Central European Economic Journal

sciendo

ISSN: 2543-6821 (online)

Journal homepage: http://ceej.wne.uw.edu.pl

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To cite this article

Kiuila, O., Lewczuk, E. (2021). Economic Dynamic Modelling of Climate Policy in Poland. Central European Economic Journal, 8(55), 246-255.

DOI: 10.2478/ceej-2021-0018

To link to this article: https://doi.org/10.2478/ceej-2021-0018

This article was edited by Guest Editor:

Mikołaj Czajkowski
University of Warsaw, Poland

as part of the Special Call to mark the 70th Birthday of Prof. Tomasz Żylicz

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Economic Dynamic Modelling of Climate Policy in Poland

Abstract
Poland is responsible for 9% of CO_2 emission in the European Union (EU), making it the fifth biggest emitter in the region. The energy sector is dominated by electricity produced from coal (around 70%). The country currently uses massive subsidies to boost the coal sector. We propose a dynamic intertemporal hybrid general equilibrium model to simulate the economic effects of sector regulations and new policy targets within environmental taxation scenarios, by accounting for a complex set of linkages between the energy sector and other components of the economy. Our simulation results suggest that positive economic growth is possible with a realistic energy mix, but it will not offer considerable emission reduction, as required by the European Commission. In the short-time horizon, the best choice is renewable energy sources indicated by less capital-intensive technologies (such as biomass). In the long-time horizon, more capital-intensive technologies (such as wind turbines) will be a better choice for economic growth. Carbon tax plays a crucial role in optimal energy mix targets, since its elimination *ceteris paribus* implies negative economic growth.

Keywords
computable general equilibrium modelling | decarbonization | energy technologies

JEL Codes
C68, D58, Q43, Q58

1. Introduction

Poland faces unique challenges in its energy transition due to its extreme dependence on coal. Carbon dioxide makes up roughly 80% of the total greenhouse gas (GHG) emissions in the country. All GHGs (in carbon-dioxide equivalent) were estimated at 419 Mt and 414 Mt in 2007 and 2017 (the last year covered by the official statistics), respectively. Poland is responsible for 9% of the European Union (EU) emission, making it the fifth biggest emitter in the block. The Polish CO_2 trend is fairly stable: It was negative in 1988–1994; thereafter it stabilized, and was negative again between 1996 and 2002. Later, it underwent several small changes, and it has been positive since 2014 – at 336 Mt and 337 Mt in 2007 and 2017, respectively.

The Polish emission comes mainly (90%) from burning fossil fuels. In other words, it is closely related to the energy demand. The main reason is historical, as after World War II it was decided that the Polish energy security would be built on domestically available coal resources – electricity produced from bituminous coal and lignite was over 90%, while currently it is at 70%. In recent years, the energy sector has been changing towards greater utilization of renewable resources. The total energy production in Poland in 2007 and 2016 were 159 TWh and 167 TWh, respectively. The official energy forecasts for 2050 assume to achieve 222 TWh, with dependence on coal at <40%, due to nuclear energy (20%) and renewables (30%) (Polish Ministry of Economy, 2015). However, although the generation of nuclear energy was planned 30 years ago, it is yet to be implemented.

The dependence on coal in heating production, currently, is of a magnitude similar to that of the electricity sector. However, the official perspective does not plan to decrease it <70%, even in 2050. The only considerable change towards a green economy in this sector is to double the utilization of renewables and increase the dependence on natural gas. In this study, we concentrate on the electricity sector only because of a lack of detailed data on the heating sector.

There is a broad range of studies that use different quantitative approaches to simulate the macroeconomic effects of environmental and energy policies. Although each country faces unique challenges in its energy transition, similar concerns can be shared. The first concern is the choice of the tool to study the economic effect of low carbon transition. Energy is a crucial economic input circulating in the economy; it is widely utilized as a production factor and consumed in different forms by households. For this reason, any changes in the energy sector will have a preponderant impact on the entire economy; thus, partial equilibrium modelling is not sufficient.

We propose a hybrid computable general equilibrium (CGE) modelling that incorporates energy technologies (bottom-up approach) directly into the macroeconomic structure (top-down approach). By accounting for wide adjustments in the economy, while controlling for all major constraints – such as energy balance and available capital stock – the model can provide a unique and detailed insight into the future shape of the energy sector and the low carbon economy in Poland. Technological details of bottom-up models, in accompaniment with the economic richness of top-down models, have been formulated in a single framework to allow utilisation of the advantages of both model types.

Boehringer and Rutherford (2008) described the techniques of hybrid modelling, where market equilibrium is formulated as a mixed complementarity problem. The complementarity approach allows us to define both model types – top-down (general equilibrium) and bottom-up (partial equilibrium) – in a single mathematical format. Bottom-up models of the energy system may impose a large number of bounds on decision variables, such as capacity constraints. These bounds introduce unavoidable complexity in the integrated complementarity formulation, as they must be associated with explicit price variables to account for income effects. The mixed complementarity approach helps to achieve it in a simple way.

Two methods of integrating bottom-up and top-down approaches (hybrid modelling) in the modelling of the economic effects of environmental policies are possible. The bottom-up abatement cost can be implemented into top-down modelling using either economy-wide or sector-specific methods. The economy-wide method treats an abatement sector as a unique set of technologies for all sectors, while the sector-specific approach distinguishes between different abatement possibilities for each sector. Kiuila and Rutherford (2013) prove that both (hybrid and the traditional) CGE modelling approaches yield similar results if the calibration process is precisely executed. However, the lack of data implies that precise calibration in traditional modelling (top-down approach) is not possible usually. Furthermore, the study proves that the emission permits are equivalent to carbon taxation only when no transaction costs are considered. However, the market for emission permits creates a transaction cost which results in a deadweight loss that is higher than carbon taxation.

Poland faces unique challenges in its energy transition due to extreme dependence on coal. Nevertheless, there are many countries that are going or will inevitably go through transition towards a low carbon economy. Gonseth and Vielle (2012) model the impacts of climate change on the energy sector in Switzerland. The analysis uses a CGE model and focuses on both the demand and supply sides. According to the authors, climate change will significantly reduce heating costs and improve the conditions for the use of renewable energy sources. As a result of climate change, reducing the costs of energy production will increase consumption of goods not related to the production chain in the energy sector. As a result of climate change, by 2050, the Swiss economy will gain US$704 million in gross domestic product (GDP) and CO_2 emissions will be reduced by 2.6%.

Some other compound quantitative studies in recent years have focused on the transition of the energy sector in the United States. Mattoo et al. (2009) present the results of the impact of different scenarios for emission reduction on the economy of the United States until 2020, based on CGE analysis. Reducing emissions by 17% between 2005 and 2020 would result in a loss of 4% of GDP. Furthermore, increased competitiveness of carbon-intensive India and China may require an increase in import tariffs up to 20%. As a result, US exports fall from 21% to 16%.

The leading approach to modelling economic effects of energy mix is general equilibrium. It does not mean that this is the best approach. Bottom-up modelling is more precise for technologies' analysis, but it usually fails to show the macroeconomic impact, and also fails to indicate the effects on factor reallocation between different non-energy sectors of production. As shown in Bhattacharyya (1996), among others, modelling approaches using general equilibrium may be very sensitive. The difference between the model results lies, among others, in the disaggregation of sectors and products, number of nests, dynamic properties, functional forms and methods for including environmental and energy components.

The choices regarding the structure of the model are important for the accuracy of the results. However, well-designed CGE models are a very powerful tool for simulating the effects of environmental reforms (see Boehringer and Loeschel, 2006). In particular, studying the effects of transitioning towards a low carbon economy in Poland using a well-developed methodology is necessary.

Our simulation results suggest that positive economic growth is possible with a realistic energy mix, but it will not offer considerable emission reduction, as required by the European Commission. In the short-time horizon, the best renewable energy sources should be indicated by less capital-intensive technologies (such as biomass). In the long-time horizon, more capital-intensive technologies (such as wind turbines) would be a better choice for economic growth.

The outline of the paper is as follows. In Section 2 we review alternative studies of the environmental and energy perspectives for Poland. Section 3 explains the details of the model. In Section 4, using around 20 decarbonisation scenarios, we report and compare the macroeconomic impacts of the various energy perspectives on the Polish economy. The last section provides the conclusions.

2. Alternative Studies

Transitioning toward a low carbon economy has been considered as one of the most important and inevitable challenges for many developing economies. Poland is an extreme case in terms of its reliance on fossil fuels for electricity generation (Skjærseth 2018). Despite this fact and despite the substantial economic impact that such a transition may cause, empirical studies on the impacts of energy transition on the Polish economy are rather scarce.

The theme of the economic impacts of energy transition in Poland is carefully investigated by the World Bank (2011). The study looks for the economic impacts of the transition required by the EU abatement rules. It uses a comprehensive methodological approach, which compiles four complementary and interlinked models: marginal abatement cost curve, the multi-region CGE model, a large-scale multi-sector dynamic stochastic general equilibrium (DSGE) model and the road transport model. The DSGE model with an incorporated marginal abatement cost curve serves to simulate the economy-wide impact of emissions reduction. The CGE model complements the analysis in the global context, i.e., by simulation of spillover effects to and from international markets. The transport sector model is used to simulate the impacts of different economic assumptions delivered by the micro-abatement cost curve on the transport market. One of the findings of the study is that Poland has a lot of space for cutting its GHG emissions, i.e. by almost one-third by 2030, at an average cost of up to EUR15 per ton of carbon dioxide equivalent abated. According to the study, the reduction would have a negative impact on the GDP, at an average of 1 pp of lesser growth by 2030 each year. The impact of the transition on the GDP is consistently negative but declining, and would be close to zero by 2030. Moreover, the study finds that onshore wind and small hydropower plants are the most efficient in terms of the metric of GDP growth. Nuclear power offers the most significant abatement potential but remains an impediment for growth in the longer term.

Bukowski and Kowal (2010) employ the above-mentioned DSGE model to derive the macroeconomic effects of continuation of the current policies, trends and convergence processes in terms of GHG abatement. In addition, the impact of 120 mitigation technologies was considered to derive the optimal scenario, i.e., the combination of levers that minimise the loss function. The loss function expresses the deviation of the reduction from the target value and increase in costs relatively to the reference scenario. The optimal scenario envisages a significant growth of nuclear capacity (up to 19% of energy mix in 2030) and onshore wind (up to 14% in 2030). This growth is accompanied by a large drop of conventional coal (from 81% to 44%) and decrease in small-hydropower plants.

Apart from these two compound studies, there are several smaller studies touching upon certain aspects of the energy transition in Poland. Bukowski et al. (2013) raises a wide range of aspects, such as links between the energy sector and economy, energy efficiency perspective, energy security and political issues around climate policy. The conclusion from the study is that resistance to transitioning of the energy sector creates a risk to the Polish economy of lagging behind highly developed economies and falling into the middle-income trap. Taking courageous, systematic and coordinated modernization activities, according to the study, is the only reasonable way to maintain the competitiveness of the economy in the coming decades. A properly designed climate policy (comprising of ecological education, active labour market policies and public support for innovations) is an opportunity to build the foundations of a modern, ecological, highly developed economy. Specific actions should involve energy management projects that enable better utilisation of installed capacity in power plants, promotion of low-emission means of transport, popularisation and subsidising of electromobility and proper allocation of infrastructural funds.

Kassenberg and Sniegocki (2015) take a narrower approach and draw the scenario for the impact of energy transitioning, specifically in relation to the labour market. According to them, public policy in Poland should focus on providing efficient reallocation of labour and capital in the direction of industries, which could ensure sustainable development, taking into account the prevailing environmental and resource constraints. One of the methods to achieve such a goal is investment in technologies with high development potential and a proper tax and subsidies policy. The green tax reform should lead to increase of the fiscal burden on companies that use scarce natural resources and pollute the environment. The government should also reduce tax rates on labour and secure the competitiveness of Polish energy intensive industries.

Kiuila (2018) focuses on the optimal energy mix for Poland. The author found that no realistic energy mix allows the achievement of positive economic growth when considerable emission reduction has to be achieved. The price of CO_2 will exceed EUR100 even with a 30% emission reduction with respect to the business-as-usual (BAU) scenario. Gradual phase-out of coal requires focusing on biomass technology (the best), nuclear and wind power (the second best). The limitation of this study is that it is a closed-economy analysis.

Antoszewicz et al. (2019) apply two models, DSGE and bottom-up, to identify the optimal energy mix for decarbonisation versus coal-dependent pathways. The authors distinguish between capital and operating expenditures to assess the energy system requirements for both these pathways. The key result is that the decarbonisation scenario exhibits lower costs of electricity production than the baseline where the current energy mix is assumed. If this were to be the case, the free lunch would exist.

Taking into account the limitations of the above studies, we have developed the intertemporal CGE model with the bottom-up electricity sector to simulate environmental taxation in an open economy. To our knowledge, there is no research tool in Poland which could accommodate these elements for long-horizon simulations. The Polish Ministry of Finance has a tool that allows the study of top-down relationships of climate policy in the EU, but the energy part is greatly simplified (Polish Ministry of Finance, 2015). We attempt to close this gap by constructing an intertemporal hybrid general equilibrium model for the Polish economy.

3. Model

The fully dynamic model is calibrated to 2007 using 21 sectors, 7 energy technologies, 2 types of capital and a single labour market, representative household and government. Producers are classified into four types to describe the production structure: electricity production, electricity distribution, fuels (coal, oil, gas), and others (heating, transport fuels, motor vehicles production, other transport equipment production, cars service, passenger land transportation, other passenger transportation, freight transportation, mining and metals, chemical, engineering, other production, construction, research, other service, agriculture and food industry). All sectors, except electricity production, are represented by nested constant elasticity of substitution (CES) function.

The core of the model is electricity production that is represented by a step function that deploys the Leontief approach. This is the bottom-up part of the model. This means that the sector of electricity production is disaggregated into energy carriers (technologies), while other sectors are represented by a single technology. In other words, the electricity sector is decomposed into several subsectors that utilise different energy sources and produce different types of energy using different technologies: coal – 91%, gas – 3%, oil – 2%, biomass and waste – 2%, hydro – 1%, wind – 0.3%, other (mostly from processed gas such as LPG) – 1%. Each electricity technology uses materials, energy, capital, and labour in a fixed proportion. Taking into account the marginal cost and production capacity for each technology, the optimisation process selects the appropriate structure of electricity production.

The electricity distribution sector has a monopoly for electricity output; thus, other agents cannot buy electricity directly from the producers of electricity. This sector and other sectors, except natural resources, are described by a similar nested structure. The basic idea was to cover substitution possibilities between (i) electricity and motor fuels in transport on the one hand and (ii) heating and fossil fuels on the other. Thus, agents have a choice either to buy a ready product for heating or to produce their own heating using fossil fuels. Renewable fuels are not an alternative, due to lack of data.

The last group of producers covers coal (mining of coal and lignite, manufacture of coke oven products), oil (crude oil extraction and services, manufacture of refined petroleum products) and gas (extraction of natural gas and other hydrocarbons, gas production and distribution). These three sectors have a unique nesting production structure due to capital and CO_2. Combustion of fossil fuels is responsible for carbon emission. Thus, purchasing of coal, oil or gas is automatically linked to purchasing permits for sectoral emission. Capital is another specific feature for these three sectors. While capital (K) used in all other sectors contributes to capital stock, the capital (R) used by fuel sectors is treated as a non-renewable (land), because a considerable part of the capital used in natural resources cannot be increased by labour.

The final demand is represented by households, investors and the government. There is one representative household that maximises the lifetime utility, subject to the lifetime budget constraint. The top-tier utility function is an intertemporal CES function over household life with elasticity of substitution at 0.5. The labour–leisure choice is defined with elasticity at 1.4. The instantaneous (period-level) sub-utility is of the CES type and covers all consumption goods, services and energy (except crude oil). The budget constraint involves the stream of all lifetime factor earnings from labour (L) and two types of capital (K and R). No mobility is considered for any of these production factors. While labour and land can only be rented, physical capital (K) can be either bought or rented.

Investors supply capital service (KS) to producers, while households supply capital (K) to investors. Capital stock (K) and capital service (KS) denote two different but interrelated concepts of capital using financial capital (KF) and depreciation rate (d): $KS = K \times d + KF$. Thus, capital service is simply a gross operating surplus. Capital service is derived from the stock of capital installed, while capital stock is defined based on the profit-maximizing behaviour of economic actors. Moving from capital stocks to capital services, the basic assumption is that capital services provided during a given period should be proportional to the stock. The return to capital must be sufficient to cover dividends and depreciation according to the market clearing condition.

Public demand is represented by the Leontief function. There are three main sources of public income: taxes on production (such as pollution taxes), taxes on products (such as VAT, excise – totally eight types) and income tax (covers labour tax only). Redistribution of income is done via transfers: social benefits (such as unemployment benefits), pension benefits (such as income for retired persons) and other transfers.

Finally, we simplified the model by excluding unemployment and other important elements that we plan to include in the future (such as prosumer energy and motor fuels black market). Apart from this simplification, the model in a current version is already quite complicated and it is able to simulate the effects of dynamic shocks such as changes in taxation, emission quotas, energy mix or production capacity.

4. Simulations

The BAU scenario assumes that the economy follows the steady-state path with an annual exogenous growth of 1%. The price for carbon emission is applied at the level of EUR18 per ton, corresponding to the actual level in 2007. Energy mix for power generation is fixed at the benchmark level: 91% coal, 3% gas, 2% oil, 2% biomass, 1% hydro, 0.3% wind and 0.9% for other. The simulated scenarios alter BAU with respect to technical capacities for power generation or costs of CO_2 emission. The description of the simulated scenarios is presented in Table 1.

The first decarbonisation scenarios (called 'coal' and 'coal_0') look for optimal energy mix in power production, assuming that coal capacity cannot exceed the 2019 level (Figure 1). The 1% economic growth exogenously assumed requires in BAU to increase coal capacity (as well as other technologies) every year. Once we fix the capacity, the model optimisation process looks for alternative ways of energy production to return to the steady-state growth path. As the figure 1 shows, the effect of fixing the coal capacity on GDP will not be negative if the carbon tax is eliminated. The immediate reaction is 'let's close coal power plants'. However, there is no free lunch. The advantage of hybrid modelling is that we can see from

Table 1. Selected scenarios

Scenarios	CO_2 tax	Coal-based electricity production	No restrictions for other energy resources	Other energy mix restrictions
BAU	Yes	No limits (coal = 91%)	Yes	No (gas = 3% oil = 2% biomass = 2% hydro = 1% wind = 0.3% other = 0.9%)
Coal	Yes	Fixed at the 2019 level	Yes	No
coal_0	No	Fixed at the 2019 level	Yes	No
mix_biomass	Yes	Exogenous decrease in 2024 and 2030	No	Exogenous increase of biomass-based electricity to reach 23% in 2030
mix_wind	Yes	Exogenous decrease in 2024 and 2030	No	Exogenous increase of wind-based electricity to reach 23% in 2030

BAU, business-as-usual.

the technical point of view how this economic growth is possible. The bottom-up part of the model gives the answer – a considerable contribution of oil (from 2% in 2007 to 32% in 2050) in electricity production (Figure 1) makes it possible to achieve a non-negative GDP trend (Figure 2). This means that traditional CGE and DSGE models give biased results for decarbonisation scenarios, since the Polish economy cannot meet the energy mix with a considerable contribution of oil technologies in power production, because it is a fully imported resource. However, when the carbon tax exists, oil-based electricity production becomes less profitable than the gas-based one.

Equal-yield constraint implies that the public budget is constant (Figure 2) except scenario ‘coal_0’, where the budget decreases due to an absence of carbon tax revenue. As a result, private consumption goes up in ‘coal_0’ (cheaper electricity due to no carbon tax), but it does not change in ‘coal’ with respect to BAU. The limited amount of coal in electricity production together with carbon tax (scenario ‘coal’) requires additional annual growth of investments by 0.2%. This is a very good option; however, it does not guarantee achievement of the planned 40% coal-based energy production, but at most 55%.

To implement the targeted energy mix, we have constructed alternative scenarios, where renewables represent 20–30% of it in 2050. The results for two of these scenarios are presented in Figures 1 and 2. The wind scenario of course requires more investments, but the long-term price of electricity will be lower than what the ‘biomass’ scenario can offer. Both scenarios require a decrease of private consumption in the short term, but long-term consumption is growing. As a result, long-term GDP growth will also be non-negative. This is very good information for a coal-dependent country.

In addition to power generation, reforms in the transportation sector might also be an option. For example, we can encourage households to switch from motor fuel vehicles to electric cars by applying extra tax on motor fuels and subsidising electricity. Combining this scenario with the ‘mix’, we ensure a reasonable energy mix in electricity production. Our results suggest that a 50% reduction in the tax rate on retail electricity will be required to increase the tax rate on retail motor fuels by 60%, to keep the yield constraint for the public budget equal. The effect on GDP is still positive, but not as good as for the renewable energy requirement.

Finally, the decarbonisation of the economy can be achieved directly through CO_2 emission limits. Gradual emission reduction up to 30% in 2050 with respect to the BAU scenario has a negative effect on the GDP, regardless of the equal yield constraint distribution (lump-sum, labour, capital, VAT). The least negative result offers labour tax recycling. If, in addition, we implement the reasonable energy mix, the effect will be even worse. The only solution is considerable technological progress.

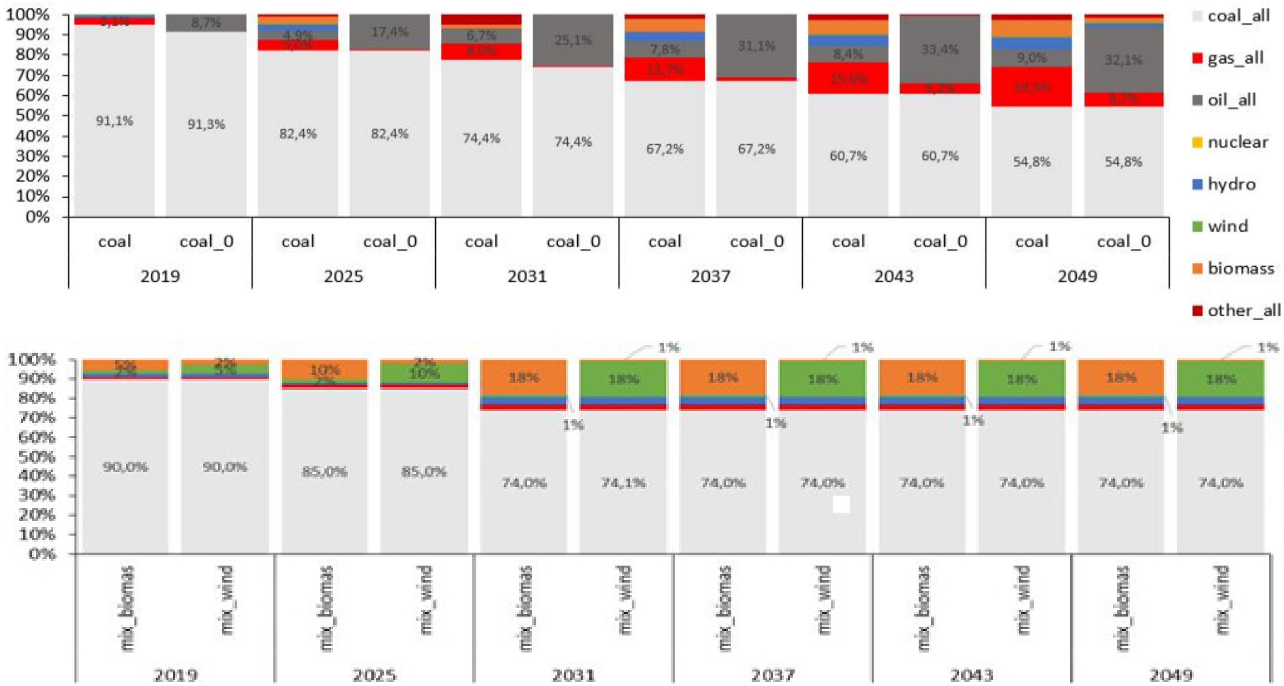

Figure 1. Electricity production structure

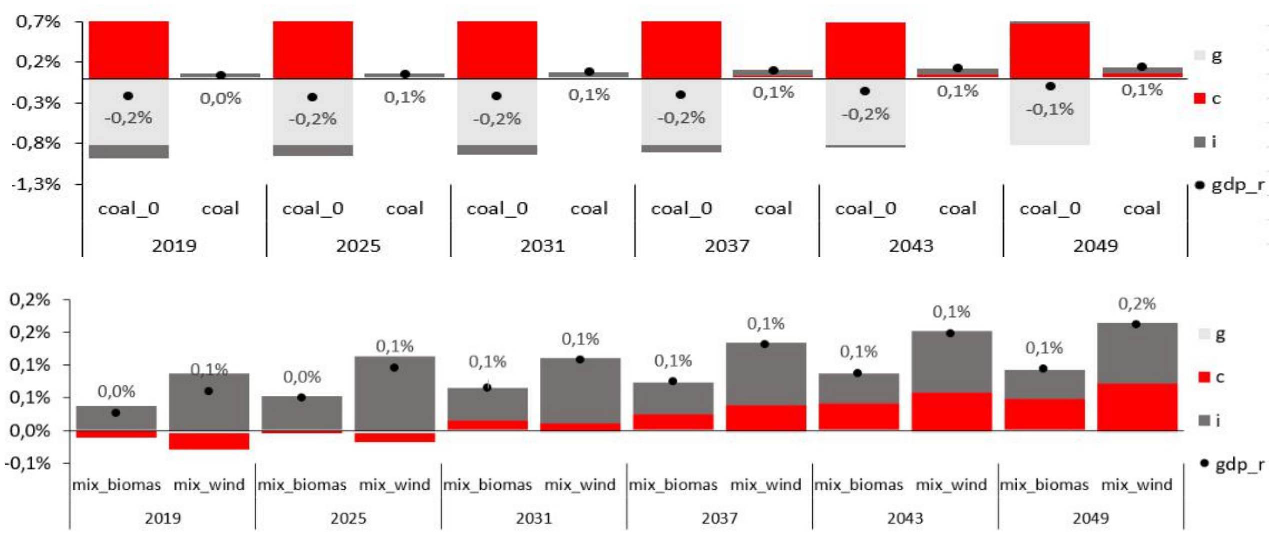

Figure 2. Macroeconomic indicators change in relation to BAU (g – public consumption, c-private consumption, i – investment, gdp_r – real GDP). BAU, business-as-usual; GDP, gross domestic product

5. Conclusion

Coal dependence in Poland has developed due to the substantial resources of coal that the country possesses. Poland currently uses massive subsidies to boost the coal sector on the one hand, but on the other hand, declares the long-term target to be a considerable reduction in the coal-based electricity production. Energy is a crucial economic input circulating in the economy, widely utilised as a production factor and consumed in different forms by households. For this reason, any changes in the energy sector will have a preponderant impact on the entire economy; thus, partial equilibrium modelling is not always sufficient. We propose a dynamic intertemporal hybrid general equilibrium modelling that incorporates energy technologies (bottom-up approach) directly into a macroeconomic structure (top-down approach) and keeps the economy open for international trade. Using such model, we simulate the economic effects of sector regulations and new policy targets within environmental taxation scenarios, by accounting for a complex set of linkages between the energy sector and other parts of the economy. These scenarios assume, in different proportions, increasing use of renewable sources and natural gas in exchange for reduction of carbon. For each scenario, the model provides a number of performance measurements such as social welfare and other efficiency indicators, including investment-to-GDP or investment-to-employment ratio.

Our simulation results suggest that positive economic growth is possible with the realistic energy mix, but it will not offer considerable emission reduction, as required by the European Commission. In the short-time horizon, the best renewable energy sources should be indicated by less capital-intensive technologies (such as biomass). In a long-time horizon, more capital-intensive technologies (such as wind turbines) will be a better choice for economic growth. Carbon tax plays a crucial role in optimal energy mix targets, since its elimination *ceteris paribus* implies negative economic growth.

The practical possibility to apply the discussed scenarios in Poland is subject to policymakers' willingness to take long-term decisions. Government intervention with market-based instruments (such as carbon tax with revenue recycling back to the economy) will allow achievement of environmental targets with the lowest cost, but there is no free lunch (meaning that economic targets will not be achieved). Once society pays more attention to environmental, rather than to economic, problems, policymakers may be required to change their current decisions.

Acknowledgments

Olga Kiuila thanks Prof. Tomasz Zylicz, who was her supervisor and mentor in her professional life and supported her in her research career.

Funding

This work was supported by the Polish National Science Center under Grant No. 2017/25/B/HS4/01143.

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