates the ~43% reduction target

Scenarios with no ETS2 implementation (BAU and S15) are the farthest from the sectoral goal of 43% reduction. By 2050 variation across the scenarios is still substantial: the BAU achieves only ~45% reduction, while scenarios with ETS2 implementation range between 84-89% reduction. Notably, S15, which does not employ an ETS2 system, but does introduce strong emission standards and revenue recycling measures targeting the transport and building sectors achieves a 72% reduction. The highest reduction is achieved in the S08 scenario, this scenario applies the highest ETS2 price and further reductions through revenue recycling leading to an 89% reduction by 2050.

**ETS – Czech Republic**

In the specific case of Czechia, we see similar trends. Reductions by 2030 are 61-66%, while by 2050 reductions reach 74% (BAU) to 86% (S14) levels. Generally in by 2030 differences are limited, but they substantially increase by the end of the modelling period. While the largest difference across scenarios is 3 percentage point (pp) in 2030, it increases to 12pp by 2050, underscoring the path dependent nature of decarbonization.

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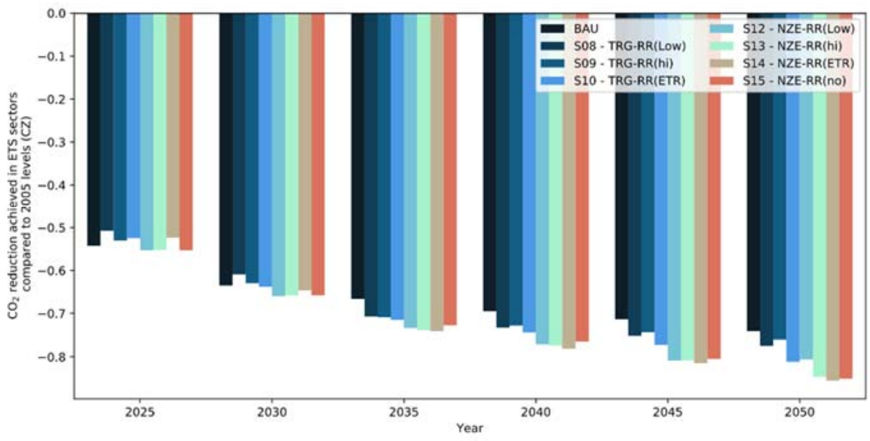
**Figure 4.3 Emission reduction in the ETS sectors in the Czech Republic**




Source(s): E3ME modelling results.

**ETS2 – Czech Republic**

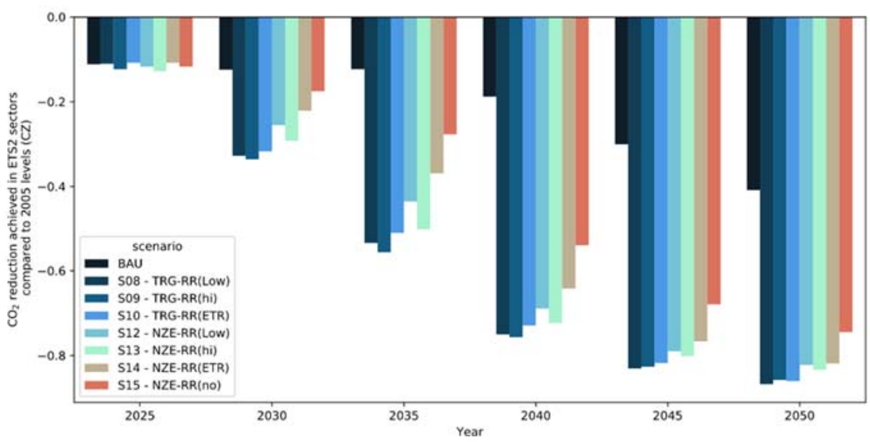
In sectors covered by ETS2 in the Czech Republic we see much smaller reduction numbers. By 2030 achieved emission reductions are in the range of 12-34%, with ~12% produced by the BAU and 34% produced by the TRG-RR(hi) scenario. Reductions are much higher in the endogenous scenarios, this has been discussed earlier when talking about EU27 results. Reductions by 2050 are in the range of 41% (BAU) to 87% (TRG-RR(low)), while reductions in the exogenous prices scenarios (WEO NZE) are in the range of 82-86%.

While results in the ETS2 sectors in the Czech Republic are generally weaker than on an EU27 level (EU27: 45-89%, CZ: 41-88%) it is interesting to see that in the case of the S15 scenario (where there is no ETS2 implemented) emission reductions are stronger in CZ then on the EU27 level.

**ETS revenues**

With regards to the revenues from ETS and ETS2, they fit into the narrative that has been emerging in this section. The BAU and S15 scenarios have relatively low revenues, while including the phasing-out of free allocations (where relevant)

**Figure 4.4 Emission reduction in the ETS2 sectors in the Czech Republic**




Source(s): E3ME modelling results.
Note: Red line indicates the ~43% reduction target

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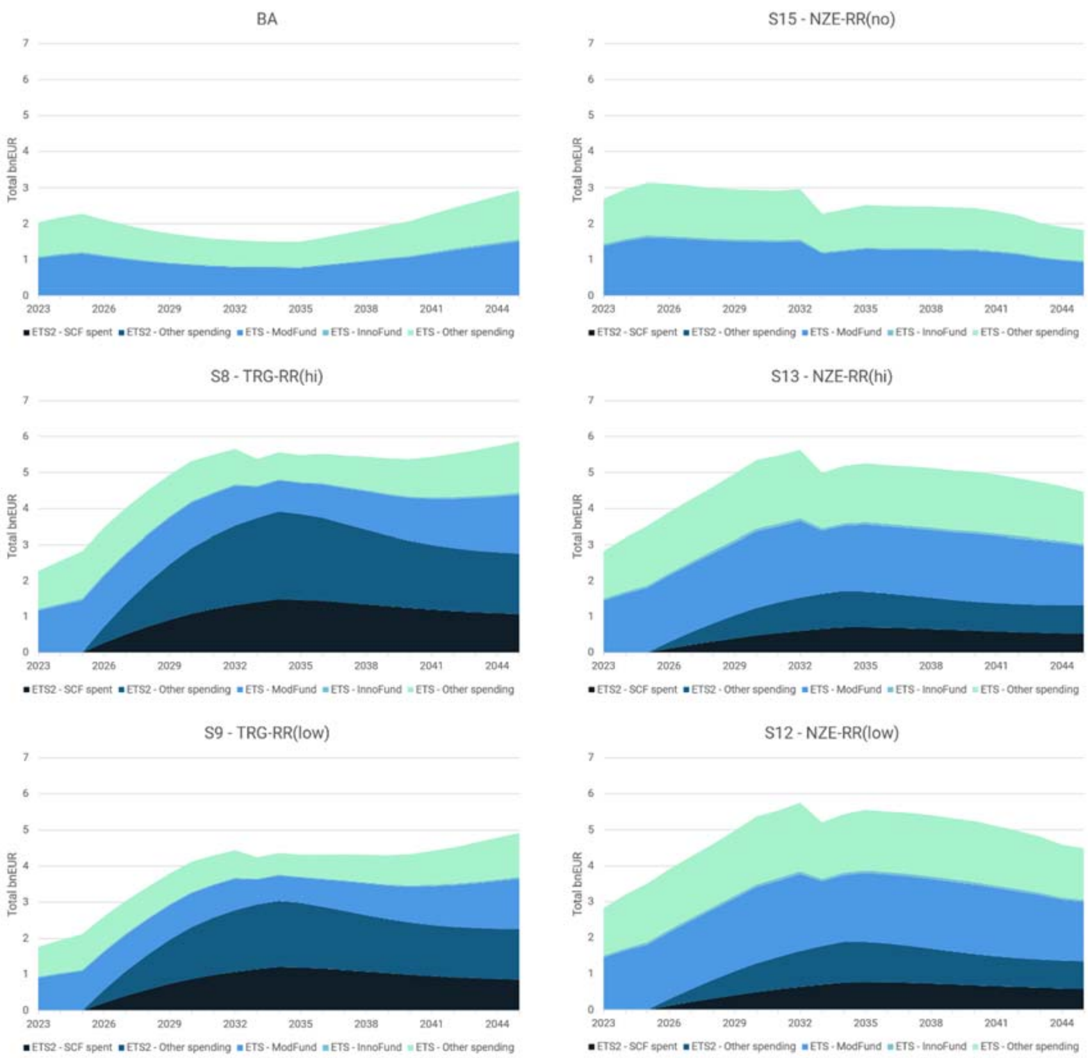
increases ETS revenues are between €15-29 bn in the period of 2023-2030, lower in the endogenous scenarios, while highest in NZE price scenarios. Due to the higher permit prices the reverse is true for the ETS2. Calculated revenues are between €4-9 bn in 2026-2030, lower in S12 and S13, while higher in S8 and S9. *Figure 4.5* presents an overview of the revenues for selected scenarios.

**Figure 4.5 Revenues from carbon pricing in different scenarios for the Czech Republic**




Source(s): E3ME modelling results.

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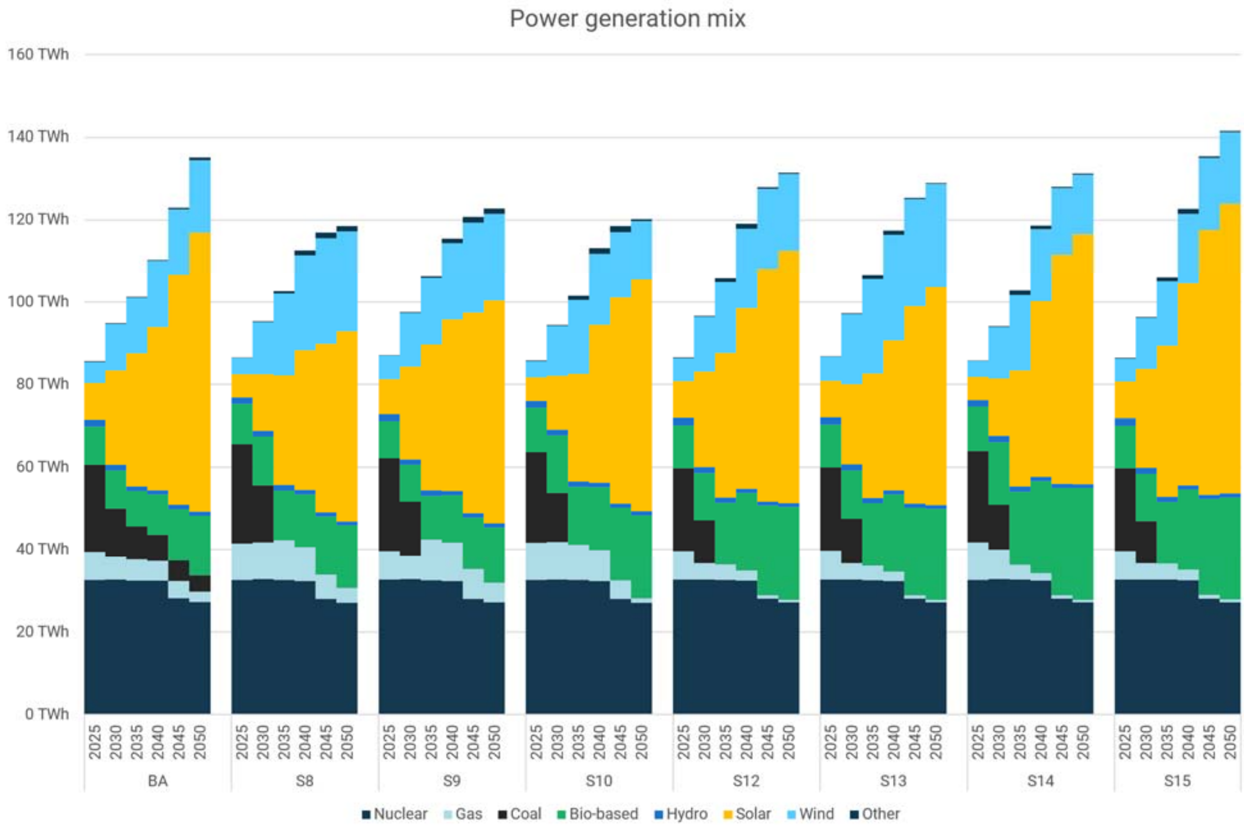
## 4.2 Power Generation mix

**Figure 4.6 Power generation mix in Czechia, TWh / year generated by technolgy**




Source(s): E3ME modelling results.

Power generation mix is dependent on the scenario assumptions in the simulations and calculated by FTT:Power. *Figure 4.6* shows the simulated mixes. Because of the way scenarios are designed coal is phased-out from 2033, except for the BAU, where it remains part of the power generation mix even into the 2040s. In the other scenarios it is mainly replaced by renewable sources, and sometimes gas as well. The role of gas largely depends on the price of the ETS permits. In the scenarios where the ETS price is endogenously determined, thus it is lower, gas remains a non-negligible part of the power mix until the end of the modelling timeline. When the WEO NZE prices are used it is largely phased-out by 2040.

An important aspect that should be noted is the effect the ETS2 has on demand. Specifically, when looking at S15, compared to S12/S13/S14, it becomes apparent that ETS2 reduces electrified transport use as well as heating demand a bit, which results in lower demand overall in scenarios where it is implemented. Notably, scenarios with endogenous pricing (S8/S9/S10) also have lower overall demand, again a result of the higher ETS2 prices.

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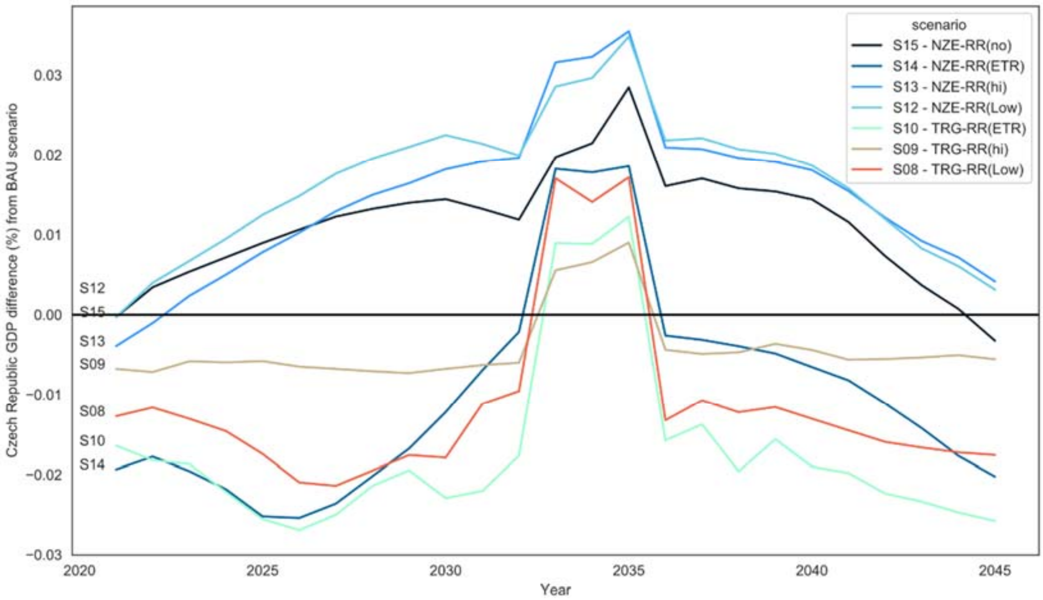
## 4.3 Socio-economic impacts of the scenarios

**Economic activity**

The GDP pathways in the scenarios reinforce much of what has been discussed previously. There is a very clear distinction between the scenarios with endogenous and exogenous carbon pricing. Endogenous one has lower ETS and higher ETS2 prices, and while the latter depresses consumption, the former results in comparatively lower government revenues, thus lower revenue recycling, and the resulting overall effect is a GDP below the BAU level for the most part. Exogenous pricing with its higher ETS and lower ETS2 prices has the reverse effect and accordingly, GDP above the BAU. Furthermore, the effect of revenue recycling can also be clearly observed, as S15, which does not have RR, and even despite not having demand depression from ETS2, has lower GDP than S12 and S13, which is due to the consumption drive from the state.

**Figure 4.7 GDP impacts in the Czech Republic. difference (%) from BAU**




Source(s): E3ME modelling results.

Comparing S14, where revenue recycling uses environmental tax reform (ETR), to other scenarios with no (S15) or different recycling options also give interesting insights. In the ETR case taxes are decreased, but this does not lead to an economic boost high enough to offset the effects of ETS2 on consumption (note: there are no lump sum transfers in this case).

In every scenario there is a sizeable peak in GDP compared to baseline levels, which is driven by a peak in investment, from the beginning of the 2030s. This is driven by the phasing-out of coal-based power generation, which requires extra investment into alternative technologies. Additionally, vehicle replacement has a notable effect in the same timeframe, due to stricter emission standards introduced from 2035.

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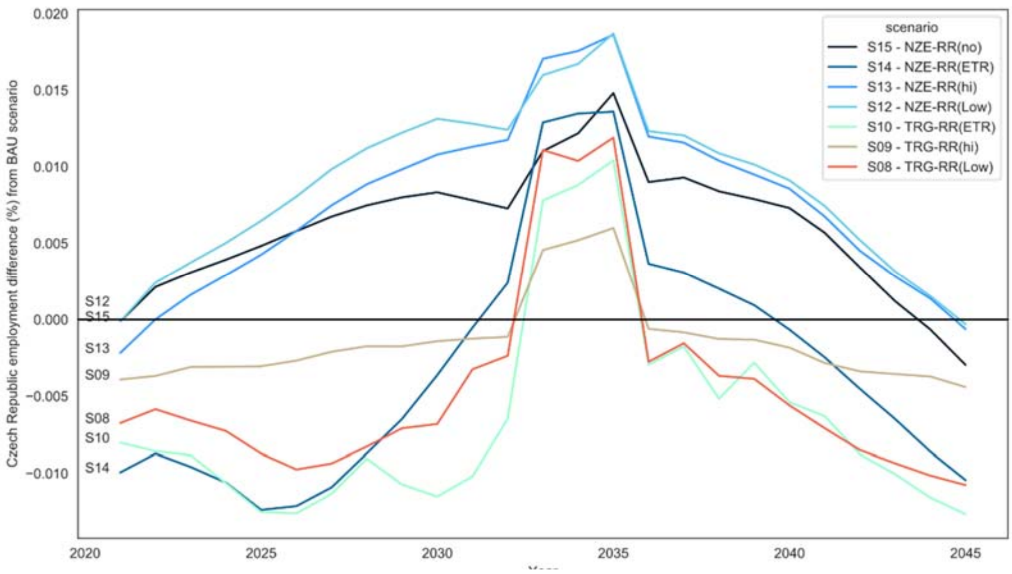
## Employment

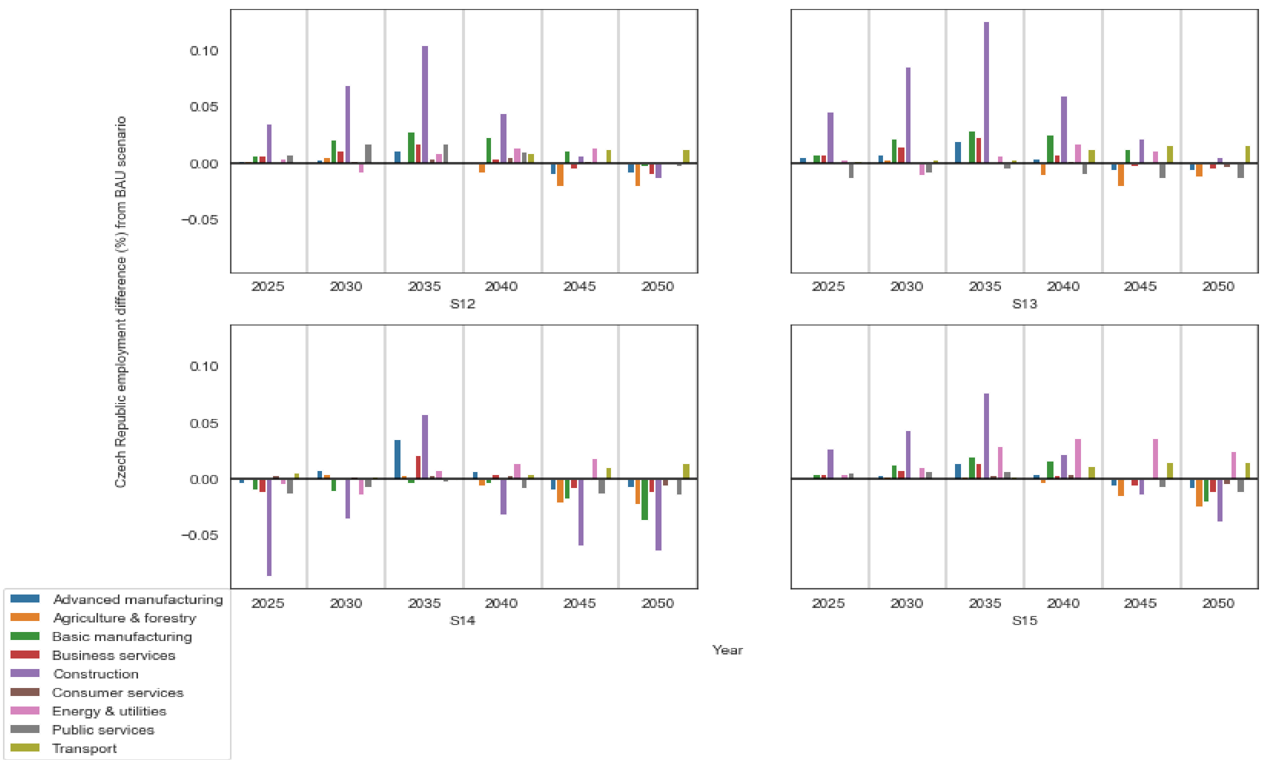
Overall trends in employment largely follow those that were seen in GDP, however the magnitudes are lower, while GDP impacts are in the range of -2% to +3%,

**Figure 4.8 Employment impacts in the Czech Republic. difference (%) from BAU**




Source(s): E3ME modelling results.

**Figure 4.9 Sectoral employment impacts in the Czech Republic, difference (%) from BAU, exogenous price scenarios**




Source(s): E3ME modelling results.

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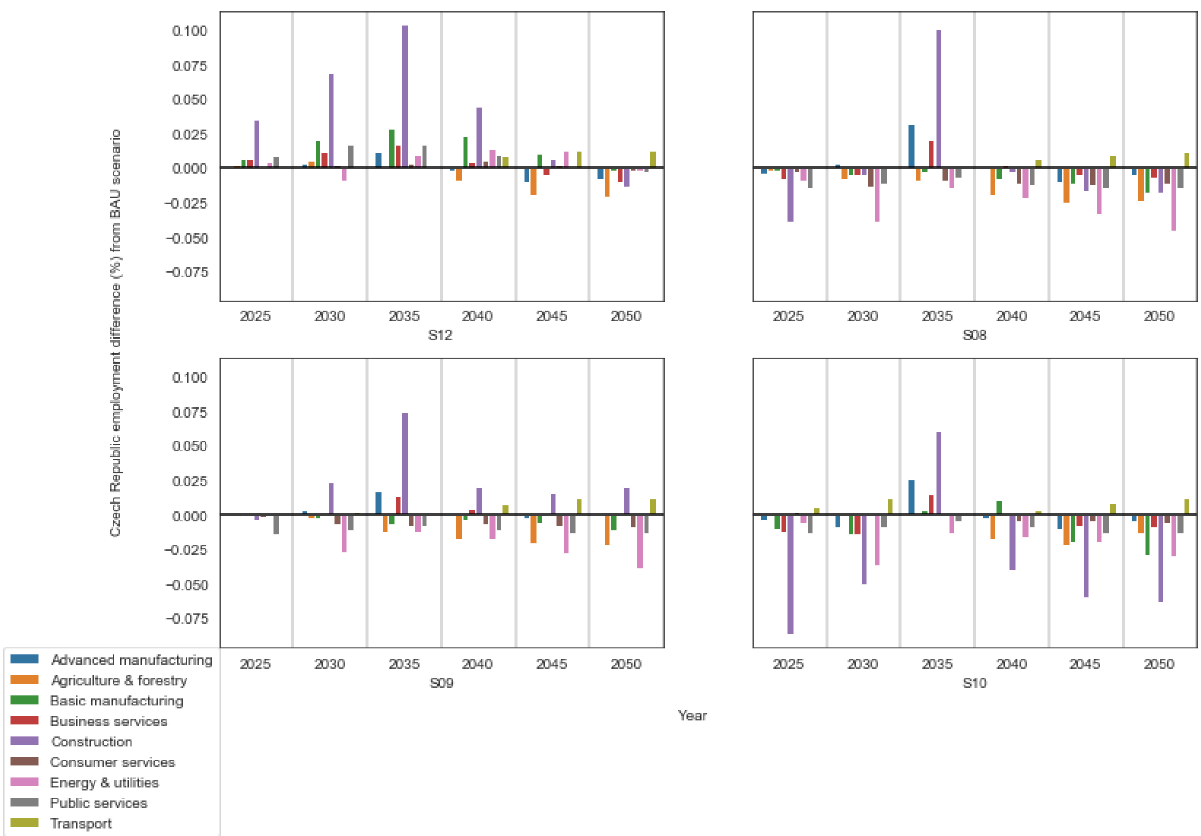
compared to the baseline, employment impacts are in the range of -1% to +2%, compared to the same.

On the sectoral level employment growth is driven by sectors supplying investment goods and services for the transition, most prominently construction (up to 12% increase from baseline, S13), but also manufacturing, business services and energy in the later part of the modelling timeframe. Construction and both basic and advanced manufacturing peaks around 2035 – here we have impacts from the coal phase-out (power sector developments), but also from transitioning to zero emission vehicles. Hence the increase both in construction and manufacturing sectors.

**Figure 4.10 Sectoral employment impacts in the Czech Republic, difference (%) from BAU, endogenous price scenarios (S12 is endogenous price, for reference)**




Source(s): E3ME modelling results.

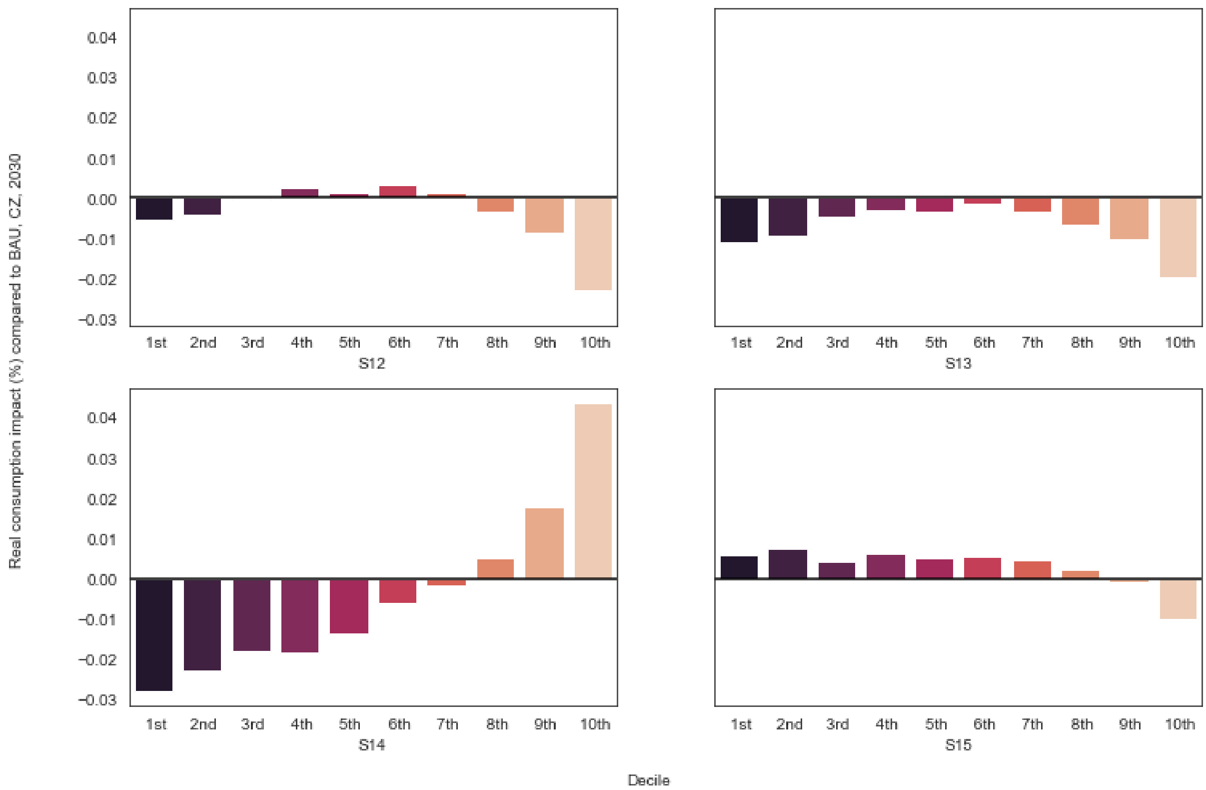
The electricity sector has a changing role through the different scenarios. Where ETS2 depresses demand employment in the sector is stagnant compared to the BAU, the higher the price, the lower the employment, but in S15 electricity supply also drives employment (as demand is increasing, not decreasing here).

In the endogenous price scenarios similar pattern can be observed. Around 2035 a large positive impact in the construction sector is visible in all scenarios, however other sectors, most prominently energy & utilities, see negative impacts in both S8, S9 and S10 scenarios. This is primarily due to how ETS2 limits demand for oil, gas and manufactured fuels. Due to the ETS2 pricing and $CO_2$ emission standards sectoral output (and hence employment) in manufactured fuels and gas decrease substantially.

## 4.4 Distributional impacts

Distributional impacts are analysed using household level consumption and income structures. Consumption category (defined as COICOP categories) are assumed to have single elasticities, but consumption shares differentiated across consumption deciles. Incomes and propensity to consume is also assumed to be heterogenous across deciles. Therefore, a hike in energy prices might lead to some demand reduction (elasticity of demand) and/or lead to reduction of consumption of other products. In the same time if there is a demand increase or decrease, that

**Figure 4.11 Real consumption impact (%) compared to BAU consumption per decile, exogenous price scenarios, 2030**




Source(s): E3ME modelling results.

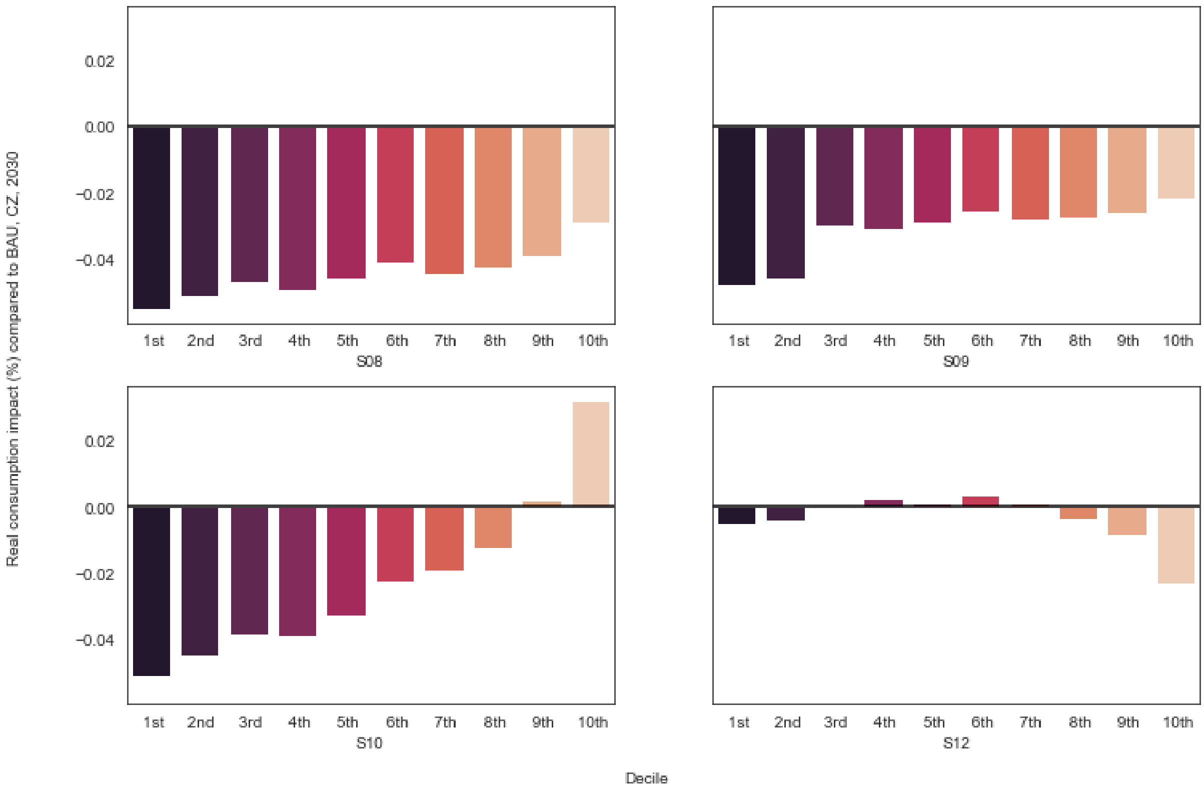
again can change decile level consumption given propensity to consume and income elasticity coefficients.

Estimated distributional impacts are the strongest in the case of the endogenous price scenarios as these have the highest ETS2 prices, which is felt directly by consumers (i.e., shows up directly in consumer prices), thus in these scenarios a loss of real consumption for all deciles can be observed, with the bottom deciles suffering the biggest impacts, a loss of up to 5%. In the exogenous price, WEO

NZE scenarios these impacts are less severe, negative effects are mostly felt in the very top and bottom deciles.

In the case of S12 and S13 scenarios, where there is both an ETS2 system implemented and revenue recycling the targets the lowest deciles we see that negative effects (at least by 2030) are mostly mitigated for up to the 8th decile and real consumption only decreases by about 2-3% for the upmost decile. Nevertheless, we can also observe a regressive outcome in the case of the ETR recycling: tax breaks favour those with higher labour and residual incomes, while the introduction of the ETS2 increases prices for all, therefore decreasing real

**Figure 4.12 Real consumption impact (%) compared to BAU consumption per decile, endogenous price scenarios, 2030**




Source(s): E3ME modelling results.

consumption of the lowest deciles by up to 3%.

In the case of the endogenous price scenarios (S8/S9/S10), as it was discussed, we see effects with overall negative impacts. Consumption is depressed in all deciles in both S8 and S9 scenarios, due to the high price signals from the ETS2 pricing. Nevertheless, the ETR recycling case (S10) shows better outcomes for the highest decile, due to what mechanisms described previously.

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# 6 Appendix A

## 6.1 ETS

The Emission Trading System (ETS) of the European Union (EU), which has been established in 2005, is facing a major overhaul as part of the European Commission's (Commission) Fit-for-55 agenda. The purpose for its creation was to establish a tool in the hands of the Commission for reducing the emission of greenhouse gases (GHG) in the most cost-effective way. The system has already had three phases, the first one from 2005 to 2007, the second one from 2008 to 2012 and the most recent third one from 2013 to 2020 (ICAP, 2021). Numerous critiques have been articulated about the ETS, mainly how it is too lenient and as such is not doing enough for the environment.

Previously the ETS had a linear reduction factor (LRF), the rate at which emissions are to be cut annually, of 2.2%, which added up to a 43% reduction in ETS emissions from 2005 levels by 2050. This rate was far from making the EU's goals compatible with the targets set out in the Paris Agreement. The Commission's new proposal **offers a more ambitious plan, which increases the LRF to 4.2%, which now sets ETS emission reduction at 62%** from 2005 levels by 2030 (European Commission, 2021). This is a significant step forward and one that takes the **EU much closer to meeting the goals of the Paris Agreement**.

There are numerous other changes to the ETS system as well, but due to the limitations of this report the discussion will focus on the question of the ETS cap and free allocations. The system of free allocations, one of the most criticised parts of the ETS, will go through a small reform which will ensure that it also aids the decarbonisation efforts. Last, but not least, the ETS will interact with the Carbon Border Adjustment Mechanism (CLEW, 2021).

The Fit for 55 package contains further changes to the system of carbon pricing, chief amongst them the introduction of a separate emission trading system for buildings and road transport. This is commonly referred to as ETS2 and it is supposed to become active in 2025, but there are a lot of uncertainties regarding the start date. New plans include restricting the coverage to commercial entities, and only extending to private consumers from 2029, but at the time of writing details could still change. One thing is for certain, the emission reduction target in these sectors is about 43% reduction of emissions compared to 2005 levels by 2030 on EU27 level.

## 6.2 Context in the Czech Republic

**Slowly declining emissions**

After the fall of the "iron curtain" and the democratisation of the former eastern bloc heavy industry, which formerly accounted for a significant part of the economy, went through a sizeable decline, which resulted in a drastic reduction in emissions. Although this trend had a heavy toll on the Czech economy as well, but the country's industry still accounts for a large share of the economy, around 30% (Jensen, 2021).

The decline in emissions have slowed down so much in the last decade or so that by 2019 Czechia became the Member State with the third highest emissions per capita. The country's emissions account for 3.5% of the EU total, which does not seem much but is slightly more than the country's population share, which stands at 2.4% of EU total. Since 2005 emissions have declined 19% in the EU, but slightly less, 13%, in Czechia (Jensen, 2021).

The energy industry accounts for the largest part of total GHG emissions in Czechia. While in 2005 power generation were responsible for 42% of total emissions, emissions from the sector fell by almost 20%, leading to a 36% share (of total) by 2019. Power generation's high share of emissions is explained by the role of coal and lignite in electricity and heating production. Fossil fuels account for around 50% of electricity production and around 60% of heat production. There are also some significant industries, which have increased their emissions over the period, like industrial processes and product use, which increased by 10% (Jensen, 2021).

There are certain industries which succeeded in reducing their emissions, mainly manufacturing and construction which achieved a 45% reduction from 2005 to 2019 and now only accounts for 7.8% share of the total (Jensen, 2021). Also, at the end of 2020 the Czech Coal Commission, the country's national commission on the future of coal, recommended phasing out coal and lignite by 2038, which with the right substitute could significantly decrease emissions (Hernández-Morales, 2020).

Importantly, the current ETS scheme covers power generation and a high share of energy intensive industries since its introduction in 2005 in the Czech Republic as well. But given the previously observed overallocation of free permits and the resulting low ETS prices the actual achievements of the system might be below previous expectations, hence the need for a stronger, tighter cap regulation.

**NECP outlook**

In accordance with Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, Czechia submitted its National Energy and Climate Plan (NECP) in November 2019. This NECP contains the main targets and policies in all five dimensions of the Energy Union for the period 2021–2030 including an outlook to 2050. This report is not going to discuss the country's planned policies in all five of those dimensions, only the ones that are necessary for understanding the topic at hand.

The main target outlined in any NECP concerns a reduction in greenhouse gas emissions. In the case of Czechia said reduction goal has been drawn at 30% by 2030 compared to 2005 levels, which in absolute terms would translate to a reduction of emissions of 44 million tonnes CO2 eq. Consequently, projections estimate that with the policies outlined in this plan the country can achieve, a 34 % reduction in greenhouse gas emissions (compared to 2005).

Another goal outlined in the NECP is a renewable energy target, more specifically it targets the share of energy from renewable sources in gross final consumption of energy. The Czech plan proposes a target of 22% which is significantly below the EU wide target of 32%. Accordingly, the Commission assessed the country's target as "unambitious".

The NECP also articulates targets when it comes to energy efficiency. These targets can be split into three categories for the period 2021-2030, namely: (i) an indicative target for the size of primary energy sources, final consumption and energy intensity; (ii) a binding energy savings target for public sector buildings; (iii) a binding year-on-year rate of final consumption saving. Czechia considers the first category as being of elevated importance and the country's targets are: to reach primary energy sources at the level of 41.43 Mtoe, final consumption at the level of 23.65 Mtoe and energy intensity of GDP at the level of 0.157 MJ/CZK in 2030.

Last, but not least energy security deserves some attention, given that it is a topic emphasized in the Czech Republic's NECP. The country's main targets are (i) moving towards increasing the diversification of its energy mix, (ii) maintaining self-sufficiency in electricity supply and (iii) ensuring sufficient development of energy infrastructure and no significant increase in import dependency.

**Figure 6.1 Real consumption impact (%) compared to BAU consumption per decile, exogenous price scenarios, 2040**

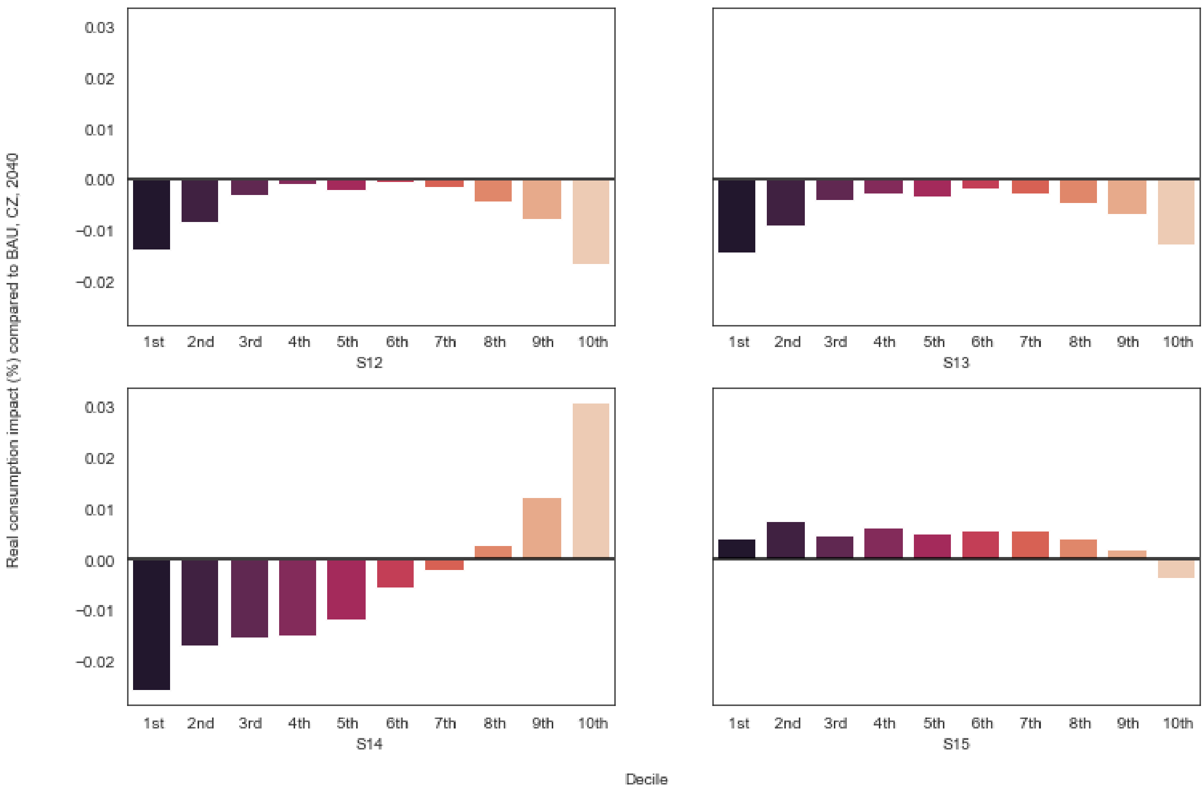
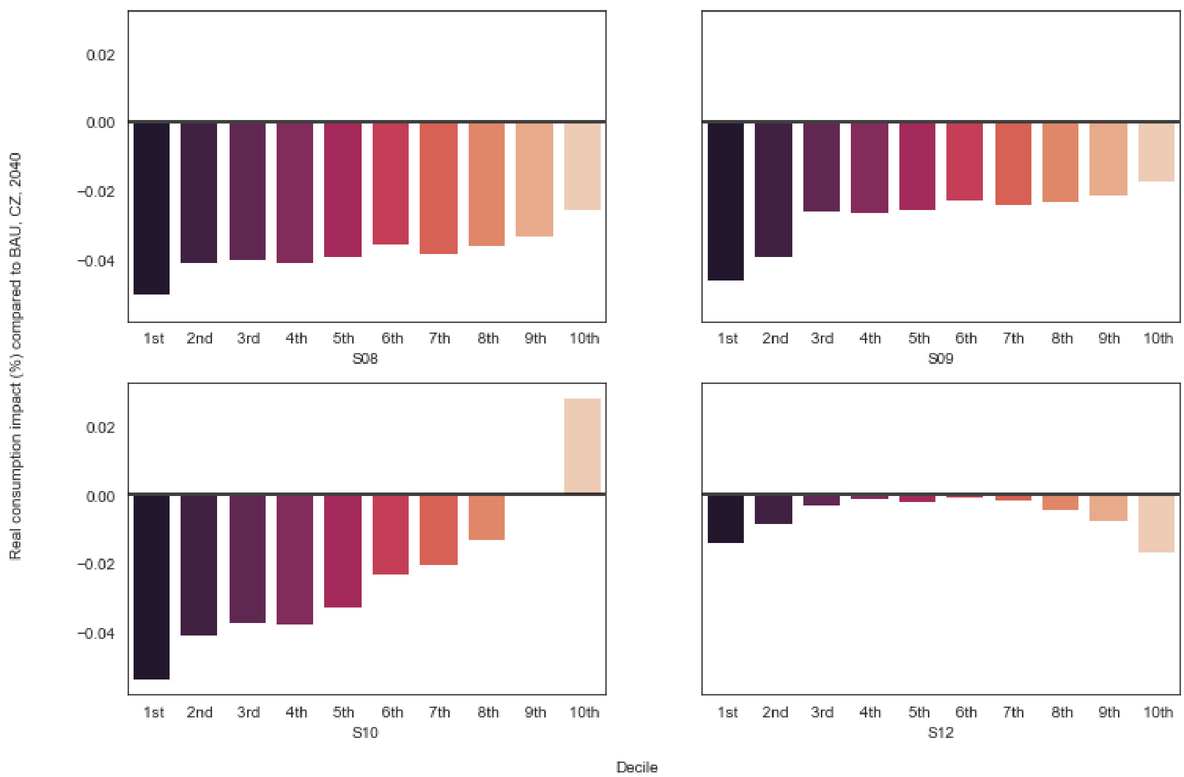



**Figure 6.2 Real consumption impact (%) compared to BAU consumption per decile, endogenous price scenarios, 2040**



# 7 Appendix B: E3ME and FTT model description

## Overview

E3ME is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes. The global version of E3ME provides:

- better geographical coverage
- better feedbacks between individual European countries and other world economies
- better treatment of international trade with bilateral trade between regions
- new technology diffusion sub-modules

This model description provides a short summary of the E3ME model. For further details, please read the full model manual available online from www.e3me.com.

## Applications of E3ME

**Scenario-based analysis**

Although E3ME can be used for forecasting, the model is more commonly used for evaluating the impacts of an input shock through a scenario-based analysis. The shock may be either a change in policy, a change in economic assumptions or another change to a model variable. The analysis can be either forward looking (ex-ante) or evaluating previous developments in an ex-post manner. Scenarios may be used either to assess policy, or to assess sensitivities to key inputs (e.g. international energy prices).

For ex-ante analysis a baseline forecast up to 2050 is required; E3ME is usually calibrated to match a set of projections that are published by the European Commission and the International Energy Agency but alternative projections may be used. The scenarios represent alternative versions of the future based on a different set of inputs. By comparing the outcomes to the baseline (usually in percentage terms), the effects of the change in inputs can be determined.

**Price or tax scenarios**

Model-based scenario analyses often focus on changes in price because this is easy to quantify and represent in the model structure. Examples include:

- changes in tax rates including direct, indirect, border, energy and environment taxes
- changes in international energy prices

**Regulatory impacts**

All of the price changes above can be represented in E3ME's framework reasonably well, given the level of disaggregation available. However, it is also possible to assess the effects of regulation, albeit with an assumption about effectiveness and cost. For example, an increase in vehicle fuel-efficiency standards could be assessed in the model with an assumption about how efficient vehicles become, and the cost of these measures. This would be entered into the model as a higher price for cars and a reduction in fuel consumption (all other things being equal). E3ME could then be used to determine:

- secondary effects, for example on fuel suppliers
- rebound effects[7]
- overall macroeconomic impacts

## Comparison with CGE models and econometric specification

E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, underlying this there are important theoretical differences between the modelling approaches.

In a typical CGE framework, optimal behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from a post-Keynesian framework and it is possible to have spare capacity. The model is more demand-driven and it is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3ME regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2020) and rebound effects[8], which are included as standard in the model's results.

**Key strengths of E3ME**

In summary the key strengths of E3ME are:

- the close integration of the economy, energy systems and the environment, with two-way linkages between each component
- the detailed sectoral disaggregation in the model's classifications, allowing for the analysis of similarly detailed scenarios
- its global coverage, while still allowing for analysis at the national level for large economies

[7] In the example, the higher fuel efficiency effectively reduces the cost of motoring. In the long-run this is likely to lead to an increase in demand, meaning some of the initial savings are lost. Barker et al (2009) demonstrate that this can be as high as 50% of the original reduction.
[8] Where an initial increase in efficiency reduces demand, but this is negated in the long run as greater efficiency lowers the relative cost and increases consumption. See Barker et al (2009).

- the econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to CGE models
- the econometric specification of the model, making it suitable for short and medium-term assessment, as well as longer-term trends

**Limitations of the approach**

As with all modelling approaches, E3ME is a simplification of reality and is based on a series of assumptions. Compared to other macroeconomic modelling approaches, the assumptions are relatively non-restrictive as most relationships are determined by the historical data in the model database. This does, however, present its own limitations, for which the model user must be aware:

- The quality of the data used in the modelling is very important. Substantial resources are put into maintaining the E3ME database and filling out gaps in the data. However, particularly in developing countries, there is some uncertainty in results due to the data used.
- Econometric approaches are also sometimes criticised for using the past to explain future trends. In cases where there is large-scale policy change, the 'Lucas Critique' that suggests behaviour might change is also applicable. There is no solution to this argument using any modelling approach (as no one can predict the future) but we must always be aware of the uncertainty in the model results.

The other main limitation to the E3ME approach relates to the dimensions of the model. In general, it is very difficult to go into a level of detail beyond that offered by the model classifications. This means that sub-national analysis is difficult[9] and sub-sectoral analysis is also difficult. Similarly, although usually less relevant, attempting to assess impacts on a monthly or quarterly basis would not be possible.

## E3ME basic structure and data

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970-2017 and the model projects forward annually to 2100. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other

[9] If relevant, it may be possible to apply our E3-India or E3-US (currently under development) models to give state-level analysis.

sources where appropriate. For regions outside Europe, additional sources for data include the UN, OECD, World Bank, IMF, ILO and national statistics. Gaps in the data are estimated using customised software algorithms.

**The main dimensions of the model**

The main dimensions of E3ME are:

- 70 countries – all major world economies, the EU28 and candidate countries plus other countries' economies grouped
- 44 or 70 (Europe) industry sectors, based on standard international classifications
- 28 or 43 (Europe) categories of household expenditure
- 23 different users of 12 different fuel types
- 14 types of air-borne emission (where data are available) including the 6 GHG's monitored under the Kyoto Protocol

The countries and sectors covered by the model are listed at the end of this document.

**Standard outputs from the model**

As a general model of the economy, based on the full structure of the national accounts, E3ME is capable of producing a broad range of economic indicators. In addition there is range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)
- sectoral output and GVA, prices, trade and competitiveness effects
- international trade by sector, origin and destination
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices
- $CO_2$ emissions by sector and by fuel
- other air-borne emissions
- material demands

This list is by no means exhaustive and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2100.

## E3ME as an E3 model

**The E3 interactions**

**Chyba! Nenalezen zdroj odkazů.** shows how the three components (modules) of the model - energy, environment and economy - fit together. Each component is shown in its own box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For each region's economy the exogenous factors are economic policies (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of the energy industries). For the environment component, exogenous factors include policies such as reduction in SO2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides measures of emissions of the main air pollutants to the environment module, which in turn can give measures of damage to health and buildings. The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

**Treatment of international trade**

An important part of the modelling concerns international trade. E3ME solves for detailed bilateral trade between regions (similar to a two-tier Armington model). Trade is modelled in three stages:

- econometric estimation of regions' sectoral import demand
- econometric estimation of regions' bilateral imports from each partner
- forming exports from other regions' import demands

Trade volumes are determined by a combination of economic activity indicators, relative prices and technology.

**The labour market**

Treatment of the labour market is an area that distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment, average working hours, wage rates and participation rates. The first three of these are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age band.

The labour force is determined by multiplying labour market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labour force and employment. This is typically a key variable of interest for policy makers.

**The role of technology**

Technological progress plays an important role in the E3ME model, affecting all three E's: economy, energy and environment. The model's endogenous technical progress indicators (TPIs), a function of R&D and gross investment, appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in the E3ME's energy and material demand equations to capture energy/resource savings technologies as well as pollution abatement equipment. In addition, E3ME also captures low carbon technologies in the power sector through the FTT power sector model.[10]

**FTT: Power Overview**

The power sector in E3ME is represented using a novel framework for the dynamic selection and diffusion of innovations, initially developed by J.-F. Mercure (Mercure, 2012), called FTT:Power (Future Technology Transformations for the Power sector). This is the first member of the FTT family of technology diffusion models. It uses a decision-making core for investors wanting to build new electrical capacity, facing several options. The resulting diffusion of competing technologies is constrained by a global database of renewable and non-renewable resources (Mercure & Salas, 2012, 2013). The decision-making core takes place by pairwise levelized cost (LCOE) comparisons, conceptually equivalent to a binary logit model, parameterised by measured technology cost distributions. Costs include reductions originating from learning curves, as well as increasing marginal costs of renewable natural resources (for renewable technologies) using cost-supply curves. The diffusion of technology follows a set of coupled non-linear differential equations, sometimes called 'Lotka-Volterra' or 'replicator dynamics', which represent the better ability of larger or well-established industries to capture the market, and the life expectancy of technologies. Due to learning-by-doing and increasing returns to adoption, it results in path-dependent technology scenarios that arise from electricity sector policies.

**FTT: Transport - the transport sector submodel of E3ME**

For passenger car transport, which accounts for by far the largest share of transport emissions, FTT:Transport provides a range of policy options. FTT:Transport assesses the types of vehicles that are purchased in three size bands (small, medium and large) and several technology classes (including basic and advanced forms of ICE, hybrid and electric cars). The policy options cover ways of differentiating costs between the different vehicles (either in terms of capital costs through variable taxation or fuel/running costs) or regulations on the sales of certain types of vehicles (e.g. phasing out inefficient old cars).

Biofuel mandates can also be imposed. These are modelled as a means of forcing a switch from consumption of motor spirit to consumption of biomass.

E3ME does not include any means for assessing mode switching, however, if the effects of mode switching can be estimated off-model, then the model could then estimate the indirect effects on the wider economy.

**FTT: Heat - the heating sector submodel of E3ME**

FTT:Heat is a new tool that was developed for European Commission work in 2016/17. Rather than assuming that the energy efficiency happens (e.g. due to public mandate), it provides a range of policy options for heating appliances (e.g. boilers, heat pumps) including subsidies, specific taxes or phase-out of old products. It thus assesses the take-up rates of the different technologies around the world.

The basic philosophy of FTT:Heat is similar to the other FTT models. Technologies diffuse according to how well they are established in the market, which is based on price differentials and other policy stimuli.

[10] See Mercure (2012).