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# Macroeconomic, Sectoral and Fiscal Implications of Decreasing Energy Intensity in the Polish Economy[1]

**Abstract**: The aim of this paper is to assess the implications of an ongoing improvement in the energy efficiency of the Polish economy. Poland is among countries that have been leading the way in reducing energy intensity in recent decades. A counterfactual analysis conducted in this study is based on a computable general equilibrium (CGE) model called GEMPOL and captures six dimensions: the overall economic activity level; the industry pattern of output; the product pattern of foreign trade; energy-related expenditures; the quantity of energy used; and the revenue and expenditure of the public finance sector. An accompanying sensitivity analysis underlines the positive relationship between the expected economic effects of improved energy efficiency and the assumed scale of such technological progress, as well as the positive relationship between the magnitude of those consequences and the assumed substitution elasticity values. The obtained results can constitute an important contribution to a scholarly debate on the long-term impacts of decreasing per-unit energy use on the characteristics of Poland's economy and resulting policy challenges.

**Keywords**: computable general equilibrium, energy intensity, energy efficiency

**JEL classification codes**: C68, D58, Q43

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## Makroekonomiczne, sektorowe i fiskalne konsekwencje spadku energochłonności polskiej gospodarki

**Streszczenie**: Celem artykułu jest ocena skutków poprawy efektywności energetycznej zachodzącej w gospodarce Polski – kraju będącego jednym z liderów redukcji energochłonności na przestrzeni ostatnich dekad. Przeprowadzona analiza kontrfaktyczna wykorzystuje obliczeniowy model równowagi ogólnej (CGE) o nazwie GEMPOL, obejmując sześć wymiarów: ogólny poziom aktywności gospodarczej, gałęziowy wzorzec produkcji, produktowy wzorzec handlu zagranicznego, wydatki związane z energią, ilość zużywanej energii oraz dochody i wydatki sektora finansów publicznych. Przeprowadzona analiza wrażliwości uwypukla dodatnią zależność rozmiaru oczekiwanych ekonomicznych skutków poprawy efektywności energetycznej w Polsce od zakładanej skali tego rodzaju postępu technologicznego, a także dodatnią zależność rozmiaru tychże konsekwencji od przyjętych wartości elastyczności substytucji. Otrzymane wyniki mogą stanowić istotny wkład do dyskusji na temat długookresowego wpływu zmniejszania się jednostkowego zużycia energii na poszczególne sfery polskiej gospodarki, jak również płynących stąd wyzwań dla polityki gospodarczej.

**Słowa kluczowe**: obliczeniowy model równowagi ogólnej, energochłonność, efektywność energetyczna

**Kody klasyfikacji JEL**: C68, D58, Q43

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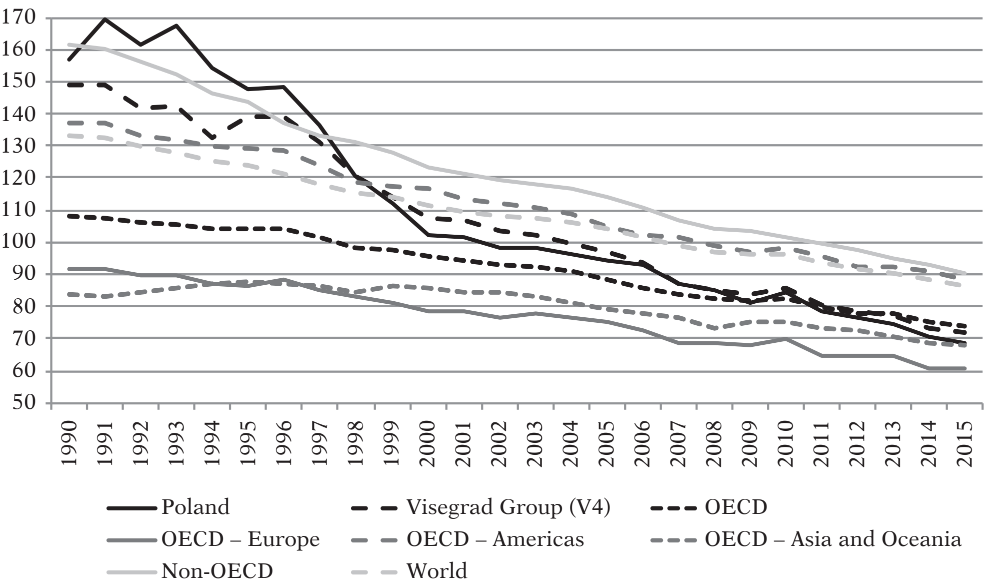
## Introduction

In the past, the implications of decreasing energy intensity (improving energy efficiency[2]) in an economy were narrowly defined as the savings resulting from lower energy use and lower energy-related expenditures. In recent years, a departure from such an approach has been observed towards measuring a wider range of *multiple benefits* resulting from lower energy use per output unit. It is nowadays argued that energy savings are not a single or unambiguously most important consequence of higher energy efficiency. Instead, this process is commonly seen as an important driver of socioeconomic development, which underlines the importance of fully understanding and quantifying all the related benefits. The International Energy Agency [2014] listed five aspects of social and economic life that are impacted by downward changes in energy intensity: *Macroeconomic development*; *Public budgets*; *Health and well-being*; *Industrial productivity*; and *Energy delivery*. The first, second and fourth of these aspects constitute the macroeconomic, sectoral and fiscal effects of energy efficiency improvements.

[2] Energy efficiency constitutes a reciprocal of energy intensity, which equals to the amount of energy used per unit of output. Hence, energy intensity improvements are equivalent to energy intensity declines.

Previous studies on the economic consequences of improving energy efficiency in the broad sense have in principle covered developed countries. None of these analyses focused on Poland even though the country has been among the global leaders in reducing the energy intensity of the economy, as compared to the 1990 s (see Figure 1). However, the question is whether this process was driven by actual technology improvements or rather by changes in the sectoral composition of the economy. Against this backdrop, Voigt et al. [2014] showed[3] that, for the vast majority of the 40 countries they analysed, technology improvements were responsible for a lion's share of the energy intensity decline between 1995 and 2007, while the impact of economic restructuring was much weaker. In Poland, energy intensity decreased by 49% over this period. Changes in the structure of the economy decreased energy intensity by 8%, while technological progress decreased per-unit energy use by 44%[4]. This paper is primarily focused on the latter effect.

**Figure 1. Changes in energy intensity in various regions of the world economy (toe/USD m, 2011 PPP*)**




* Total final energy consumption (toe) divided by GDP (millions of USD in constant 2011 prices and in purchasing power parity).

Source: own elaboration based on IEA [2017] and World Bank [2018] data.

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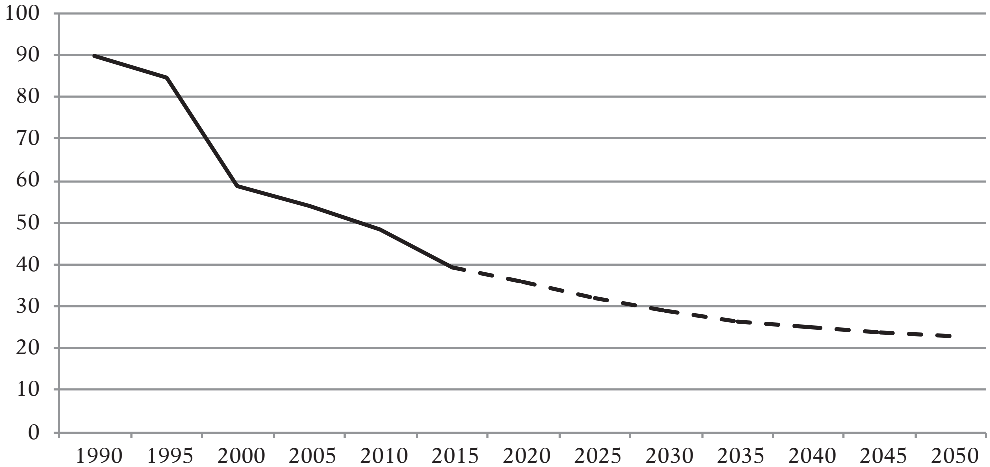
[3] This analysis was performed using the Logarithmic Mean Divisia Index (LMDI) method – see Ang [1999].

[4] Due to the multiplicative nature of the LMDI method, the two numbers related to the particular effects do not add up to the total figure.

However, historical changes in energy intensity do not necessarily need to be a good predictor for the future. Instead, future energy intensity can be assessed using technical-engineering projections derived from external sources. For Poland and other EU member states, such projections are compiled by the European Commission [2016]. According to these projections, Poland's energy intensity is expected to decrease further in the decades to 2050, by around 41% compared to 2015. The drop would be less pronounced than in the 1990–2015 period, when the country's energy intensity fell by around 56%. Overall, the energy intensity of the Polish economy would decrease by around 74% from 1990 to 2050 if the EU projections panned out (see Figure 2).

**Figure 2. Projected energy intensity of Poland's economy (toe/2010 PLN m)**




Source: own elaboration based on European Commission [2016], IEA [2017] and World Bank [2018] data.

Against this backdrop, this paper seeks to identify the main implications of decreasing energy intensity (improving energy efficiency) in Poland and trace how this process impacts the key characteristics of the country's economy, such as:

- level of economic activity, measured by basic macroeconomic aggregates;
- sectoral pattern of production and trade;
- pattern of household consumption and government expenditure;
- revenue and expenditure of the public finance sector;
- level of energy use – in the form of intermediate and final demand.

The paper focuses on analysing adjustment processes in the Polish economy triggered by improvements in the technological conditions of intermediate and final energy use, as well as on emphasising the challenges involved. Therefore, the article does not intend to assess the benefits and costs of specific policy measures aimed at improving energy efficiency.

To the best of the author's knowledge, this paper constitutes the first attempt to offer such a comprehensive analysis of the multiple, long-term economic implications (not determinants) of a decrease in Poland's energy intensity in macroeconomic, sectoral and fiscal terms – in line with the concept outlined by the IEA [2014]. Previous research treated those issues rather fragmentarily as it focused on measuring the benefits of investment aimed at improving energy efficiency [Bukowski et al., 2013] as well as on assessing how changes in taxation impact the effectiveness of natural resource use [Antosiewicz et al., 2016]. Other previous studies examined historical changes in Poland's energy intensity at the sectoral level, including inter-sectoral connections [Plich, Skrzypek, 2016] and aimed to identify eco-efficient sectors within the Polish economy [Gurgul, Lach, 2019a][5].

The paper is structured in the following way. After an introduction in this section, the next section briefly tracks the disaggregation of energy-related products and industries within GEMPOL, and the following one covers the main features and characteristics of the model. The three remaining sections present the details of the performed simulations; the obtained results; and the conclusions, respectively.

## Analytical toolbox – CGE model: GEMPOL

GEMPOL[6] (***G**eneral **E**quilibrium **M**odel for **Pol**and*) is a single-country CGE model of the Polish economy that distinguishes between 83 products and industries, as well as three labour skill groups, based on data provided by Timmer et al. [2015]: high-, medium- and low-skilled. The model covers a rich representation of direct and indirect taxes and/or subsidies: value added tax, excise duties, other product taxes, product subsidies, producer taxes/subsidies, and production factor taxes levied on labour and capital. GEMPOL is a recursive-dynamic model, solved as a mixed complementarity (MCP) problem in five-year intervals until 2050.

### Nesting structures

The production function structure[7] is industry-uniform (see Figure 3). At the top nest, non-energy materials are combined in fixed proportions with

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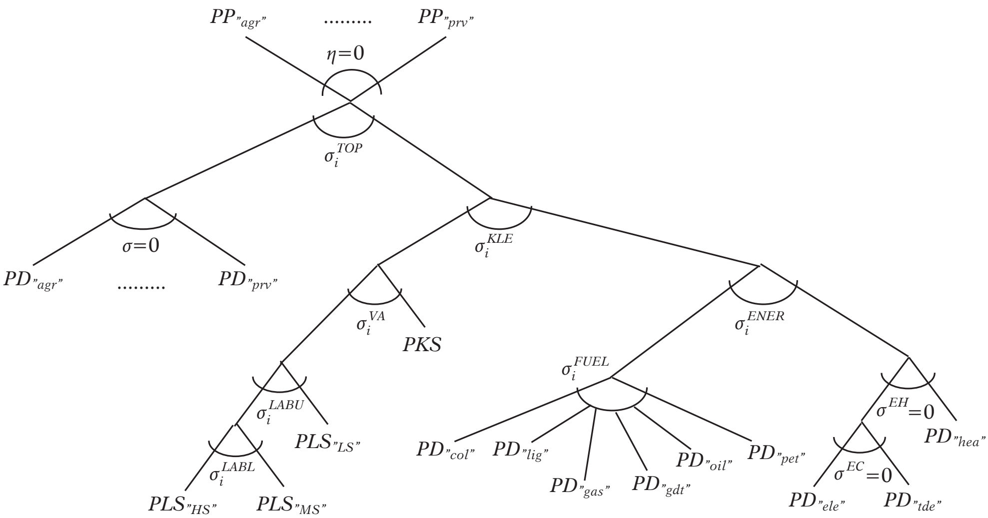
5 Notably, the last two of the analyses were based on input-output (IO) models. Within the framework of dynamic input-output models with endogenous coefficients, Gurgul and Lach [2016; 2019b] performed excellent simulations related to the long-term evolution of the sectoral composition of Poland's economy, combined with an identification of key sectors with the most influence on the rest of the economy. Further information on this area of research can be found in Lach [2020].

6 Antoszewski [2019a] provided a more detailed description of the GEMPOL model as well as a discussion on the appropriateness of using CGE models in analyses related to energy efficiency improvements. A full description of the model can be found in Annex 1 which is available on the article's website: https://doi.org/10.33119/GN/125464

7 The production and consumption functions discussed in this paper are based on the dual representation of cost functions. Therefore, all the variables presented on the nesting scheme graphs

the labour-capital-energy composite, which itself consists of value added and energy bundles. The former is made up of the labour composite (a combination of low-skilled labour and the aggregate of medium- and high-skilled labour), as well as of capital[8]. The latter constitutes a product of the electricity-heat bundle and the fossil fuels (hard coal, lignite, natural gas, gas distribution, crude oil, refined petroleum) aggregate. The electricity-heat composite combines fixed proportions[9] of electricity, its distribution and heat.

**Figure 3. Nesting structure of production function for industry *i***




$PLS_{"HS"} = (1 + ltx) \cdot PL_{"HS"}$

$PLS_{"MS"} = (1 + ltx) \cdot PL_{"MS"}$

$PLS_{"LS"} = (1 + ltx) \cdot PL_{"LS"}$

$PKS = (1 + ktx) \cdot PK$

* Annex 1 provides an explanation of the acronyms used.

Source: own elaboration based on Antoszewski [2019b], Beauséjour et al. [1995] and Rutherford [2010].

Domestic and imported (including tariffs) products are bound into Armington [1969] composites that are subsequently combined with fixed proportions of trade and transport margins[10], and afterwards augmented with excise duty

refer to particular prices inside the model. Such an approach was derived from Rutherford [2010]. Annex 1 contains an analogical representation of the model equations.

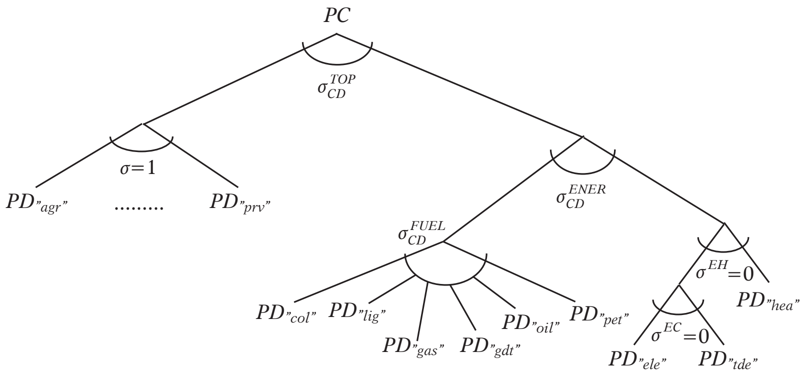
8 All primary factors are expressed in after-tax values.

9 This implies the lack of substitution possibilities between electricity, its distribution and heat. Technically, this pattern is captured by a Lenotief production function.

10 Trade margins constitute a Leontief combination of the products: *Sale and repair services of motor vehicles and motorcycles* (mvs), *Wholesale trade services* (whs), and *Retail trade services*

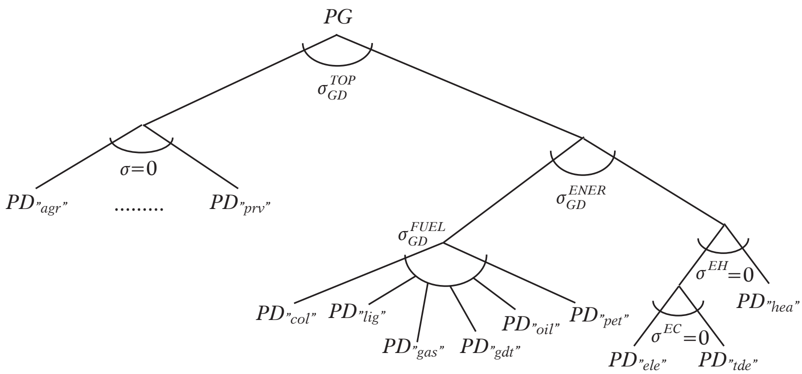
and other product taxes, adjusted for product subsidies. Finally, once value added tax is levied, this aggregate is split between domestic and export markets via a constant elasticity of transformation (CET) function.

**Figure 4. Nesting structure of household consumption**




* Annex 1 provides an explanation of the acronyms used.
Source: own elaboration based on Antoszewski [2019b] and Rutherford [2010].

**Figure 5. Nesting structure of government consumption**




* Annex 1 provides an explanation of the acronyms used.
Source: own elaboration based on Antoszewski [2019b] and Rutherford [2010].

Consumption and investment spending by households and the government constitute the domestic sources of final demand. The private and public consumption functions are nested in a similar fashion to the industry-uniform production functions (see Figures 4–5). Non-energy materials are put

(trd). Transport margins constitute a Leontief combination of the products: *Transmission, distribution and trade of electricity* (tde), *Land and pipeline transport services* (ltr), and *Water and air transport services* (wtr).

together with the energy composite at the top nest. For household (government) consumption, the non-energy materials composite aggregates non-energy products with the Cobb-Douglas (Leontief) function, which implies that the respective substitution elasticity equals one (zero). The energy composite is made up of the electricity-heat composite and the fossil fuels composite. The electricity-heat composite combines fixed proportions of electricity, electricity distribution services and heat. In addition, both private and public investment goods constitute Leontief composites of individual products purchased by households and the government.

Unlike the industry-uniform nesting structures, a vast majority of the substitution elasticities (σ) are industry- and product-specific (see Table A4 in Annex 1).

There are two economic agents within the model: households and the government. Households collect income from the remuneration of labour and private capital as well as from social transfers. Household expenditures include consumption and investment goods as well as product, producer and production factor taxes. The government obtains income from the remuneration of public capital and from product, producer and production factor taxes. Government expenditures include consumption and investment goods as well as product and producer subsidies and social transfers. The difference between the expenditures and revenues of the government is defined as the budget deficit, or the negative budget balance.

**Closure and numeraire**

The research problem under investigation is of a long-term and structural nature, unrelated to business cycle changes. This fact to a large extent determines the model's closure, which is consistent with neoclassical assumptions suited for long-term scenario analysis[11] (see Table 1). Notably, the exogenisation of the trade and budget balances originates from the need to preserve a stable internal (budget balance) and external (trade balance) equilibrium of the economy. As projections by the European Commission [2016] point to a continuous decline in energy intensity in both Poland and other EU member states, their economies should be expected to improve their competitiveness over time. However, under the framework of a single-country CGE model, it is assumed that the simulated energy efficiency improvement leads to greater competitiveness of Poland's economy against the rest of the world, whose energy intensity is implicitly treated as constant. Consequently, a relaxation of the fixed trade balance assumption could result in an uncontrolled increase or decrease of the budget and/or trade deficit, which is used to finance domestic expenditure, in response to assessed simulation shocks. Hence, the obtained simulation results should be interpreted as deviations

[11] The closure choice is one the most challenging aspects of setting up a CGE model since it constitutes a key determinant of simulation results. Therefore, the closure choice for a given CGE model is often put into question [Dietzenbacher et al., 2013].

of particular variables from the baseline scenario, under the assumption of a stable internal and external equilibrium of the economy.

**Table 1. Model's closure specification**

| Dimension | Characteristics |
|---|---|
| Labour | Fixed labour stock in a given year: mobile between industries, but immobile between skills. No unemployment. Market equilibrium guaranteed by adjustments of industry-uniform and skill-specific real wage. Exogenous changes of labour stock over time. |
| Capital | Capital stock fixed in a given year and immobile between industries. Market equilibrium guaranteed by adjustments of industry-specific real capital rental rates. Changes in total capital stock over time due to investment outlays. New capital directed to particular industries based on relative rates of return, corrected by depreciation. |
| Productivity | Fixed productivity of production factors and intermediate inputs in a given year. Exogenous productivity changes of labour and capital productivity over time. |
| Trade | Fixed real trade balance in a given year. Market equilibrium guaranteed by real exchange rate adjustments. Exogenous changes in trade balance over time. |
| Investment | Real private and public investment proportional, respectively, to real private and public consumption[12]. Investment determines the level of savings, as well as next period's capital stock. |
| Government | Endogenous real government consumption. Real government investment proportional to real government consumption. Real expenditure on social transfers, as well as real budget balance fixed in a given year, but exogenously changing over time. |

Source: own elaboration.

The reference price (*numeraire*) against which all changes in the remaining prices are interpreted is the price of household consumption, i.e. the consumer price index (CPI). This implies that all price changes within the model should be perceived in real terms – after correcting for inflation.

## Data sources: disaggregation of energy-related products and industries

The 2010 supply and use tables (SUTs) for Poland [CSO, 2014] constitute the key data source used in the calibration of the GEMPOL model. The data contains detailed information on the cost structure, intermediate and final demand, foreign trade, factor incomes and tax payments for 77 products and 77 industries within the Polish economy. However, one visible weakness of these tables is their excessive aggregation of energy-related commodities and industries (see Table 2). Consequently, this data does not make it possible to track changes in output and trade patterns in individual fossil fuel and

12 The adopted investment closure implies that the shares of real consumption and investment spending within both public and private real expenditures are constant over time. The rationale for such an approach can be implicitly derived from the famous Kaldor [1957] facts on the stability of key economic ratios over the long run – which is precisely the horizon of this analysis.

energy sectors in sufficient detail, and the same is true of intermediate and final demand for energy-related products. This issue was mitigated through a unique, in-house disaggregation of products and industries in publicly available supply and use tables. This in turn allowed for an increase in the number of products and industries from 77 to 83. Antoszewski [2019a] provided a comprehensive description of the entire splitting procedure.

**Table 2. Disaggregation of energy-related products and industries**

| Commodities/industries in supply and use tables *(CPA 2008/NACE Rev 2)* | Commodities/industries after disaggregation |
|---|---|
| *Coal and lignite (05)* | Hard coal |
| | Lignite |
| *Crude petroleum and natural gas, metal ores, other mining and quarrying (06-09)* | Crude petroleum |
| | Natural gas |
| | Metal ores, other mining and quarrying |
| *Electricity, gas, steam and air conditioning (35)* | Electricity |
| | Transmission, distribution and trade of electricity |
| | Distribution and trade of gas fuels |
| | Heat (steam and hot water) |

Source: own elaboration based on Antoszewski [2019a].

## Simulation design

The GEMPOL model, whose structure and key characteristics were discussed in previous sections, was used to carry out an empirical analysis. This comprised a quantification of the macroeconomic, sectoral and fiscal consequences of long-term energy efficiency improvements, including two important dimensions. The first one is a productivity increase for production processes within the Polish economy, i.e. a decrease in the energy intensity of individual industries, resulting from an improved efficiency of available production technologies. The second dimension captures a change in household and government preferences towards higher consumption of non-energy goods and services at the expense of energy-related products. Within this context, this second dimension can also be perceived as an improvement in the "efficiency" of using energy carriers by both households and the government, which makes it possible to increase the level of utility achieved from a given bundle of consumption goods. The simulations discussed in this chapter were carried out using the full-fledged version of the model, distinguishing 83 products and 83 industries, i.e. including the disaggregation of energy-related sectors, as described in the previous section[13].

[13] Detailed results of the performed simulations can be found in Annex 2 which is available on the article's website: https://doi.org/10.33119/GN/125464

The model's characteristics discussed in the previous section apply mainly to its static dimension. The supply and use tables present the state of the economy only in the base year 2010. For the purpose of conducting long-term simulations and analyses, it is however necessary to track the economic picture in the following years. This is possible by building a **baseline**—the so-called **business-as-usual (BAU) —scenario**, accompanied by the recursive dynamization of the model. After the initial solution for 2010, a transition to subsequent periods takes place, with the horizon of the analysis in 2050 and with a five-year interval. This horizon is determined by the availability of appropriate external projections, provided by the European Commission [2015, 2016]. Moreover, solving the model year by year would not actually be more informative because exogenous projections with an annual frequency would require interpolations of the projections available with the five-year interval.

The transition to the next period on the time path occurs through a modification of the values of the following parameters and the exogenous variables within the model:

- labour supply changes according to projections from the *2015 Ageing Report* [European Commission, 2015];
- availability of capital in a given industry evolves according to the accumulation equation: the capital stock in the subsequent period is the sum of undepreciated capital from the current period and the capital stock generated in the current period (by both the private and public sectors), directed to the given branch based on its relative profitability;
- labour and capital productivities evolve according to projections from the *2015 Ageing Report* [European Commission, 2015];
- real trade balance evolves in line with changes in the "effective" supply of labour – taking into account both the number of hours worked and labour productivity[14];
- real budget balance as well as real spending on social transfers evolve in line with changes in the "effective" supply of labour – taking into account both the number of hours worked and labour productivity.

Notably, the baseline scenario assumes no changes in energy intensity over the 2015–2050 period. This implies determining energy intensity in individual branches of the economy at a constant level, resulting from the calibration of the model parameters to the supply and use tables for the base year 2010 and taking into account the trends between 2010 and 2015 [European Commission, 2016].

The variables treated as endogenous within the model are adjusted in order to maintain the economic equilibrium in a given year. Their values can also be interpreted as projections conditional to the adopted exogenous assumptions.

The **central scenario** adopts almost the same set of exogenous assumptions as the baseline scenario, except for the changes in some technological param-

[14] See the actual numbers in Tables 8 and 10 in Annex 1.

eters related to energy products[15]. In contrast to the BAU, energy efficiency improvements occur not just between 2010 and 2015, but throughout the 2010–2050 period. The simulation shock reflects the expected energy efficiency improvement in specific industries, i.e. a decrease in energy intensity resulting from technological developments, and not from structural changes within the economy. From a technical point of view, an energy efficiency improvement boils down to an increase in the productivity of fossil fuels, electricity, heat, and related goods, i.e. a decrease in the per-unit use of products manufactured by a given branch. The products whose use is accompanied by the described increase in productivity include *Hard coal* (col), *Lignite* (lig), *Crude petroleum* (oil), *Natural gas* (gas), *Coke, refined petroleum products* (pet), *Electricity* (ele), *Transmission, distribution and trade of electricity* (tde), *Distribution and trade of gas fuels* (gdt), and *Heat/steam and hot water* (hea). The simulated increase in productivity affects equally all energy-related products used by a given industry, but its scale differs across the economy. Such an approach, common in the literature [Allan et al., 2006], stems from the unavailability of appropriate (i.e. with the fuel dimension) technical-engineering projections with respect to energy efficiency. It is also assumed that a further improvement in energy efficiency does not occur in energy-related sectors themselves. As noted by Allan et al. [2007], it is claimed that such industries already operate at their "thermodynamic limits", so it is not possible to increase their production volume while maintaining the current level of energy product consumption. Detailed information on the adopted projections of energy intensity changes in individual branches of the economy and within final consumption are presented in Table A9 in Annex 1. Their source is a report released by the European Commission [2016] and entitled *EU Reference Scenario 2016 – Energy, transport and GHG emissions – Trends to 2050*. This report provides projections of the macroeconomic and sectoral situation for individual EU member states, with particular emphasis on the energy sector, until 2050. These projections assume that economic policy measures agreed at the EU and national levels by the end of December 2014 will be fully implemented in the future.

It is the comparison of the results from the central scenario with those from the baseline (constant energy intensity) scenario that makes it possible to assess the macroeconomic, sectoral and fiscal implications of decreased energy intensity in Poland's economy over the considered time horizon.

The conducted simulations were also accompanied by a sensitivity analysis of the obtained results, comprising two dimensions. First, it measured the sensitivity of simulation results with respect to the scale of considered exogenous shocks, related to energy efficiency improvements over time. Its aim

15 This productivity improvement is treated as exogeneous and hence implies no direct costs for the economy. Such an approach stems from the fact that the European Commission [2016] did not explicitly provide information on such costs. Therefore, all the simulation scenarios in fact assess only the benefits of lower energy intensity. Consequently, the obtained results may be perceived as an upper band of potential net benefits related to energy efficiency improvements – under the assumptions of a given scenario.

was to highlight the uncertainty accompanying the European Commission's [2016] projections. For this purpose, simulation scenarios, alternative to the central scenario, were defined. In these scenarios, energy efficiency improves at a rate 50 percent faster (**low intensity**) or 50 percent slower (**high intensity**) than in the central scenario. Second, the sensitivity analysis measured the sensitivity of simulation results with respect to the assumed values of substitution elasticities within the production functions. The aim was to highlight the uncertainty accompanying their econometric estimation, as performed by Antoszewski [2019b] as well as McKibbin and Wilcoxen [1999]. For this purpose, additional simulation scenarios, alternative to the central scenario, were defined. They included a 50% decrease (**low elasticities**) and a 50% increase (**high elasticities**) in substitution elasticity values, as compared to the benchmark calibration of the model.

## Simulation results

The three following subsections present the results of the empirical analysis, which comprises a quantification of the macroeconomic, sectoral and fiscal implications of energy efficiency improvements in various sectors of Poland's economy until 2050 under the central scenario. The presented numerical values represent the percentage and absolute deviations of particular variables from their levels in the baseline scenario (BAU), which assumes fixed energy intensities at their 2015 levels. The fourth subsection provides a brief discussion of the sensitivity analysis of the simulation results with respect to the scale of energy efficiency improvement and the assumed values of substitution elasticities.

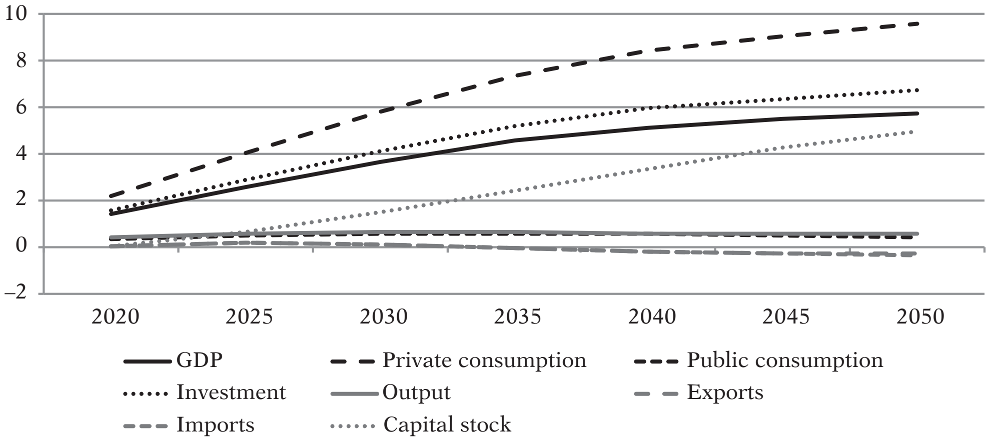
From the viewpoint of economic theory, the energy efficiency improvement in individual sectors of the economy is equivalent to the appearance of a positive technological shock connected with the "efficiency" of the intermediate and final use of particular product categories – in this case energy carriers. This context makes it possible to better understand the qualitative conclusions from this empirical analysis.

All the simulation results presented in the following subsections can be found in the tables in Annex 2.

### Macroeconomic results – central scenario

In macroeconomic terms, the gradual decrease of per-unit energy use in Poland's economy is obviously a positive process (see Figure 6). It translates into an increased level of real GDP and other real macroeconomic aggregates compared to the baseline scenario (BAU). Importantly, the deviations of particular variables from the BAU are, as a rule, increasing over time. This results from the fact that the differences between energy intensity in the central scenario and the baseline scenario, which assumes its stability at the 2015 level, become even greater over time. In particular, a further extension of the time horizon would point to a further increase in the deviations of particular variables from the baseline scenario – given that the exogenous projections suggested a further improvement in energy efficiency.

**Figure 6. Real macroeconomic aggregates (percentage change vs. BAU) – central scenario**




Source: own elaboration.

Due to the reduction in per-unit energy use against the baseline scenario, real GDP increases from 1.39% in 2020 to 5.68% in 2050. Private and public consumption grow from 2.19% and 0.33% respectively in 2020 to 9.52% and 0.41% in 2050. The relatively low upswing in real public consumption is due to a significant increase in its price. Hence, the increase in nominal public consumption is much stronger and similar to the increase in nominal budget revenues. In addition, investment increases from 1.58% in 2020 to 6.69% in 2050. Gross output rises as well, but far less markedly than GDP: from 0.40% in 2020 to 0.51% in 2050. This is because improving energy efficiency leads to a reduction in the "energy-related" intermediate use of manufactured products, in exchange for value added and "non-energy-related" intermediate use. As a result of GDP growing faster than gross output, the growth of total intermediate demand within the economy turns out to be markedly weaker than in the case of domestic demand[16], and may even enter negative territory[17]. The higher overall level of economic activity accelerates the process of capital accumulation, which increases its total stock from 0.62% in 2025 to 4.91% in 2050. Unlike other macroeconomic variables, the stock of capital in the economy starts to differ between the central and baseline scenarios, but not until 2025. This is because the level of capital in the current period is

[16] The Gross Domestic Product constitutes a sum of final expenditures within the economy, while the global output is a sum of both intermediate and final expenditures.

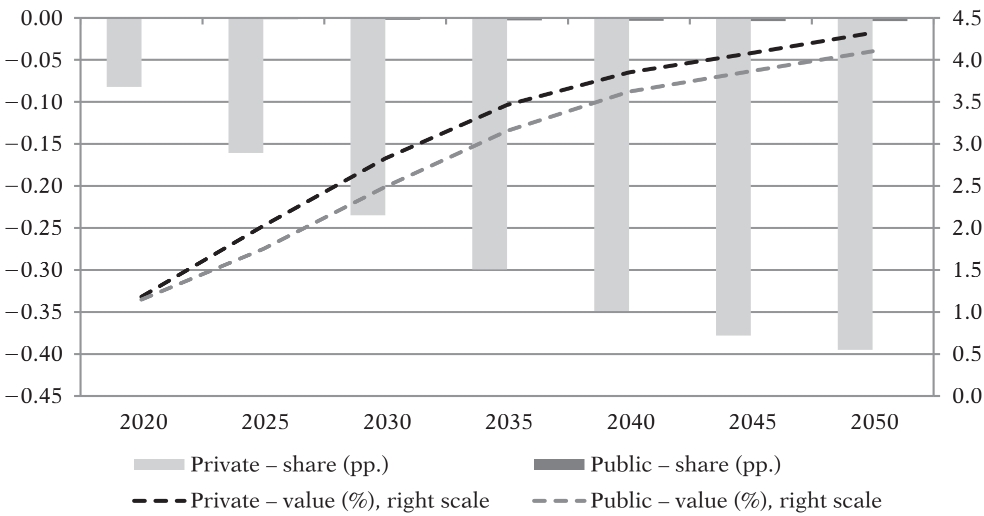
[17] In fact, the performed simulations point to a decrease in aggregate intermediate demand against the baseline.

determined by the investment volume from the previous period. Therefore, since the level of investment differs between scenarios starting in 2020, the level of capital stock shows such differences no earlier than 2025.

The changes in exports and imports are characterised by a similar trajectory. The initial years of the analysis show a steady albeit slow uptick, while the final period is marked by a somewhat more pronounced downward trend. In 2020, exports and imports are seen growing by 0.04% and 0.05% respectively, while in 2050, they are projected to decrease by 0.33% and 0.36% respectively. The almost parallel changes in exports and imports volumes stem from the adopted closure of the model, i.e. the fixed real trade balance in a given year. After the initial upswing, those volumes record a downswing, starting from 2035. This results from the fact that, over the initial periods, the effect of higher domestic demand and imports of non-energy goods and services, induced by a higher level of economic activity, outweighs the effect of lower domestic demand and imports of energy-related products – mainly fossil fuels. The relative magnitude of these effects reverses in 2035.

Looking at energy consumption, there is only a slight decrease in the percentage share of expenditures related to energy products (i.e. fossil fuels, electricity and heat) in the total consumption spending of households: from 0.08 p.p. in 2020 to 0.39 p.p. in 2050. In the case of the government, this share remains almost unchanged over the entire time path. In addition, due to the increased overall level of economic activity and the related increase in private and public income, the absolute value of private and public expenditures for such products shows an increase from 1.18% and 1.15% respectively in 2020 to 4.32% and 4.10% respectively in 2050 (see Figure 7).

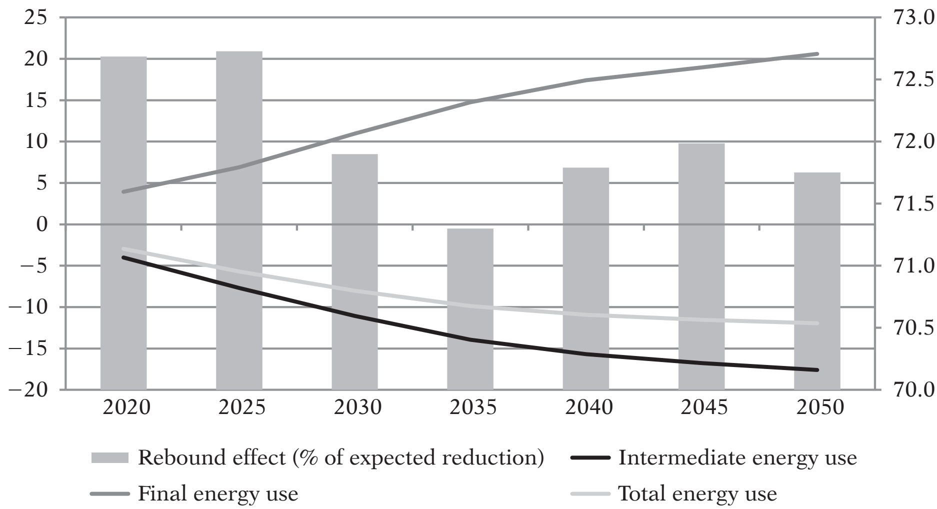
**Figure 7. Energy-related consumption expenditures (percentage points change vs. BAU) – central scenario**




Source: own elaboration.

Total energy use is reduced, and this reduction ranges from 2.95% in 2020 to 11.94% in 2050. It consists of a decrease in intermediate use (ranging from 4.02% in 2020 to 17.60% in 2050) and an increase in final use (ranging from 3.94% in 2020 to 20.60% in 2050) – see Figure 8. Therefore, it turns out that lower energy intensity makes the industries (source of intermediate demand) use less energy, but the energy use of households and the government (final demand) increases due to the income effect. The projections of the European Commission [2016] suggest that energy efficiency in the economy as a whole would improve from 10.81% in 2020 to 42.26% in 2050, compared with 2015. The relative decrease in energy use turns out to be much weaker than the relative decrease in energy intensity. This implies a relatively strong macroeconomic rebound effect[18], standing at approximately 71% to 73% – depending on the considered period.

**Figure 8. Energy use in the economy (percentage change vs. BAU) – central scenario**




Source: own elaboration.

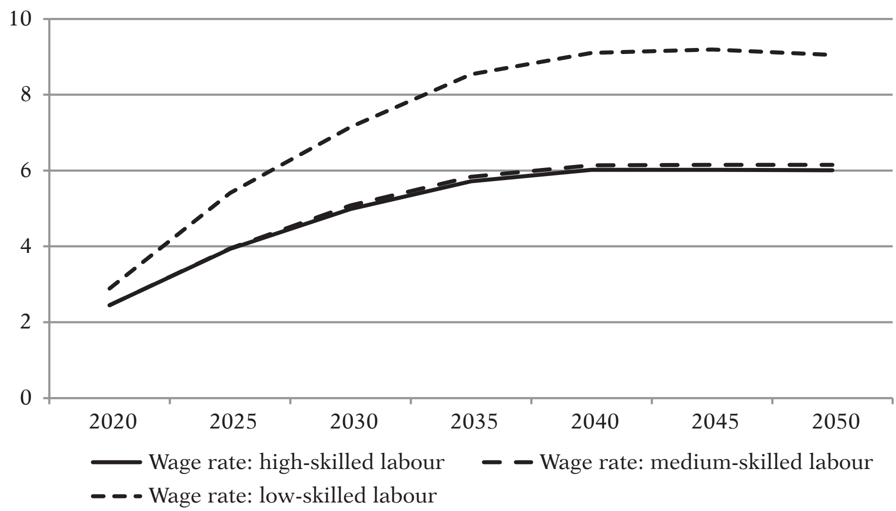
In response to the decline in energy intensity, remarkable increases can be observed in real wages[19]; they vary depending on the level of qualifications

[18] The rebound effect defines a situation in which the part of the total energy use reduction which results from the energy efficiency improvement is reversed by increased demand for energy carriers. Hence, the extent of this effect depends on changes in total energy use and changes in assumed per-unit energy use in the economy. Technically, the metrics of the rebound constitutes the difference between the expected energy use reduction, implied by the extend of the efficiency improvement, and the actual energy use reduction, divided by the expected reduction [Gillingham et al., 2016]. Both measures of energy use reduction are defined as a difference between the level of total energy use under the baseline and central scenarios.

[19] The reference price (*numeraire*) against which all price changes should be interpreted is the price of household consumption – the consumer price index (CPI). This means that any wage

(see Figure 9). These increases are the strongest in the case of low-skilled labour (from 2.89% in 2020 to 9.05% in 2050), followed by medium-skilled (from 2.45% in 2020 to 6.15% in 2050) and high-skilled labour (from 2.45% in 2020 to 6.01% in 2050). The higher increase in the unit cost of low-skilled labour in comparison to other qualification levels originates from the fact that the simulated energy efficiency improvement results in a decrease in the production volume of energy-related industries, accompanied by an increase in energy-intensive industries. Data provided by Timmer et al. [2015] indicates that energy-related industries are characterised by a relatively low share of low-skilled labour in total employment, while energy-intensive industries have a relatively high share of low-skilled labour in total employment. Due to the fixed labour supply of all skill types, low-skilled labour shows a stronger increase in demand than medium- and high-skilled labour, leading to a stronger upswing in remuneration.

**Figure 9. Real wages (percentage change vs. BAU) – central scenario**



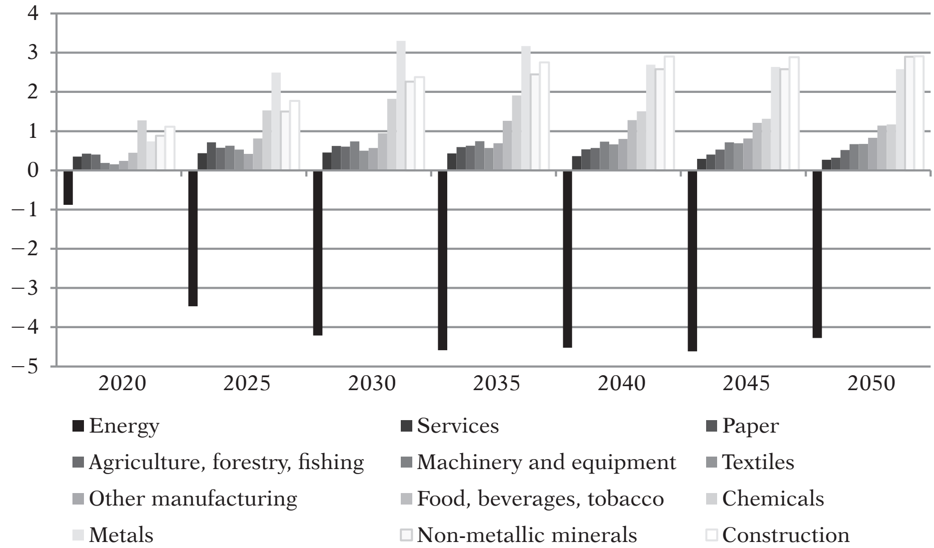

Source: own elaboration.

changes should be interpreted in real terms, i.e. after correcting for inflation. This also implies that the price of household consumption does not change between the scenarios. Its changes over time are purely technical and take place outside the model. It is assumed that the growth of household consumption price is equal to consumer inflation (CPI): in 2011–2018 consistently with historical data (CSO, 2020), and in 2019–2050 equal to the central bank's inflation target of 2.5% per annum. Such calculations are especially important for sectoral and fiscal variables expressed in current prices.

## Sectoral results – central scenario

For the sake of transparency, the obtained results were aggregated[20] from 83 to 12 product/industry groups[21] – after the model's calibration and the scenario runs. Such an approach also limits the granularity level of the simulation outcomes and increases their credibility in light of the model's limitations and the assumption made. Besides, it is of crucial importance to distinguish between the aggregation of the model's database before the calibration and the simulation runs and the ex-post aggregation of results obtained from simulations based on the disaggregated version of the model. Simulation outcomes based on the former approach (i.e. an over-aggregated CGE model) may turn out to be biased. This stems from the fact that excessive aggregation misses important details and insights on sectoral specificity (unobserved heterogeneity) and may lead to the model being misspecified [Alexeeva-Talebi et al., 2012; Caron, 2012]. Notably, Antoszewski [2019a] assessed the aggregation bias for the GEMPOL model based on energy efficiency improvement simulations.

**Figure 10. Output by industry groups (percentage change vs. BAU) – central scenario**



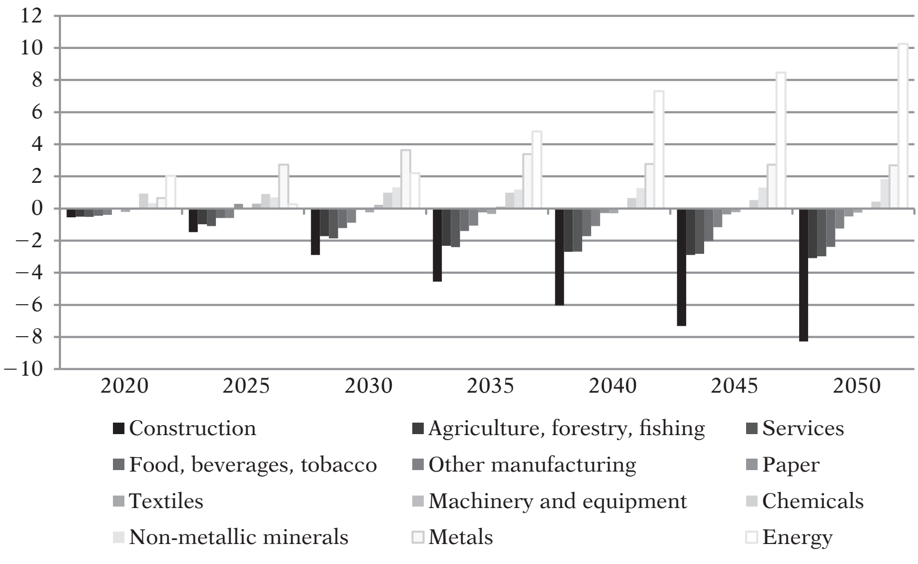

* The results have been ordered from minimum to maximum value of output changes.
Source: own elaboration.

Changes in production volumes in individual branches of the economy are the basic measure of sectoral heterogeneity for the impact of energy efficiency improvements (see Figure 10). Production volumes decrease in *Energy* indus-

[20] All the full-fledged, disaggregated results at the sectoral level are available upon request.
[21] Table A2 contains a sectoral aggregation scheme used in this procedure.

tries – with the drop ranging from 0.88% in 2020 to 4.28% in 2050. This is connected with a strong decline in demand for core products manufactured by those industries, resulting from their lower use in production and consumption processes. The highest increase in production volumes is experienced by branches with a high level of energy intensity, such as *Construction*, *Non-metallic minerals* and *Metals*. This is because these industries report the greatest improvement in competitiveness among all industry groups, in part due to their highest initial share of energy-related expenditures and an accompanying decline in the prices of energy carriers. Consequently, the respective production volumes of these branches increase from 1.11%, 0.88% and 0.74% in 2020 to 2.91%, 2.90% and 2.58% in 2050. Notably, all the remaining industry groups – not only energy-intensive industries – also record higher production volumes as a result of an increased overall level of economic activity. At the disaggregated level, 53 of the economy's 83 branches experience a rise in production volumes in the horizon of 2050.

**Figure 11. Exports by product groups (percentage change vs. BAU) – central scenario**

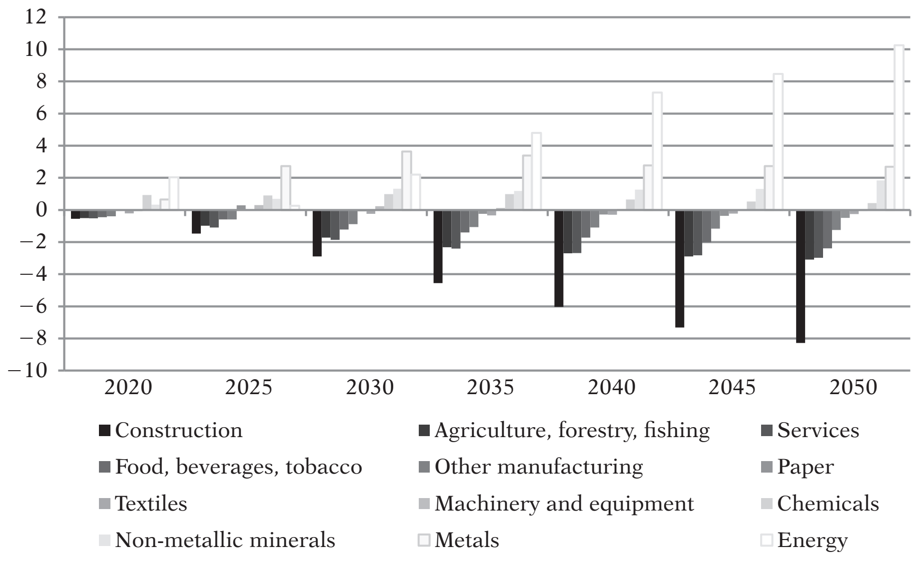



* The results have been ordered from minimum to maximum value of export changes.
Source: own elaboration.

The product pattern of export changes is totally different from the changes in output volumes in specific industry groups (see Figure 11). The largest drop in export volumes is recorded in the case of product groups that experience a strong increase in domestic demand, such as *Construction*; *Agriculture, forestry, fishing*; *Services*; and *Food, beverages, tobacco* – ranging from 0.55%, 0.50%, 0.52% and 0.45% respectively in 2020 to 8.28%, 3.09%, 2.97% and 2.39% in 2050. The strongest export growth occurs in the case of *Energy* products that record a decline in domestic demand as well as the most energy-intensive industrial products that experience a significant increase in relative competitiveness, such as *Metals* and *Non-metallic minerals* – from 2.03%, 0.66% and 0.33% respectively in 2020 to 10.25%, 2.69% and 1.84% in 2050. At the disaggregated level and in the horizon of 2050, a decline in export volumes is observed for 51 of 66 exportable products.

In addition, the product pattern of import volume changes is very different from that for output and export volumes (see Figure 12). As a result of decreased domestic demand for fossil fuels and energy carriers, the largest drop in import volumes is observed for *Energy* products – ranging from 5.78% in 2020 to 22.92% in 2050. This allows for a redirection of spending streams to the purchase of foreign non-energy goods and services, whose imports in turn experience the strongest growth. These include *Construction*; *Food, beverages, tobacco*; *Agriculture, forestry, fishing;* and *Other manufacturing*. The imports of these goods and services increase, respectively, from 2.53%, 1.04%, 1.14% and 0.99% in 2020 to 13.81%, 4.11%, 3.93% and 3.79% in 2050. For the majority of energy-intensive industrial product groups, the import volumes show an upswing despite an improvement in the relative competitiveness of domestic production and an accompanying increase in exports. This results from the strong import intensity of domestic energy-intensive industries. At the disaggregated level and in the horizon of 2050, import volumes increase for 55 of 70 importable products.

**Figure 12. Imports by product groups (percentage change vs. BAU) – central scenario**

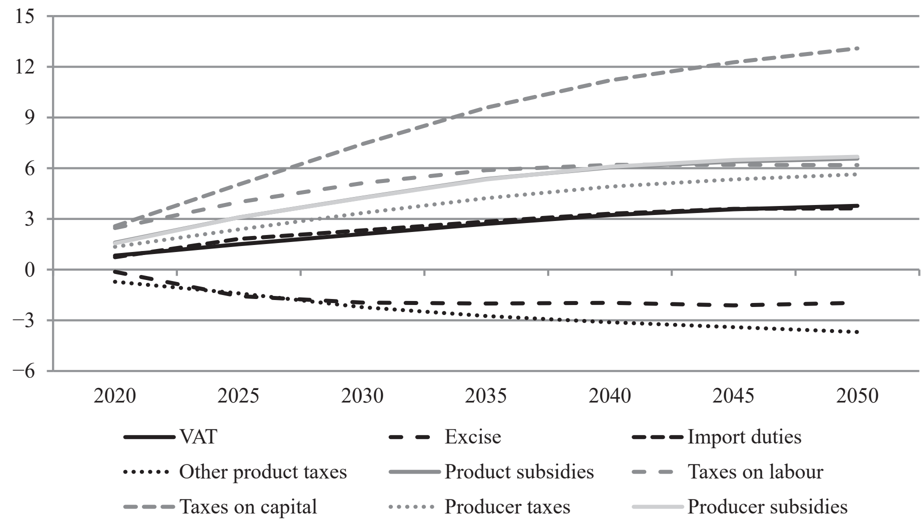



* The results have been ordered from minimum to maximum value of import changes.
Source: own elaboration.

### Fiscal results – central scenario

In addition to the macroeconomic and sectoral effects of the decreased energy intensity of production and consumption, fiscal consequences, such as changes in revenues and expenditures in the public finance sector, are also of great importance. It is not justified to *a priori* exclude a potential increase in income from certain types of taxes and assets held, at the expense of a decline in revenues from other sources. Hence the question arises about the net effect, i.e. the direction of changes in total budget revenue[22].

**Figure 13. Budget revenues and expenditures (percentage change vs. BAU) – central scenario**




Source: own elaboration.

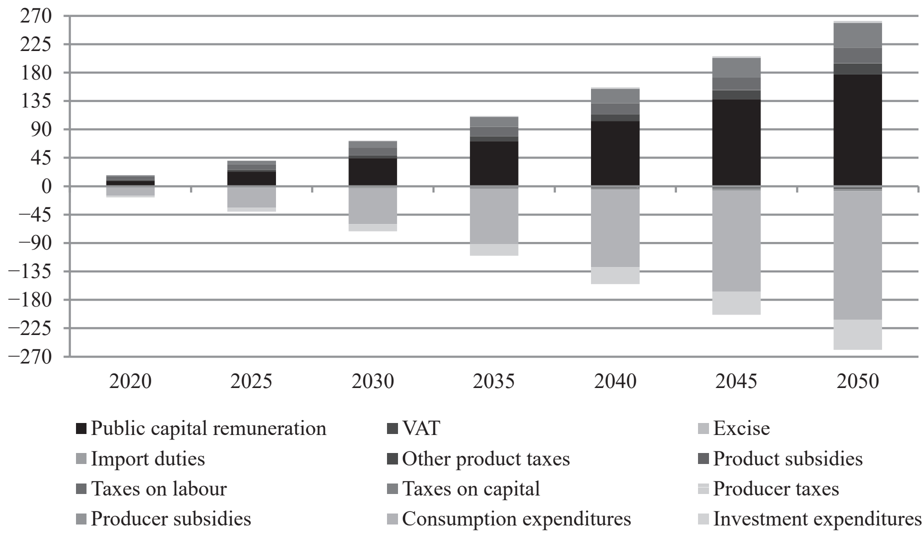
The obtained results confirm the existence of such a tax trade-off (see Figure 13). An increased overall level of economic activity leads to an increase in revenue from value added tax (from 0.83% in 2020 to 3.77% in 2050) and taxes on producers[23] (from 1.35% in 2020 to 5.63% in 2050). The acceleration of capital accumulation and the consequent increase in capital stock result in higher revenues from capital taxes (from 2.57% in 2020 to 13.09% in 2050).

22 Obviously, fiscal outcomes are to a large extent driven by the adopted closure of the model, which is however determined by the long-term nature of the considered research problem.

23 The use table compiled by the Central Statistical Office (2014) lists only *Taxes on producers minus subsidies for producers*. It does not separately identify taxes paid by producers in various branches of the economy and the received subsidies, but only provides the net effect of these operations. Therefore, a technical assumption has been made to treat the positive value of producer taxes minus subsidies in a given industry as the tax on producers, while treating the negative value as a subsidy for producers. This also implies that it is not possible to track both of these categories simultaneously within a single branch of the economy.

Increased import volumes and/or changes in their structure – in favour of industrial goods with relatively high duty rates, at the expense of energy carriers with relatively low duty rates – result in higher revenues from import duties (from 0.73% in 2020 to 3.62% in 2050). An increase in wages leads to higher revenues from labour taxation (from 2.46% in 2020 to 6.19% in 2050). On the other hand, there are revenue losses from excise duties (from 0.13% in 2020 to 1.97% in 2050) and other taxes on products (from 0.71% in 2020 to 3.70% in 2050), the key component of which is a fuel surcharge imposed on the product *Coke, refined petroleum products* (pet). In addition, an increased overall level of economic activity and a growing production volume result in higher spending on subsidies for producers (from 1.56% in 2020 to 6.68% in 2050) as well as on manufactured products (from 1.60% in 2020 to 6.57% in 2050).

**Figure 14. Budget revenues and expenditures (change in bn PLN vs. BAU) – central scenario**




* Expenditure categories are expressed in negative terms.
Source: own elaboration.

From the viewpoint of the public finance sector, however, the key role is played by absolute, not percentage, changes in income from various types of taxes and from assets held (see Figure 14). In this perspective, the largest increase in budget revenues is related to the acceleration of capital accumulation and the consequent increase of its resources in the economy. As a result, receipts from the remuneration of capital held by the public sector increase from PLN 8.64 billion in 2020 to PLN 176.92 billion in 2050, while revenue from capital taxation, both private and public, rises from PLN 1.93 bn in 2020 to PLN 39.51 bn in 2050. An important role is also played by rising revenue from labour taxation (from PLN 5.45 bn in 2020 to PLN 24.08 bn in 2050) and value added tax (from PLN 1.31 bn in 2020 to 17.81 PLN bn in 2050). The increase in revenue from producer taxes (from PLN 0.26 bn in 2020 to PLN 3.22 bn in 2050) and import duties (from PLN 0.02 bn in 2020 to PLN 0.29 bn in 2050) is much smaller. In this context, revenue losses from excise duties (from PLN 0.08 bn in 2020 to PLN 1.92 bn in 2050) and from other taxes on products (from PLN 0.10 bn in 2020 to PLN 1.53 bn in 2050) do not seem to be significant. Also insignificant is an increase in spending on subsidies to producers (from PLN 0.22 bn in 2020 to PLN 2.89 bn in 2050) and subsidies to manufactured products (from PLN 0.11 bn in 2020 to PLN 1.43 bn in 2050). In summary, there is a strong increase in budget revenue in net terms, accompanied by increased public spending in terms of both consumption (from PLN 14.62 bn in 2020 to PLN 203.81 bn in 2050) and investment (from PLN 2.47 bn in 2020 to PLN 47.45 bn in 2050).

The changes in the overall budget balance relative to the baseline scenario do not add up exactly to zero because Figure 14 presents public revenues and expenditures in nominal terms. The exogeneity of the budget balance refers to its expression in real terms, i.e. excluding changes in particular price categories. These changes have a varying influence on the nominal values of particular revenue and expenditure categories.

**Sensitivity analysis**

This section provides a brief description of the simulation results for all the alternative scenarios. As a rule, the reactions of individual variables in the low/high energy intensity scenario are stronger/weaker than in the central scenario. This is chiefly because of a greater/smaller improvement in simulated energy efficiency. In addition, the reactions of particular variables in the high/low elasticities scenario are stronger/weaker than in the central scenario because the economy reacts more/less flexibly to simulated energy efficiency improvements. Some more complex outcomes, especially for macroeconomic and fiscal variables, are discussed below in more detail.

The above general conclusion is especially true of macroeconomic aggregates and capital stock in the low and high intensity scenarios. However, this pattern is to some extent different for alternative elasticity values. Both public consumption and gross output volumes in the low elasticities scenario are not only lower than in the central scenario, but also record a downswing compared to the baseline. Such an outcome for public consumption results from a decline in budget revenues from value added tax and energy taxation (i.e. excise tax and other product taxes), as well as a sluggish upturn in revenues from labour taxes. For gross output, this is caused by the lower potential of the economy to take advantage of higher energy productivity and to substitute cheaper energy for other inputs in order to boost domestic output of non-energy industries. Another contributing factor is the resulting lower output of energy-related industries. Moreover, lower substitution possibilities limit flows of production factors from energy-related to non-energy-related industries, which limits the output volume increase in the latter group. An interesting pattern can also be observed for energy use. In the low/high energy intensity scenario, the downswing in intermediate and total energy use and the upswing in final energy use are stronger/weaker than in the central scenario. The scale of the rebound effect is negatively related to the size of energy efficiency improvement, but the differences are less crucial than for energy use. This can be explained by the different speed of capital accumulation, and the faster the rate of capital accumulation, the deeper the decrease in energy intensity. A higher supply of capital yields greater possibilities to substitute intermediate products, including energy, with capital in production processes. This makes it possible to curb the upward pressure on energy use resulting from a higher level of economic activity. In the high/low elasticities scenario, the downswing in intermediate and total energy use is weaker/stronger than in the central scenario. Final energy use in the low elasticities scenario stays not only below the level observed in the central scenario, but also shows a decrease against the baseline. This is due to a sluggish upturn in income and a limited scale of substitution of non-energy production inputs with energy.

The share of energy-related expenditures in the total consumption spending of households and the government falls with the rate of energy efficiency improvement: the faster the rate of energy efficiency improvement (or, equivalently, the lower the energy intensity) the lower the share of energy-related expenditures. However, the scale of the observed differences is relatively small. Notably, the absolute value of energy-related spending (both private and public) increases against the baseline regardless of how strong the energy efficiency improvement is. The increase is the greater, the lower the energy intensity assumed in a given scenario. This finding is consistent with the positive relationship between the speed of energy efficiency improvements and the upswing in final energy use, as discussed in the previous paragraph. The impact on relative and absolute energy-related spending is much more pronounced for various substitution elasticity values. In the low elasticities scenario, both relative and absolute expenditures show a significant downswing, which originates from the limited possibilities of substituting relatively cheaper energy for other production inputs. Exactly the opposite is true for the high elasticities scenario as more pronounced substitution towards cheaper energy drives an increase in such spending, in both relative and absolute terms. In particular, this relative increase implies that the absolute upturn in energy-related consumption is stronger that the increase in total consumption stemming from higher private and public incomes.

Given the fixed supply, the greater the substitution elasticity values, i.e. the flexibility of the economy, the greater the upswing in economic activity and labour demand, and the stronger the increase in real wages. In contrast with the other scenarios, the upturn in low-skilled wages in the low elasticities scenario is much more evident than in the case of medium- and low-skilled wages. This can be attributed to the large slump in the output of *Energy* industries and the related decline in labour demand, as those industries mainly employ medium- and high-skilled labour.

Due to limited space, this section does not extensively discuss the sectoral outcomes. However, the pattern of heterogeneous reactions for individual sectors of the economy does not differ drastically between the scenarios, while the differences in the obtained results are to a large extent connected with the size of energy efficiency improvements or the flexibility of the economy, proxied by substitution elasticity values[24].

The direction of changes in public revenues from particular taxes and in public expenditures on particular subsidies against the baseline remains unchanged across various energy intensity scenarios. Namely, revenues from value added tax, import duties, producer taxes, as well as labour and capital taxes show an upswing. Moreover, an increase can be observed in spending on subsidies to products and producers. In contrast, there is a decrease in revenues from excise duty and other product taxes, the key component of which is a fuel surcharge imposed on the product *Coke, refined petroleum products* (pet), manufactured by specific industries. In absolute terms, the deviations of budget revenues and expenditures in the low/high energy intensity scenario are stronger/weaker than in the central scenario. However, this picture is more complex for various elasticity values. Although the increase in revenues from import duties as well as from labour and capital taxes is positively linked to the assumed values of substitution elasticities, such a relationship ceases to hold and becomes much more complex for other revenue categories. Revenues from value added tax decrease in the low elasticities scenario due to changes in output composition: lower output of highly taxed *Energy* goods is accompanied by higher output of manufacturing products subject to lower effective tax rates. For the same reason, a slump can be observed in revenues from energy taxation, i.e. excise and other product taxes. In the high elasticities scenario, a noticeable upturn in revenues from VAT and excise and other product taxes stems from an increased output volume in *Energy* industries. Product and producer subsidies exhibit an even more complicated pattern of changes. Product subsidies display the strongest increase in the central scenario, followed by the low elasticities scenario and the high elasticities scenario. This pattern constitutes an outcome of output changes in two product groups with the highest subsidy rates: *Agriculture, forestry, fishing* and *Services*. For the former, the strongest output growth is observed in the low elasticities scenario, followed by the central scenario and the high elasticities scenario. For the latter, the strongest output growth is observed in the high elasticities scenario, followed by the central scenario and the low elasticities scenario. Producer subsidies show a stronger/weaker upswing from the baseline in the low/high elasticities scenario than in the central scenario – not the other way around. This is related to the pattern of output changes in heavily subsidised *Agriculture, forestry, fishing* industries.

The detailed results of the sensitivity analysis are provided in Tables A10–A12 and A14–A15 in Annex 2.

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[24] The detailed sectoral results of the sensitivity analysis are available upon request.

## Conclusion and policy implications

The main purpose of this paper was to conduct a comprehensive examination of the macroeconomic, sectoral and fiscal implications of improving energy efficiency in Poland, which has been a global leader in reducing the energy intensity of the economy in recent years.

On the basis of the obtained results, a number of research conclusions can be drawn. Notably, all the results mentioned below are expressed as differences against the baseline of constant energy efficiency. First, a continuing decrease in the energy intensity of the Polish economy should increase the overall level of economic activity. Second, a heterogeneous pattern can be observed for sectoral output changes, with a clear decline in production in energy-related industries, accompanied by greater activity of energy-intensive industry groups. Third, the product pattern of foreign trade should change significantly. The imports of energy-related products are likely to fall, while imports of non-energy goods and services as well as energy-intensive products are expected to increase. Higher exports of energy-intensive products are accompanied by lower exports of non-energy goods and services. Fourth, only a slight decrease might be expected in the shares of energy-related expenditures in total consumption spending. However, the absolute value of such expenditures should grow. Fifth, simulated energy efficiency improvements lead to lower public sector revenues from the taxation of energy products. However, this decrease is more than offset by higher income from other sources, resulting from an increase in the overall level of economic activity. As a result, government spending can be expected to increase. Sixth, total energy use decreases due to lower intermediate demand coupled with higher final demand. In relative terms, the downswing in total energy use turns out to be smaller than the decrease in energy intensity, which implies the occurrence of a rebound effect.

The sensitivity analysis conducted in this study emphasises the positive relationship between the expected, economic effects of energy efficiency improvements in Poland and the assumed scale of such technological progress, as well as a positive relationship between the magnitude of those economic consequences and the assumed substitution elasticity values. Therefore, the obtained results should be viewed as conditional on the adopted projections for per-unit energy use changes in the Polish economy until 2050, as well as on the assumed values of substitution elasticities within the production functions.

The results obtained from this research can be viewed as an important contribution to a scholarly debate on how decreased per-unit energy use impacts the key characteristics of the Polish economy in the long term, as well as on what effect this has on resulting policy challenges. Notably, similar research and analytical activities will be welcome as long as Poland's economy continues to improve its energy efficiency. And there are no indications that this process could end anytime soon.

There are three directions in which the conducted research can be extended. First, energy efficiency changes could be modelled not only as sector-specific, but also as fuel-specific. However, such an approach is currently limited by the unavailability of detailed energy intensity projections. Second, non-linear changes could be introduced in consumption demand for specific products in response to both private and public income changes. The currently used CES consumption functions are characterised by unitary income elasticities of demand, which implies the constancy of expenditure shares for particular commodities against income changes (keeping their prices fixed). In order to relax this assumption, alternative functional forms could be used, such as the Stone-Geary function [Stone, 1954], also known as the linear expenditure system (LES), or An Almost Ideal Demand System (AIDADS), proposed by Deaton and Muellbauer [1980]. However, the calibration of such systems is much more parameter-demanding than in the case of the CES function as they need to be fed with information on price and income elasticities as well as on the minimum required level of consumption for specific products. Third, the analysis could directly take into account energy intensity changes taking place outside Poland. This would call for the construction of a global CGE model, one explicitly covering not only Poland, but also all the other countries and regions of the world economy. In order to calibrate this model with appropriate data, databases such as the Global Trade Analysis Project [Rutherford, 2010] or the World Input-Output Database [Timmer et al., 2015] could be used. However, those datasets provide fewer details in sectoral and fiscal terms than the supply and use table complied by the CSO [2014]. Hence a model calibrated to one of them would provide much less insight into sectoral and fiscal aspects than the GEMPOL model.

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