Modelling the Effects of the EU Emissions Trading System in Poland: A Comparison Between IO And CGE Results

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Abstract

As a number one Europe's coal generator, Poland is the European Union (EU) member state mostly affected directly by European green policies. In this context, this paper aims to measure the impact of the EU Emissions Trading System on the Polish economy. Additionally, we compare the results based on two different methodologies – Input-Output model and Computable General Equilibrium model. To the best of our knowledge this is the first time when these approaches are directly compared in this context. Our results show the same directions and general conclusions in both methodologies; however, the IO approach may overestimate the impact of carbon tax on national economy and the emissions. We find that while IO simulations predict a reduction in emissions between 5.13% and 8.77%, CGE model indicates that expected fall in emissions oscillates between 1.24% and 2.32% only. Sectoral analysis shows however, that the differences in results are not necessarily linear.

1 Introduction

Since the late 1960s, energy input-output (IO) analysis has been widely used for modelling purposes in energy and climate-related studies (e.g., Miller and Blair, 2009; Suh, 2009). Still, in recent decades, computable general equilibrium (CGE) models have become a strong competition for energy IO models. As a consequence, even though CGE models are often criticized as being insufficiently validated (e.g., Beckman et al., 2011), there can be observed an increasing number of CGE based energy studies. Both IO and CGE use similar databases and rely on similar assumptions[1] – the IO model can be considered as a linear approximation of CGE.

Empirical research comparing outcomes between IO and CGE models is limited. In many cases, at the macroeconomic level results from IO are slightly higher (in magnitude) than those from CGE (Koks et al., 2016; Perrier and Quirion, 2018; Jackson et al., 2019; Tan et al., 2019). At the sectoral level, this is not always true. Comparisons with both models were conducted for the assessment of job creation (Perrier and Quirion, 2018), environmental setting (Jackson et al., 2019), and natural disasters (Koks et al., 2016; Tan et al., 2019).

Perrier and Quirion (2018) assessed the mechanisms of job creation and investigates the degree to which outcomes from basic IO models differ from those obtained through CGE models in a context of installation

[1] As compared to the CGE, the IO model relies on certain unrealistic assumptions such as the lack of supply side constraints, absence of household and government budget constraints or fixed prices (e.g., Cardenete and Sancho, 2012)

of solar panels and weatherization in France. These authors pointed out that the results derived from IO model offer similar outcomes in CGE models for solar energy (-14% to +34%) and demonstrate a slight increase for weatherization (+22% to +87%).

Jackson et al. (2019) employed a static CGE model to estimate the long-term economic impacts of introducing woody biomass processing in a rural region of the Central Appalachians in the United States. By juxtaposing the outcomes of these simulations with estimates from an IO model, the authors contend that, overall, the results exhibit greater magnitudes for most sectors, attributable to the potential for factors of production substitution and price changes.

According to Tan et al. (2019), IO and CGE models are frequently employed in the literature to assess the economic impacts of natural disasters. In this context, the authors utilized both models to estimate the economic losses resulting from a rainstorm in Beijing. The findings from the CGE model surpass those of the IO model, and a more extensive distribution of the impact across sectors is evident in the former model.

To the best of our knowledge, there are no papers that directly compare both methodological approaches in terms of the results of simulations concerning emissions tax policies. In this sense, it is not clear to what extent the conclusions of studies based on different approaches can be considered as complementary or inconsistent.

Considering its dependence on solid fuels[2], Poland plays an important role in the achievement of the European Union (EU) climate and energy policy objectives. Poland has substantially reduced the GHG emissions since the beginning of its economic transformation in the late 1980s. Overall GHG emissions fell by around 20% between 1988, the Kyoto base year, and 1994, while a further decrease of more than 10% had occurred by 1999[3]. Since the early 2000s, annual GHG emissions have remained broadly stable, abstracting from cyclical movements. In managing to cut its total GHG emissions by more than 30% between 1988 and 2009, Poland went well beyond its Kyoto commitment of a 6% reduction between 1988 and the average of 2008-2012 (e.g., Égert, 2012). However, the strong dependence on coal casts serious doubts about fulfilling the targets set in the 2030 EU's framework for energy and climate (e.g., European Parliament, 2018)[4] and the strategy for a climate neutral economy by 2050 (e.g., European Commission, 2019). It also raises many concerns about the impact of the EU climate policy measures on Polish economy and society. Two factors play the key role here. First, the recently adopted government's program for the hard coal sector assumes that coal will still be the main source of energy in 2030. Second, the price of carbon allowances has recently reached its 10-year high and is expected to go beyond 50 euro/ton within the next few years (e.g., Lewis, 2018). The latter has to significantly increase the cost of electricity, both for firms and households.

In this context, this paper aims at comparing the results of IO model and CGE model simulations that measure the impact of the EU-ETS on both Polish economy and households. For the IO model, we use a Leontief price model, extended using a Polish input-output matrix weighted by the intensity of GHG emission of each industry. In the CGE approach, we elaborate a Polish version of simple ORANI-G model, that is further modified to include specific carbon tax and different household types. Using both models calibrated for the same year and database, we are able to compare simulations and access whether methodological differences may affect our predictions about the impact of carbon tax on national economy, the income distribution and the emissions.

Compared to previous research, this paper has three main contributions. First, by simulating a very recent policy that targets specific sectors and directly comparing the outcome of two different methodological frameworks. This is something very hard to find in the existing literature. Second, by estimating expected reduction in greenhouse emissions at a given level of carbon tax, applying unique data on emissions by industry provided by Polish National Centre for Emissions Management. Finally, by verifying whether the distributional impact of carbon tax in Poland is progressive, as suggested in previous papers.

The remainder of the paper is organized as follows. In the next section, we provide a literature review on climate policy in Europe, with special attention to Poland. The third section describes the empirical approach and database, followed by the review of simulation results. The last section summarizes the main

[2]Poland is the EU member state with the highest share of solid fuels in energy production. Actually, in 2020 it became Europe's number one coal generator for the first time ever (Energiewende and Sandbag, 2021)

[3]The reduction after 1994 reflects mainly investment in more energy-efficient technologies.

[4]Initially, the 2030 framework included the commitment to cut GHG emissions by at least 40% by 2030. Still, in 2018, European Parliament supported updating the EU's target to reduce GHG emissions to 55% below 1990 levels by 2030.

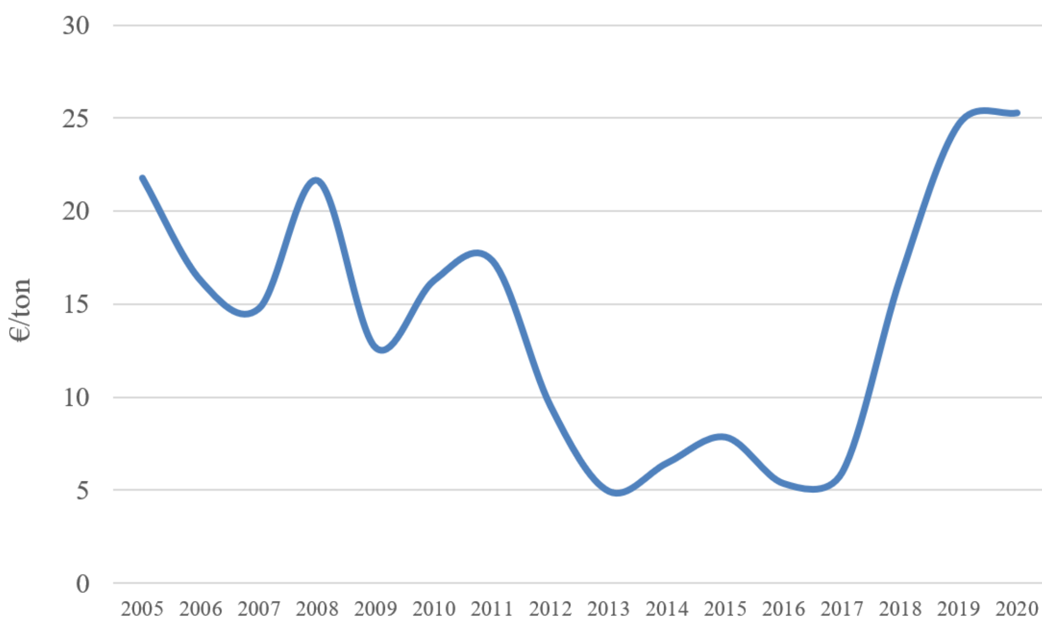
findings and discusses some policy implications.

2 Background

As claimed by World Bank (2018), carbon pricing is widely implemented and in 2018 covered 45 national and 25 subnational jurisdictions. The European Union Emissions Trading System (EU ETS) is a 'cap and trade' system introduced in 2005[5] to meet emissions reductions required by The Kyoto Protocol. It caps the total volume of greenhouse gas emissions from installations and aircraft operators[6] and it allows trading of emission allowances. In a shorter perspective, the EU ETS is assumed to allow to achieve the 2030 energy and climate framework target by reducing the emissions cap by 2.2% yearly as of 2021 (currently the reduction is by 1.74 % per year). Still, until 2050 the EU objective is to reduce GHG emissions by 80-95%[7] as compared to 1990 level (e.g., European Commission, 2011).

Since the introduction of EU ETS system, the price of auctioned emission allowances has dropped significantly from over €20 t/CO_2e in 2005 to slightly over €6 t/CO_2e in 2017 (see Figure 1). The main reason is that EU-ETS has been severely over-allocated in the first and second trading period. However, in 2018 the price has reached its 10-year high around €20 t/CO_2e and has continued to rise, topping over €60 per t/CO_2e in October 2021. This is, at least partly, due to the EU ETS phase 4 reforms adopted in 2018 (e.g., World Bank, 2018).

Figure 1: Price of EU ETS carbon emissions allowances (yearly averages, €/ton)



Source: Authors' preparation based on data from `www.investing.com`

Poland still records relatively high level of per capita emissions, even though the country is one of the few states to have an explicit carbon tax for industrial sectors outside the EU-ETS[8]. Poland's high per

[5]As a result of the EU ETS Directive adopted in 2003 (e.g., consolidated version of Directive 2003/87/EC of the European Parliament and of the Council establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC).

[6]Responsible for around 45% of EU GHG emissions.

[7]From the Polish perspective, the most important assumption of the plan concerns the reduction of CO_2 emissions in the power sector between 93% and 99%.

[8]Still, it is only symbolic at €0.065/ton of CO_2.

capita emissions are due to the predominance of fossil fuel combustion, in particular, in electricity and heat production[9]. In accordance with data from the National Centre for Emissions Management (KOBiZE), in 2017 almost 50% of all CO_2 emissions belonged to the electricity, gas, steam and air conditioning section. This is mainly because historically, Polish energy system has relied on coal, which still accounts for about 80% of fuel used for Polish electricity production. The problem is that Poland seeks to use coal as long as possible, because the country's important coal reserves can guarantee energy security and the coal-mining industry employs around 80,000 workers (Witajewski-Baltvilks et al., 2018)[10]. As a result, coal is indicated as the main source of energy in 2030, in the recently adopted government's program for the hard coal sector[11].

Note, that apart from the symbolic carbon tax for industrial sectors outside the EU-ETS, Poland does not have any other specific policy measures aimed at decreasing GHG emissions in the non ETS sectors. Instead, in 2019, a new law was adopted to compensate higher electricity prices for enterprises from energy-intensive industries. At the same time, however, there is no any explicit compensation measure with focus on the households[12]. Poland also strongly subsidies conventional energy power plants as compared to renewable energy sources. As shown in the recent report by (Stoczkiewicz and Śniegocki, 2019), in 2018 overall public support for conventional energy sources reached almost PLN 30 billion versus less than PLN 15 billion dedicated to renewable sources. Given the above, serious concerns arise in respect of the possible impact of GHG emissions reduction, required by EU climate policy objectives, on both Polish economy and society.

There are many studies, both theoretical and empirical, that deal with the impact of carbon tax on national economies, however few papers deal with this issue in Poland. The European Commission (2008) shows that in the case of Poland, the negative change in GDP between 2005 and 2020 with respect to the baseline (no green policies), will be 1.5–1.6% (depending on whether emission permits are auctioned or distributed freely) *versus* 0.35%–0.54% of GDP for EU-27. In his review paper, Tol (2010) argues that in the case of Poland, the mean loss in welfare by 2020 will reach 1.4%.

The World Bank (2011) estimates the negative impact of EU ETS on Polish real GDP, measured as a deviation from the baseline scenario (no low carbon policy), to be around 1.8% by 2020. Finally, Kiuila and Śleszyński (2003) or Hagemejer and Żółkiewski (2013) have shown that an increase in carbon tax would have a degressive negative impact on households' consumption. The above results are, however, surprising taking into account that usually in the literature carbon tax is found to be regressive.

For other countries, while a range of different methodologies can be found, China seems to be of particular interest here. For instance, Chen and Nie (2016) develop a computable social optimal welfare model and show that in the case of China, imposition of carbon tax on production sector could lead to an increase in welfare, due to productivity improvement. This effect is, however, nonlinear – beyond the certain point, further increase in carbon tax would induce social welfare loss. Liu and Lu (2015) employ dynamic CGE model to claim that the introduction of carbon tax has only mild negative impact on Chinese economy. At the same time, they prove it to be an efficient mechanism of emissions reduction. Jiang and Shao (2014) estimate distributional effects of carbon tax on households in Shanghai, relying on input-output model. They find that, due to the expenditure structure, carbon tax is regressive and leads to an increase of income inequality between different household groups. Hence, certain compensation mechanism should be introduced in order to mitigate this effect.

Regressive feature of carbon tax is proved also in the case of other countries. For instance, Hasset et al. (2007) or Mathur and Morris (2014) find carbon tax to be regressive in the case of the US, Meng et al. (2014) in the case of Australia, while Freitas et al. (2016) in the case of Brazil. In the European context, Symons et al. (2002) find carbon tax to be regressive in the case of Germany, France and Spain. Also, Callan et al. (2009) find carbon taxation to have relatively larger negative impact on welfare of poorer households in the case of Ireland.

Even though, nowadays most of the empirical studies related to the carbon tax rely on CGE modelling

[9]In 2009, only Finland, Greece, the Czech Republic and Estonia recorded higher per capita emissions in heat production.

[10]Note, this is purely political decision since Poland has enough coal for around 40 years only. Polish coal is also much more expensive than imported, those results in a significant increase in importations, mainly from Russia.

[11]See Ministerstwo Energii (2018).

[12]Although the electricity prices in 2019 were frozen at mid-2018 levels for all households, they are supposed to increase by more than 10% in 2020. The government is considering an introduction of compensation measure with particular focus on poorest households in 2021, however, no legal acts have been adopted yet.

approach, input-output framework is still used in many papers (e.g., Freitas et al., 2016; Gemechu et al., 2014; Zhang et al., 2019). However, there are very few studies that systematically compare both methodological frameworks on a theoretical (e.g., Rose, 1995; Okuyama and Santos, 2014; West, 1995) and on empirical ground (e.g., Hu et al., 2014; Koks et al., 2016). As claimed by Koks et al. (2016), such a comparison is highly valuable from both a scientific and policy perspective, as there exist several differences between input-output models and CGE models. For instance, the former does not consider relative price[13] changes or substitution effects. The latter are more complex, allowing for both relative price changes and substitution effects, as well as for diversified economic behavior at the household, firm, and government levels. As a result, it is very likely that, due to differences in methodology, the magnitude and distribution of impacts related to carbon taxation policies may vary significantly. Several papers show that IO models tend to overestimate the economic impact as compared to CGE models in the case of analyses concerning natural disasters or tourism sector (e.g., Allan et al., 2017; Koks et al., 2016). There can also be found papers that compare the impact of model's assumptions on simulation results (e.g., Cardenete and Sancho, 2012). However, we are not familiar with any study that makes a similar effort analyzing the macroeconomic impact of carbon tax policies. Below, we aim at filling the existing gap in the literature, presenting simulation results based on both input-output and computable general equilibrium model.

3 Methodological Approach and Data

3.1 Input-Output Model

The input-output model used in this paper follows the approach by Freitas et al. (2016). Hence, we construct a Leontief price model based on an input-output matrix weighted by the intensity of GHG emissions of each industry in Poland. This approach allows evaluating the distributive impact of carbon taxation among ten household groups according to their income level as well as among selected industries[14]. In accordance with the basics of input-output modeling, emissions specification can be defined as follows:

$$e = m'(I - A)^{-1} \tag{1}$$

where e is a vector which represents the emission's intensity by sector, m is a vector which represents the emission's coefficient, i.e., the ratio between GHG emissions of each sector and the total production, and $(I\text{-}A)^{-1}$ is the Leontief Inverse Matrix.

All the equations' specifications are almost the same as used by Freitas et al. (2016). The first difference is related to the euro rate per ton of CO_2 equivalent. Considering the EU ETS system, we decided to use two different rates, i.e., €16.3 and €30. The first one reflects the average price of the EU ETS carbon emissions allowances in 2010, while the second one refers to the level assumed to be reached by 2020. Additionally, differently of Freitas et al. (2016), who simulated a homogeneous tax for all sectors, in our benchmark specification we simulate the tax over the sectors covered by the permits' system only.

Basically, the model assumes that variations in production costs are converted into price change. Thus, we incorporate a tax on the amount of emitted CO_2 equivalent only for the ETS sectors. The tax vector (T) can be defined as:

$$T = \varphi e' \widehat{d} \tag{2}$$

where φ the rate per ton of CO_2 equivalent, and d is a dummy vector indicating ETS sectors. When this vector is summed up with previous value added and the Leontief model is recalculated, by comparison, we have the effect caused by relative price changes in the economy.

[13]It is important to notice that although in the traditional input-output models the price relationship is fixed, for the Leontief price model used in this paper, it was possible to introduce changes in relative prices, if they were caused by changes in the price of primary inputs.

[14]We selected sectors covered by the permits' system only: Paper and paper products; Coke, refined petroleum products; Chemicals and chemical products; Pharmaceutical products; Rubber and plastic products; Other non-metallic mineral products; Basic metals; Electricity, gas, steam, and air conditioning; and Water and air transport services.

Following Freitas et al. (2016), household welfare change Δw_k for decile k is estimated as:

$$\Delta w_k = (\sum_i c_{ik} * \breve{p}_i) - (\sum_i c_{ik} * \widetilde{p}_i) \quad (3)$$

where c_{ik} is the quantity consumed by decile k from industry i, $\breve{p}_i$ is the price index for the base year, and $\widetilde{p}_i$ is the adjusted price (after tax).

Although input-output models consider sectoral, regional and household interdependencies, it ignores crucial aspects in the distribution impacts throughout the economic system, such as: i) imperfect substitution between inputs; ii) spatial price differentiation; iii) productive factors mobility; iv) imperfect substitution between goods of domestic and imported origin, among others. It is noteworthy, however, the importance of input-output in the CGE models' construction. According to Rose (1995), multisectoral formulations would be of limited value without a sectoral interdependence model as part of their theoretical core and without an empirical input-output table to make them operational. More than that, "many key features of IO are at the heart of a newer modeling approach CGE analysis - which extends the range of applications and of Leontief's influence" (Rose, 1995).

3.2 Computable General Equilibrium Model

In our CGE based simulations, we use a Polish version of ORANI-G model. ORANI-G is a generic version of the Australian ORANI model developed by Centre of Policy Studies at Victoria University. Note, that ORANI-G has been previously applied by McDougall (1993) to assess the short-run effects of carbon taxation in the case of Australia. However, in our case, the approach to include carbon tax in the model is different and follows the logic of the IO framework discussed above. This kind of approach allows us to compare simulation results of two different approaches that are, however, as close as possible to each other.

Theoretical structure of ORANI-G is typical for static applied general equilibrium models. For instance, the behavior of private agents follows assumptions derived from neoclassical microeconomics. Hence, they are supposed to be price-takers and deal with optimization problems such as cost minimization or utility maximization. At the same time, perfect competition prevents the existence of economic profits for producers. All model equations are linear – in the case of typically non-linear equations, they are expressed in linearized form. This is known as a percentage change approach to the model solution.

Each industry in ORANI-G model uses as inputs domestic and imported commodities, labor of several types, land and capital. Export goods are distinguished from those for local use. Each commodity composite is a CES (constant elasticity of substitution) function of a domestic good and its imported equivalent (elasticities used are described in Table 1). The primary-factor composite is a CES aggregate of land, capital and composite labor. Composite labor is a CES aggregate of occupational labor types. While all industries share the above production structure, input proportions and behavioral parameters may vary between them[15]. In our extension of the model, we include carbon tax as an additional production tax that adds up to the total industry cost to determine tax-inclusive cost of production. This way carbon tax influences directly output prices, and it is transmitted to the rest of the economy through relative price changes. The value of carbon tax collected from each industry depends on amount of GHG emissions and carbon tax rate. The change in amount of emissions is related in turn to the emissions intensity and to the change in value added. Note, that to provide as much similarity to the IO framework as possible, we do not include a specific energy system in the model (substitution between energy sources, renewables etc.). Therefore, tax and emissions were calculated identically as in the IO model, in such a way that all the resulting differences are due to the production and consumption behavior assumptions.

In order to assure the results to be comparable to the IO simulations, we apply typical short-run closure. In such a specification, variables such as real wages, aggregate real government demand or aggregate real investment expenditure are set to be exogenous, Table 2 details all exogenous variables. We also extend the generic version of the model and instead of single representative household, we distinguish ten household groups based on income levels in 2010. The model is solved using the GEMPACK software.

[15] A detailed description of the ORANI-G model can be found in Horridge (2000)

Table 1: Parameters and Elasticities

Code*	Description	Values/Range
SIGMA1PRIM	Elasticity of substitution between primary factors	0.35
SIGMA1	Armington elasticity for intermediate inputs demand	2
SIGMA2	Armington elasticity for investment demand	2
SIGMA3	Armington elasticity for household demand	2
FRISCH	Frisch Parameter	-1.82
EPS	Household Expenditure elasticities	0.005132 - 0.023460
EXP_ELAST	Individual Export Elasticities	4
EXP_ELAST_NT	Collective Export Elasticity	4

*Standard Code used in ORANIG models, see Horridge (2000)
Source: Author's own elaboration.

Table 2: Exogenous variables, all the rest are endogenous

Variable*	Description
a1cap	Capital-augmenting technical change
a1lab_o	Labor-augmenting technical change
a1lnd	Land-augmenting technical change
a1tot	All input augmenting technical change
a2tot	Neutral technical change - investment
a3_s	Taste change, household import/domestic composite
aprimtot	general factor augmenting technical change
capslack	Slack variable to allow fixing aggregate capital
delctax	Carbon tax per ton
delPTXRATE	Change in rate of production tax
f0tax_s	General sales tax shifter
f1lab_o	Industry-specific wage shifter
f1oct	Shift in price of "other cost" tickets
f1tax_csi	Uniform % change in powers of taxes on intermediate usage
f2tax_csi	Uniform % change in powers of taxes on investment
f3tax_csh	Uniform % change in powers of taxes on household usage
f3tot_h	Over-all shifter for consumption
f4p	Price (upward) shift in export demand schedule
f4p_ntrad	Uniform upward (price) demand shift for collective exports
f4q	Quantity (right) shift in export demands
f4q_ntrad	Uniform right (quantity) demand shift for collective exports
f4tax_ntrad	Uniform % change in powers of taxes on non-tradable exports
f4tax_trad	Uniform % change in powers of taxes on tradable exports
f5	Government demand shift
f5tax_cs	Uniform % change in powers of taxes on government usage
finv1	Shifter to enforce Dixon et al. (1982) investment rule
fx6	Shifter on rule for stocks
pf0cif	C.I.F. foreign currency import prices
phi	Exchange rate, local currency/$world
q	Number of households
realwage	Average real wage
t0imp	Power of tariff
w3lux	Nominal luxury consumption
wemisrate	Emissions intensity per industry
x1cap	Current capital stock
x1lnd	Use of land
x2tot_i	Aggregate real investment expenditure
x5tot	Aggregate real government demands

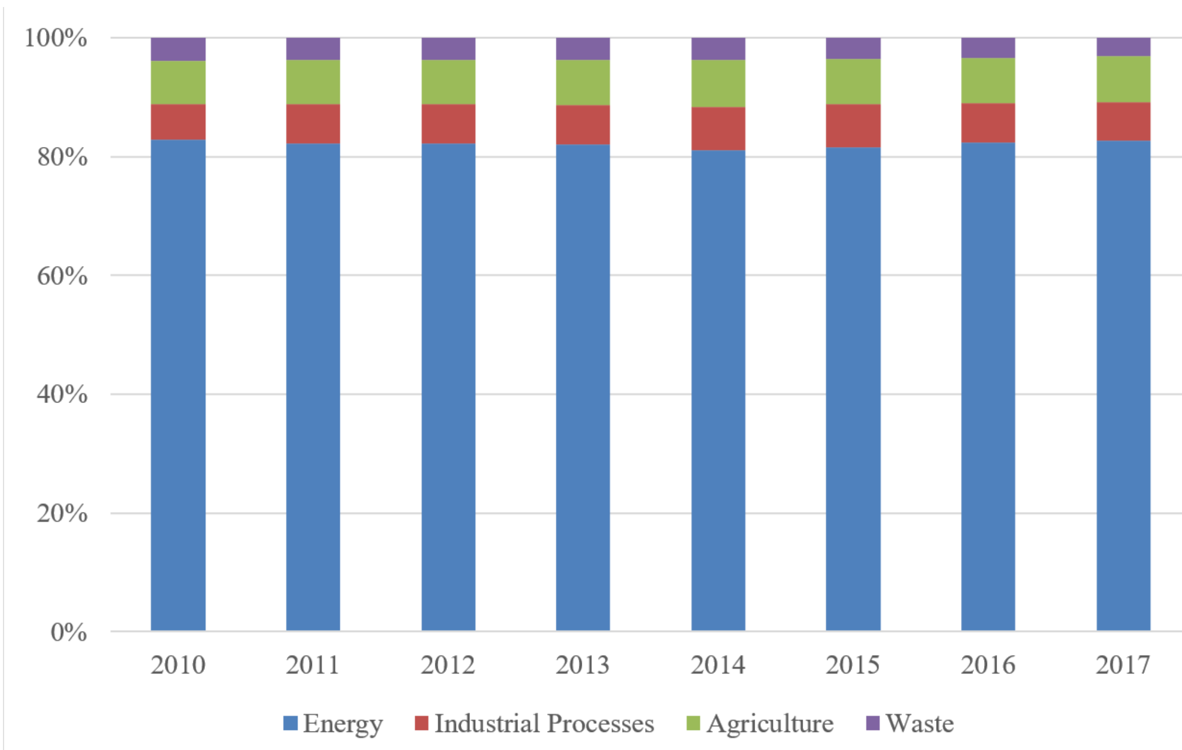
*Standard names used in ORANIG models, see Horridge (2000)
Source: Author's own elaboration.

3.3 Data

Both models used in our study are based on 2010 input-output matrix (IOM) provided by the Polish Central Statistical Office. Originally, this IOM has 77 sectors. However, to make all the data compatible it was aggregated to 58 sectors. Following Freitas et al. (2016), to construct the GHG emissions vector, the following gases were considered: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) measured in carbon equivalents. The emissions data was taken from National Centre for Emissions Management (KOBiZE). The household consumption and income were broken down into different income deciles using data from the Household Budget Survey, conducted by the Polish Central Statistical Office.

Figure 2 shows GHG emissions in Poland per gas source between 2010 and 2017. Sectoral composition of emissions is very stable among the period. The main source of GHG emissions is fuel combustion in energy production, which represents, on average, over 80%. Industrial processes account for around 5%, while agriculture and waste for 8% and 3% respectively.

Figure 2: GHG emissions in Poland per source (2010-2017)



Source: Author's own elaboration based on KOBiZE data.

Table 3 resumes information on emissions and production of the nine industries covered by the EU-ETS in 2010. Note, that Electricity, gas, steam and air conditioning accounts for 64% of the Polish industrial GHG emissions and over 46% of the total GHG emissions in Poland. However, although the nine industries are responsible for more than 62% of total emissions in Poland, they account only for less than 17% of total production. That fact directly reduces the expected economic cost of imposing carbon taxation.

As already mentioned, the household consumption and labor income were broken down into ten different income deciles using microdata from the Polish Household Budget Survey (HBS). Initially, at the individual level, HBS data were employed to compute labor and non-labor income categorized by the sector of employment and income decile. This allowed the determination of each decile's proportion in the income generated from each sector, as well as the corresponding consumption share of each decile within each sector. In essence, the share of consumption spending within each decile, as identified in the household survey, was

Table 3: Emissions and production for industries covered by the permits system

Sectors	CO2 equivalent emissions		Production	
	(in Gg)	(in % of total)	(in 2010 million PLN)	(in % of total)
Paper and paper products	4,454	1.23	40,623	1.17
Coke, refined petroleum products	11,344	3.29	73,533	2.12
Chemicals and chemical products	14,872	4.32	102,496	2.96
Pharmaceutical products	128	0.04	30,218	0.87
Rubber and plastic products	299	0.09	76,981	2.22
Other non-metallic mineral products	15,843	4.59	50,93	1.47
Basic metals	9,847	2.86	87,764	2.53
Electricity, gas, steam and air conditioning	166,667	46.42	102,354	2.95
Water and air transport services	1,286	0.37	11,973	0.35
Total for selected sectors	224,738	62.22	576,872	16.65
Total for the economy	361,196	100	3,464,107	100

Source: Author's own elaboration based on KOBiZE data.

utilized to break down the household consumption vector of the IO table. This maintains the consistency of the breakdown of consumption in income deciles with the original data from the matrix.

Additionally, HBS data were employed to ascertain the proportion of specific occupations within households belonging to varying income deciles. Subsequently, IO table data on labor compensation was applied to compute sector and occupation-specific wages, presuming a consistent share of wages in total labor compensation. Finally, utilizing the aforementioned datasets, a wage matrix per household decile and occupation was computed. A parallel methodology was employed to calculate non-labor income (encompassing capital income, public transfers, and other sources) per household decile.

Data obtained from the Household Budget Survey shows certain degree of income concentration in Poland (see Table 4). In 2010, the first decile had an average household per capita income of PLN 367.63 per month, i.e., 10% of Polish households disposed of monthly income below €100 per head. On the other hand, disposable per capita income reached PLN 3544.14 for the 10% richest people.

Table 4: Descriptive statistics of the monthly income data by representative household (in PLN)

	Mean	Std. Dev	Min	Max
Decile 1	367.63	104.66	0	497.09
Decile 2	582.66	48.28	497.12	664.23
Decile 3	735.18	40.44	664.25	802.83
Decile 4	868.51	38.15	802.88	935
Decile 5	1 005.72	40.72	935.07	1 077.81
Decile 6	1 151.03	43.89	1 077.90	1 230.88
Decile 7	1 317.53	52.66	1 230.89	1 415.94
Decile 8	1 537.48	76.7	1 416.00	1 681.27
Decile 9	1 902.81	147.2	1 681.47	2 200.76
Decile 10	3 544.14	4 560.11	2 200.93	192 282.50
Total	1 232.33	1 645.15	0	192 282.50

Source: Author's own elaboration based on HBS.

4 Results

Our simulations evaluate the impact of carbon taxation policy on both GHG emissions and welfare in Poland. Both models assume that all tax costs are incorporated into prices. Hence, selected industries need to reduce their emissions because their commodities are relatively more expensive. As a consequence, final demand is lower either because there is no income compensation effect (IO model) or because real income is lower and people can substitute between imported versions of the same good or completely different commodities (CGE model). Therefore, the expected result is a reduction in emissions, production, employment, and welfare, as well as an increase in prices. The size of these adjustments is, in turn, a direct consequence of the production and emissions structure of the country. For instance, the most pollutant industries pay higher taxes and exhibit higher price effects. Nevertheless, emissions are reduced both, by the direct effect over sectorial final demand, and indirectly through intermediate consumption relations. Accordingly, even industries that pollute less or that are not even included in ETS policies, may reduce their production and consequently their emissions.

To evaluate the impact of ETS policy in Poland we assume two scenarios: in Simulation 1 the tax is €16.275 per t/CO_2e and in Simulation 2 it is €30 per t/CO_2e[16]. The results discussed below refer to simulations where carbon tax is imposed on sectors covered by ETS policy only. However, we also simulate effects covering all industries. The expected size in aggregate production or welfare loss due to the carbon tax is higher in the case of the IO simulations as compared to the CGE simulations. This is due to the fact that the CGE model captures both substitution and scale effects, while IO models concentrate on scale effects. Still, the question is the scale of differences and whether the impact on particular industries is proportional or not.

Table 5 reveals the aggregated results for both scenarios. In the case of IO model, we find a substantial drop in the level of Polish GHG emissions, ranging from 5.13% to 8.77% of reduction between simulations. A decrease in emissions is much lower, though, once the CGE model is applied. Here, expected reduction oscillates between 1.24% and 2.32% only. As expected, the policy aimed at reduction of emissions comes with an economic cost. IO model predicts a fall of total production between 0.90% and 1.60%, while results of CGE simulations indicate a decrease from 0.46% to 0.87%. The reduction in employment is very similar in both frameworks and varies roughly from 0.62% (IO model) to 1.25% (CGE model). Still, there are significant differences in the impact on both welfare and prices. While IO model forecasts overall welfare loss between 1.10% and 2.02%, its CGE counterpart estimates that the decline in welfare should vary between 0.19% and 0.36%. On the other hand, the total estimated effect on the general price index oscillates between 0.93% and 1.72% in the case of IO model, and ranges from 0.38% to 0.74% in the case of CGE framework.

Table 5: Main macroeconomic results (% change)

Variable	**IO results**		**CGE results**	
	Simulation 1 (€16.275)	**Simulation 2** (€30)	**Simulation 1** (€16.275)	**Simulation 2** (€30)
GHG Emissions	-5.13	-8.77	-1.24	-2.32
Production	-0.9	-1.6	-0.46	-0.87
Employment	-0.62	-1.11	-0.66	-1.25
Welfare	-1.1	-2.02	-0.19	-0.36
Prices	0.93	1.72	0.38	0.74

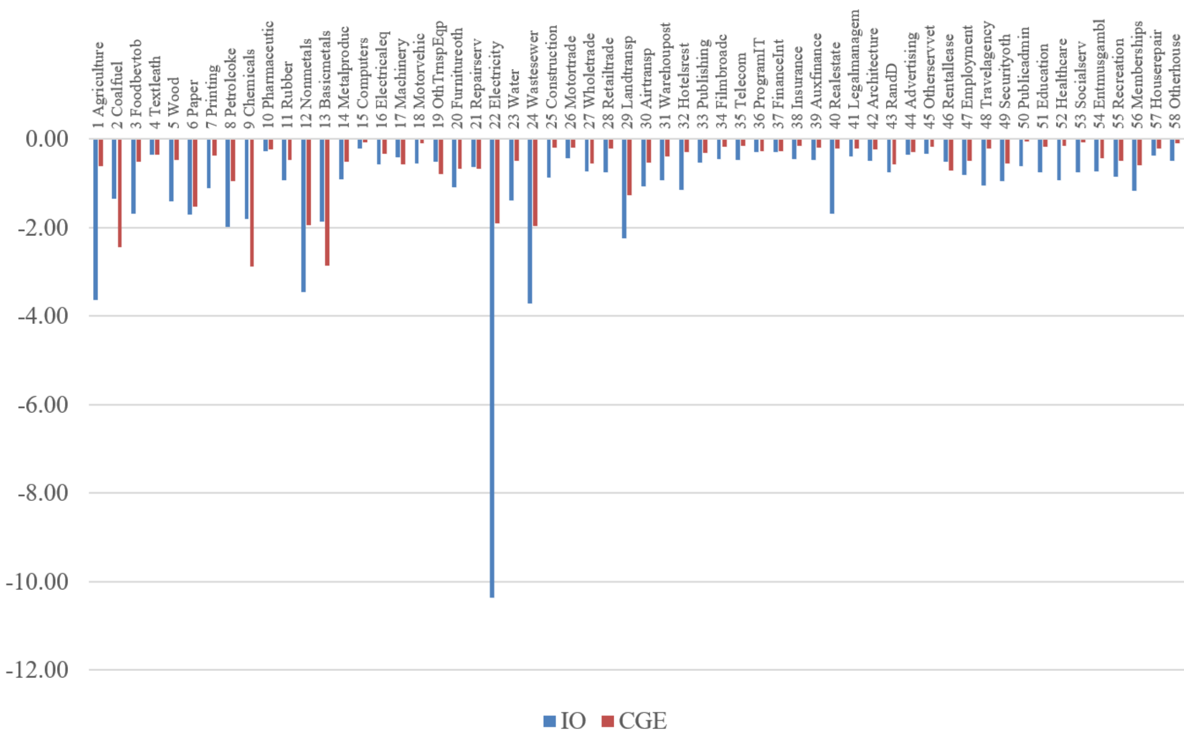
Source: Author's own elaboration.

Overall, the aggregate input-output model results are higher (in magnitude) than those of the CGE model. As mentioned earlier, this is due to the flexibility of hypotheses of the first model, such as the possibility of price-induced substitution. This possibility allows, in the CGE model, for changes in the input source composition (between national and imported commodities) for firms, and between commodities and

[16] As mentioned previously, the first one reflects the average price of the EU ETS carbon emissions allowances in 2010, while the second one refers to the highest price reached by 2020.

source compositions for households. Therefore, in a short-run tax simulation, agents are able to avoid price changes by moving away from relatively more expensive goods (due to the tax), attenuating the firm's ability to pass on cost changes. In contrast, in the IO price model, all prices changed exactly in the same size as the tax imposed, and all firms and final demanders keep their consumption composition as before, but with less available income. Yet, our findings change significantly once we analyze the results by particular industries. It appears that the differences in results vary significantly across industries (see Figure 3). The differences may be as much as almost 10 percentage points (in the case of electricity) although in most of the cases do not exceed 1 percentage point. Furthermore, in certain cases the negative impact of carbon tax in the CGE model can be even bigger as compared to the results of IO simulations. This refers for instance to mining, chemical industry or basic metal product's industry (although there are more industries that follow this pattern).

Figure 3: Production change by industry – Simulation 1)



Source: Author's own elaboration.

The main reason behind the differences in the overall impact predicted by both models can be found in Table 6. IO simulation results show that the most intensive GHG industry, electricity, gas, steam and air conditioning, accounts, by far, for the largest percentage changes in production and thus emissions (between -10.04% and -17.06%)[17]. This sector is extremely interrelated with other sectors of the economy, since all other industries demand their commodities. Consequently, any small reduction in its final demand has not only powerful effect reducing emissions directly but also indirectly, through intermediate demand from all other industries. However, CGE model indicates that once we introduce general equilibrium and substitution effects, the impact of carbon tax on this sector in terms of output and emissions reduction is much lower. Here, expected reduction in emissions for the electricity, gas, steam and air conditioning ranges from 1.80% to 3.30% only. In fact, greater decrease in emissions is expected in the case of chemicals and chemical products (between 2.80% and 5.48%), basic metals (between 2.73% and 5.23%) or other non-metallic mineral products (from 1.86% to 3.54%).

[17]The change in emissions by sector is proportional to the change in production.

Table 6: Total CO_2 equivalent emissions by industry (% change)

Sectors	IO results		CGE results	
	Simulation 1 (€16.275)	Simulation 2 (€30)	Simulation 1 (€16.275)	Simulation 2 (€30)
Paper and paper products	-1.45	-2.64	-1.44	-2.75
Coke, refined petroleum products	-1.32	-2.41	-0.71	-1.37
Chemicals and chemical products	-1.65	-2.99	-2.8	-5.48
Pharmaceutical products	-0.2	-0.37	-0.21	-0.41
Rubber and plastic products	-0.75	-1.38	-0.42	-0.8
Other non-metallic mineral products	-3.15	-5.66	-1.86	-3.54
Basic metals	-1.6	-2.9	-2.73	-5.23
Electricity, gas, steam and air conditioning	-10.04	-17.06	-1.8	-3.3
Water and air transport services	-0.93	-1.71	-0.5	-0.96

Source: Author's own elaboration.

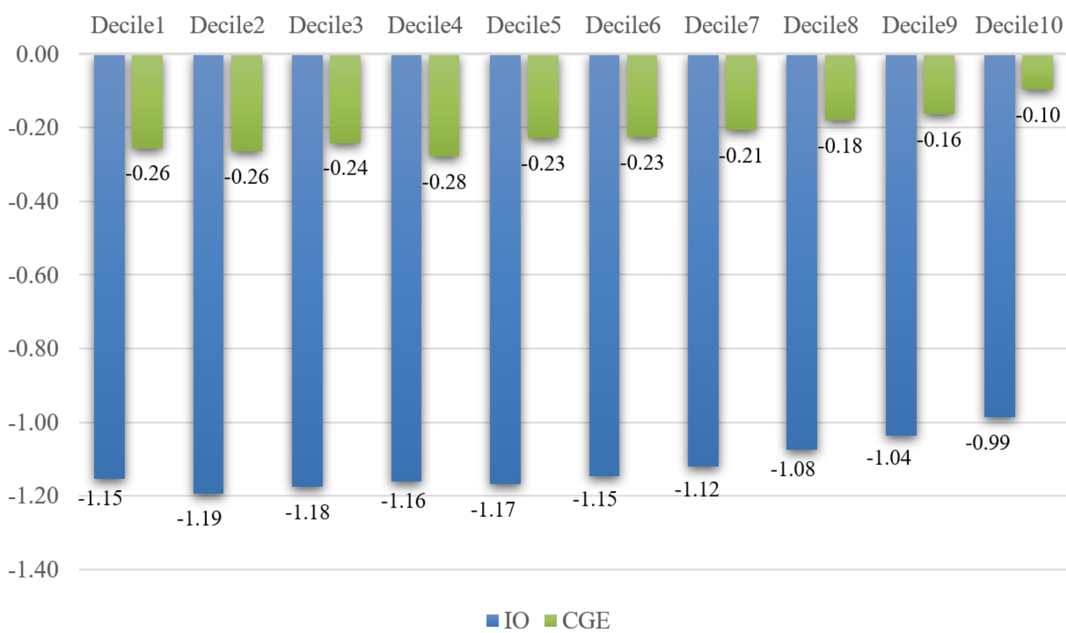
Figures 4 and 5 reveal the compensatory variation related to real household consumption. Once again, IO framework seems to significantly overestimate the welfare loss, as compared to its CGE counterpart. Still, both applied models show a slightly regressive effect of the tax. Here, the decline in welfare for Decile 1 ranges between 1.15% and 2.13% in the case of IO model, and between 0.26% and 0.47% in the case of CGE. At the same time, Decile 10 experiences a fall in consumption in the range of 0.99% - 1.82% and 0.10% - 0.18% respectively. The difference is even greater if we compare the results for Decile 10 with the results for Decile 2. This is an important finding given the fact that previous studies by Kiuila and Śleszyński (2003) or Hagemejer and Żółkiewski (2013) report exactly opposite results. As a matter of fact, Kiuila and Śleszyński (2003) even expect an increase in welfare of poorer households, in most of the analyzed scenarios. Here, the Authors recognize though that their results are surprising and attribute them to the fact that their model is better suited for analyzing producers' behavior. However, most likely, the main reason behind the progressive character of the carbon tax found by Hagemejer and Żółkiewski (2013) is the way of compilation of consumption vector data. They match consumption data to sectoral data using non-specified concordance table for 39 sectors only. High level of sectoral aggregation together with imprecise matching process may lead to bias in household consumption vector. In any case, our results cannot be compared directly since both Kiuila and Śleszyński (2003) and Hagemejer and Żółkiewski (2013) distinguish only between poor and non-poor households and rely on older I-O tables (1995 and 2005 respectively).

5 Conclusions and Policy Implications

This paper aims to measure the impact of the EU Emissions Trading System on the Polish economy and on households at different levels of income. Furthermore, we compare the results based on two different methodologies, Input-Output (IO) model and Computable General Equilibrium (CGE) model. To the best of our knowledge, this is the first paper that directly compares the results of the above frameworks in the carbon tax context. We consider two alternative taxation scenarios under the European Union's Emissions Trading System, where the carbon tax ranges between 16.3 euro/ton and 30 euro/ton of GHG emissions. Our results indicate that IO framework may significantly overestimate the overall impact of carbon tax on national economy and emissions. For instance, while IO simulations predict a significant reduction in emissions (between 5.13% and 8.77%), CGE model indicates that the expected fall in emissions oscillates between 1.24% and 2.32% only[18]. This is a very important finding from the policy point of view. We also show, however, that, at least in the short run, the EU ETS cannot be an effective tool in policy aimed at the reduction of greenhouse gas emissions, given the structure of emissions in Poland. Here, electricity, gas, steam and air conditioning sector accounts for almost 50% of all GHG emissions. Any significant change

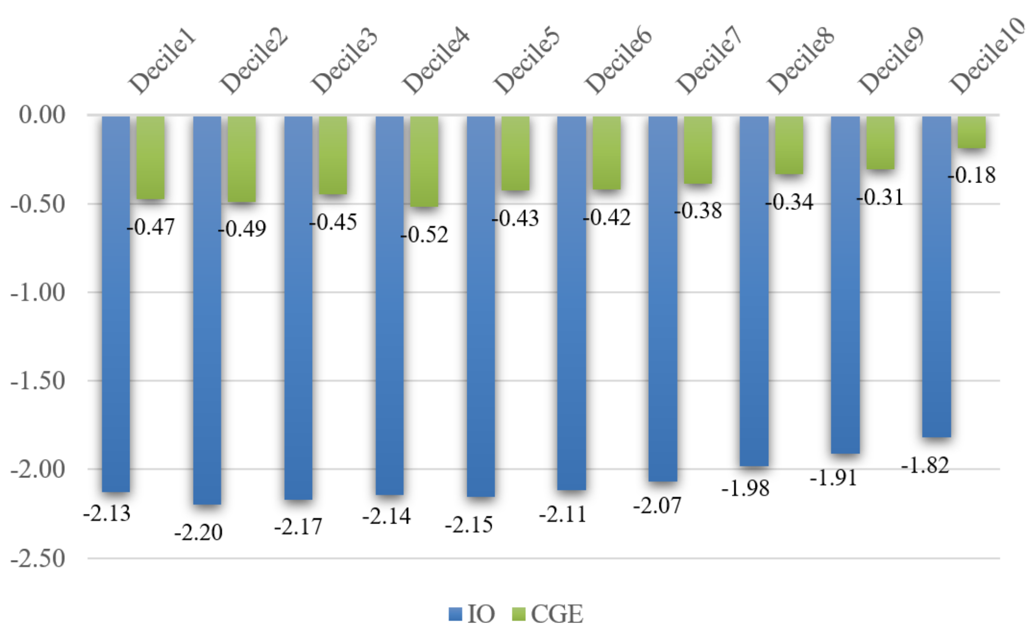
[18]This result hardly changes in the case when all the sectors were covered by carbon taxation.

Figure 4: Welfare losses measured by compensatory variation (% change) – Simulation 1)



Source: Author's own elaboration.

Figure 5: Welfare losses measured by compensatory variation (% change) – Simulation 2)



Source: Author's own elaboration.

in the level of emissions of this sector requires long-term investment programs that must be preceded by according political decision[19]. As claimed in the introduction, the latter is unlikely to be taken within the next few years, considering the concessions recently granted to the carbon industry.

Concerning sectoral impact on production, the IO model forecast electricity, gas, steam and air conditioning to be the most affected industry, followed in a much lower scale by other non-metallic mineral products and chemicals and chemical products. This is, though, not the case of the CGE simulation results. Here, the highest decline in production is expected in chemicals and chemical products, basic metals and other non-metallic mineral products. On average, predictions of both models are not so different, in terms of the impact of carbon tax on particular industries. The key difference concerns the electricity, gas, steam and air conditioning sector and is mainly due to the fact that IO model does not capture any substitution effect. The latter makes the output in this sector collapse after the introduction of the carbon tax, regardless the fact that the elasticity of demand for energy is rather low in the short-term (e.g. Kim *et al.*, 2017).

The analysis of distributional effects of carbon tax indicates that the welfare loss associated with carbon tax is relatively lower for the richest household groups. This is even though they consume in absolute terms more products and services that contribute to environmental degradation. On the other hand, any price changes may cause important changes in poor household's budget constraints, mainly because their consumption bundle is concentrated in agricultural and manufacturing goods which are more polluting compared to services. In this sense, our results differ from previous papers by Kiuila and Śleszyński (2003) or Hagemejer and Żółkiewski (2013) who found exactly opposite results.

The IO framework appears to significantly overestimate the welfare loss compared to its CGE counterpart. Specifically, the decline in welfare for Decile 1 ranges from 1.15% and 2.13% in the case of IO model, whereas it ranges between 0.26% and 0.47% in the CGE model. Simultaneously, Decile 10 experiences a fall in consumption in the range of 0.99% - 1.82% and 0.10% - 0.18%, respectively. From the Polish standpoint, it is crucial to note that these findings unequivocally refute recent government assertions attributing massive welfare losses to the EU ETS system. Nevertheless, it is essential to acknowledge that a substantial, imminent escalation in carbon taxes may lead to noteworthy welfare reductions. In an effort to circumvent this, the Polish government has announced plans to build several nuclear plants in the near future.

Overall, our findings suggest that European energy policies should include a compensation mechanism for poorer households. There are at least several different sources of financing potential redistribution policies, such as revenues from auctioning of emission allowances or penalty payments for non-compliance. Nevertheless, up to now, Polish government seems to use the above resources to offset budget deficit. The question related to possible compensation measures seems to be particularly important considering proposals included in the recent European Commission "Winter package"[20]. One of the proposed measures sets the maximum level of emissions at 550 kg/MWh, that would exclude from the power market all conventional coal power plants which were not competitive[21]. Taking into account the structure of Polish energy sector, this could have much more significant impact on the economy than taxation scenarios analyzed in this paper.

As our results are based on simulation models, it is important to address the caveats of the CGE and IO modeling approaches. The latter does not consider relative price changes, substitution effects, spatial price differentiation and productive factors mobility. On the other hand, given the complexity of CGE models and the requirement of large amount of data, equations and parameters the model is compared to a "black box". In general, we could see that the results of both models are in the same direction.

The most important difference is related to the magnitude. Overall, IO results are larger (in magnitude) compared to CGE results. As mentioned earlier, this difference is expected in short run tax simulations, due to the possibilities of substitution in the CGE model, not available in the IO price model. However, this result raises important implications relating to the use of IO results for tax policy design. First, at the aggregated level, IO results are showing a larger capacity of tax policies to reduce emissions, and a larger economic cost (reducing the size of the economy). Considering the substitution effects in the CGE results, we could say the policy is not as effective on reducing emissions, but as a counterpart, it has less economic cost. Second, sectorial differences are relevant. While IO is clearly penalizing sectors with direct emissions, CGE

[19]State is the biggest shareholder in Polish energy sector.
[20]See European Commission (2016)
[21]Hence, coal-fired power plants would have to be built without such subsidies.

shows the drawback on other sectors, indirectly affected by the overall change in the aggregated composition, but always with less negative results. Those differences, combined with the smaller economic cost, may be relevant on convincing policymakers to pass on tax emissions policies.

Moreover, for a rapid policy assessment, IO models prove more suitable owing to their simplicity in construction and the need for a smaller dataset. Conversely, for a thorough and comprehensive evaluation of the economic system, CGE models are more appropriate, providing a more detailed depiction. It is crucial to note that throughout all simulations, we refrain from assuming any possibilities of technological change. This assumption aligns with the selection of a short-run closure for the CGE model and the fixed economic structure inherent in any static model, whether CGE or IO.

It is worth to mention that, as a step forward of this study, it could be worth to account for potential costs related to GHG emissions. Here, as shown in the recent report by the European Environment Agency (2018), Poland is one of the European countries with the highest health impacts of exposure to fine particulate matter, ozone and nitrogen dioxide. Finally, another interesting possible extension is an analysis concerning the regional impact of carbon tax. Given the concentration of industrial activity in certain regions of Poland, such an impact is likely to be highly nonlinear.

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