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TRANSRISK MITIGATION "MEMO TOOLBOX" INSTRUCTION MANUAL

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1. Toolbox outline

The toolbox for mitigation policy pathways is a web application which allows non-experts to conduct simulations of various policies using the macroeconomic MEMO (MacroEconomic Mitigations Options) model. MEMO, developed at the Institute for Structural Research, is a large-scale Dynamic Stochastic General Equilibrium (DSGE) model. It has been successfully used to analyse the macroeconomic implications of various policies relating to climate change, energy sector, taxes, resource use, etc. within several national and international studies.

Operating such a model presents a significant barrier of entry for non-experts, as it usually requires advanced programming and technical skills. The toolbox enables policy makers and analysts, who are not experts in quantitative economics, to run macroeconomic simulations. We are convinced that, when the process is automated, successfully conducting and interpreting results of macroeconomic simulations can be carried out by policy makers. It is enough to become familiar with the general principles governing the model, its basic structure and the interpretation and format of the input data to be simulated. These elements are provided in a concise form in this tutorial.

The toolbox incorporates three country-level MEMO models calibrated for Chile, Greece and Poland. It contains several predefined simulation types, requiring the end-user to provide only input data. The simulation types are:

- Environmental taxes
- Direct expansion plans and investments in the energy sector, investments and mitigation actions in remaining sectors and the household
- Sequencing simulations linking investments in the energy sector with environmental taxes
- Optimisation simulations

The main features of the MEMO model are:

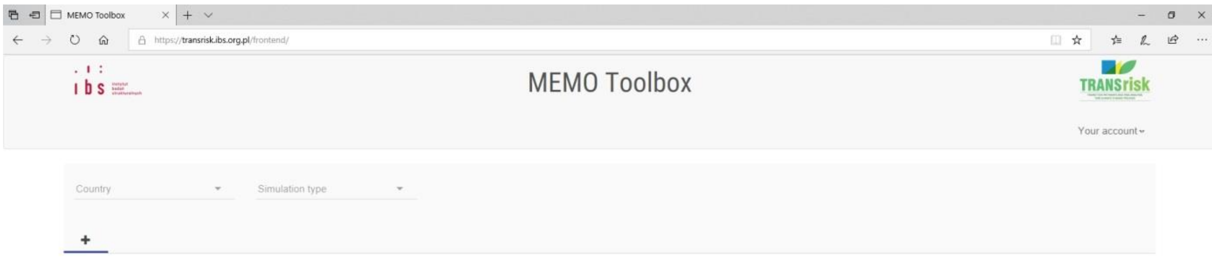
- Production structure, including labour, capital energy and materials (intermediate use) as factors of production (according to KLEMS approach)
- A multisector production structure calibrated directly to input/ output (IO) matrices, endogenous technological choice, various frictions, an elaborate labour market using the search mechanism
- Open economy, government sector and accounts for greenhouse gas emissions

These elements of the model allow it to realistically simulate the effect of various interventions related to climate change mitigation on a range of macroeconomic indicators such as gross domestic product, value added, employment, unemployment, wages, exports, imports, tax revenue and others on an aggregate and sector level. This report is divided into several sections. In the first, we provide a description of the application and the graphical user interface, whereas the second section provides examples on how the simulations can be used in practice. The final section provides a semi-technical outline of the model with basic equations, general structure, calibration and simulation procedure.

2. Application outline

The application is available online at the webpage https://transrisk.ibs.org.pl/. After registering and signing in with a login and password, the user is taken to the main menu of the application, which is shown in Figure 1. In the top right corner of the application is the "*Your account*" menu. Under this menu the users have the option to change their password, manage their profile, open the tutorial for the application and sign out. In the "*profile*" submenu it is possible to change the language of the application. The starting language is by default English, but the user has also the option to switch to Polish or Spanish.

Figure 1. Main menu of the application

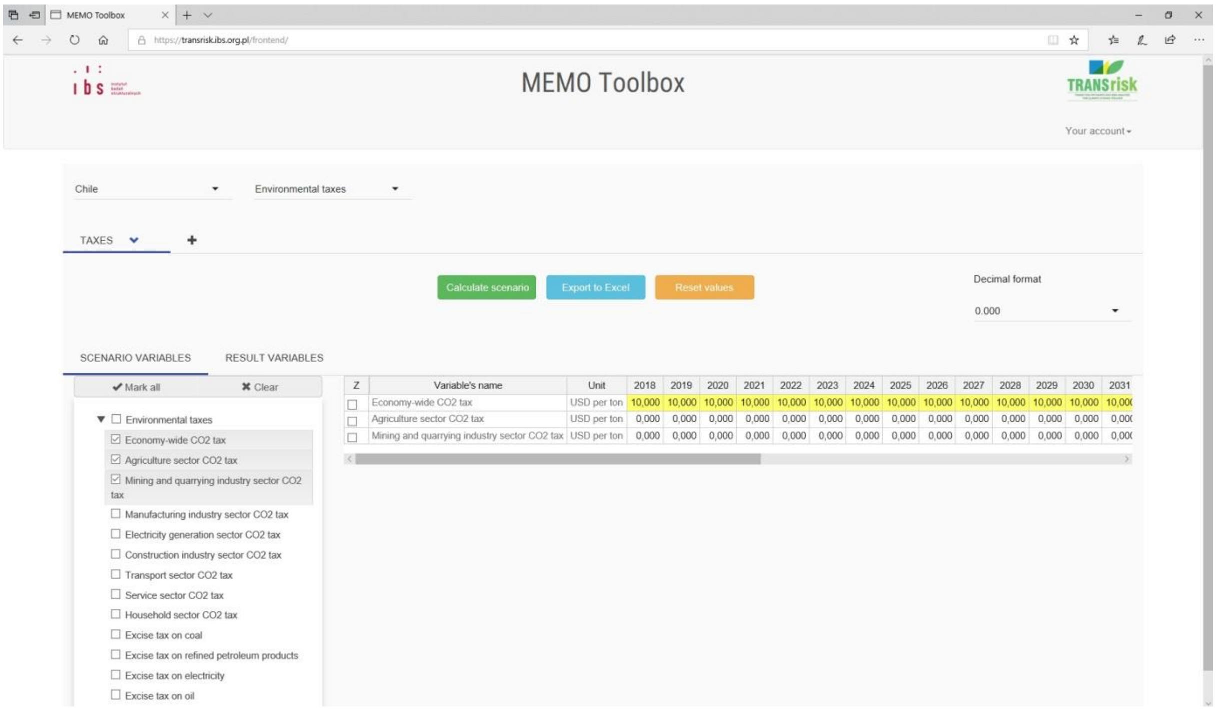


Running simulations is managed through the "*Country*" and "*Simulation type*" menus. In order to run a simulation, the user must select one of the three country models and one of the four simulation types. After this selection has been made the user must click the "+" icon and a popup window will appear where the user can create a scenario for the country-simulation combination and give it a name, e.g. "*CHILE TAX*". After introducing data and running simulations, the data will be stored in the scenario, allowing the user to load it for work during subsequent sessions.

Upon opening a scenario two tabs appear with "*Scenario variables*" and "*Result variables*", along with the main table located in the centre for setting input data for the years 2018-2050, as can be seen in Figure 2. The first of these tabs holds the variables defining the interventions (scenarios) that can be simulated. The user can then select a subset of these and, after they appear in the main table, she can input data for them manually or copy them from a spreadsheet. If the data has been incorrectly inputted, the user can reset the data to the default zero values by clicking "*Reset values*". Conducting simulations is done by clicking the "*Calculate scenario*" button. The user is then automatically moved to the second tab, which shows the result of the simulation. These variables are divided into the following groups:

- Main macroeconomic variables
- Environmental variables
- Gross domestic product in sectors
- Employment in sectors
- Wages in sectors
- Investment in sectors
- Capital stock in sectors
- CO_2 emissions in sectors
- Environmental taxes

Figure 2. Inputting intervention (scenario) data



When analysing the result of a simulation one must keep in mind that MEMO is a macroeconomic model, in which the energy sector is not modelled in such detail as in bottom up energy system models. The main aim of the model is to shed light on possible developments in the general economy. Therefore the results for the environmental variables, such as energy use from intermittent and non-intermittent sources and materials use, should be interpreted as a rough estimate. The environmental taxes result variables should be analysed when one is running the optimisation simulations, in order to check the resulting tax rate. In case of running environmental tax simulations, the result will simply be the tax rates that were provided as input.

In order to view the result of a particular group of variables, or a particular variable, the user must select a folder (or expand it) and select single variables. The results appear as time series in the main table, with variables affected highlighted in yellow. The user can now select variables from the main table and draw a graph for them by right-clicking in the main table and selecting "*Draw graph*". Results can also be exported to a spreadsheet through the use of the "*Export to Excel*" button. The application only supports basic graph drawing and we recommend conducting an in-depth analysis of the results in a separate spreadsheet program.

The simulations are conducted using a Kalman filter numerical procedure which provides the values of shock variables corresponding to the intervention variables. All results are shown as percent deviations from the steady state of the model. The steady state of the model should be interpreted as the business as usual (non-intervention) scenario for the main macroeconomic variables such as GDP, employment etc. up to the year 2050. The set of result variables for the Environmental taxes, CAPEX OPEX simulations and sequencing simulations is the same. Results for the optimisation simulations are shown in a different format. Due to the fact that the model is solved using a linear approximation around the steady state, the deviations from the steady state should not be excessively large for the results to be feasible. As a rule of thumb, we encourage to use and interpret results for which this deviation is not larger than 50% for any variable.

Figure 3. Sample simulation results

3. Simulations

In this section we describe the predefined simulation types that the user can run using the toolbox. The simulations are divided into the following four groups:

1. Environmental tax simulations
2. Capital expenditure (CAPEX) and operational expenditure (OPEX) simulations
3. Sequential simulations
4. Optimisation simulations

3.1 Tax simulations

This group encompasses the simplest and most straightforward types of simulations: environmental taxes and subsidies. The taxes that the application supports are:

- CO_2 emissions tax. The user can set an economy-wide CO_2 tax, or can chose to place a tax on one of the following groups of sectors: Agriculture, Mining and Quarrying, Manufacturing Industry, Electricity Generation, Construction Industry, Transport and Service sector. The rate for the tax rates is USD per ton of CO_2 emissions[1] and the application calculates these tax rates into model units automatically.
- Excise tax on the sale of coal, crude oil, gas, refined petroleum products and electricity. The rate of the tax is defined as USD per relevant quantity of given product.

[1] Only CO_2 emissions, not CO_2-equivalent emissions.

- Subsidy for the use of renewable energy sources. The rate of this subsidy is given as a percentage of the price.

The user may choose to simulate any number of taxes and subsidies simultaneously. When doing so, it is important to remember that the CO_2 tax rates are additive. For example, setting the economy-wide CO_2 tax to 10 USD per ton and the Transport sector CO_2 tax to 10 USD per ton will result in a simulation, where the Transport sector is taxed at 20 USD per ton, and remaining sectors are taxed at the rate of 10 USD per ton. In the model we assume that the tax revenue is transferred to the household, and that the subsidy is financed by a reduction in transfers to the household (or equivalently in the form of a lump sum tax).

3.2 CAPEX and OPEX simulations

This simulation type assesses the macroeconomic consequences of interventions in the energy sector, other sectors of the economy and the household. Example simulations for the energy sector can include interventions such as a large scale investment in renewables or the phase-out of fossil fuels. Possible simulations for remaining sectors are electrifying the transport system or investment in more energy efficient means of production in the manufacturing sector. Regarding the household, it is possible to simulate the effects of a thermal insulation of buildings project. The input data differs between the energy sector simulations and remaining ones. The input data needed for the energy sector simulation is the following:

- Investment for new scenario relative to business as usual scenario in millions of the given currency
- Percent change in the energy price relative to the business as usual scenario
- Change in the expenditure on coal consumption relative to the business as usual scenario in millions of given currency
- Change in the expenditure on oil and gas use relative to the business as usual scenario in millions of given currency

The input data for this simulation should ideally come from a bottom-up energy system model which calculates the necessary investment and changes in fuel consumption for various scenarios for the energy system. In order to compare the differences in the macroeconomic effects of various energy system scenarios, one should define a baseline (e.g. business as usual scenario involving continued fossil fuel use) and the alternative scenario (e.g. switch to renewable energy sources). The input data should then be calculated as differences between an alternative scenario and the baseline.

The simulations for remaining sector and household interventions require the user to provide data on the required investment and the resulting change in the use of materials, disaggregated between all the sectors of the economy. For each sector, there is a total of 15 time series for the user to provide data for, however typical simulations will involve inputting data for only a small subset. For example, if one is interested in assessing the effects of a thermal insulation program for the household, it is enough to provide data on the amount of required investment and the change in the use of coal, gas, oil and electricity. Likewise, if the mitigation action involves investment in electric vehicles or more fuel-efficient vehicles, then the user should provide the change in the use of refined petroleum products and electricity, and the required investment.

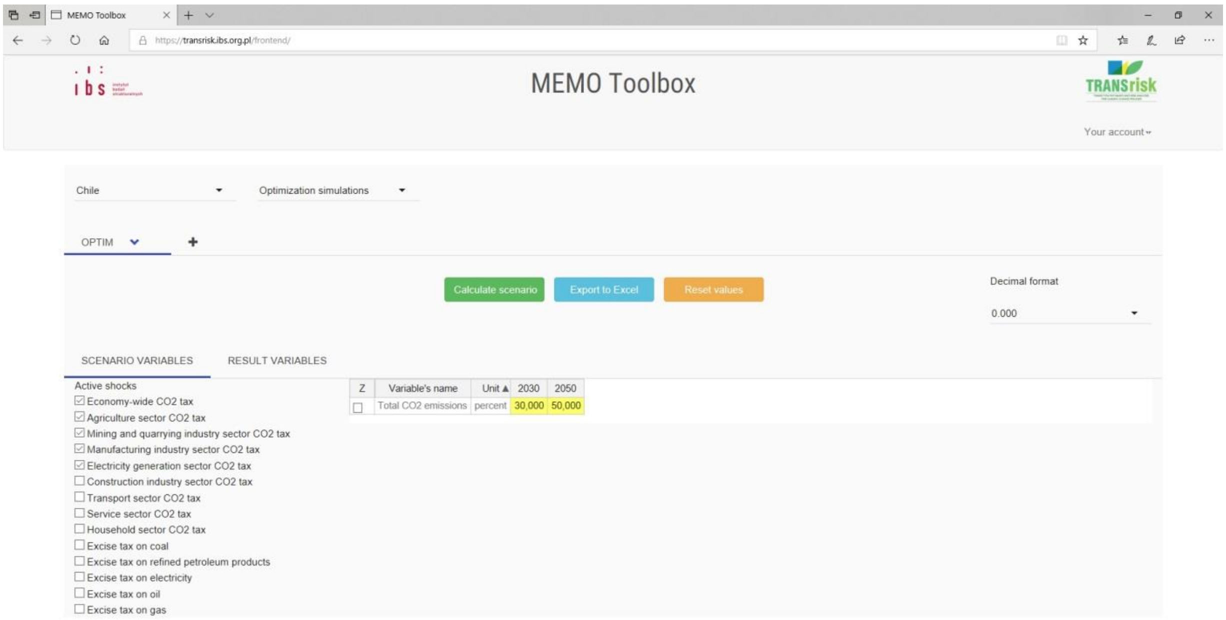
3.3 Sequencing simulations

The structure of the sequencing simulations are similar to the CAPEX and OPEX simulations for the energy sector, however the underlying economic question answered is different. In these simulations, the policy maker is interested in the interrelation between a fixed investment plan for the energy sector and a carbon tax on the entire economy, which is placed after the investment plan has been set in motion. In this simulation the user inputs the same data as for the CAPEX OPEX simulation and additionally defines a target drop in CO_2 emissions. The additional carbon tax necessary to bring CO_2 emissions to the desired level is calculated endogenously as part of the simulation.

3.4 Optimisation simulations

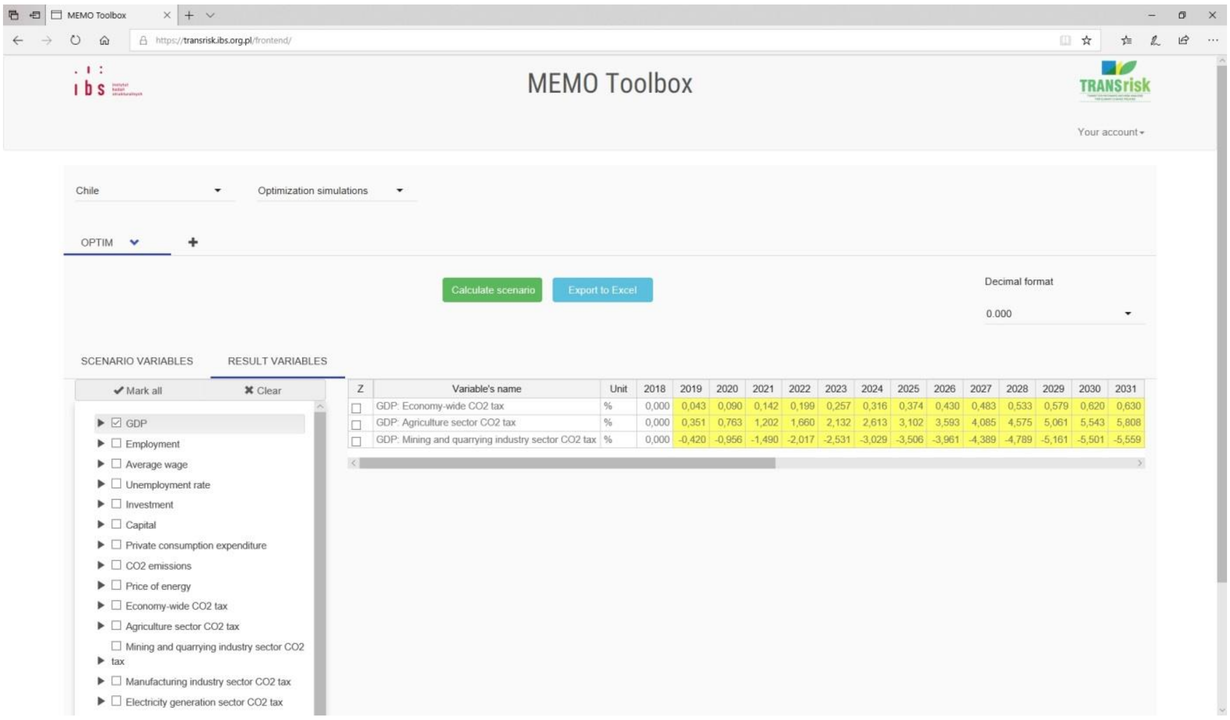
These simulations allow for the study of the optimal level and type of taxation of the economy. In this simulation the user selects several environmental taxes that they wish to examine, and define a desired drop in CO_2 emissions for the years 2030 and 2050 (note that the drop should be set as a negative number). The application then separately calculates the necessary rates for each of the taxes necessary to achieve the drop in CO_2, as shown in Figure 4.

Figure 4. Setting optimization simulations



The user can then compare the results of each tax on selected main macroeconomic variables and learn which of these has the smallest negative impact, as shown in Figure 5. For the sample simulation shown here, the economy wide CO_2 tax has the smallest negative impact on GDP. By selecting other variables it is possible to see which is the optimal tax with respect to setting that variable as the target we wish to optimise.

Figure 5. Analysing the result of optimization simulations



4. Sample simulations

In this subsection we show in detail how a sample CAPEX and OPEX simulation for the energy system was prepared for Poland as part of the TRANSrisk project. We first discuss how the input data was prepared using a bottom up energy system model, how this model is soft-linked to the MEMO model and then we briefly analyse the results.

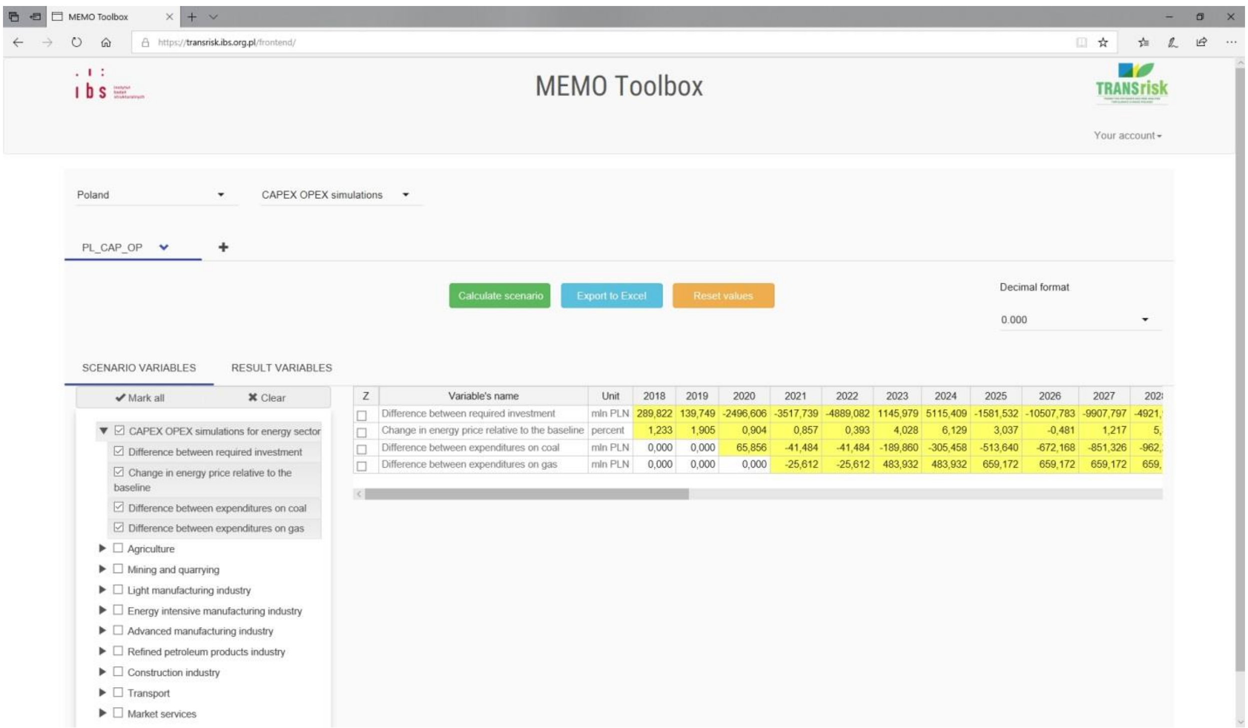
The input data for developments in the electricity generation sector is prepared using the Model of Optimal Energy Mix for Poland (MOEM), which was developed by the Department of Strategic Analysis within The Chancellery of the Prime Minister. The MOEM model is a central planner least cost linear optimisation model. It takes the current energy system and provides an investment plan into new power plants and the generation structure for the time horizon up to the year 2060 that satisfies the projected path of electricity demand. The model takes into account the entire cost structure, namely that of installing new capacity, fuel, maintenance, EU ETS prices and other operational costs and a range of additional exogenous constraints such as maximum allowed emissions or minimum installed renewable energy source capacity.

Using this model we create two possible scenarios for the electricity generation system. We feed the input data into the model: electricity demand, assumptions regarding costs of technologies from 2017 Annual Technological Baseline by the National Renewable Energy Laboratory, EU ETS price increasing up to 80 USD per ton in the year 2050. For the first scenario, which we will refer to as the baseline scenario we assume no additional constraints on the energy mix. For the second scenario, which we will refer to as the decarbonisation scenario we assume an additional constraint that CO_2 emissions must be reduced by 60% relative to the 2018 level. The output of the MOEM model is the path of capital expenditure that the least cost energy system requires in each of the scenarios, the change in the expenditure on resources and the change in the cost of generating electricity. This is shown in Figure 6.

Figure 6. Capital expenditure (CAPEX) and operational expenditure (OPEX) required by the energy system in the baseline and decarbonisation scenarios

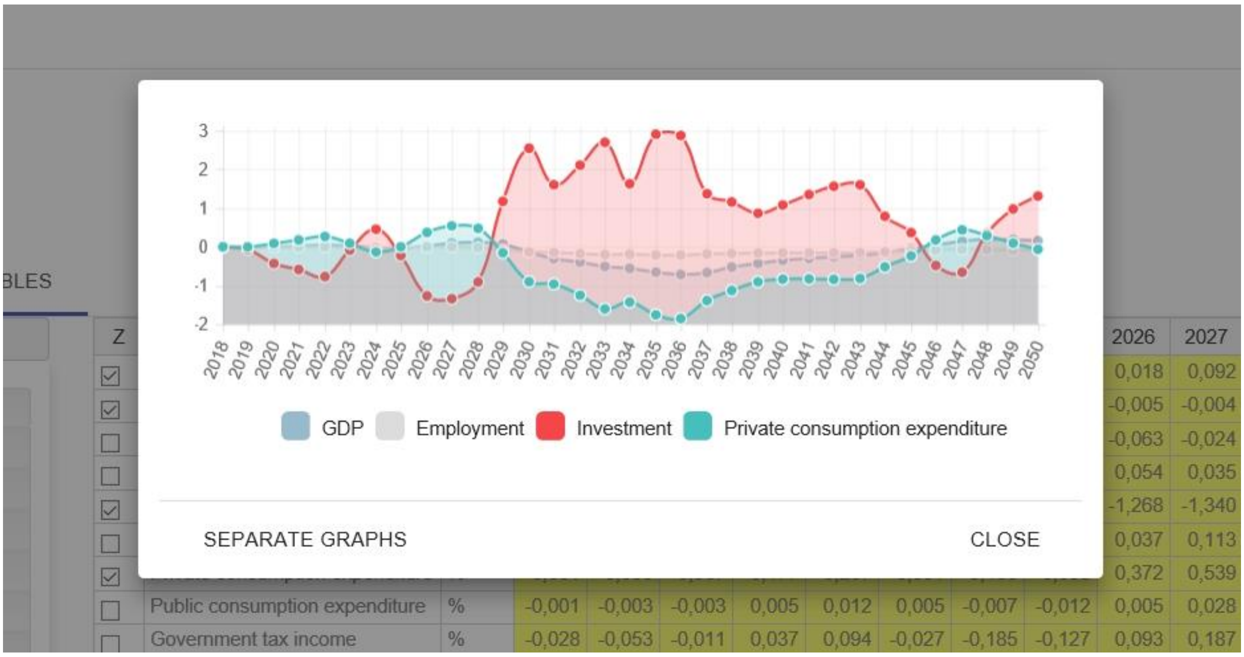
The input data for the MEMO model is calculated as the difference between the scenario pathways for capital, gas and coal and prices. In order to account for the difference in remaining costs between scenarios, we calculate the percent difference in total yearly costs for the two scenarios. These four time series are then used as input for the MEMO model, as can be seen in Figure 7.

Figure 7. Inputting data for the CAPEX OPEX simulation for Poland



The monetary values that the user provides are translated into shares of GDP using the baseline for this value which is encoded in the application. Now it is enough to click the "Calculate scenario" button in order to run the simulation and analyse the results. One can then select main macroeconomic variables and analyse the impact upon them. The main stand out result is the increase in total investment in the economy, which is due to the increased investment in the energy sector. However, this increase crowds out investment in other sectors of the economy; this contributes to a slight fall in GDP and employment, and a much larger decrease of private consumption. These results are shown in Figure 8.

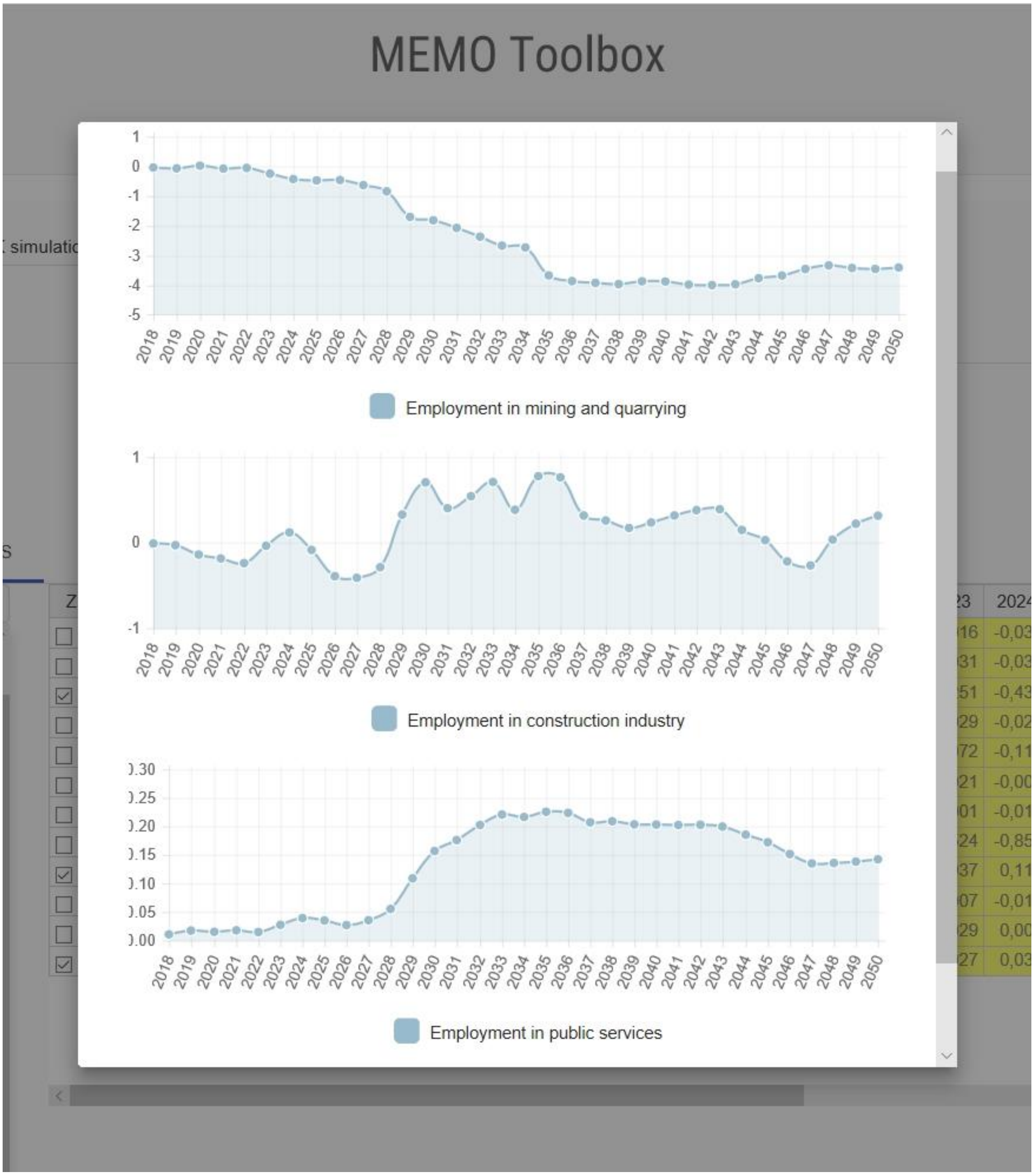
Figure 8. Analysing the results for main macroeconomic variables for CAPEX OPEX simulation for Poland



It is also informative to study the sector developments that result from the intervention, in particular for employment. These results for selected sectors are shown in Figure 10. First of all, employment in the mining and quarrying sector is significantly reduced. When interpreting this and other results, it is important to keep in mind that this is an additional change in employment with respect to the business as usual scenario in which this intervention does not take place. While we do not specify a BAU scenario for Poland, all projections for employment in the mining sector in Poland show a decrease, and the change simulated by the model is an additional decrease. This is a direct result of the fact that the electricity sector intervention is linked to a decrease in the use of coal, much of which is produced domestically in Poland. The second picture shows the results for employment in the construction sector, which increased by approximately 1 percent. A close inspection of the IO matrix for Poland (or for any other country for that matter) would shed light on the reason for such developments.

Construction sector output is one of the main elements of the aggregate investment good, and the electricity sector intervention is linked to an increase in demand for capital. The final picture shows the result for the public services sector. This sector is not affected directly and most of the product is purchased by the government which operates a rather stable fiscal rule. Employment in the public sector is only affected slightly through the general equilibrium effect due to the intermediate use structure. Altogether, the impact on employment here is negligible.

Figure 9. Analysing the results for sector employment for CAPEX OPEX simulation for Poland

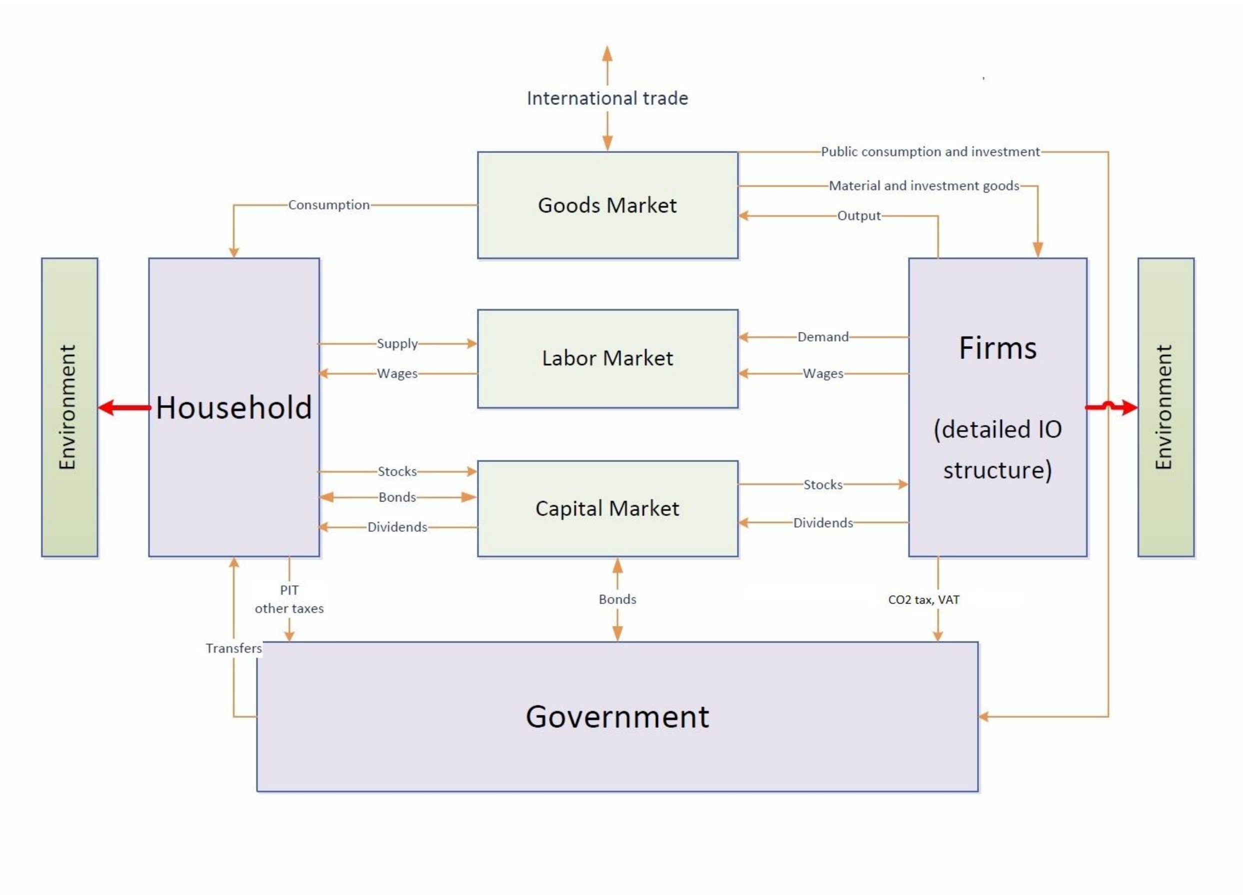


5. Model outline

In this section we discuss the basic structure and features of the MEMO model, concentrating on its aspects which are crucial for understanding and interpreting results of the simulations. The number of equations presented here is limited in order to not burden the reader with difficult technical matters. It is important to note that the three country models for Chile, Greece and Poland share the same mathematical structure of all equations, with the difference between the models stemming from different country-specific parameterisations.

Readers interested in a detailed technical description of the model are referred to the IBS research report by Antosiewicz and Kowal (2016), which is available online.

Figure 10. Main building blocks of the model and their connections



The main agents represented in the model are the household, firms (divided into sectors of the economy), government and the foreign sector (which represents the rest of the world from the point of view of a particular country). The decision rules of particular agents are based upon the optimisation of an 'intertemporal' utility or profit function: agents take into account not only the present state of the economy but also expectations about the future. The agents of the model interact with each other on markets, where relative prices are established and exchange is conducted. For example, the household offers labour to firms in exchange for wages on the labour market, whilst also purchasing consumption goods from firms on the goods market. The government collects several taxes from the household and firms, and uses its revenue to finance public consumption and transfers. The connections between model agents are shown in Figure 10.

5.1 Household

The household seeks to maximize utility from consumption, which is given by:

$$\max_{C_t} E_0 \sum_{t=0}^{\infty} \beta^t u(C_t),$$

Where β is the subjective discount factor, $u(C_t)$ is a concave utility function of consumption C_t, and E_0 denotes the expectations operator, which signifies that the household does not know the future but only makes decisions based on expectations about it. The household budget constraint consists of expenditures on the consumption good, taxes paid to the government at rate τ_X, investments in assets A_t and cost of searching for a job Ξ_t. The income side includes wage income $W_t N_t$, income from asset holdings A_{t-1} which generate income given by the rate r_t, dividends from firms Π_t and transfers from the government T_t. This is encapsulated in the budget constraint equation:

$$(1+\tau_{VAT})P_t^C C_t + A_t + \Xi_t = W_t N_t(1-\tau_W) + (1-\tau_D)\Pi_t + T_t + A_{t-1}(1+r_{t-1}).$$

In each period, the household decides how much effort its unemployed members spend on searching for a job, which is reflected in the monetary cost Ξ_t. Unemployed job seekers are matched with vacancies posted on the labour market and may become employed. The fraction of employed population is denoted by N_t. The details of the labour market are presented in the section devoted to the firm.

5.2 Firm

In the MEMO model firms are divided into 14 sectors denoted by the set S. For each sector $s \in S$ there is a representative firm which maximises its expected stream of profits discounted by the discount factor Λ_t:

$$\max E_0 \sum_{t=0}^{\infty} \Lambda_t \Pi_t^s ,$$

Each firm operates a multi-stage production function using as input capital, labour, energy and intermediate use materials from other sectors. In the first stage capital K_t^s and energy ENG_t^s is combined to produce the composite KE_t^s using a constant elasticity of substitution (CES) production function with share parameter $\theta_E^s$and elasticity parameter ϵ_E^s.

$$\mathrm{KE}_t^s = \left[(1-\theta_E^s)(K_t^s)^{\frac{\epsilon_E^s-1}{\epsilon_E^s}} + \theta_E^s(\mathrm{ENG}_t^s)^{\frac{\epsilon_E^s-1}{\epsilon_E^s}}\right]^{\frac{\epsilon_E^s}{\epsilon_E^s-1}}$$

In the second stage this composite is combined with labour N_t^s to arrive at the subsequent composite product KLE_t^s also using a CES function:

$$\mathrm{KLE}_t^s = \left[\theta_{KE}^s(\mathrm{KE}_t^s)^{\frac{\epsilon_{KE}^s-1}{\epsilon_{KE}^s}} + (1-\theta_{KE}^s)\,(N_t^s)^{\frac{\epsilon_{KE}^s-1}{\epsilon_{KE}^s}}\right]^{\frac{\epsilon_{KE}^s}{\epsilon_{KE}^s-1}}.$$

In the final stage it is linked with materials M_t^s to produce the final sector good Y_t^s:

$$Y_t^s = \left[(1-\theta_M^s)(\mathrm{KLE}_t^s)^{\frac{\epsilon_M^s-1}{\epsilon_M^s}} + \theta_M^s(M_t^s)^{\frac{\epsilon_M^s-1}{\epsilon_M^s}}\right]^{\frac{\epsilon_M^s}{\epsilon_M^s-1}}.$$

The materials input M_t^s for each sector s is composed of materials coming from all sectors except energy (which as described above is treated as a separate input).

$$M_t^s = f(M_t^{s,u}), u \in S$$

We model the material M_t^s input assuming substitution (through a CES function) between fuels $s \in S_F$ and remaining non-fuel materials $s \in S_{NF}$, and perfect complementarity between non-fuel materials (through a Leontief production function). We assume that the set of fuels in the model is the following: coal, oil, gas and refined petroleum products. Finally, we assume that each material input $M_t^{s,u}$ is a CES composite of domestically produced $M_t^{s,u,H}$ and imported $M_t^{s,u,F}$ input, thus taking into account foreign trade. The final product of each firm is divided according to the final use part of the IO matrix and sold to the (i) household and (ii) government for private and public consumption, (iii) to other firms as investment (iv) exported or (v), as materials to other sectors according to the intermediate use part of the IO matrix.

In order to secure the necessary capital and labour for the production process, firms make investment decisions and post job vacancies. Vacancies are matched with unemployed job seekers on the labour market according to the search and matching framework. The model is therefore particularly useful for studying the short and medium term effects of climate policies on the labour market.

CO_2 emissions are modelled at the firm and household levels, and are a function of the amount of fuel materials used. Parameters $\theta_{CO2}^{s,u}$ are used to calibrate the emissions in sectors to values observed in the data.

$$CO2_t^s = \sum_{u \in S_F} \theta_{CO2}^{s,u} M_t^{s,u} \ , s \in S \cup \{Household\}$$

5.3 Government

In the model we assume that the government collects three main taxes: personal income (wage) tax, value added tax and a dividend tax. Furthermore, it can levy various environmental taxes, such as a CO_2 tax and excise tax on fuels. The size of these taxes is set by the user during the simulations. We assume that the government spends revenue on the purchase of public consumption and on transfers. It is crucial to note that we assume a closure of the government budget through the transfer to the household. This contrasts to other possible uses of the tax revenue such as reducing labour taxation or introducing various green subsidies, which has been advocated by environmentalists and economists alike. The rationale behind this choice is that in the simulations we wish to show the macroeconomic distortionary effect caused by a single environmental tax only. Combining an environmental tax with another distortionary mechanism would impede the analysis of the tax alone. Furthermore, while in reality the green tax revenue might be spent on more productive goals, this would require a completely new study.

5.4 Calibration

In order to calibrate the model for each of the countries we use several data sources. The most important element of the models is the sector structure which is calibrated to an IO matrix which distinguishes domestic and imported intermediate use for each sector. Depending on the data source, a typical IO matrix contains data on flows for at least 40 sectors, while for numerical reasons a DSGE model can accommodate up to 20 sectors. Constructing the model therefore requires the aggregation of sectors which are not crucial from the point of view of the analysis, whilst distinguishing the ones which are important. In our analysis, private services can be aggregated into a single sector (with the exception of transport, which is carbon intensive) without harm to the environmental aspect of the model. On the other hand, the manufacturing industry sector should be disaggregated into those sections based on their carbon intensity, as this will give a more detailed view of the impact of interventions. Finally, since the model is mainly used for the analysis of the electricity production sector, we make a detailed disaggregation of it.

The way firms are divided into sectors is shown in Table 1. The structure of the model is based on Eurostat IO matrices according to the Statistical Classification of Economic Activities in the European Community NACE, Rev. 2 for Greece and Poland, whereas for the Chilean model we use IO matrices from the Structural Analysis Database. A basic symmetric structure of the model has been altered in two ways. First of all we assume that the Mining and Quarrying sector produces several distinct goods which are crucial from the point of view of climate policy: coal, oil gas and 'other'. Second, we assume that there are four distinct sectors responsible for the production of electricity: a) coal and lignite, b) remaining fossil fuels (mainly gas and oil), c) intermittent renewable energy (wind and pv) and d) non-intermittent renewable energy (mainly biomass and hydro). The disaggregation into these four sectors was conducted using data on the structure of installed capacity and electricity generation from International Energy Agency.

Data for sector employment, unemployment and government revenue with respect to different taxes was taken from the OECD database for all countries in order to ensure consistency. Sector CO_2 emissions were calibrated using data from International Energy Agency.

Table 1. Sector structure of the model

Sector name	NACE sections
Agriculture	A01-A03
Mining and quarrying (which produces following products: coal, oil, gas and other)	B05-B09 (coal: B05, oil: B061, gas: B062, other: B07-B09)
Light Manufacturing Industry	C10-C16
Energy Intensive Manufacturing Industry	C17,C18,C20, C22-C24
Advanced Manufacturing Industry	C21, C25-C33
Refined Petroleum Products Manufacturing Industry	C19
Coal Electricity Production	Subset of D35
Remaining Fossil Fuel Electricity Production	Subset of D35
Intermittent Renewable Electricity Production	Subset of D35
Nonintermittent Renewable Electricity Production	Subset of D35
Construction Industry	F41-F43
Transport	H49-H53
Market Services	E36-E39,G45-G47,I55-N82,R90-U99
Public Services	O84-Q88

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