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Abstract

We estimate the macroeconomic and distributional effects that a ban on fuel imports from Russia would have in Poland. We simulate the embargo as a hike in oil, gas and coal prices, and evaluate the macroeconomic effects with a dynamic general equilibrium model. We soft-link it with a microsimulation model based on Household Budget Survey data to assess the impacts on various income groups. We find that the effects of an embargo on Russian fuels would be substantial but manageable. Depending on the severity of the price hikes, we expect Poland's GDP to be lower by 0.2–3.3% by the end of 2022, and by 2.1–5.7% by 2025. Furthermore, depending on the price increases, high-income households would spend an additional 0.2–1.3% of their incomes on energy in 2022 and 0.7–1.6% in 2025, and low-income households would spend 0.3–4.7% more of their incomes on energy in 2022 and 2.6–4.8% in 2025. We suggest direct money transfers to less affluent households, and investments in alternative gas and oil supplies, energy efficiency, renewable energy and nuclear power as instruments that could ease the negative economic impacts of the embargo.

Keywords: embargo; distributional effects; microsimulation; general equilibrium

JEL: H23, P18, O15

[•] This paper uses data from Eurostat and Statistics Poland. Eurostat and Statistics Poland have no responsibility for the results and conclusions presented in this report, which are those of its authors. The usual disclaimers apply. All errors are ours.

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1. Introduction

Sanctioning purchases of Russian oil, gas and coal is likely to be the fastest and the most economically efficient way to impede Russia's invasion of Ukraine (Guriev and Itskhoki, 2022). However, such an embargo would also be costly for the European Union countries that import substantial amounts of fuels from Russia; Poland in particular. Assessing the total size and distribution of these costs is vital for EU countries to prepare economic and social policies that would alleviate the impact of such an embargo on domestic economies and societies. In this paper, we estimate the aggregate macroeconomic effects in Poland of a ban on fuel imports from Russia and assess the distributional effects of such an embargo on individual households.

First, we assess the dependence of the Polish economy on oil, gas and coal imports from Russia. We focus on the share of these imports in gross available energy (Eurostat, 2022), on how particular fuels are used in different sectors of the Polish economy (IEA, 2022a), and on the expenditures of households on oil, gas and coal by deciles of income (Statistics Poland, 2021). Importantly, we account for the fact that Poland decided to stop importing Russian coal at the end of March 2022, using coal import statistics from 2021 to calculate the effects this decision may have on future coal prices. We also take into account Russia's decision as of the end of April 2022 to cease all gas exports to Poland.

We apply a multi-sector, dynamic stochastic general equilibrium model to analyse the aggregate economic adjustment cost to the embargo, modelled as a price shock. The macroeconomic model is soft-linked with a microsimulation model that allows us to estimate the distributional impacts of the shock. We follow the methodology of Antosiewicz et al. (2022) who used these two soft-linked models to analyse the aggregate and distributional impacts that a carbon tax would have on the Polish economy. To model the effects of the embargo, we define shock prices following assumptions made in scenario analyses by Oxford Economics (2022) and the German Council of Economic Experts (Grimm et al., 2022).

There are four main findings in our study. First, we expect the aggregate economic effects in Poland to be substantial but manageable. We predict losses in GDP of around 0.2–3.3% at the end of 2022. Based on our results and OECD economic forecasts for Poland, the country's GDP would still grow by 1.9–5.0% in 2022, even if fuel prices were to rise sharply.

Second, it is worth noting that a majority of the negative economic effects (an average of more than 80% across all the scenarios) result from an increase in oil prices. Moreover, since Poland is no longer importing Russian gas and coal, we expect the impacts of these fuels to be more immediate. Nevertheless, their impacts on Poland's aggregate economic situation remain less pronounced than in the case of oil – if coal and gas prices were to increase sharply by the end of 2022 (by e.g. 50%), the Polish GDP would be reduced by only 0.18%.

Third, we find that the services sector is at the highest risk of negative economic impact. We expect a decrease in value added of 0.2–3.2% (and 2.3–5.9% in 2025) which would translate into a negative contribution to GDP of 0.1–1.4 pp in 2022 (or 1–2.6 pp in 2025). It should be acknowledged that services have a substantial economic capacity, high growth potential and capability to change and reorient to new economic conditions – therefore, these negative impacts are manageable as the services sector can be supported to avoid potential losses. This has been demonstrated during the COVID-19 pandemic in 2020/2021.

Finally, low-income households would be affected by fuel price hikes the most in relative terms, while high-income households would be most affected in nominal terms. These results reflect the structure of expenditures on oil, gas and coal among Polish households. Low-income households spend the highest share of their income on energy, while high-income households exhibit the highest nominal expenditure. If prices increase by around 10% by the end of 2022, the impact on households would amount to about 0.5% of their monthly incomes. If energy prices were to rise sharply, the impact would amount to approx. 1.5% (for the tenth decile) and 4.5% (for the first decile) reduction in disposable incomes after paying the energy and fuel bills.

Our study relates to previous evaluations of the effects of reducing energy imports from Russia, e.g. Bachmann et al. (2022), who used a multi-sector trade model of the German economy and estimated a reduction in GDP of 0.2–3.0%. Baqaee et al. (2022) quantified impacts for selected EU countries, e.g. Lithuania, Bulgaria, Slovakia, Finland or the Czech Republic, estimating GDP drops between 1–5%. Oxford Economics (2022), calculated a deduction of 1.2–2.2 % in the Euro Area GDP in 2022 compared to forecasts made before the war. Previous macroeconomic studies found that oil price increases were often not accompanied by economic contraction (Baumeister and Hamilton, 2019; Kilian, 2009). Consequently, researchers argue that short-run shortages of natural gas and coal supplies resulted in demand cutbacks (Fischer et al., 2022). Moreover, Holz et al. (2022) demonstrate that energy supply reductions would not have a substantial negative impact on energy security.

Our paper has important policy implications. In the short term, imports of Russian oil must be compensated with supplies from other countries. As the global market for crude oil is highly integrated, we expect alternative supplies to be compensated by intensified production in another country. In the medium term, increased use of renewable energy and energy efficiency improvements could contribute significantly towards lowering energy demand. Gas and coal consumption in the residential sector can be reduced by switching to renewable energy sources. In the long run, introducing nuclear energy in the electricity sector is a plannable option. The first nuclear power plant in Poland is planned to go into operation in 2033. From the point of view of energy infrastructure, substituting imports of Russian oil and coal should be less challenging in the short term than switching away from gas. Oil and coal can likely be shipped in from other countries or, in the case of coal, produced domestically. However, by the end of 2022, Poland should have sufficient capacity via LNG terminals and pipeline imports from other countries to substitute natural gas supply from Russia (Maćkowiak-Pandera and Gawlikowska-Fyk, 2022).

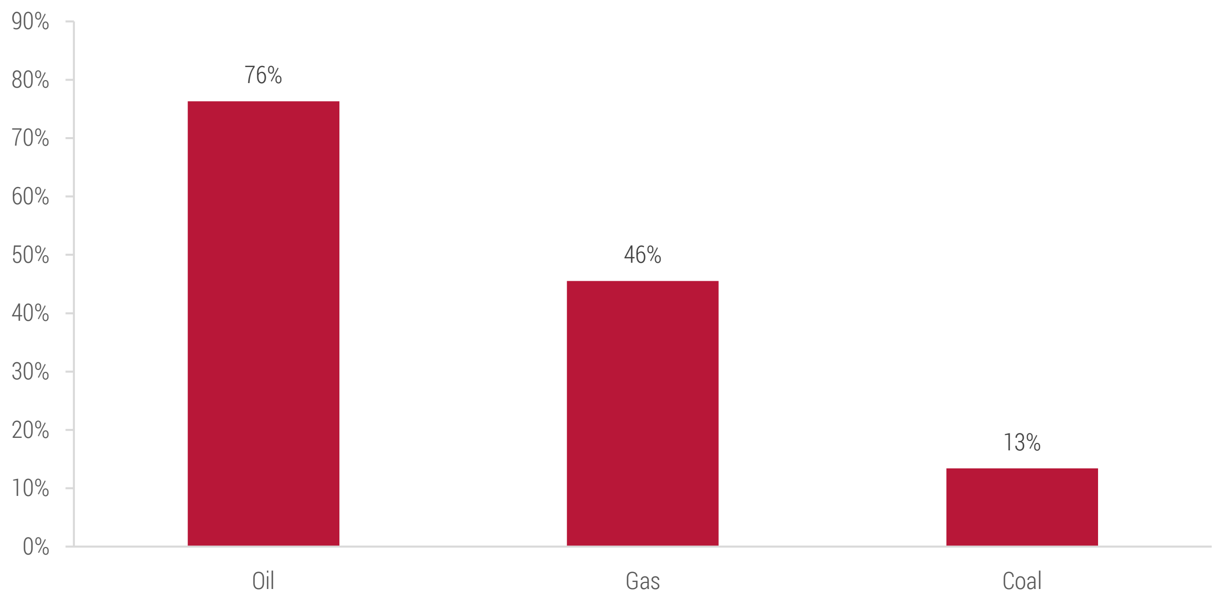
Distributional consequences should be managed with tax and benefit policies, targeted particularly at low-income households. Following energy price increases in late 2021, the Polish government decided to introduce a support policy package consisting of reduced VAT and excise tax on fuels coupled with a relief allowance. Although these measures decreased energy expenditures, the tax reliefs were regressive and helped high-income households the most (as they spent the most on energy in nominal terms). Existing measures should be improved by introducing either a lump-sum transfer for all households (Antosiewicz et al., 2022) that would help reduce income inequalities, or a targeted allowance for low-income households (e.g. in the form of an energy voucher; Sokołowski et al., 2021). Depending on the severity of future energy price hikes, we estimate the total cost of governmental support to be between 1.5–9 billion PLN (0.3–2 billion EUR) in the case of the lump sum support scheme, and 0.5–2 billion PLN (0.1–0.5 billion EUR) in the case of targeted allowance.

The remainder of this paper is structured as follows. In section two, we analyse how dependent the Polish economy is on Russian fuel imports and the energy use structure in Poland. In section three, we present our methods and data. Section four contains our results. In section five, we discuss the policy implications of the embargo and end with a conclusion.

2. Institutional setting: dependence on Russian fuels and fossil fuel intensity of the Polish energy mix

In 2020, Poland imported 35% of its energy from Russia (Figure 1), with Russia's shares in imports ranging from 13% for hard coal and 46% for gas to 76% for oil (Eurostat, 2022).[1] In 2020, the value of fossil fuel imports from Russia amounted to more than 8 billion EUR, or over 1.5% of Poland's GDP (Maćkowiak-Pandera and Gawlikowska-Fyk, 2022). It should be noted that Poland decided to stop importing Russian coal at the end of March 2022. We, therefore, expect coal imports to fall substantially in the following months and reach zero in the years to come. The ban on Russian coal will most likely be compensated by an increase in domestic coal supply (GOV.PL, 2022). Most recently, Russia decided to halt all exports of natural gas to Poland at the end of April 2022. The Polish administration claims that the country's stockpiles are big enough to withstand an eventual gas shortage. Additionally, a new LNG terminal and pipeline connection with Norway (Baltic Pipe) is slated to begin operations in 2023.

Figure 1. Imports from Russia in gross available energy, 2020 (%)

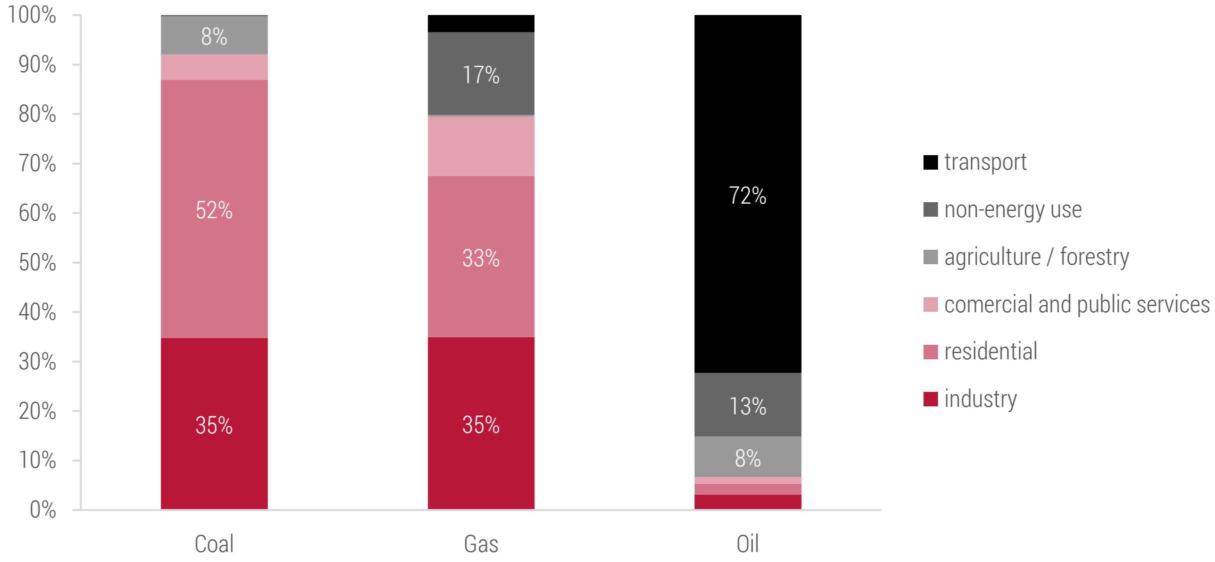


Source: Eurostat

In Poland, coal and gas are predominantly used in the industrial (35%) and residential sectors (coal 52% and gas 33%, respectively; Figure 2). In manufacturing, coal is mostly used for energy and heat generation (about 65% of Polish power generation capacity is based on coal). Most of the coal used in the energy sector in 2020 (85%) was produced domestically. In the residential sector, about 80% of coal used for individual heating in 2020 was imported from Russia (Maćkowiak-Pandera and Gawlikowska-Fyk, 2022). Natural gas is primarily used for industrial production (35%), e.g. by the chemical industry in fertilizer production. Additionally, more than 1/3 of all gas consumed in Poland is used in the residential sector for heating and cooking. Oil is predominantly used in the transport sector (72%).

[1] At the time of writing, the most up-to-date data is from 2020.

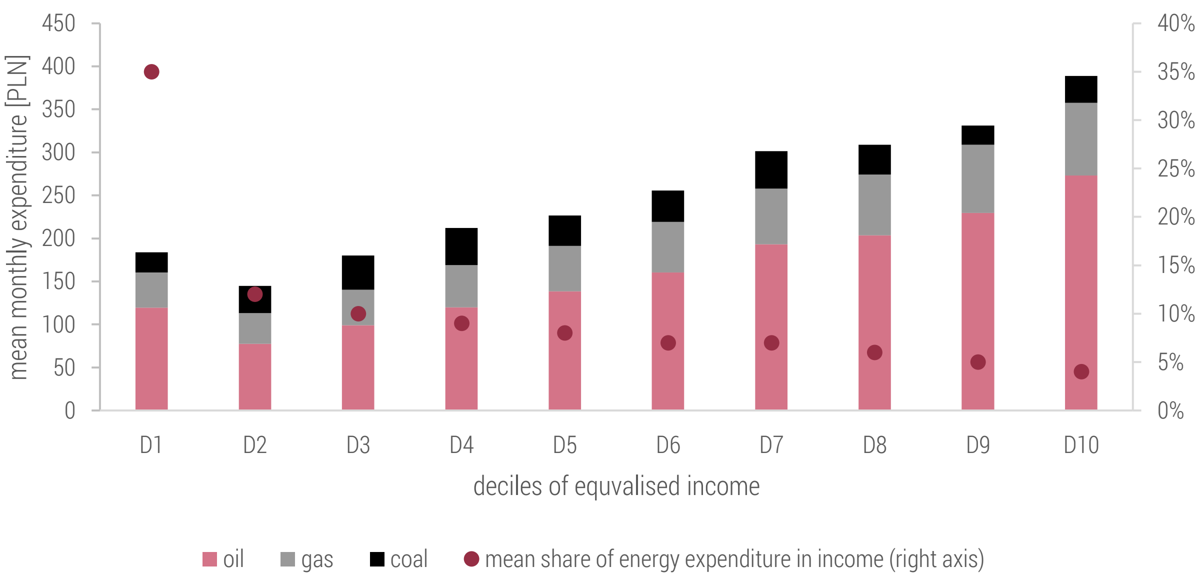
Figure 2. Energy consumption by fuels and sectors in Poland, 2020 (%)



Source: own calculation based on IEA (2022).

High-income households spend more on oil, gas and coal in nominal terms than low-income households (Figure 3). The average monthly expenditure of the tenth income decile amounts to about 400 PLN (app. 85 EUR), while the first deciles spend half of this amount. Oppositely, low-income households spend more on energy in relative terms. The monthly share of energy expenditure in different incomes ranges from as much as 35% in the first decile to 4% in the tenth decile of the income distribution. These differences demonstrate income disparities in Poland, one of the countries with the highest levels of income inequality in the EU (Brzeziński, 2017; Bukowski and Novokmet, 2017). Income inequalities are also reflected in living standards and patterns of energy consumption: low-income deciles predominantly use biomass and coal for heating, while households at the higher end of the income distribution heat their homes with coal or gas (Sokołowski et al., 2020).

Figure 3. Household consumption of coal, gas and oil according to equivalised incomes



Source: own elaboration based on Household Budget Survey data (Statistics Poland, 2020).

3. Methodology

This section is structured as follows: first, we discuss the macroeconomic model we have applied to assess the aggregate impacts of price hikes on the Polish economy caused by an embargo on Russian fuels. Second, we present the microeconomic model we use to assess the distributional effects on households in Poland. These two models are soft-linked using the approach of (Antosiewicz et al., 2022), who applied this methodology to analyse the impacts of a carbon tax in Poland. Third, we introduce data from the Household Budget Survey. Finally, we present our assumptions of price increase scenarios.

3.1. Macroeconomic model

We apply a macroeconomic multi-sector dynamic stochastic general equilibrium (DSGE) model named MEMO (MacroEconomic Mitigations Options). We use this model to simulate changes in employment, wages, and prices of goods at a sector-wide level in response to the introduction of an embargo on Russian fuels.

MEMO combines two strands of economic modelling: it is an Input-Output (IO) model embedded in a dynamic stochastic general equilibrium framework. The advantages of using such a framework over a static IO model are that it enables us to account for a variety of dynamic economic adjustment mechanisms. The most important features of MEMO are that it has an open economy search and matching mechanism on the labour market, as well as endogenous technical adaptation of energy efficiency in response to changes in the prices of oil, gas and coal.

The main agents of the model are:

a) households, which maximise utility from consumption;
b) firms, which maximise profits;
c) the government, which collects taxes and spends the revenue on public consumption; and
d) the foreign trade sector.

The firm's production side of the model is divided into several sectors and calibrated to the NACE Rev. 2 symmetric Input-Output table for 2015 (provided by Eurostat). A representative firm operates a nested constant elasticity of substitution (CES) production function in each sector. In the first stage, the firm combines capital and energy, which is then combined with labour, and, finally, with materials (intermediate use). Materials are composed of products of all sectors, which are further disaggregated into imported and domestically produced materials. The output of each sector can be used by the household and government for consumption, investment, put to intermediate use by firms, or exported. The parameters controlling the shares of each flow in production and use structure are set according to the data in the IO matrix.

When defining the aggregation of NACE Rev. 2 sectors into those used in MEMO, we pay particular attention to distinguishing between sectors related to the energy system. We identify 11 sectors and three types of fossil fuel products. These sectors are agriculture, mining (which distinguishes between specific fossil fuel products), light industry, energy-intensive industry, advanced industry, coke and refined petroleum products, electricity generation (further divided into renewable and fossil fuel generation), construction, transport, market services, and non-market services. Emissions are modelled as linear functions of the intermediate use of fossil fuel products: coal, oil, gas, and refined petroleum products.

The results of the MEMO model are expressed as per cent deviations from the no-embargo scenario.[2] We consider different deductions in the economic growth to overlap as we assume the consequences of a complete halt on Russian energy imports and potential fuel shortages.

3.2. Microeconomic model

The microsimulation model translates the sector output of the macroeconomic model into changes in the distribution of household income. It is based on data from the Household Budget Survey described in section 3.3.

The microsimulation consists of calculating the change in the equivalised income of households resulting from changes in labour income and expenditures on energy and other goods and services. In particular, a single run of the microsimulation model consists of the following steps:

1. Start with the pre-processed household and individual database.
2. Update the labour income of individuals according to the output of the macroeconomic model. We assume that the labour income of all individuals employed in each sector changes by the same percentage deviation implied by the macroeconomic model.
3. Simulate the direct price effect, i.e. changes in expenditures on energy goods resulting from price changes.

All results are scaled using the weights of households provided in the survey data.

3.3. Data

We use data from the 2020 Household Budget Survey (HBS) which contains information from a sample of 36,886 households. Each household is surveyed for a full month and discloses detailed information on incomes, expenditures, and various other socio-economic characteristics of its inhabitants. Defining individual labour income, labour market status, and household income are key operations we performed on the HBS data to build our microsimulation model. We aggregate each person's labour income, defined as the sum of income from all forms of dependent employment and self-employment. We then aggregate each household, the labour income of its members, and its expenditures on categories of goods consistent with the sector classification used in the macroeconomic model.

All types of income are considered in defining household income, including labour, pensions, benefits, financial, capital, and transfers. We equivalise household income using the OECD scales.[3] Next, we define the position of each household in the income distribution by assigning its decile to the equivalised income distribution. For employed household inhabitants, we additionally define the sector they work in and calculate their position (decile) in the sector-specific wage distribution. We also calculate the position of unemployed inhabitants in the equivalised income distribution.

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[2] A detailed description of the MEMO model is available in Appendix A1.

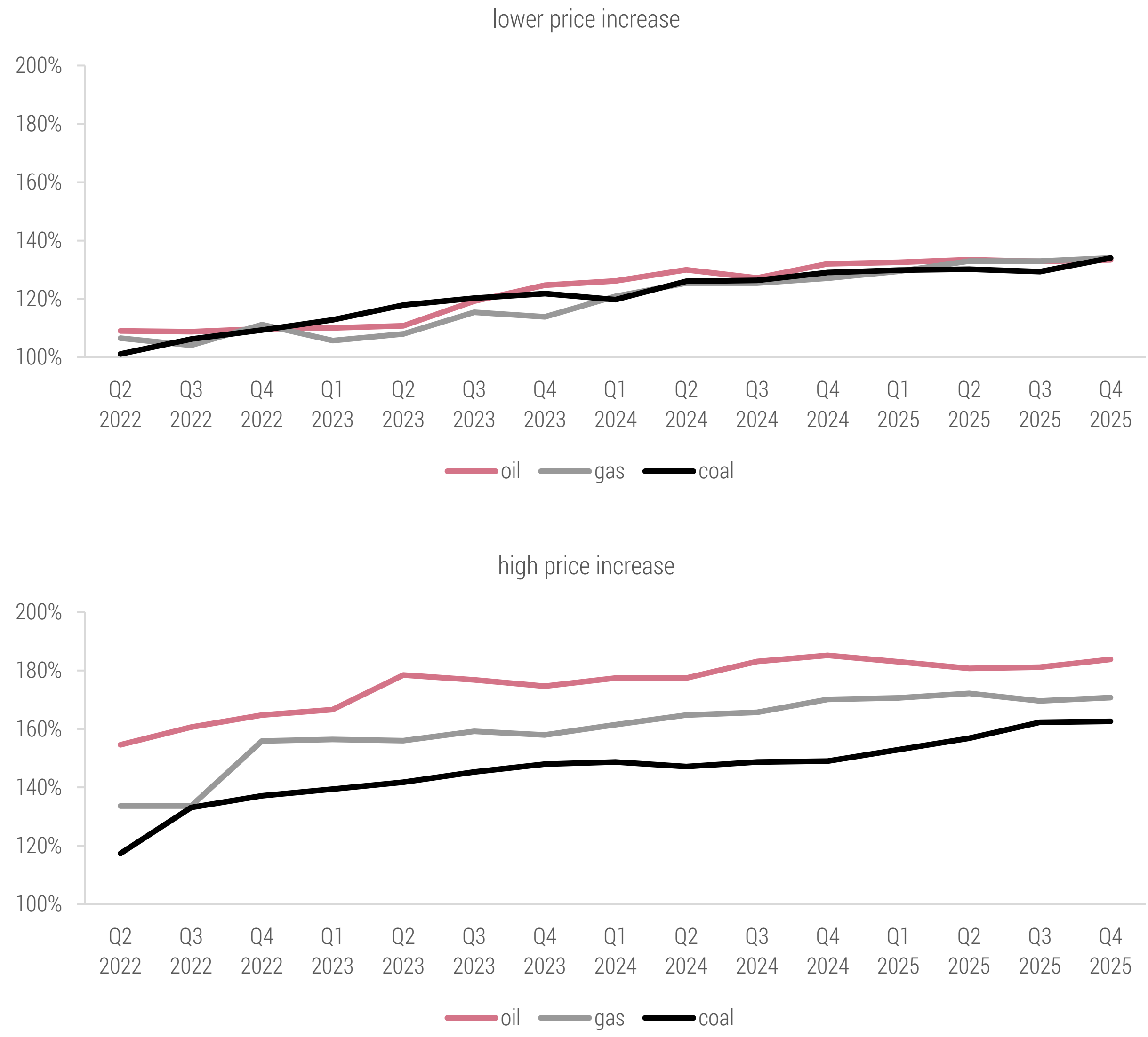
[3] We assign a weight equal to one to the first household member, 0.5 to each additional member aged 14 or older, and 0.3 to each additional member aged 13 or younger.

3.4. Possible scenarios for fossil fuel prices after an embargo on Russian fuels

We made the following assumptions to construct plausible price scenarios for the shock experienced by the Polish economy as a result of an embargo on Russian fuel imports. First, our scenarios assume a discontinuance in imports of crude oil and natural gas from Russia, leading to higher prices for hard coal, crude oil and natural gas. We follow similar assumptions as e.g. the scenario analysis of (Grimm et al., 2022; Oxford Economics, 2022). Second, we account for the fact that prices for coal, oil and gas have increased substantially between mid-2021 and Q1 2022. It is challenging to estimate the exact extent to which gas, hard coal and oil prices will continue to rise in the short term, so we take this high degree of uncertainty into account by providing two different scenarios for each fuel (Figure 4). Finally, we assume the price of coal will rise to a lower extent than the remaining two fuels (in both scenarios) as Poland is capable of supplying coal through domestic production.

We present the aggregate results of each scenario, assuming that coal, fuel and gas prices would increase simultaneously. We have labelled these as "lower" and "higher", although fuel prices hikes are substantial even in the more conservative scenario (by an average of 30% until 2025).

Figure 4. Price scenario assumptions for coal, gas and oil, 2022–2025 (%)



Source: own elaboration.

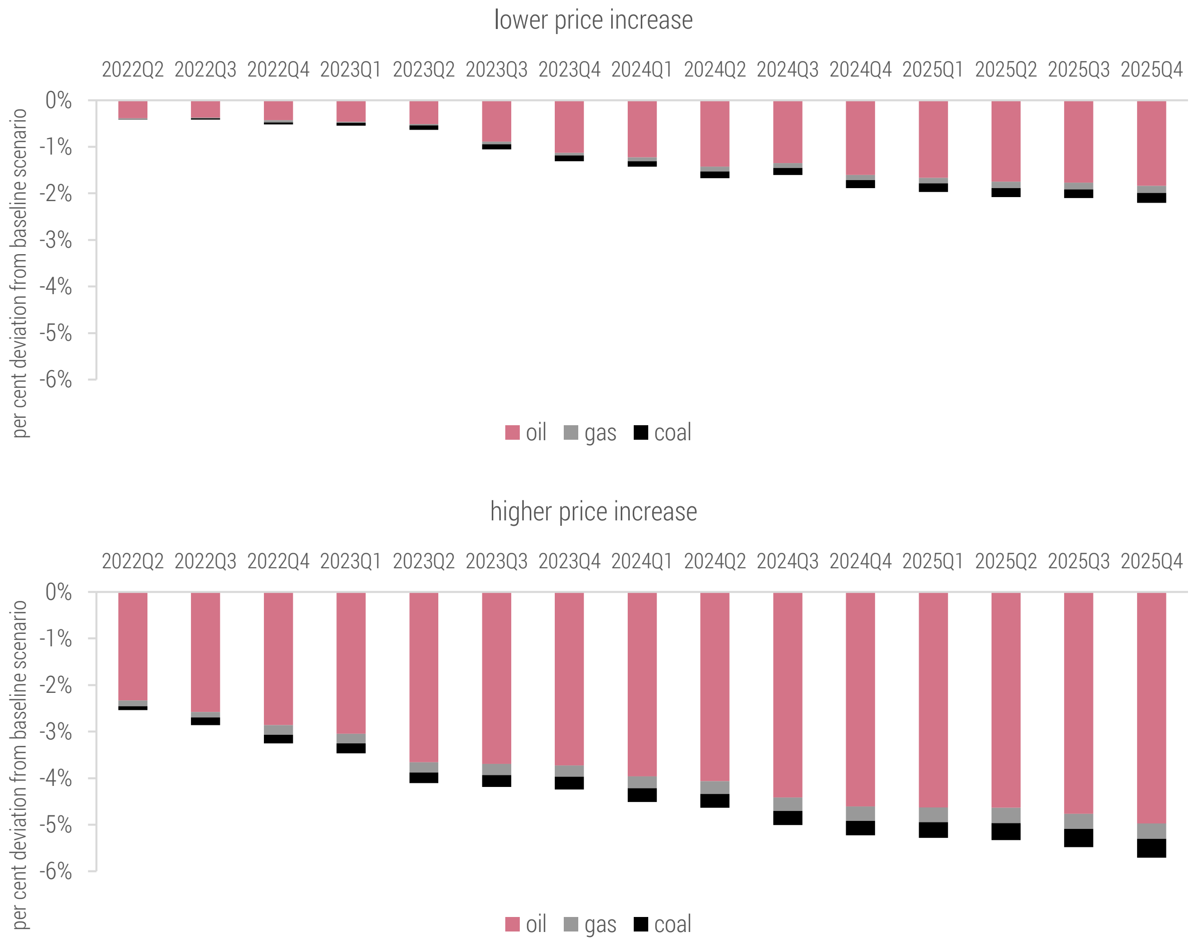
4. Results

In this section, we first discuss the results of the aggregate effects of the fuel price increases. We then assess the distributional effects.

4.1. The macroeconomic effects of an embargo on energy imports from Russia

According to our results, the aggregate effects of an embargo on Russian fuels in Poland would be substantial, but manageable. We find that GDP would be lower by 0.2–3.3% at the end of 2022, and by 2.1–5.7% if prices increase further until 2025 (Figure 5). The range of modelled economic losses depends on energy price hikes. Although the share of fossil energy imports from Russia is small in terms of Poland's total GDP, negative consequences would intensify if prices on the international energy markets reach the estimated heights. Importantly, most of the negative effects (on average more than 80% across scenarios) can be attributed to rising oil prices. If these particular impacts are tackled, the overall effect on Poland's GDP would be reduced substantially. The contributions of gas and coal prices are much smaller – each amounts to about 10% of the overall effect.

Figure 5. Differences in Polish GDP under particular price increase scenarios, until 2025. Compared to the no-price-increase scenario (%)



Note: figure shows per cent deviations from the no-price-increase scenario.
Source: own elaboration based on the MEMO model.

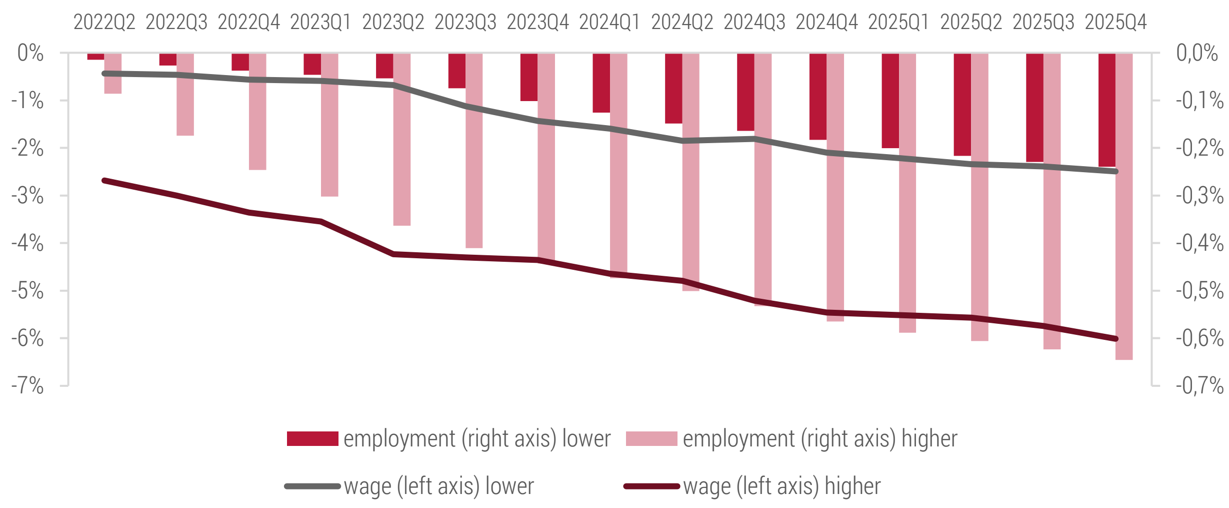
Second, we assess which sectors are most exposed to the risks associated with an embargo on Russian fuels and how they would contribute to the overall effect (Figure 6). The services sector would have the highest contribution to the decrease in the GDP, both in 2022 (0.1–1.4 pp of GDP in the lower and higher price increase scenario), and in 2025 (0.8–2.6 pp according to the two scenarios), followed by construction (0.5 pp in 2022 in the higher increase scenario, and 0.3–0.7 pp in 2025, according to two scenarios that we consider). Although some other sectors at more exposed (e.g. the refined petroleum sector, which is heavily dependent on oil prices), their contribution to the GDP change would be much smaller – below 1 pp – as their initial share in GDP is limited (they fall under the "other" category in Figure 6). Therefore, the impacts on sectors that are at a lower risk but have a higher contribution to Poland's overall economy should be tackled first.

Figure 6. Differences in added value in relation to the share of a particular sector in the Polish economy, from 2022 until 2025. Compared to the no-price-increase scenario (%)

Note: figure shows per cent deviations from the no-embargo scenario.
Source: own elaboration based on the MEMO model.

The labour market effects of an embargo on Russian fuel imports would mainly be channelled through lower wages (Figure 7) rather than lower employment. We estimate that wages would decrease by 0.1–3.4% in 2022 and by 2.2–6.0% in 2025. It is worth noting that the impact of the embargo on wages is similar across several sectors[4]. This means that these consequences could be alleviated through lower taxation of labour. The effects on employment range from 0.0–0.2% in 2022 and 0.2–0.6% in 2025, i.e. are approx. ten times lower than the effects on wages. We expect the magnitude of the effects on employment to be more pronounced in the medium- and long-term. Therefore, adjustments in the labour market resulting from the embargo should be tackled by e.g. increasing unemployment benefits. These negative labour market consequences would require policy responses to alleviate their social impact. However, Poland has recently experienced record-low levels of unemployment, labour shortages and strong wage growth, so the labour market should remain relatively unscathed.

Figure 7. Differences in employment and wages in the Polish economy, from 2022 until 2025. Compared to the no-price-increase scenario (%)



Note: the figure shows per cent deviations from the no-embargo scenario.
Source: own elaboration based on the MEMO model.

4.2. Distributional effects

Next, we discuss the distributional effects of the price increases that would be triggered by the embargo (Figure 8). Importantly, the direct price impacts in 2022 under the "lower" price increase scenario are small, both in nominal and relative terms, and irrespective of income.

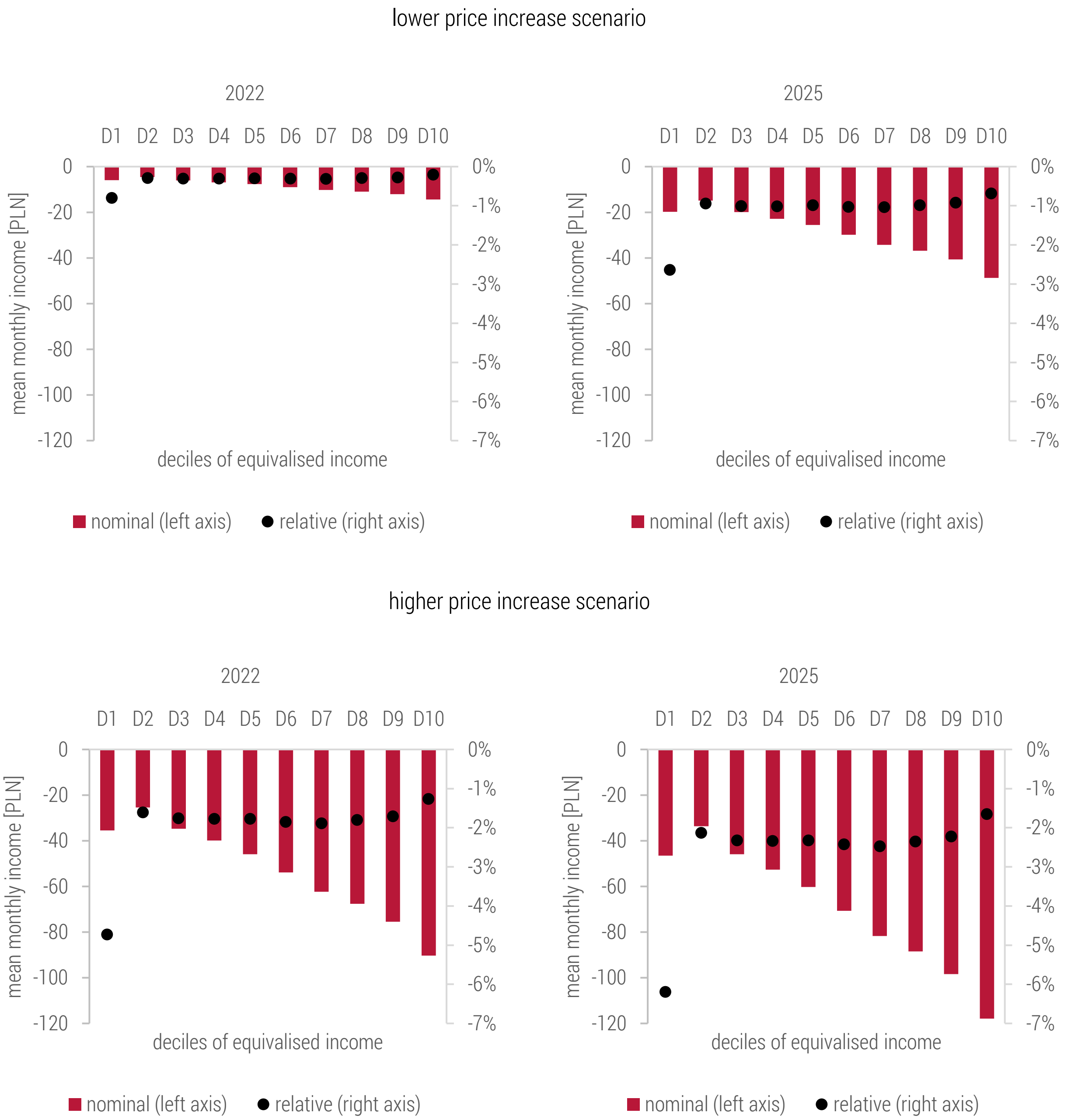
In nominal terms, fuel price increases will affect high-income households the most. The impacts on high-income deciles range between 50–120 PLN per month in 2025 (i.e. 11–25 EUR).[5] Oppositely, the average nominal impact on low-income households (i.e. the first four deciles of the income distribution) ranges from approx. 20 PLN (4.5 EUR) in 2025 in the "lower" price increase scenario, and up to 35 PLN (7.5 EUR) in the "higher" scenario.

[4] We report these results in Appendix A2 and A3.

[5] We use the average exchange rate of the National Polish Bank (NBP) in 2021, i.e. 1 EUR = 4.56 PLN.

In relative terms, fuel price hikes would primarily impact low-income households. An increase in fuel prices would shrink the disposable incomes (energy costs deducted) of low-income households by 0.8% in 2022 and 2.6% in 2025 in the “lower” scenario, and by 4.7% in 2022 and 6.2% in 2025 if the price hikes are higher. Meanwhile, high-income households would see disposable income shrink by 0.2–1.3% in 2022 and 0.7–1.6% in 2025. Low-income households were already spending 10–30% of their incomes on energy before the war, compared to high-income households spending approx. 5%. A safety net to cushion low-income households from this income shock is necessary to efficiently ban all imports of Russian fossil fuels to Poland.

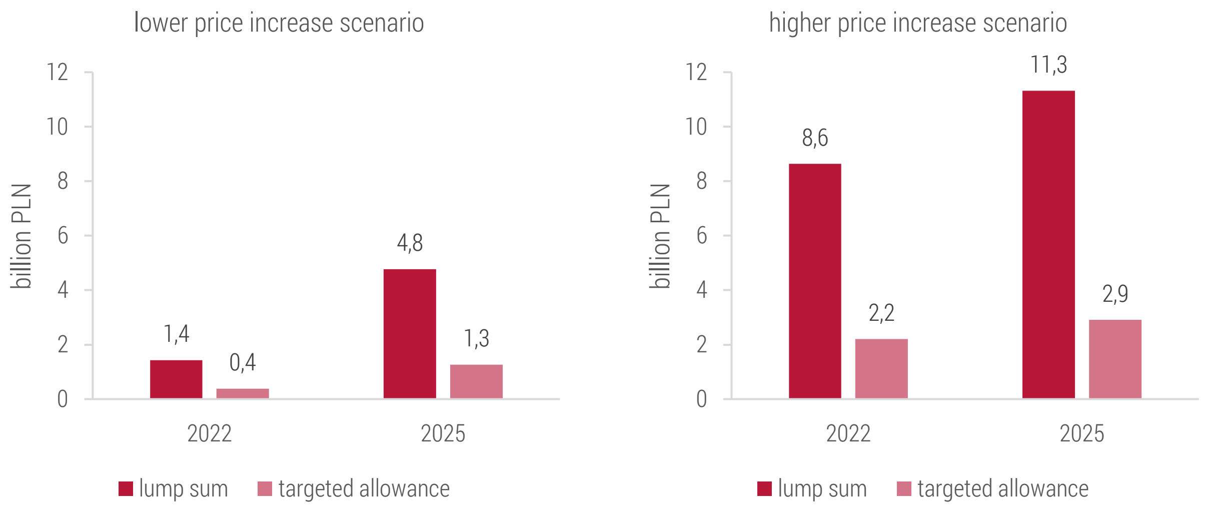
Figure 8. Differences in the mean monthly incomes of households due to fuel price increases in Poland, 2022 and 2025. Compared to the no-price-increase scenario. Equivalised income deciles [nominal and relative]



Source: own elaboration based on Household Budget Survey data (Statistics Poland, 2020).

We estimated the total costs of transfers required to compensate Polish households for increasing energy prices, evaluating the costs of two separate support schemes – a lump-sum transfer that would cover the average additional cost across all households in Poland, and a targeted support scheme for households in the first four deciles of the equivalised income distribution (Figure 9). Contingent upon the severity of the price hikes, annual support costs would be between 1.4–8.6 billion PLN (0.3–1.8 billion EUR) in the case of the lump sum support scheme, and 0.4–2.2 billion PLN (0.1–0.5 billion EUR) in the case of targeted allowance. It is noteworthy that the cost of the lump sum support scheme is lower (by 1 billion PLN; 0.2 billion EUR) than the cost of the support package implemented by the Polish government at the end of 2021 (i.e. the "Anti-Inflation Shield") to mitigate the impact of rising energy prices.

Figure 9. Estimated cost of compensation to Polish households, 2022 and 2025



Source: own elaboration

5. Conclusions

We studied the effects of oil, gas and coal price increases on the Polish economy due to an embargo on Russian fuels. We demonstrated that the impacts would be significant, yet manageable.

Our paper has important policy implications. In the short term, an embargo on Russian fuels must be compensated with alternative energy sources from other countries and domestic sources to meet electricity, transport, heating and industrial demand. Primarily, we find that the Polish economy would be most negatively impacted by oil price hikes. As the global market for crude oil is highly integrated, past events have shown that restrictions in the production of crude oil in one country were compensated by intensified production in another (Caldara et al., 2019; Kilian, 2009). These impacts will most likely be tackled by adjustments on the international markets and reinforced cooperation with alternative oil suppliers.

In the medium term, increased use of renewable energy and energy efficiency improvements can contribute significantly to lowering energy demand (IEA, 2022b). Gas and coal consumption in the residential sector can be reduced by switching to renewable energy sources – i.e. domestically obtained biomass for less financially affluent households, and heat pumps for high-income households. Savings in the total amount of gas currently used by Polish households would free up close to 10% of the country's total gas consumption.

In the long run, switching to nuclear power is a plannable option. Poland's first nuclear power plant is scheduled to go into operation in 2033, according to the Energy Policy of Poland until 2040 (GOV.PL, 2021). Additionally, supplying energy from unused nuclear power plants in Germany seems to be a feasible scenario, although it relies on the will of German politicians to bring this capacity back to operation. It is worth noting that the Polish parliamentary opposition proposed to rent German nuclear plants, yet this proposition has yet to be taken up by either country's government.

From the point of view of energy infrastructure, substituting imports of Russian oil, coal and gas would be challenging but possible to implement. First, other oil and coal exporting countries can make up for the shortfall and decreases in imports from Russia. Additionally, coal can be produced domestically in Poland. Furthermore, although the gas market is limited to the existing pipeline network and terminal capacities, Poland should have enough infrastructural capacity to switch away from Russian gas via LNG terminals and increased pipeline imports from other countries (Baltic Pipe). Moreover, the EU internal energy market should be further integrated with substantial investment increases in transnational energy links to lower the costs of such a substitution.

The impact on households must be reduced by direct transfers. This was the case during the energy price crisis at the end of 2021, when the Polish government introduced a support package consisting of a VAT and excise tax reduction and relief allowance. Unfortunately, the Polish government's policies were ineffective in terms of social and climate policy. Firstly, the policy package reduced energy and transport costs for rich households the most, meaning that it was regressive and ineffective in reducing inequality. Secondly, it discouraged households from making investments in energy-efficient, non-carbon energy sources or cleaner transport. Reduced prices were in no way an incentive for wealthy families to reduce their consumption of energy and transport fuels, having an overall adverse effect on the achievement of climate policy and energy security goals. Alternatively, (Sokołowski et al., 2021) proposed issuing energy vouchers, i.e. a targeted financial relief that would compensate low-income households for high energy costs.

Our study has its limitations. We limit our estimates to the direct price effects of increases in oil, gas and coal prices. We understand that producers and households will switch to other inputs to a particular extent and change their consumption baskets. The effects of a demand-side response from changing consumer heating habits, increasing the deployment of small-scale renewables, and raising the energy efficiency of buildings remain uncertain and require further behavioural and experimental research. Additionally, we did not discuss which groups of workers face lower labour incomes after an embargo would come into force, nor the potential welfare loss due to unemployment or relocation to other sectors. We did not study the effects of social transfers that could be introduced to address the increased fuel prices, or account for regional disparities in Poland. Finally, our model does not assume monetary and fiscal policy effects on nominal rigidities in the economy, e.g. a trade-off between stabilising output and inflation, or second-round effects, e.g. in the financial sector.

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Appendix

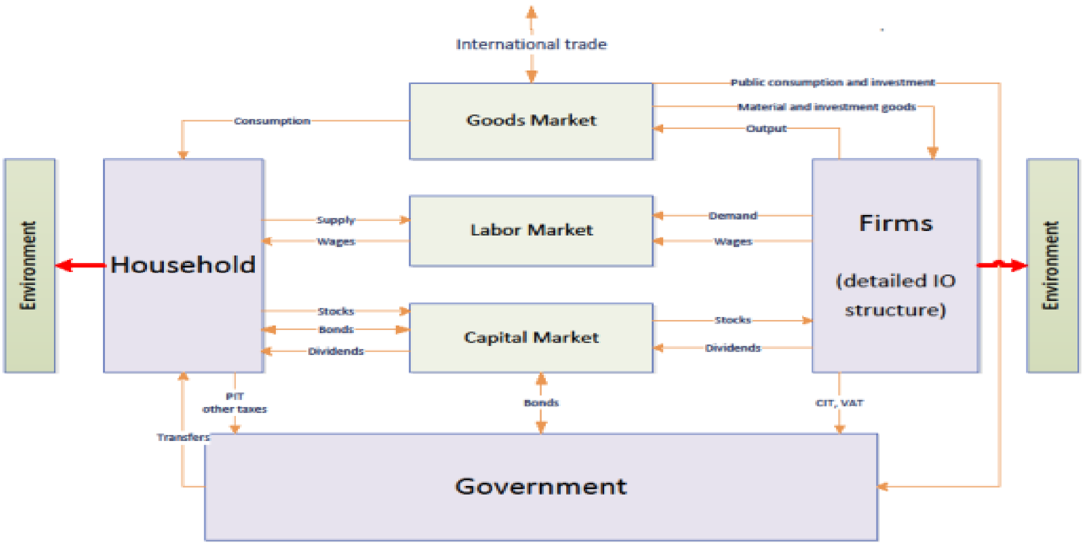
A1. MEMO – Macroeconomic mitigations options model

For the assessment of the policy package we use the dynamic stochastic general equilibrium model MEMO, developed at the Institute for Structural Research (Antosiewicz & Kowal, 2016). The model combines two strands of research – input-output and general equilibrium modelling. The main agents of the model and their interrelations are depicted in Figure A1. The model consists of the household sector, which maximises utility from consumption and leisure, the firm sector which maximises profits, the government sector which collects various taxes and finances public consumption, and a foreign sector responsible for trade with the rest of the world. The model's main features include division of the firm into sectors calibrated to input-output matrix, search and matching on the labour market to model transition of workers between sectors, and endogenous adaptation of technology related to energy use.

The sector structure of the model is calibrated using the 2015's Polish industry by industry input-output matrix from the OECD statistics database which uses the International Standard Industrial Classification of All Economic Activities (ISIC), Rev.4. In the model we distinguish the following sectors and products: (1) Agriculture and Forestry; (2) Mining of Coal; (3) Mining of Crude Oil; (4) Mining of Gas; (5) Mining of Other; (6) Manufacturing Industry, (7) Manufacturing of Refined Petroleum Products; (8) Energy; (9) Construction; (10) Transport; (11) Market Services; (12) Public Services.

The technical details such as exact equations, calibration and solution methods of the MEMO model can be found in the research report by Antosiewicz & Kowal (2016). The exact specification of the model used in this study slightly differs from the model described in the aforementioned research report, as we tailored it to the needs of the current assessment.

Figure A1. Main model agents



Source: Antosiewicz et al., 2022.

Model structure

Antosiewicz et al. (2022) lay down the main structure of the model. The model assumes a small open economy with four agents: (a) households, (b) firms, (c) government, and (d) the foreign demand sector. These agents interact in three markets: (1) labour (2) capital, and (3) goods market.

Households

There are many identical households in this economy that conform a representative household that chooses consumption from maximizing an inter-temporal CRRA utility function. There is no leisure in the utility function. The usual budget constraint applies. The household uses labour income, firms' profits, the return from previous savings to pay consumption, value-added and income taxes, quadratic search costs in the labour market expressed in terms of consumption good. The working-age population is divided between employed and unemployed workers.

Firms

The model is composed of 12 sectors described in the introduction. It must include raw materials and energy sectors, given the nature of our problem (the macroeconomic effects of a carbon tax). The calibration of the production function and the relations across sectors comes directly from the input-output matrix.

Following Figure 1, firms produce a basic sectoral good under monopolistic competition, employing capital, labour, materials and energy as production factors. There are trading firms that purchase this good and sell it to domestic and foreign sectoral markets. The agents that buy this good are: (i) (as intermediate demand) producers of basic goods (in each sector); (ii) (sectoral) export firms, which distribute domestic production in foreign markets; and (iii) three types of domestic final goods producers, providing investment, government, and private consumption goods. The final production is traded on the goods market with households, basic producers and the government in accordance with the flows established from the input/output matrix.

$$KLEM_t^s = \left[(1-\theta_{M,t}^s)^{\frac{1}{\epsilon_M^S}} (KLE_t^s)^{\frac{\epsilon_M^S-1}{\epsilon_M^S}} + (\theta_{M,t}^s)^{\frac{1}{\epsilon_M^S}} (M_t^s)^{\frac{\epsilon_M^S-1}{\epsilon_M^S}}\right]^{\frac{\epsilon_M^S}{\epsilon_M^S-1}}$$

$$Y_t^s = e^{\xi_t^Y} \times KLEM_t^s$$

where KLEM is an aggregate production factor that uses capital (K), labour (L), electricity (E) and materials (M). This is constructed using CES aggregator between *K* and *E*, then we add *L*, and finally *M*. Where Y_t^s represents output of sector s at time t, $\theta_{M,t}^s$ represents the share of materials in the production process of the basic good and ϵ_M^s is the elasticity of substitution between materials and the capital labour-electricity (KLE) composite production factor. ξ_t^Y is an economy-wide productivity shock that we use to calibrate the dynamics properties of the model.

Materials play a key role in the model to estimate the CO_2 emissions. Intermediate material used in sector *s*, M_t^s is obtained from a composite of fuels ($FUELS_t^s$) and a composite of all other intermediate inputs.

$$M_t^s = \left[(\theta_{FLS,t}^s)^{\frac{1}{\epsilon_{MF}}} (FUELS_t^s)^{\frac{\epsilon_{MF}-1}{\epsilon_{MF}}} + (\theta_{MO,t}^s)^{\frac{1}{\epsilon_{MF}}} (\theta_{MO,t}^s)^{\frac{\varepsilon_{MF-1}}{\varepsilon_{MF}}}\right]$$

Where $\theta_{FLS,t}^{s}$ and $\theta_{MO,t}^{s}$ denote the share of fuels and other material in the intermediate input, with $\theta_{FLS,t}^{s} + \theta_{MO,t}^{s} = 1$, while ε_{MF} represents the elasticity of substitution between inputs. In turn, combining materials $M_{i,t}^{s}$ in a Leontief production function generates the composite MO_{t}^{s}, used from all the basic goods sector:

$$M_{i,t}^{s} = \theta_{i,t}^{s} MO_{t}^{s}$$

where $\theta_{i,t}^{s}$ (with $\sum_{i\in s} \theta_{i,t}^{s}$=1) denotes the shares of intermediate good *i* in overall material consumption in sector *s*. Note that this specification allows for the introduction of energy material input into the composite MO For the purpose of calibration, energy only enters in the production of electricity and raw materials, to replicate the high volatility of these two energy inputs observed in the data.

Raw materials intermediate goods (different from fuels, e.g. coal, oil gas, etc.), use raw materials in a Leontief production function. In the case of fuels, a CES aggregator combine all the relevant types of fuels needed for their production.

$$FUELS_{t}^{s} = \left[\sum_{k\in FLS} (\theta_{k,t}^{s})^{\frac{1}{\epsilon_{FLS}^{s}}} (M_{k,t}^{s})^{\frac{\epsilon_{FLS}^{s}}{\epsilon_{FLS}^{s}-1}} \right]^{\frac{\epsilon_{FLS}^{s}}{\epsilon_{FLS}^{s}}}$$

Where $\{FLS\}$ is the set of fuels, $M_{k,t}^{s}$ denotes input of k-th type of fuel, $\theta_{k,t}^{s}$ is the share of k-th fuel type in fuels intermediate input composite, and ϵ_{FLS}^{s} denotes the elasticity of substituting between different fuels in sector *s*.

In summary, the set of intermediate sectoral input, $M_{i,t}^{s}$, is the union of the sets of all intermediate inputs, raw materials different than fuels and fuels. Since, this is a small open economy, $M_{i,t}^{s}$ is a composite goods produced with inputs made at home ($M_{i,H,t}^{s}$) and abroad ($M_{i,F,t}^{s}$), combined according to the Armington aggregator.

The final basic good in sector s, $\bar{Y}_{t}^{s}$ is a composite made of intermediate goods produced in the way just described. The final firm produces the final good using the Dixit-Stiglitz aggregator and selling it in a perfectly competitive market.

$$\bar{Y}_{t}^{s} = (\int_{0}^{1} (Y_{t}^{s}(i))^{\frac{p^{s}}{p^{s}-1}} di)^{\frac{p^{s}-1}{p^{s}}}$$

Where parameter p^{s} sets the markup.

Investment decisions

Firms make capital accumulation decisions in a way which maximizes the profit.

Government

The government collects value added tax, corporate income tax, labour income tax, some specific taxes and CO_2 emission tax. The revenue is spent on public goods, transfers to households and interests on public debt.

External sector

Given the small open economy assumption, the economy is price taker in international markets for exports and imports. There is open capital account, which defines external assets (debt) accumulation.

Crucial aspects of the model

CO_2 emissions

Firms and households produce CO_2. Firms in sector s produce CO_2^s as a by-product while using intermediate goods.

Formally:

$$CO_2^s = \theta_{H,CO2,t}^s \times Y_t^s + \sum_{j\in T} \theta_{j,CO2,t}^s \times (M_{i,H,t}^s + M_{i,F,t}^s)$$

where $\theta_{H,CO2,t}^s$ defines the amount of CO2 in sector s by using j-type material produced in home (H) or foreign country (F). The main assumption is that only fuels consumption generates CO2, in other words $\theta_{H,CO2,t}^s \neq)$ for $j \in \{FLS\}$. Moreover, chemical processes other than fuel combustion can also produce CO2. We assume that such CO2 emission is proportional to the amount of goods and services produced in a given sector and is controlled by the parameter $\theta_{H,CO2,t}^s$. Similarly, the amount of CO2 emitted by households is equal:

$$CO_2^{CNS} = \sum_{j\in t} \theta_{j,CO2,t}^{CNS} \times M_{j,t}^{CNS}$$

Labour market

Sectoral supply and total demand for labour Wages in the model are sector specific. They are determined in general equilibrium, and hence they react to changes in sectoral demand induced by climate policy. The sectoral demand for labour is determined in the optimization of representative firms in all sectors. To model labour supply curves at sectoral level we assume existence of an intermediary between representative worker and sectoral firms that allocates workers to different sectors using Constant Elasticity of Substitution technology. In addition, we let the intermediary decide on the total number of vacancies in the economy, which we use to determine unemployment rate.

The intermediary optimization problem is given by

$$\max_{\{N_t, n_t, Vac_t\}_{t=0}^{\infty}} V_t^L = \pi_t^L + \lambda_{t+1} V_{t+1}^L$$

Subject to:

$$\pi_t^L = \sum_s w_t^s n_t^s - w_t N_t - v_{Vac} Vac_t$$

$$N_t = \omega_N \left(\sum_s \omega_N^s \left(n_t^s\right)^{\frac{\varepsilon_L - 1}{\varepsilon_L}} \right)^{\frac{\varepsilon_L}{\varepsilon_L - 1}}$$

$$N_t = (1 - \delta_L) N_{t-1} + \Phi_t Vac_t$$

Where V_t^L is the discounted sum of profits, π_t^L is the profit in period t, λ_{t+1} is the discount factor (determined endogenously based on the interest rate), w_t^s is wage in sector s, n_t^s is the supply of workers in sector s, w_t is the aggregate wage (received by representative worker) and N_t is the total demand for labour, v_{Vac} is the cost of having an open vacancy (which could be interpreted as a search cost), Vac_t is the number of open vacancies, ω_N and ω_N^s are parameters calibrated to ensure that number of workers in each sector and total number of workers are the same as in input-output matrices for Poland, ε_L is the elasticity of transformation between sectors, δ_L is a job destruction rate (exogenous in the model) and Φ_t is the probability of filling the vacancy.

The intermediary takes aggregate wage (w_t), sectoral wages (w_t^s) and probability of filling the vacancy (Φ_t)) as given and decides on total demand for labour (N_t), its allocation across sectors (i.e. supply of labour at a sectoral level, n_t^s) and total number of vacancies (Vac_t).

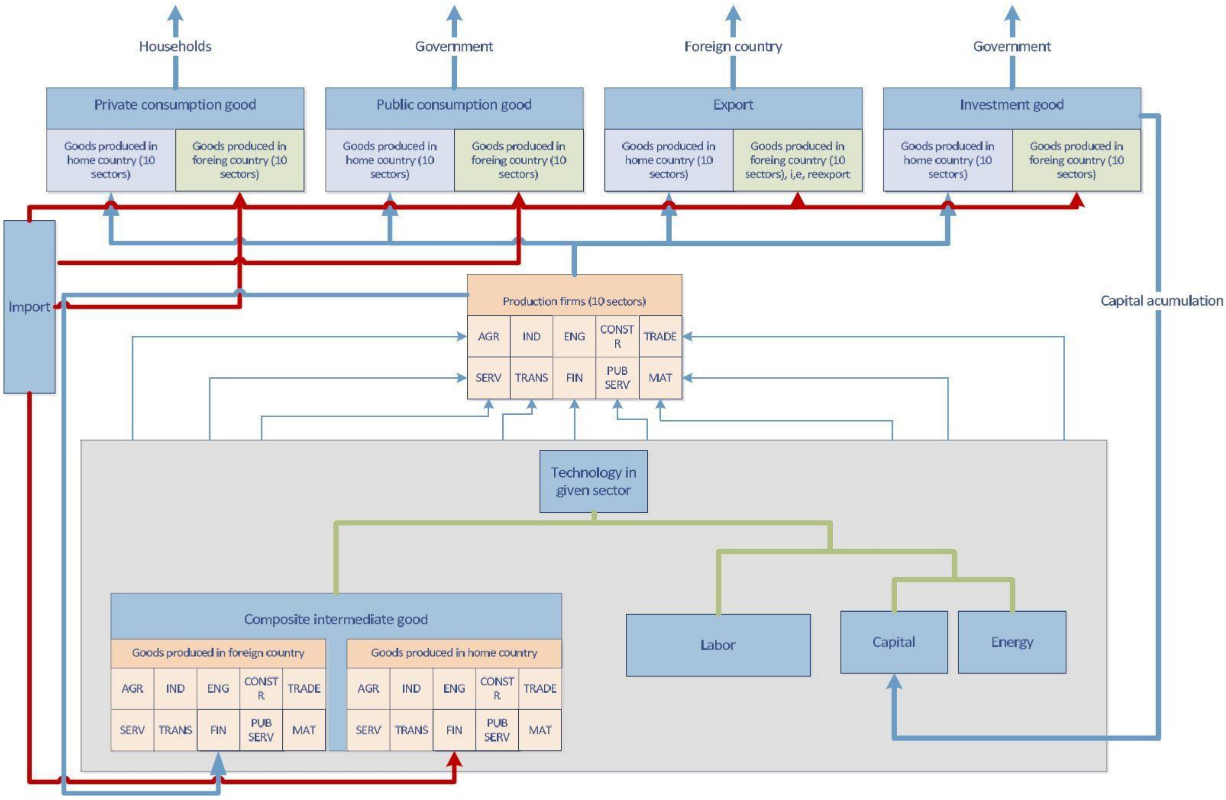
Input-Output sector structure and emissions

There are several distinct sets of parameters whose values need to be calculated. The main one is the parameters governing the firm and production side of the model. These parameters can be further specified as those which govern the value added[6] structure of the sectors, investment and compensation of employees in each sector, the intermediate use structure which considers domestically produced and imported goods and final use structure which also takes into account domestically produced and imported goods. A scheme of the production structure is shown in Figure A2. Each firm operates a production function which utilises a nested CES (constant elasticity of substitution) specification to combine the factors of production. In the first stage the firm combines capital and energy, the second stage consists of adding labour, whereas in the final stage this bundle is combined with materials (intermediate use). The material bundle is composed of products of each sector, which are further disaggregated into the imported and domestically produced parts. On the use side, the goods produced by each sector are purchased by the household for private consumption, by the government for public consumption, by firms as investment or they can be exported.

To calibrate the firm side of the model, we use the input-output (IO) matrix from the OECD statistics database. This is a 36 activity by 36 activity matrix which uses the International Standard Industrial Classification of All Economic Activities (ISIC), Rev.4. However, for this study, we have to disaggregate some sectors and products which are collapsed into a single activity in the OECD matrix. To conduct this disaggregation, such as the disaggregation of specific fossil fuels.

[6] It is defined as the value of output minus the value of purchased inputs (Abel et al., 2011)

Figure A2. Production process in MEMO model



Source: Antosiewicz & Kowal (2016)

In the first step the OECD IO matrix is aggregated into the following sectors: 1) AGR: Agriculture, forestry and fishing; 3) RPP: Manufacturing of refined petroleum products; 4) IND: Remaining manufacturing industry; 5) ENERGY: Electricity, gas, water supply and sewerage; 6) CONSTR: Construction; 7) TRANS: Transport; 8) SERV: Market services; 9) PBL: Public services. Table 1 summarizes this sector aggregation. In the second step, we conduct a disaggregation of several sectors related to fossil fuels and the electricity sector using the highly disaggregated IO matrix and data from the International Energy Agency regarding electricity generation by source.

In MEMO we directly model CO_2 emissions from the use of fossil fuels: coal, oil and gas. The volume of carbon emissions in a particular sector is modelled as a linear function of the use of these fuels, with coefficients set to match sector data regarding emissions. We do not model directly other, non-carbon emissions, such as those resulting from industrial processes, waste processing, agriculture or captures in the forestry sector. Such emissions are treated indirectly in the post-processing phase of the modelling exercises. In the case of running a carbon tax simulation, the agents in the model only react to the fossil fuel emissions which are modelled directly and do not for example reduce output in the agriculture sector to cut non-carbon emissions.

A2. Differences in value added by sectors

	Lower price increase scenario				Higher price increase scenario			
	2022	2023	2024	2025	2022	2023	2024	2025
agriculture	-0.6%	-1.3%	-1.9%	-2.3%	-3.2%	-4.3%	-5.3%	-5.9%

construction	-1.2%	-2.8%	-3.8%	-4.1%	-7.1%	-8.4%	-9.6%	-9.8%
energy	-0.4%	-1.4%	-1.9%	-2.2%	-3.1%	-4.4%	-5.4%	-6.0%
light industry	-0.5%	-1.2%	-1.8%	-2.2%	-2.9%	-4.0%	-4.9%	-5.6%
energy intensive industry	-0.7%	-1.7%	-2.3%	-2.6%	-4.3%	-5.2%	-6.0%	-6.3%
advanced industry	-0.5%	-1.1%	-1.6%	-1.8%	-2.9%	-3.6%	-4.2%	-4.4%
manufacturing of refined petroleum products	-2.9%	-8.5%	-10.3%	-9.1%	-18.3%	-18.6%	-23.2%	-23.4%
raw materials	2.5%	4.5%	6.3%	7.5%	8.5%	9.7%	9.4%	11.9%
services	-0.5%	-1.3%	-1.9%	-2.3%	-3.2%	-4.3%	-5.3%	-5.9%
public services	-0.5%	-1.1%	-1.6%	-1.8%	-3.0%	-3.7%	-4.4%	-4.7%
transport	-0.6%	-1.4%	-1.9%	-2.1%	-3.5%	-4.3%	-5.0%	-5.3%

Note: the figure shows per cent deviations from the no-embargo scenario.
Source: own elaboration based on the MEMO model.

A3. Differences in wages by sectors

	Lower price increase scenario				Higher price increase scenario			
	2022	2023	2024	2025	2022	2023	2024	2025
agriculture	-0.5%	-1.3%	-1.9%	-2.3%	-3.4%	-4.4%	-5.5%	-6.1%
construction	-0.6%	-1.5%	-2.1%	-2.5%	-3.7%	-4.8%	-5.9%	-6.5%
energy	-0.6%	-1.5%	-2.2%	-2.7%	-3.9%	-5.2%	-6.4%	-7.0%
light industry	-0.5%	-1.3%	-1.9%	-2.3%	-3.3%	-4.4%	-5.5%	-6.0%
energy intensive industry	-0.5%	-1.4%	-2.0%	-2.3%	-3.5%	-4.5%	-5.6%	-6.2%
advanced industry	-0.5%	-1.3%	-1.9%	-2.3%	-3.3%	-4.3%	-5.4%	-6.0%
manufacturing of refined petroleum products	-0.8%	-2.1%	-2.9%	-3.3%	-5.4%	-6.7%	-8.1%	-8.6%
raw materials	-0.3%	-0.8%	-1.2%	-1.4%	-2.4%	-3.1%	-4.1%	-4.4%
services	-0.5%	-1.3%	-1.9%	-2.3%	-3.4%	-4.4%	-5.5%	-6.1%
public services	-0.5%	-1.3%	-1.9%	-2.2%	-3.3%	-4.3%	-5.3%	-5.9%
transport	-0.5%	-1.4%	-1.9%	-2.3%	-3.4%	-4.4%	-5.5%	-6.0%

Note: the figure shows per cent deviations from the no-embargo scenario.
Source: own elaboration based on the MEMO model.

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