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Macroeconomic, sectoral and fiscal consequences of decreasing energy intensity of the Polish economy

Summary of a PhD thesis

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Warsaw, February 2019

1) Introduction

Due to the acceleration of the economic growth rate, on an unprecedented scale that had not been recorded before the industrial revolution, the global energy use also recorded a sharp increase in comparison with the levels from the mid-nineteenth century. At the beginning of this process, the increase in the economic activity was associated with an almost proportional increase in energy use. This implied an approximately constant energy intensity of the economy, i.e. the amount of energy required to produce a unit of a product. However, a gradual decoupling of the growth in energy use from the growth in economic activity, measured by the GDP changes, has started to be observed over time (Metcalf, 2008). This phenomenon has strengthened over the last decades (Allcott, Greenstone, 2012). Decoupling was, and still is, caused by a number of factors that can be attributed to three phenomena (Matheny, 2010). Firstly, a structural change within the developed economies – a departure from the energy-intensive industry towards the services with a low energy use per unit of output – had a major impact on this process. Secondly, the technical progress played a key role in reducing the energy intensity of the production processes (Sorrell, 2007). This phenomenon is equivalent to an increase in energy productivity, i.e. an improvement of energy efficiency, defined as the value added/product that can be generated from a unit of energy (Mulder, de Groot, 2004; Barker, Foxon, 2008). Thirdly, the energy intensity decline constituted and still constitutes an adjustment process of the economy to the external shocks, as well as the economic policy measures. Such shocks included the rapid changes of commodity prices in the 1970s (Metcalf, 2008), while the economic policy tools comprised the activities related to the environmental and climate policy challenges and the need to ensure a sustainable development (Mulder, de Groot, 2004).

The previous research on the consequences of decreasing energy intensity of the economies, i.e. improving their energy efficiency, was only limited to a measurement of the direct savings related to the reduction of energy use – in a form of the reduced energy-related expenditures. The broadly understood, direct and indirect economic benefits of the decrease in the energy intensity of the economies are however much higher (Environment Northeast, 2012), but their scale is commonly underestimated (Ecofys, 2013). It is therefore extremely important to fully understand the socio-economic consequences of this phenomenon. A reduction of the per unit energy use spills over the entire economy, triggering a number of positive chain reactions. From the economic perspective, the consequences of the energy intensity decrease that are particularly interesting, are those of the macroeconomic, sectoral and fiscal type. Therefore, a gradual departure from such a narrow approach, limited only to measuring the reduction of energy demand, towards the identification and quantification of a wide spectrum of the socio-economic benefits resulting from the energy efficiency improvement has been observed over the recent years. However, such benefits have not been comprehensively and systematically analysed so far – also at the level of individual economies. The first step in this direction was taken by the International Energy Agency (IEA), which enumerated five main areas affected by the improvement of the energy efficiency (IEA, 2014):

1) Macroeconomic development;
2) Public budgets;
3) Health and well-being;
4) Industrial productivity;
5) Energy delivery.

In this context, the energy efficiency is perceived as an "abundant, clean and low-cost energy resource" that allows to reduce the impact of high energy costs, improve the productivity, spur the economic growth and reduce the environmental burdens (Environment Northeast, 2012). It should also be noted that the decline in the energy intensity of the world economy is a permanent process, hence its continuation in the future is also commonly expected (Matheny, 2010). For this reason, research on the economic responses to the expected energy efficiency improvement is still required.

The previous studies on the broadly defined, economic consequences of energy efficiency improvements have been focused on the developed countries. None of those analyses concerned however Poland – a country that has been one of the leaders in reducing the energy intensity of the economy, starting from the nineties of the twentieth century. Hence, the purpose of this dissertation is to fill this research gap by identifying the consequences of the ongoing energy intensity decrease (energy efficiency improvement) for particular spheres of the Polish economy, including:

- the overall level of economic activity, measured by the main macroeconomic aggregates;
- the sectoral structure of production and employment;
- the structure of the trade balance and the competitiveness of the economy;
- the pattern of household consumption and the structure of government expenditures;
- the revenues and expenditures of the general government sector;
- the level of energy consumption – in a form of intermediate and final demand.

Due to the availability of adequate economic modelling techniques, this dissertation focuses on the first, the second and, to some extent, the fourth of the five thematic areas identified by the IEA (2014). These areas can be described as macroeconomic, sectoral and fiscal consequences of the decreasing energy intensity of economic activity. The economic consequences of a decrease in energy intensity can also be divided into two groups:

- demand-side effects – related to the increase in investment outlays aimed at improving the energy efficiency;
- supply-side effects – related to the reduction of energy costs.

Within both of the groups, one can also distinguish direct and indirect effects, the latter being related to the general equilibrium mechanisms functioning in the economy. Noteworthy, the supply-side effects may also occur without any specific investments in energy-efficient goods and services. In such a situation, they are a consequence of the technological progress and the so called autonomous energy efficiency improvement (AEEI). It is estimated that direct and indirect effects related to the decrease in energy-related expenditures play a much more important role than the direct and indirect investment effects, and account for 88-91% of the total macroeconomic consequences (Malone et al., 2009). Moreover, modelling the impact of various investment programmes aimed at improving energy efficiency requires detailed information on their subjective and objective scope, the value and source of financing, or the time frame. For this reason, this dissertation analyses only the second type of those effects, i.e. those related to the energy cost reduction.

To the best of the author's knowledge, this dissertation constitutes the first attempt to comprehensively analyse the multiple, long-term economic consequences of the decreasing energy intensity of Poland's economy in macroeconomic, sectoral and fiscal terms. The previous research conducted in this area focused on measuring the benefits of investments aimed at improving the energy efficiency (Bukowski et al., 2013), on the assessment of the impact of changes in the taxation structure on the effectiveness of using the natural resources in the economy (Antosiewicz et al., 2016), or on the analysis of historical changes in the energy intensity at the sectoral level, including the inter-sectoral linkages (Plich, Skrzypek, 2016). It should be clearly emphasized that the conducted research focuses on the analysis of the adjustment processes in the Polish economy, whose occurrence should be expected in response to the improvement of technological conditions of the intermediate and final energy use, as well as on emphasizing the challenges arising thereof. Hence, it does not intend to assess the benefits and costs associated with using specific economic policy tools, aimed at improving energy efficiency.

This PhD thesis consists of six parts: the introduction, four chapters labelled with the numbers 2-5 and the summary. Chapter 2 presents the historical background of the research related to the energy efficiency improvement within the economic processes. It also discusses the factors determining this phenomenon and a wide spectrum of its consequences, reaching far beyond the reduction of the energy-related expenditures. In addition, it refers to the previous research on the macroeconomic, sectoral and fiscal consequences of the declining energy intensity of the economies. This chapter concludes with an analysis of the current trends of energy intensity changes in Poland's economy, as well as their expected future development. Chapter 3 presents the computable general equilibrium (CGE) models, which are an appropriate tool for conducting economic analyses regarding the effects of the changes in energy intensity/energy efficiency of the economic processes. Chapter 4 describes the analytical tool used in this dissertation – an in-house, multisectoral CGE model calibrated for the Polish economy – called GEMPOL (*General Equilibrium Model for Poland*). This chapter describes the partucular stages of the construction of the model GEMPOL, as well as its key characteristics. Chapter 5 presents the results of an empirical analysis carried out with the use of the model GEMPOL. This analysis comprises an examination of the macroeconomic, sectoral and fiscal consequences of the long-term energy efficiency improvement. The summary includes a wrap-up of the results obtained, as well as of the most important conclusions that can be drawn from the empirical analysis.

2) Literature review

Allan et al. (2007b) noted that energy plays a much more important role in stimulating the economic growth than it is generally believed to. From the macroeconomic point of view, the question of whether the improvement of energy efficiency is a one-off phenomenon or is an ongoing process is extremely important. Only a continuous kind of this process can have a lasting impact on the economic growth, while a one-off drop in the energy intensity leads only to a sharp increase in the level of economic activity, i.e. the level of GDP (Allan et al., 2006).

Decreasing energy intensity of the economy has also a direct and indirect impact on the pattern of household consumption. This process tends to reduce the share of energy-related expenditures in the household consumption baskets (direct effect), which allows to allocate a larger part of their budgets to other goods and services (indirect effect), thereby reducing the scale of the energy poverty – quite commonly defined as spending over 10% of income for the energy (Heffner, Campbell, 2011). In addition, the upswing in employment and wages induced by the higher level of economic activity increases disposable incomes, triggering further demand impulses and determining a change of the sectoral production structure of the economy – in a form of indirect effects.

The sectoral effects are mainly related to the heterogeneous responses of particular branches of the economy to the decrease of energy intensity, i.e. improvement of their competitiveness (lower energy costs – primary effects) and productivity (more effective technology – secondary effects) – see Worrell et al. (2003). The energy prices have an impact on the production costs of the majority of goods produced in the economy (de Gregorio, 2012). Such effects clearly play a special role for the industries in which the energy carriers constitute a significant item in the cost structure. The general equilibrium effects resulting from the interlinkages of individual branches in the supply chain are also very important. The improvement of energy efficiency also determines the flows of capital towards the less energy-intensive and more labour-intensive branches of the economy, which induces significant changes in the sectoral structure of production and employment (Ryan, Campbell 2012). In particular, the reduction in the demand for energy in the economy leads to a reduction in the activity level of the fuel and energy industries (Barker, Foxon, 2008; Environment Northeast, 2012). On the other hand, in the case of other branches of the economy, the improvement of competitiveness and the increase in production volume are all the greater, the higher the share of energy-related expenditures in the total production costs. Notably, it is the fuel and energy sectors that belong to the most energy intensive industries, so in their case the improvement of competitiveness and the induced drop in product prices and the increase in production volume are the most remarkable. The negative effect of a strong drop in demand for their products from other industries, which leads to a reduction of the production scale, is stronger than the positive, supply-side effect, related to the improvement of energy efficiency (Allan et al., 2006).

The decrease in energy intensity affects also the trade balance and the international competitiveness of the economies (Ryan, Campbell, 2012) – of different characteristics for the importers and the exporters of energy products. In the case of the net importers, the energy efficiency improvement results in an increase in their exports due to a decrease in the production costs and the consequent improvement of price competitiveness. This effect is the strongest for the most energy-intensive industries (Allan et al., 2006). The reduced use of fuels and energy leads in turn to a reduction in the imports of such products (Barker, Foxon, 2008). As a result, an improvement in the trade balance of the net importers of energy carriers in response to a decrease in the energy intensity of their economies can be expected. In the case of the net exporters, the improvement in energy efficiency of their trading partners' economies leads however to a drop in their demand for energy carriers and, as a consequence, a reduction in the exports of such products to those countries and a deterioration in the trade balance.

The fiscal consequences of energy efficiency improvements play also an important role. These are closely related to the expected macroeconomic effects. The long-term impact of the decrease in energy intensity on the public finance sector is an outcome of two opposite effects. On the one hand, a decline in the role of revenues from taxation of energy carriers in the structure of budget revenues is observed – it is related to a reduction in the demand for fuels and energy (Environment Northeast, 2012). This applies in particular to the revenues from the excise duty. Notably, the budget revenues from this tax may even decrease in absolute terms in case of a significant scale of the departure from the fossil fuels (Olmos et al., 2011). On the other hand, the energy-related expenditures of the public sector, as well as the subsidies to the production and consumption of energy should be reduced (Ryan, Campbell, 2012). Equally, if not even more important, are the indirect effects resulting from the expected increase in the level of economic activity – especially of the energy-intensive industries. They should cause an increase in the receipts from the value added tax (VAT) and the personal income tax (PIT), as well as from the corporate income tax (CIT). It is also believed that the net effect of the revenue changes, resulting from the occurrence of the described economic mechanisms, should be positive and lead to an increase in the overall level of tax revenues (Environment Northeast, 2012).

A decline in the per unit energy use may also reduce the price of energy carriers. A necessary condition for such an outcome is a decrease in the global energy use, i.e. at the level of the world economy (Ryan, Campbell, 2012). In such a case, the level of energy prices would decrease, but with respect to the baseline scenario that assumes no changes in energy efficiency. In comparison with their current levels, energy prices are expected to increase over time in all the considered scenarios (IEA, 2014). In the global energy efficiency improvement scenario, this upswing would however be smaller than in the scenario of no energy demand reduction (Ecofys, 2013). Noteworthy, the energy efficiency improvement increases the resilience of the economy to the external shocks associated with the strong changes in global fuel prices. In such situations, the economies with lower energy intensities experience a proportionally smaller increase in unit production costs, which negatively affects competitiveness of the domestic enterprises (Matheny, 2010).

So far, the theoretical considerations and empirical observations have suggested that a part of the total energy use reduction that results from the energy efficiency improvement can be reversed by the increased demand for the energy carriers. As a result, the percentage reduction in the total energy use is weaker than the percentage decrease of the unitary energy use. This phenomenon is referred to as the rebound effect. It also implies that improving energy efficiency can provide less energy savings than implied by a simple multiplication of the relative change in energy intensity by the initial energy use (Gillingham et al., 2016). In an extreme case, even an absolute increase of its use, referred to as backfire (Sorrell, 2007, Gillingham et al., 2016), may take place. Jevons (1865), with his famous paradox, was the first to suggest such a possibility; this concept was then developed by Khazzoom (1980) and Brookes (1990). Saunders (1992, 2000) called it 'the Khazzoom-Brookes postulate'. This concept states that all the cost-effective measures related to the energy efficiency improvement tend to increase the energy use, as compared to its initial level. However, it should be noted that while the increase in energy use observed in a such a case results from an increase in the level of economic activity, the fundamental issue, i.e. a reduction in energy intensity induced by the improvement of energy efficiency, remains unchanged (Environment Northeast, 2012).

3) Research goals and hypotheses

As part of this dissertation, the following research hypotheses, whose validity was empirically verified, were formulated:

1. A continued decrease in the energy intensity of the Polish economy will boost the overall level of economic activity, relatively to the baseline scenario of a constant energy intensity.
2. Due to the heterogeneity of the initial level of energy intensity and its expected changes in particular industries, a significant change in the sectoral structure of the economy will take place; this process will be accompanied by the flows of capital and labour from the shrinking industries to the fastest growing branches of the economy.
3. For a given level of trade balance (external equilibrium), the product structure of foreign trade – both imports and exports – will change significantly.
4. The value and share of expenditure on the energy-related products in the total household and government spending will decrease; this process will be accompanied by an increase in value and share of the consumption of the non-energy goods and services.
5. The energy efficiency improvement will lower the general government revenues from the taxation of energy products; however, this decrease will be to some extent compensated by the higher revenues from other sources, resulting from the upswing in the overall level of economic activity.
6. A decrease in the total energy use in the economy will be observed; in relative terms, it will however be weaker than the expected decrease in energy intensity.

4) Research method

As noted by Greening et al. (2000), the prices in the economy are subject to numerous and comprehensive adjustments due to changes in energy efficiency. In this context, only an analytical approach based on the general equilibrium theory is capable of providing their full and credible quantification. The energy efficiency improvement spills over the entire economy through a number of adjustment mechanisms which affect the prices and volumes of production and consumption of particular goods and services. The heterogeneity of energy intensities, substitution possibilities between the inputs in the production processes and demand elasticities in particular branches of the economy (Allan et al., 2006) results in asymmetric reactions of particular prices in response to the changes in energy efficiency, which requires to include a sectoral dimension in the analyses. For the abovementioned reasons, the computable general equilibrium (CGE) models constitute an adequate tool for assessing the overall economic impacts of the energy efficiency changes affecting almost all areas of the economy (Allan et al., 2006, 2007a). The multisectoral nature of such models allows for studying the interlinkages and feedback effects between particular branches of the economy and their interactions with the foreign sector, taking into account the differences in production cost structure (labour, capital and material intensity, use of domestic and imported products), the recipient structure of the manufactured products (intermediate/final demand, domestic demand/exports), the degree of trade openness, the tax burdens or the substitution possibility between inputs in the production processes. As a consequence, the model allows to track the direct and indirect (second round, general equilibrium) effects, as well as the distribution consequences related to the heterogeneous impact of the considered simulations on particular sectors of the economy (Allan et al., 2007a; Barker, Foxon, 2008; Gillingham et al., 2016). It is worth noting that CGE models are widely used not only in analyses related to the energy intensity changes, but also to other climate and energy issues (Allan et al., 2007a).

For those reasons, the analytical tool used in this dissertation is an in-house, multisectoral, recursively dynamic, computable general equilibrium (CGE) called GEMPOL (*General Equilibrium Model for Poland*), calibrated for the Polish economy and treating Poland as a small economy open (SOE), with a base year 2010. The model includes 83 products and industries of the economy, three categories of the labour supply (high, medium and low skilled), as well as a detailed disaggregation of indirect and direct taxes: VAT, excise duty, import duties, other product taxes, product subsidies, producer taxes and subsidies, as well as income taxes levied on labour and capital. GEMPOL adopts certain assumptions that are standard for the vast majority of CGE models: constant returns to scale, perfect competition as well as nested production and consumption functions. The model was written in GAMS/MPSGE and is solved as a mixed complementarity problem (MCP).

The model GEMPOL was calibrated to the 2010 supply and use tables (CSO, 2014), with an initial resolution of 77 products and industries of the economy. The base year choice was constrained by the fact that it is 2010 for which the newest supply and use tables for Poland's economy with an extraordinary level of detail are available. Such detailed tables are prepared at five years intervals, with about four years of delay. However, an important drawback of this dataset is an excessive aggregation of the fossil fuel and energy products and industries (*Hard coal and lignite*; *Crude petroleum and natural gas, metal ores, other mining and quarrying products*; *Electricity, gas, steam and air conditioning*). Thus, it prevents from tracking detailed changes in production volume, imports, as well as use of fossil fuels, electricity and heat by particular industries of the economy. Due to this insufficiently detailed sectoral representation, for the purpose of the model's construction it was necessary to further disaggregate the tables provided by the CSO, which allowed to increase the level of detail of represented fuel and energy products and industries, as well as their number up to 83. The values of non-calibratable (flexible), substitution elasticity parameters for the nested production functions predominantly stem from an in-house estimation (Antoszewski, 2017), using panel estimation techniques and based on the *World Input-Output Database* (Timmer et al., 2015).

The model GEMPOL, constructed for the purposes of this dissertation, was subsequently used to conduct an empirical analysis – in a form of counterfactual simulations. It concerned an examination of the macroeconomic, sectoral and fiscal consequences of the long-term energy efficiency improvement, including two important dimensions. The first one comprises the increase in the productivity of manufacturing processes in Poland's economy, i.e. the decrease in the energy intensity of particular industries, resulting from the improved efficiency of available production technologies. The second one captures the change in the preferences of households and the government – towards greater consumption of the non-energy goods and services at the expense of the energy-related products. This may be perceived as equivalent to the improvement in the "efficiency" of using energy carriers by households and the government, which enables to increase the level of utility achieved from a given bundle of energy goods. The use of counterfactual simulations for this purpose results from the fact that direct assessment of the economic effects of decreasing energy intensity of production and consumption is extremely difficult due to the inability to observe an alternative reality in which the energy intensity of production and consumption remained unchanged over time.

The recursively dynamic nature of the model GEMPOL enables the construction of a business as usual (BAU) scenario that reflects the future trends of the development for Poland's economy, assuming no further decrease in its energy intensity. After the model's calibration and determination of the values of endogenous variables for a given year, starting from the base year, a transition – in a five-year interval – to the next period takes place, through the capital accumulation equation, as well as by the changes in labour stock and the other exogenous assumptions, including the technological parameters, i.e. through the productivity changes. Worth emphasizing is the fact that the baseline scenario assumes no changes in energy intensity over the 2015-2050 period. Therefore, it implies a determination of the energy intensity of production and consumption at a constant level, resulting from the initial calibration of the model and the historical changes in the per unit energy use that took place over the 2010-2015 period.

The scenario of a further energy efficiency improvement, i.e. the central scenario, adopts almost the same set of exogenous assumptions as the baseline scenario – except for the changes in the values of some technology parameter values, related to the energy products. Contrary to the baseline scenario, the energy efficiency improvement in the central scenario occurs not only in the 2010-2015 period, but throughout the whole 2010-2050 period. The shocks, which are simulated within the model, reflect the expected improvement in the energy efficiency of the production processes in particular branches of the economy, i.e. the decrease in the energy intensity resulting from the technology improvement, and not from the changes in the sectoral structure of the entire economy. From a technical point of view, they are associated with an increase in the productivity of fossil fuels, as well as electricity and heat, i.e. with a decrease in their use per unit of product manufactured by a given industry. The simulated productivity increase affects uniformly all the energy products used by a given industry, but its scale differs between particular branches of the economy. Such an approach is the most common in the literature (see Allan et al., 2006), and is related to the availability of appropriate technical-engineering projections. It was also assumed that a further improvement in energy efficiency does not occur in the strictly defined, fuel- and energy-related industries. As noted by Allan et al. (2007a), it may be argued that such industries already operate close to the "thermodynamic limits", so it is not possible to increase their production volume while maintaining the current level of the energy use. The projections of the expected energy intensity changes in particular branches of the economy and in the final consumption were derived from the European Commission's (2016) report *EU Reference Scenario 2016 – Energy, transport and GHG emissions – Trends is 2050*. It is the comparison of the results from the central scenario with those from the scenario of a constant energy intensity (BAU) that allows to assess the macroeconomic, sectoral and fiscal consequences of the decreasing energy intensity of the Polish economy that takes place over the considered time horizon. This comparison provides also an answer to the question about the scale of the socio-economic benefits associated with the observed energy efficiency improvement in the Polish economy.

The conducted simulations were also accompanied with a sensitivity analysis of the obtained results with respect to the scale of the considered exogenous shocks, related to the energy efficiency improvement over time. Its aim was to highlight the uncertainty accompanying the European Commission's (2016) projections. For this purpose, additional simulation scenarios, alternative to the central scenario, were defined. They included a half faster and a half slower improvement in energy efficiency. The sensitivity analysis also includes a scenario of the "costly" energy efficiency improvement – of the same magnitude as in the central scenario. Its accomplishment requires to incur specific investment expenditures that do not lead to the capital accumulation, but to some extent "unlock" the technical possibilities of reducing the per unit energy use.

5) Results obtained and their importance

On the basis of this study and the results obtained, a number of conclusions on the macroeconomic, sectoral and fiscal effects of the decreasing energy intensity of Poland's economy can be drawn. These conclusions are broadly consistent with the formulated research hypotheses – with a partial exception regarding the fourth hypothesis on the changes in the value and structure of the private and public consumption.

However, it should be noted that the deviations of particular variables presented below, measured in relation to the baseline scenario, should not be interpreted as forecasts whose accuracy can be verified with a precision to several decimal places in *ex post* terms – after the observation of their actual value. In the counterfactual simulations, two hypothetical states of the economy in the future are compared, and the results obtained are conditional on the parameterization of the model and the realisation of the adopted exogenous assumptions. The results of the performed simulations are therefore not directly comparable with the regularly published, official statistical data which records the changes in the state of the economy over time. Noteworthy, the qualitative conclusions on the direction of changes in the values of particular variables and the mutual relations between them are equally important as the precise, quantitative results of the simulations.

Firstly, a continuation of the decrease in the energy intensity of the Polish economy, modelled as a positive technological shock, will increase the overall level of economic activity, measured by such macroeconomic aggregates as the GDP (from 1.39% in 2020 to 5.67% in 2050), the gross output (from 0.40% in 2020 to 0.51% in 2050), the private consumption (from 2.19% in 2020 to 9.52% in 2050), the public consumption (from 0.33% in 2020 to 0.41% in 2050), the investment (from 1.58% in 2020 to 6.69% in 2050) or the capital stock (from 0.62% in 2025 to 4.91% in 2050) – relatively to the baseline scenario of a constant energy intensity. Hence, the obtained results confirm the research hypothesis no. 1.

Secondly, due to the heterogeneity of the initial energy intensity level and its expected changes in particular industries, a significant change in the sectoral structure of the economy takes place. A clear decline in the production of the fuel and energy branches can be expected (with a maximum from 3.60% in 2020 to 16.09% in 2050) and an activity increase in the energy-intensive industries (with a maximum from 2.05% in 2020 to 6.71% in 2050). This process is accompanied by the flows of capital and labour resources from the shrinking industries to the fastest growing branches of the economy. Hence, the obtained results confirm the research hypothesis no. 2.

Thirdly, changes in the product structure of foreign trade – both imports and exports – are observed. For a given level of trade balance (external equilibrium), the decrease in domestic demand for fuels and energy products reduces their imports (with a maximum from 8.20% in 2020 to 34.91% in 2050) and boosts the exports of their domestic production (with a maximum from 2.32% in 2020 to 12.76% in 2050). This enables a redirection of the expenditure streams, resulting in the higher imports of non-energy goods and services (with a maximum from 2.76% in 2020 to 19.29% in 2050), while the increased domestic demand reduces the scale of the exports of such products (with a maximum from 2.16% in 2020 to 18.70% in 2050). The competitiveness improvement of domestic production of the energy-intensive goods results in an increase of their exports (with a maximum from 1.38% in 2020 to 4.25% in 2050). The strong import intensity of energy-intensive branches leads also to an increase in the imports of such products (with a maximum from 1.53% in 2020 to 5.30% in 2050). However, the total value and volume of exports and imports do not change significantly, which in combination with the higher GDP implies a reduction in the openness degree of Poland's economy. Hence, the obtained results confirm the research hypothesis no. 3.

Fourthly, there is a relatively small decrease in the percentage share of expenditures on the energy products, i.e. on fossil fuels, electricity and heat, in the total household and government spending: from 0.08 pp. and around zero respectively in 2020 to 0.39 pp. and 0.01 pp. respectively in 2050. In addition, due to the increase in the overall level of economic activity and the related increase in the private and public income, the absolute value of the private and public expenditures for such products records however an increase from a maximum of 3.67% and 1.60% respectively in 2020 to 12.36% and 7.97% respectively in 2050. Moreover, the expenditures on non-energy goods and services also increase – from 2.28% in 2020 to 10.00% in 2050 in the case of households and with a maximum from 3.25% in 2020 to 30.70% in 2050 in the case of the government. Hence, the obtained results do not fully confirm the research hypothesis no. 4.

Fifthly, the energy efficiency improvement leads to a decrease in the general government revenues due from the taxation of energy products, i.e. fossil fuels, electricity, heat and related. As a result, there is a drop in the revenues from the excise tax (from PLN 0.08 bn in 2020 to PLN 1.92 bn in 2050) and from the other taxes on products (from PLN 0.09 bn in 2020 to PLN 1.43 bn in 2050), of which the fuel surcharge constitutes a key part. However, this decrease is more than offset by the higher revenues from other sources, resulting from the increase in the overall level of economic activity: public capital compensation (from PLN 8.06 bn in 2020 to PLN 165.04 bn in 2050), capital taxation (from PLN 1.80 bn in 2020 to PLN 36.86 bn in 2050), labour taxation (from PLN 5.08 bn in 2020 to PLN 22.46 bn in 2050) and the VAT (from PLN 1.22 bn in 2020 to PLN 16.62 bn in 2050). As a result, it is possible to increase the government expenditures – both the consumption (from PLN 13.64 bn in 2020 to PLN 190.12 bn in 2050) and investment spending (from PLN 2.30 bn in 2020 to PLN 44.26 bn in 2050). Hence, the obtained results confirm the research hypothesis no. 5.

Sixthly, a decrease in the total energy use in the economy (from 2.95% in 2020 to 11.94% in 2050) takes place. This consists of a reduction in the intermediate use (from 4.02% in 2020 to 17.60% in 2050) and an increase in the final use (from 3.94% in 2020 to 20.60% in 2050). In relative terms, the total decrease in energy use is however lower than the decrease in energy intensity (from 10.81% in 2020 to 42.26% in 2050). This implies an occurrence of a rebound effect in energy use, accounting to around 71-73%, depending on the period considered. Hence, the obtained results confirm the research hypothesis no. 6.

The sensitivity analysis conducted in this study emphasizes the positive relation between the size of the expected, economic effects of the energy efficiency improvement in Poland on the assumed scale of such a technological progress. Therefore, the obtained results should be perceived as conditional upon the adopted projections of per unit energy use changes in the Polish economy in the 2050 horizon. Particularly important is the fact that the overall economic consequences of this phenomenon are clearly positive even in case of the need to incur additional investment expenditures aimed at reducing the per unit energy use. This suggests that the policy measures aimed at improving energy efficiency should be considered desirable.

The counterfactual simulations carried out in this dissertation may contribute to an increase in awareness of the long-term consequences of the ongoing decrease in per unit energy use for the particular areas of the Polish economy. A direct assessment of the economic consequences of this phenomenon is extremely difficult due to the inability to observe an alternative reality, in which the energy intensity of production and consumption would remain unchanged over time. The obtained results suggest also the need to implement specific adaptation measures by both the private and the public sector. The owners and managers of enterprises in particular industries should be aware of the ongoing structural changes within the economy which result from the energy efficiency improvement and which are not directly related to the current business cycle fluctuations. In particular, those changes will require flexible reactions – with respect to the production volume, the use of production factors or the involvement in the foreign markets – in response to the multidirectional changes in the domestic demand for the manufactured products. The households should realise that the share of expenditures on the energy carriers in their budgets will decrease over time, thus freeing up additional financial resources to purchase the non-energy goods and services. This knowledge will allow for a more efficient planning of the expenditures within the household budgets. In the case of the general government sector, a raising of the awareness of the changes that apply not only to the amount but also to the structure of the tax revenues should be particularly important. This stems from the fact that the dynamics of the tax base values for particular types of taxes are not equal to the dynamics of the overall level of economic activity. This clearly raises the need for a realistic budgetary planning with respect to the tax revenues. Noteworthy, similar research and analytical activities will be welcome as long the energy efficiency improvements within Poland's economy are still underway. However, nothing suggests currently an imminent end of this process.

6) References

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