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To Whom Should We Grant a Power Plant? Economic Effects of Investment in Nuclear Energy in Poland

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Abstract: Poland is the most coal-dependent economy and one of the biggest polluters in the EU. In order to alleviate this problem, meet CO_2 emission requirements set by EU, and improve the country's energy security, Poland decided to introduce nuclear power to its energy mix. So far, several potential locations for nuclear power plants have been officially proposed, mainly based on technical parameters, but no comparisons of the economic impact of such locations have been considered. Consequently, the main goal of this paper is to compare the national and regional economic effects of investments in nuclear power plants—for both the construction and exploitation phases—in the four most probable locations, which are similarly beneficial from a technical point of view. In order to simulate these effects, the spatial recursive dynamic Computable General Equilibrium model was calibrated until 2050 including agglomeration effects and featuring the regional economies of all Polish regions. The results show that although the construction phase is beneficial for economic development in all four regions, the exploitation phase is good for only one. The economies of the other regions suffer, to a greater or lesser extent, from the Dutch disease. The paper argues that the regional economic effects of such an investment differ significantly, due to differences in the regions' economic structures; hence, they should always be taken into account in the final decisions on the power plants' locations.

Keywords: nuclear power station; location; national and regional economic effects; spatial Computable General Equilibrium (CGE) modelling; agglomeration effects; energy policy; Poland

1. Introduction

The EU aims to be a climate-neutral economy with net-zero greenhouse gas emissions by 2050. This objective was established on 28 November 2018 in a document entitled "A Clean Planet for All—A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy" [1] and reinforced on 6 March 2020 in "Long-Term Low Greenhouse Gas Emission Development Strategy of the EU and Its Member States" [2]. It is also at the heart of the "European Green Deal" [3], which declares that by 2050 economic growth should be decoupled from resources, and in line with the EU's commitment to the "Paris Agreement" [4] aiming to limit global warming to 1.5 °C. As part of the "European Green Deal", on 4 March 2020, the Commission proposed the first European Climate Law [5] to legally enshrine the 2050 climate-neutrality target. The law aims to ensure that all EU policies contribute to this goal, where all sectors of the economy and society play their part, and that the transition to climate neutrality is irreversible.

This policy, however, is a huge and urgent challenge for countries in which economic growth is heavily dependent on natural resources and which generate a high level of greenhouse emissions. The most evident such case is Poland, which is the biggest polluter and the most coal-dependent economy in the EU. Since nuclear energy is the second largest source of low-carbon power in the world (i.e., 29% of the total in 2017) and provides ca. 10% of the world's electricity coming from ca. 440 power reactors in 30 countries [6], the Polish government has also made an official statement on its willingness to launch nuclear energy plants in Poland. On the one hand, the decision was made due to increasing pressures stemming from tough EU energy policy requirements and an increased forecasted demand for energy in Poland in the face of depleting coal seams and limited capacities of gas-fired power plants. On the other hand, there are expected economic benefits from such an investment, both at the national and regional scales.

Prognoses and analyses prepared by the Polish government were mainly presented in the Nuclear Power Programme for Poland in 2014 [7] and predicted that the main economic benefits of nuclear power plants would be related to increased energy security at the national level, human capital development as an answer to demand for the new nuclear sector, and economic development related with construction and operation of the power plant (also through growth in branches cooperating with the nuclear sector). At the regional and local levels, the main benefits are expected to be related to new jobs (with an estimated two new jobs per workplace in the power plant), infrastructure, and local tax revenues. According to the Ministry of Economy [7], the whole nuclear programme in Poland should generate over 12,000 new jobs. However, all those estimations are generic, i.e., not related to any specific location of the power plants. Implicitly, they assumed that the economic effects will be the same wherever in Poland the plants are located.

The main motivation of our paper is to check if, and to what extent, the economic effects of building nuclear power plants depend on the specific location (region). Hence, the main goal of the paper is to compare the national and regional economic effects of constructing nuclear power stations in Poland in the four most probable sites (regions) selected by the government based on a mix of technical criteria. Although the locations are similarly good from a technical point of view, the question remains as to whether those locations are also similarly good from an economic point of view. Namely, does the investment create similar economic growth, employment, wage, and other economic effects in the entire economy and in the economies of the regions where the power plants are located? Our question from the title "To whom should we grant a power plant?" has the following answer—from economic point of view, to that region which brings the best economic effects both nationally and regionally from that investment. So, the problem is determining how to accurately assess the economic effects of the location of the nuclear power station. In order to address this problem, both the construction and exploitation phases of building the power stations are simulated in a spatial recursive dynamic Computable General Equilibrium (CGE) model named POLTERMDyn calibrated until 2050 for all 16 regions NUTS2 (level 2 units in Nomenclature of Territorial Units for Statistics) in Poland and all economy sectors aggregated to 19 sections (compatible with sections of NACE rev.2 (European Classification of Economic Activities revision 2).

Our paper fills in a literature gap in the following ways. First, most of the studies analyse either one specific location of the nuclear power plant or a generic location (not particular but imaginary), while our study provides a comparative study of four real alternative locations. Second, our paper fills in a methodological gap, as it links the location of nuclear power stations with new economic geography by explicitly linking the model of demography (population cohorts) and the labour market thanks to extending a typical CGE model. Third, it is novel at the national level as it investigates the problem not yet explored for Poland—that of the regional economic effects of constructing nuclear power stations in a dynamic, consistent modelling framework with forecasts to the year 2050.

The contribution of the paper to scientific literature lies in proving that the same investment may have totally different (sometimes even negative) effects depending on location due to agglomeration effects. There is also a contribution of the paper to policy-related literature, because economic effects are underestimated in energy policy decisions where technical parameters prevail.

The paper is structured as follows. The second section provides a background providing rationale for nuclear energy in Poland, a literature review on economic effects of nuclear plants, and an overview on the governmental decisions concerning nuclear power plant investments and locations. The third section explains the model, data, and simulation scenarios applied in the analysis, whilst the fourth section presents the results, both at the national and regional levels. In the fifth section, we discuss the possible theoretical and evidence-based explanations of our results. Section six concludes the paper, detailing the implications of our findings and considering the pathways for further research.

2. Background

2.1. Rationale for Nuclear Energy in Poland

The Polish energy system is characterised by the highest emission rates among EU countries as measured by CO_2/TPES, i.e., carbon dioxide per total primary energy supply (Figure 1). Poland ranks highest among EU polluters, with level of the emissions equal to 2.95 CO_2/TPES, significantly above the EU-28 average (1.99 CO_2/TPES) and close to Cyprus and Estonia. Among the countries with above average emissions are several other post-communist economies: Romania, Bulgaria, and the Czech Republic. However, their levels of emission are closer to the EU-28 average than to Poland.

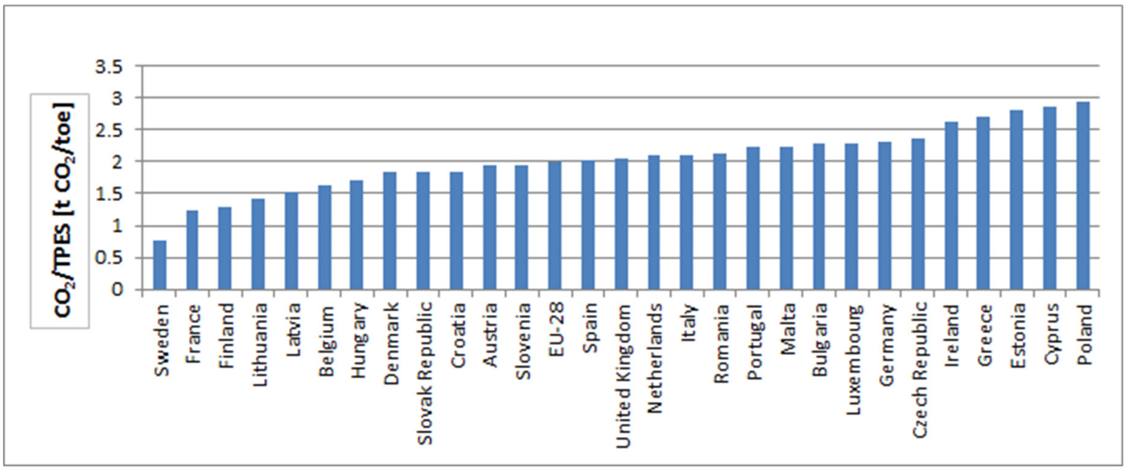

Figure 1. Emission indicator of CO_2/TPES in EU countries in 2017. Source: Authors' calculations based on [8].

The main reason for the unfavourable situation in Poland is a substantial share of domestic mine resources, i.e., hard coal and lignite, in the energy mix. In 2017, the total share of these fuels in the structure of total energy consumption was 47.7% and was the highest in the EU (Figure 2). In the electricity sector, 80% of the electricity generated came from coal-fired power plants. The dominant role of coal in the Polish energy sector is for two main reasons. First, Poland has a large national base of this natural resource (the largest in the EU). Second, it is a historical heritage of post-communist time. Communist parties considered miners to be the "archetypical proletarians", and they were the ultimate symbol of the communist image [9]. It is important to notice that, out of the 10 Central and Eastern European Countries in the EU, only 4 do not currently have nuclear reactors, namely Poland, Estonia, Latvia, and Lithuania. Moreover, all of the top three most polluting countries in EU28—Poland, Cyprus, and Estonia—do not have nuclear energy.

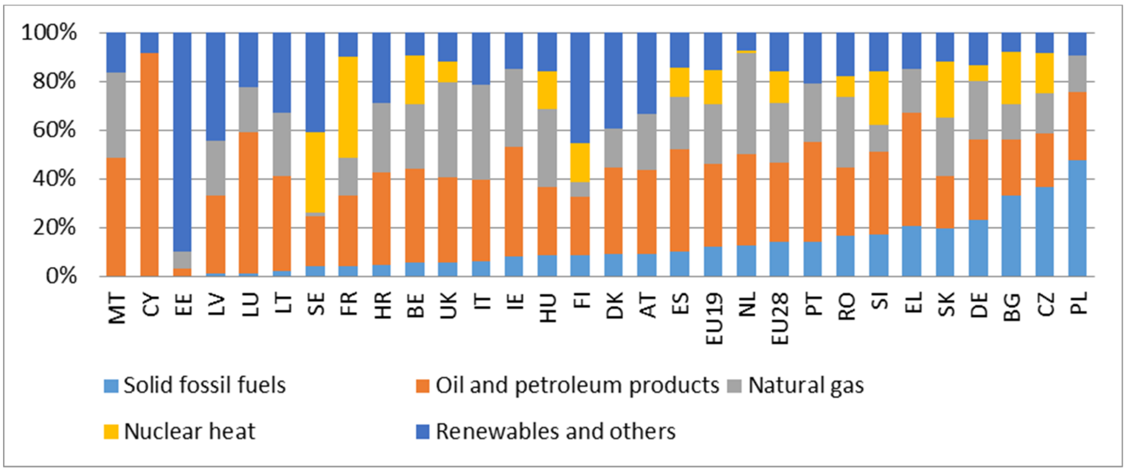

Figure 2. Total energy supply by product in 2017 (in %). Source: Authors' calculations based on [10].

Hence, Poland is under huge pressure to reduce its emissions. It seems that without major changes in its energy strategy it will not meet the requirements and may be penalised by the EU. Hence, it has to find an effective and relatively quick way of transitioning from a coal-dependent economy. The planned nuclear power plants are meant to enable Poland to meet the requirements of the EU's climate and energy policy. However, their introduction will bring significant changes in the Polish energy mix. According to the forecasts of the Ministry of Energy, net CO_2 emissions in the power plants and the combined heat and power plants are projected to be 394 kg/MWh in 2040, compared to 863 kg/MWh in 2020. Achieving such a result will be possible, subject to significant changes in electricity generation technology. The draft of the Energy Policy of Poland until 2040 [11] assumes a decrease in the share of coal from 69.3% to 27.9%, and its place will be increasingly taken by gas fuels, renewable energy sources, and also by nuclear energy, as shown in Table 1.

Table 1. Forecast of the net electricity production structure by source in 2020–2040.

Sources	2020	2025	2030	2035	2040
Lignite	26.6	26.8	24.8	12.9	7.7
Coal	42.7	38.5	31.4	25.0	20.2
Nuclear Energy	0.0	0.0	0.0	9.6	13.6
Gas fuels	6.8	8.1	10.3	14.7	17.0
Heating oil	1.1	1.0	0.9	0.8	0.8
Wind energy	13.3	14.1	19.0	21.5	24.4
Solar energy	1.1	2.4	3.4	5.1	6.6
Biomass	5.4	5.2	5.8	5.4	4.6
Biogas	0.9	1.4	1.9	2.4	2.6
Hydropower	1.4	1.5	1.5	1.4	1.4
Hydropower from pumping water	0.4	0.4	0.4	0.6	0.7
Municipal and industrial waste	0.4	0.5	0.5	0.6	0.6
SUM:	100	100	100	100	100

Source: Based on [11].

The second important reason for building nuclear power plants in Poland is the expectation of positive economic effects, both nationally and regionally. Public and private sector analyses, as well as scientific research, provide numerous estimations regarding the economic benefits of launching a nuclear power plant [12–18]. Similar information can also be derived from the opposite analyses of nuclear phase-out [19–24]. Apart from studies based on relatively simple statistical techniques, econometric modelling is often used in such research, especially analysis based on input–output models (e.g., [17,25–27]) and general equilibrium models (e.g., [18–20,28–30]).

Typically, three main types of economic benefits are distinguished in the literature: Gross Domestic Product (GDP) increase, employment creation, and increased tax revenues. GDP benefits are visible mostly at the national level and are derived from the cheaper electricity produced by the power plant and the economic activity of new and existing firms related—whether directly or indirectly—to the construction of the power plant and its operation, as well as the whole new nuclear energy sector. For example, estimations for the 1600 MWe power plant in Slovenia indicate contribution to the national GDP of 2.2% for the construction phase and 0.5% for operational one [13]. At the regional level, large nuclear power plant (5900 MWe) operation and construction may contribute even 70% to the regional output and 20% to the regional income, as it was in case of Korea [26]. The employment benefits are more regional and local in their scale, referring not only to the direct employment in the new power plant (including highly skilled jobs such as engineers, physicists, chemists, IT specialists, administrative, and security) but also to the indirect employment based on multiplying effects (jobs in companies engaged in the construction and maintenance of the power plant and related supply chains, as well as in local service companies supporting power plant employees). The benefits, especially at the local scale, depend to a large extent on the size of the power plant as well as the economic situation of the hosting region, e.g., its labour force resources, employee qualifications, and economic structure [31]. The employment impact estimation varies depending on the adopted methodology, ranging from 0.5 to 0.9 jobs per 1 MWe in terms of direct employment and even reaching 10 jobs/1 MWe in the case of direct and indirect labour market impact [12,17,24,32]. The last type of benefits results from increased tax revenues, contributing to national and local budgets. They include taxes collected directly from the power plant, as well as from collaborating and subcontracting companies and employees. The extent of the increase in tax revenues depends on the size of the power plant and its economic impact, as well as national and local tax policies (e.g., whether and to what extent national taxes are refunded to local budgets, whether there are any tax breaks and reliefs for the nuclear sector). Additionally, economic benefits of reduced CO_2 emissions could also be included in the analysis [24,33]. Apart from the described benefits, negative economic effects of the power plant construction and operation are described in the literature. These are mostly local and related with a decline in housing prices in the area surrounding the power plant [34–36] as well as possible increased demand for local public services and social infrastructure resulting from the inflow of labour migrants to the region [12].

In summary, our study is to some extent similar to those which apply general equilibrium theory to analyse nuclear energy; however, it extends them by incorporating in practice the concepts from theory of the new economic geography—namely agglomeration effects. Our approach also differs in the respect that we compare the same investment placed in different locations, while other studies either analyse different investments in the same locations or generic investment (then missing the comparability of the location effect). Our approach belongs to the studies which analyse the problem within a recursive dynamic setting and consider regional effects, while most CGE models applied to nuclear power problems are national or multinational.

2.2. Development of Nuclear Energy in Poland

Poland has considered nuclear energy for more than 50 years. The first ideas on the introduction of nuclear energy in Poland go back to 1955 when the government launched the Nuclear Research Institute. Then, in 1971, there was the first official decision made to start building the first power plant in Poland. The realisation of these intentions began in 1982 with the initiation of the construction of the "Żarnowiec" Nuclear Power Plant. Despite the advancement in the work reaching over 40% of construction, in 1990, the Council of Ministers decided to put the "Żarnowiec" Nuclear Power Plant into liquidation. In their justifications, apart from the arguments that were a consequence of the

Chernobyl disaster, there were issues of questionable profitability and increased efficiency of current sources of energy due to economic transition. Twenty years later, in 2010, Poland developed a new strategic document entitled "Energy Policy of Poland until 2030" and the "Polish Nuclear Power Program" in 2014. This document provides for the construction of two nuclear power plants with a total installed capacity of 6 GW. These activities were confirmed in the latest draft of the "Energy Policy of Poland until 2040" [11]. Although according to the still-valid "Energy Policy of Poland until 2030" the first nuclear power plant should be launched in 2020, no formal decision regarding the start of the construction works has been made. Additionally, in the next draft version of the document [11], the new date for the launch of the first nuclear power plant in Poland is 2033.

It is estimated that the first nuclear plant will be an investment of 70 billion PLN (PLN is abbreviation for Polish zloty, that is a national currency of Poland) (17.5 billion EUR), as the cost of building 1 MW of power is USD 6 million; the first nuclear power plant in Poland will have a capacity of ca. 2500 to 3000 MW, so investment costs will be ca. 70 billion to 80 billion PLN [37–39]. These figures were also confirmed by the Polish Ministry of Energy, which estimates that the total programme of all investments in nuclear energy in Poland will reach 200 billion PLN (or ca. 50 billion EUR). In case of nuclear plants, the fuel costs are only a minor part of total generating costs, although capital costs exceed those for coal-fired plants and gas-fired plants. System costs for nuclear power are substantially lower than for intermittent renewables, and this also holds in the cases of coal and gas-fired generation plants. Typically, the main cost categories of nuclear plant investments comprise the following:

- Capital costs: These include site preparation and building the reactor, which involve manufacturing (steel and concrete), construction services, commissioning, and financing not only nuclear power plant but also its immediate surrounding. That involves employment of thousands of workers as well.
- Plant operating costs: These include the costs of fuel, operation, and maintenance. An important part of this category is the costs of decommissioning the plant and managing the costs of waste and used fuel. Operating costs are divided into two subcategories: (a) fixed costs, which exist whether the plant is generating electricity or not, and (b) variable costs, which vary depending on the output.
- External costs to society: These are the societal costs of operating the plant, which in the case of nuclear power are sometimes neglected. These comprise, e.g., the costs of dealing with a serious accident exceeding limit of insurance and in practice shifted on the government.
- Other costs: These include system costs and nuclear-specific taxes.

The cost structure is typically as follows: capital costs, 91.8%; fixed operational costs, 7.22%; variable operational costs, 0.04%; costs of fuel, 0.60%; nuclear waste disposal, 0.24%; other costs, 0.10% [38] (see also other studies on economics of nuclear energy [40–42]).

2.3. Selection of Locations for Nuclear Power Plants

Selection of the nuclear power site is a complex and extensive process requiring the engagement of a number of disciplines [43]. It is also one of the most vital and usually controversial decisions for policy makers. In 2009, the Polish Ministry of Economy, in consultation with local governments and non-governmental organisations, prepared a list of 27 spots for potential nuclear power plant locations, as illustrated in Figure 3.

Subsequently, the Ministry of Economy ordered an assessment and ranking of those indicated locations from the Energy Studies and Energy Projects Office "Energoprojekt", using the methodology recommended by the International Atomic Energy Agency [11]. This methodology largely considers aspects of safety and potential threats. The economic aspects of the location are missing among the 17 proposed indicators for ranking the sites [43] (pp. 26–27):

1. Integration into the electric grid system
2. Geology, tectonics, and volcanic studies

3. Seismology and seismic engineering
4. Hydrology (including ground water, floods, and tsunamis)
5. Cooling water availability, intake, and discharge
6. Demography and land use
7. Meteorology and atmospheric dispersion (including wind patterns, tornados, and hurricanes)
8. Study of flora and fauna
9. Nuclear safety and radiation protection aspects
10. General environmental effects
11. Risks from man-made events
12. Local infrastructure
13. Cultural and historic sites
14. Access and emergency response roads
15. Air, land, and sea transportation patterns
16. Legal aspects
17. Public consultation

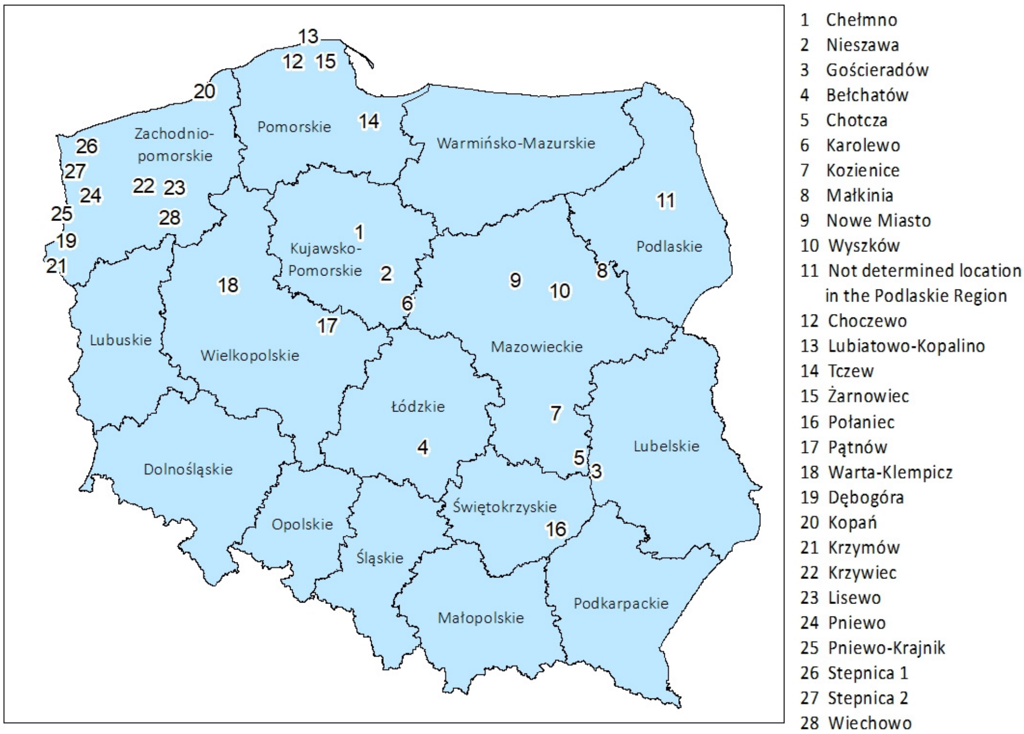

Figure 3. Potential locations of nuclear power plants in Poland. Source: [44].

The results of the ranking prepared on the basis of these 17 indicators for Poland are presented in Table A1 in Appendix A.

Based on Figure 3 and Table A1, one can draw several conclusions on the most promising/probable regions for the first power plant in Poland. First, one can see that the scores range from 65.6 points for the best site, Żarnowiec, to 39.6 points in the case of Pątnów, so the selection will likely narrow to the 10 highest ranked regions (Table A1). Second, some regions have more locations than others and thus seem generally more appropriate for the location of a power plant, such as Zachodniopomorskie (nine sites), Mazowieckie (five sites), and Pomorskie (four sites). Third, the top five sites are located in the regions of Pomorskie, Wielkopolskie, Zachodniopomorskie, Mazowieckie, and Łódzkie.

Since there is no official decision yet on the location, we selected the four most probable locations for our analyses based on the aforementioned information:

- Pomorskie region, located in North Central Poland (with Żarnowiec site ranked first, marked as No. 15 on Figure 3).
- Zachodniopomorskie region, located in Northwest Poland (with Kopań site ranked third, marked as No. 20 on Figure 3)
- Mazowieckie region, the capital region in Central Poland (with Nowe Miasto site ranked fourth, marked as No. 9 on Figure 3)
- Łódzkie region, located in Central Poland (with Bełchatów site ranked fifth, marked as No. 4 on Figure 3)

These four regions are therefore treated in the paper as similarly good locations from a technical point of view. Thereafter, the construction of the same nuclear power plant is simulated in each of them in order to assess the economic impact of such investment both for the regions and for the whole economy. In other words, we investigate if they are similarly good from an economic point of view as they are from a technical one.

3. Materials and Methods

3.1. POLTERMDyn Model and Data

Computable General Equilibrium (CGE) models are widely applied tools for economic impact assessments of policies and investments. This is because they have ability to link sectoral changes with economic growth in a theoretical framework which is consistent and produces computable outcomes. Hence, we apply a CGE model named POLTERM, which is a Polish version of the Australian TERM, i.e. The Enormous Regional Model [45]. The original model has gained a reputation due to its various applications to many important economic questions and policy-relevant issues. It is also recognised for its detailed publicly available documentation in [46,47], allowing for adaptation of the model to other countries and research cases. It is also important to mention that our study is replicable and can be even extended. That is because the source codes of the TERM model and the GEMPACK software are available from Centre of Policy Studies, Melbourne (Australia) —see [48,49], respectively—and the database is freely available from EUROSTAT at [50,51]. Furthermore, this is even easier for those countries for which the TERM model has been already calibrated, such as Austria, Brazil, Canada, China, Finland, Germany, Indonesia, Italy, Japan, Korea, New Zealand, South Africa, Sri Lanka, Sweden, and the USA.

The structure of the TERM model is in line with neoclassical economic theory and resembles many other applied general equilibrium models in that respect. The dynamics of the model are assured by the following types of equations: relationship between year-to-year capital growth and rate-of-return expectations, equations linking investment to capital in year-to-year simulations, and equations governing adjustments on labour market (as described in detail in [52]).

In this paper, we modernised and updated its recursive dynamic version called POLTERMDyn, compared to its previous applications [53–55]. In earlier versions, population and labour have been exogenous variables. In this version, both national and regional population growth rates are endogenous. Migration to and from the rest of the world (RoW) is steered by the changes in the labour market. The population module is formulated according to the specifics of the iconic method in demography, i.e., the cohort-component model of population projection, which has belonged to the toolbox of demographics for more than a century (for an overview, see [56]).

Fundamentally the cohort component model based projection "relates the age structure of a population to fertility, mortality, and migration, with the current age structure being the result of fertility, mortality, and migration at each age in the past. Most commonly, a future age structure of the population is 'predicted' given a time series of age-specific fertility, mortality, and net migration assumptions" [56] (p. 40).

In our application, the demographic module is fully integrated with the rest of the CGE model, which enables the interaction between the labour market and the population. We keep track of the population by 1-year age cohort from 0 to 85+ years by gender and by region. Fertility and mortality rates and their development over time are taken from the national population projections published by Statistics Poland [57,58]. For the base year, we have constructed age- and gender-specific matrices of in- and outmigration, both within the country and for international migration. A similar demographic module has been applied in the earlier Finnish RegFinDyn regional model [59], as well as in an application of the Finnish one-country VATTAGE model [60].

The moving of people within the country is assumed to be governed by unemployment rate differentials between the own region and the national total (see Equation (1) below).

$$\text{(all, d, DST)}\ RINMIG\ (\mathrm{d}) \cdot rinmigch\ (\mathrm{d}) = MIGPARA \cdot POP\ (\mathrm{d}) \cdot (d\_UR\ (\mathrm{d}) - d\_URN) \tag{1}$$

where all represents the whole set of elements, d is regions, DST is destinations, *RINMIG* (d) is the sum of in-migration, *rinmigch* (d) is the change in the in-migration total, *MIGPARA* is the estimated migration –unemployment parameter, *POP* (d) is the regional population, *d_UR* (d) is the ordinary change in regional unemployment rate, and d_*URN* is the ordinary change in the national unemployment rate.

The responsiveness of migration to changes in unemployment is defined by the parameter *MIGPARA*, which was estimated from the Polish regional data on migration and unemployment. Its value was set at −12.5, meaning that when the regional unemployment rate *d_UR* (d), measured in fractions (1% = 0.01), declines in relation to the national rate by one percentage point, the regional in-migration grows by 0.125%.

We take the initial age and gender structure of regional arrivals from the statistics and assume that the age structure of in-migrants follows the general change in the national population age structure, given the age-specific initial outmigration rates. However, as the regional in- and outmigration must add up to the same level nationally, the regional outmigration rates have to be calibrated each year to produce the exact balance between in- and outmigration. This is enabled by age- and gender-specific shifter variables at the national level.

The international migration flows are also assumed to follow developments in the labour market in neighbouring countries. As the EU is the main destination of contemporary Polish migrants, we have named the growth rate of RoW (rest of the world) wages as *EU_rwage*. The difference between national wages and RoW wages affects the rate of in- and outmigration, but with different elasticities. *WEMIGELAS*, i.e. the elasticity of the outmigration rate to wage differentials, was estimated to be −0.6, whereas *WIMIGELAS*, i.e. the elasticity of the outmigration rate to wage differentials, was set to 3. Therefore, we assume that the growing number of Polish expatriates is rather eager to return to Poland when and if the labour market conditions are favourable. In the base year 2010, Polish outmigration outnumbered immigration by around 2000 persons.

The historical time series of migration and wage development lead us to the following equation specifications:

(a) For outmigration rate by region (as share of age cohort):

$$\begin{gathered}\mathrm{WOUTMIGRATE\ (d, ag, s) \cdot woutmigrch\ (d, ag, s) = WOUTMIGRATE\ (d, ag, s)} \cdot \\ \mathrm{[WEMIGELAS \cdot [realwage\_io\ (d) - EU\_rwage]\ ]}\end{gathered} \tag{2}$$

where d is region; ag is age; s is gender; *WOUTMIGRATE* (d,ag,s) is the RoW out-migration rates by region, age, and gender; *woutmigrch* (d,ag,s) is the change in outmigration rate to RoW; *WEMIGELAS* is the elasticity of the outmigration rate to wage differentials; *realwage_io*(d) is the average real wage by region; and *EU_rwage* is the average real wage of other EU countries;

(b) For immigration total, the equation is as follows:

$$\begin{gathered}\mathrm{UNITY} \cdot winmigch\ (\mathrm{d}) = \mathrm{UNITY} \cdot (\ winmigch\ (\mathrm{d}) + f\_winmig) + WIMIGELAS \cdot \\ [realwage\_io\ (\mathrm{d}) - EU\_rwage];\end{gathered} \tag{3}$$

where d is region, UNITY is parameter 1, *winmigch* (d) is the sum of in-migration from RoW; *winmigch* (d) is the share of in-migration from RoW, *f_winmig* is the reconciling shifter for the sum of RoW in-migration, *WIMIGELAS* is the elasticity of the outmigration rate to wage differentials, *realwage_io* (d) is the average real wage by region, and *EU_rwage* is the average real wage of other EU countries.

The change in the region's share of immigration total, *winmigch* (d), is assumed to depend on the past growth in the region's share of the national population. In other words, central regions with higher population growth are assumed to gain more than others from the international movement of people.

The labour market participation rates vary markedly by age and gender as people's life situations evolve over time. Therefore, it is natural that we make use of the demographic information now available inside the model and calculate the aggregate labour force from the age- and gender-specific population data by using cohort- and gender-specific participation rates taken from the statistics.

The participation rate is assumed to react to differences in wage development within Poland and the rest of the world. The general elasticity rate of participation, *PARTELAS*, i.e. the participation rate's wage elasticity, is set to 0.33. However, we make use of the empirical fact that the groups of populations with lower participation rates, like students, women with small children, and elderly persons, seem to be more responsive to changes in the labour market (see, e.g., [61,62] and an overview in [63]). Consequently, we multiply the participation elasticity with the regional non-participation rate of the gender-specific age group [1 − *RPARTRATE* (d, aw, s)] (see the equation below). For the age-sex cohorts with high labour market participation, this means that their labour supply is very inelastic to changes in the wage rate. This solution was also used by [60].

$$100 \cdot f\_rpartrch\ (\mathrm{d, aw, s}) = [1 - RPARTRATE\ (\mathrm{d, aw, s})] \cdot PARTELAS \cdot [realwage\_io\ (\mathrm{d}) - EU\_rwage]; \tag{4}$$

where d is regions, aw is age work cohorts, s is gender, *f_rpartrch* (d, ag, s) is the ordinary change in regional participation rate, *RPARTRATE* (d, ag, s) is the regional gender- and age-specific labour market participation rate, *PARTELAS* is the participation rate's wage elasticity; *realwage_io* (d) is the average real wage by region, and *EU_rwage* is the average real wage of other EU countries;

The wage dynamics also differ from earlier models. Whilst the earlier increase in labour use led to higher wages, now the decrease in the unemployment rate is assumed to be the variable transmitting the wage pressure. In addition to this, we also assume an exogenous annual growth *flab_iod* in wages, so that the share of labour in value-added remains similar to its initial value. However, one needs to ensure that the different exogenous values of the labour-market-related variables make sense. For example, there needs to be a sensible relationship between productivity of labour (*blab_o* (i, d)), RoW reference wage (*EU_rwage*), and *flab_iod*. This is assured by the subsequent equation:

$$realwage\_i\ (\mathrm{o,d}) = [-1/0.2] \cdot [100 \cdot d\_UR\ (\mathrm{d})] + flab\_iod + flabsupA\ (\mathrm{o,d}); \tag{5}$$

where o is labour skill categories, d is regions of use, *realwage_i* (o,d) is average real wages, *d_UR* (d) is the ordinary change in unemployment rate, *flab_iod* is the national wage shifter, and *flabsupA* (o, d) is the labour migration shifter.

Finally, we have incorporated one of the central ideas of the core–periphery model's new economic geography (see [64]; for a more recent overview, see [65]), namely that of agglomeration. Agglomeration benefits are the "positive externalities" by which economic agents such as firms and households benefit from the closeness and increasing number of other economic actors. The benefits are in terms of higher productivity and output growth created by them. Agglomeration is measured in the model through change in share of each region in national labour costs in comparison to the previous year. Therefore, we use the regional labour cost's share as a proxy for the effective density of economic activity and for the "thickness" of the labour market. Those regions which increase their share of labour use also gain from additional increase in productivity, which can be explained, for example, by the labour pooling and knowledge diffusion between nearby firms, as hypothesised by the new economic geography models. However, we assume that agglomeration effects vary by industry according to elasticity estimates—we assumed the ones by Kernohan and Rognlien [66]. The highest agglomeration productivity gain is the largest in knowledge-intensive services. Hence, for the financing sector, the elasticity values are the largest and range from 0.08–0.09, while for primary production they are the smallest and range from 0.03–0.04. In transport and the related services, the estimated elasticity is 0.057.

As mentioned previously, apart from the agglomeration effect, we assume a general exogenous, industry-specific increase in labour productivity. The general productivity growth of labour *blab_o* (i,d) is large in relation to the agglomeration-induced productivity growth.

$$f\_aprim\ (\mathrm{i,d}) = AGGELAS\ (\mathrm{i}) \cdot slab\_ioch\ (\mathrm{d}); \tag{6}$$

where i is industry, d is region, *f_aprim* (i,d) is the industry- and region-wise shifter for technical change, *AGGELAS* (i) is the agglomeration elasticity, and *slab_ioch* (d) is the percentage change in the region's labour share;

The model is calibrated for the years 2010–2050 to grasp the targets which are set up for 2050. The model's main database consists of Supply and Use tables produced by the Polish Central Statistical Office [67,68], which are also available from EUROSTAT [50]. The original Supply and Use tables comprise 77 sectors but were aggregated into 19. They comply with the sections of the European activity classification for System of National Accounts (NACE rev. 2). The only difference is that we desegregated section M into two subcategories: Resarch and Development sections and the rest of section M (i.e., professional services). We thought it could be useful for this kind of study requiring the application of both technology and knowledge. Moreover, the 19th section, entitled "Other services," is an aggregation of the last four NACE sections (R, comprising recreation, arts, and entertainment; S, remaining services; T, household activities as employers; and U, extraterritorial organisations' activities). This is because they are small and not important from the point of view of the study, and so they were combined into one sector without any harm. All in all, the 19 sectors' aggregation used in the paper is as follows: (1) Agriculture (section A); (2) Mining (section B); (3) Manufacturing (section C); (4) Electricity (section D); (5) Water (section E); (6) Construction (section F); (7) Trade (section G); (8) Transports (section H); (9) Food and accommodation (section I); (10) Information and communication (section J); (11) Finances (Section K); (12) Real estate activities (section L); (13) Professional activities (Section M without R&D); (14) R&D (remaining part of Section M); (15) Administration (section N); (16) Public administration and defence (section O); (17) Education (section P); (18) Health services (section Q); (19) Rest of services (sections R, S, T, and U). The national database was regionalised at the NUTS2 level based on data from the annual Statistical Yearbook of Regions [69] and in line with the TERM regionalisation routine, described in detail by Mark Horridge in Chapter 2 of the book [52].

The Polish database shows that the four regions selected for our study, Pomorskie, Zachodniopomorskie, Mazowieckie, and Łódzkie, differ both in the size of their economies and in terms of the importance of the energy sector in their gross regional outputs. Out of the four regions, the biggest is Mazowieckie (22.3% of Poland's GDP), followed by Łódzkie (6% of national GDP), Pomorskie (5.8% of GDP), and Zachodniopomorskie (3.7% of GDP). Additionally, the richest is Mazowieckie (capital region), where average monthly gross wages and salaries in 2018 were 1400 EUR; in Pomorskie, this value is 1140 EUR. The two remaining regions were similar: 1057 EUR for Łódzkie and 1055 EUR for Zachodniopomorskie. In Mazowieckie, therefore, the level of wages and salaries was 21.8% above the national average. In Pomorskie, they were very close to average (99.2% of the national average), while in Łódzkie and Zachodniopomorskie they were 91.9% and 91.7% of the national average, respectively. The regions also differ with respect to their gross value-added composition. The most industrial is Łódzkie (industry 37.3% of GVA), the most agricultural is Zachodniopomorskie (3% of GVA), and Mazowieckie is the most dependent on services (72.4% of GVA). Pomorskie is in between, where agriculture comprises 2.1% of GVA, industry and construction comprise 36% of GVA, and services comprises 61.9% of GVA.

The regions also differ in terms of the capacity of their energy sectors. Mazowieckie and Łódzkie are the regions with the largest electricity production and consumption among all four regions, and also second and third, respectively, in the whole of Poland (after the Śląskie region). Moreover, 95% of their energy constitutes conventional fuels. In Mazowieckie, the primary source is hard coal; in Łódzkie, it is brown coal. On the contrary, Pomorskie and Zachodniopomorskie have the highest shares of electric power generated from renewable energy sources (RES) in Poland, and in 2018 their shares were 51.3% and 44.2%, respectively (Table 2). From the point of view of our modelling, the most crucial factor is their installed capacity in power plants in MW, as we will replace electric plants with nuclear power plants.

Table 2. Basic characteristics of the power sector in Poland in 2018.

Specification	Installed Power	Production	Consumption	RES	Production to Consumption
	MW	GWh	GWh	%	%
Poland	42,989.7	170,039.5	166,840	12.7	101.9
Dolnośląskie	2379.5	9917.7	14,080	6.5	70.4
Kujawsko-pomorskie	1983.3	6798.8	8549	48.7	79.5
Lubelskie	565.8	2066.8	6339	22.9	32.6
Lubuskie	785.3	3290.8	3960	19.9	83.1
Łódzkie	**6536.7**	**38,641.0**	**13,509**	**3.8**	**286.0**
Małopolskie	1890.9	5888.7	13,631	7.0	43.2
Mazowieckie	**6795.9**	**30,441.0**	**28,046**	**4.8**	**108.5**
Opolskie	2034.3	10,087.2	5600	5.2	180.1
Podkarpackie	1039.9	2462.0	5708	23.1	43.1
Podlaskie	412.9	1051.2	3230	68.3	32.5
Pomorskie	**1943.7**	**4104.9**	**8464**	**51.3**	**48.5**
Śląskie	7218.7	24,905.9	27,273	3.2	91.3
Świętokrzyskie	1941.9	11,213.1	5521	16.2	203.1
Warmińsko-mazurskie	477.3	1170.2	3998	82.8	29.3
Wielkopolskie	3615.4	9840.7	12,694	21.3	77.5
Zachodniopomorskie	**3368.2**	**8159.4**	**6238**	**44.2**	**130.8**

Source: Statistics Poland [58].

The most installed power in MW is in Mazowieckie (6789.9 MW), which is 16% of Poland's total and it similar to Łódzkie (6536.7 MW or 15% of the national total). Much smaller are the amounts and shares of the other two regions—in Zachodniopomorskie it is 3368.2 MW or 8%, and in Pomorskie it is 1943.7 MW or 5% (Table 2). Mazowieckie, Łódzkie, and Zachodniopomorskie are fully self-sufficient in terms of electrical power, but electricity consumption in Pomorskie is more than twice the amount of production (Table 2). Hence, the region depends on energy imports.

3.2. Simulating a Nuclear Power Plant in POLTERMDyn

Our simulations are divided into two periods. First is the construction period, during the years 2025–2040 (the first 15 years), before the operational phase begins in 2041 and our observations end at 2050, which is the current policy perspective. We assume that the investment activity, estimated by the government to be 70 billion PLN, will loosely follow the normal distribution over time, with the highest level of investment activity in the middle of the investment period. Thus, the spending increases proportionally over the first 7 years; after reaching its maximum, it stabilises for one year, and then starts diminishing for 7 years proportionally, when the construction works finally end. The operational phase begins by nuclear power replacing coal mainly for electricity generation purposes.

Four simulation scenarios are run in order to depict the situation that each time the same size nuclear power plant (costing 70 billion PLN) is built in one region at the time. This is in order to compare, ceteris paribus, the impact of that investment on the region where it was located and on the whole economy. This is translated into the following shock statements and values (calculated based on energy data for Poland from the Central Statistical Office).

In the construction phase (2025–2040):

- The shock variable is investments in the electric sector in each region separately for years 2025–2040.
- Shock statement is: tshock < year > xinvitot ("elecgas",“REG”).

Here, tshock is a year-specific shock; xinvitot is investment by industry; elecgas is electricity sector (section D in NACE 2); and REG is Zachodniopomorskie, Pomorskie, Mazowieckie, and Łódzkie.

This shock operationalises the increase in the demand for construction and other activities that are needed. The increased final demand leads to an increase in intermediate input demand in the regions themselves, as well as from other regions. The increase in labour demand tightens the local labour market, which leads to increases in wages and induces migration from other regions to the investment regions. The historical patterns of production, trade, and migration influence the outcomes of the demand shock.

In the operational phase:

- Shock variables:
    - ○ first, reverting investments in 2041 and turning into capital;
    - ○ second, taking away part of coal power.
- Shock statement 1: ashock faccum(“elecgas”,“REG”) = X.
- Shock statement 2: ashock faccum(“elecgas”,NONNREG).

Here, ashock is year-specific shock, faccum is the shifter to switch on accumulation equation, elecgas is the electricity sector (section D in NACE 2), X is the relative value of the investment in the region taking into account the fact that capital stock has to grow in proportion with electricity generation capacity (based on regional statistics of electricity production in MW), and NONNERG are non-nuclear regions (only one nuclear region is shocked at a time).

When the construction phase is finalised, the new nuclear plant turns into a part of the productive capital stock (faccum). When the nuclear plant is operational, it is assumed to decrease the use of coal proportionally in other regions by reducing their electricity generation capacity. This has to be done as coal power is being used to cater for the increased electricity demand as long as nuclear power is unavailable.

4. Results

This section discusses the results of our simulations of building a single nuclear power plant in each of the four regions (Zachodniopomorskie, Pomorskie, Mazowieckie, and Łódzkie). We distinctly consider the construction phase, which is held from 2025–2040, and the exploitation phase, spanning 2041–2050. First, we investigate the impact on the national economy and then the impact on the region in which the nuclear power plant is located. The results are presented in terms of percentage changes in real GDP components (expenditure side), trade outcomes, labour market (employment and wages), capital stock, and outputs of all economic sectors (aggregated into 19 sectors). All the changes are presented with respect to the counterfactual (baseline) that is compared to the situation as if there is no power plant built (status quo situation).

4.1. National Economic Results

The results obtained from the CGE simulations with use of the POLTERMDyn model shows that the impact of the same investment—a nuclear plant worth 70 billion PLN (17.5 billion EUR)—has different impacts on the economy, depending on the region selected.

In the construction phase, the impact of the investment in each of the locations is positive for the national economy and follows a similar pattern. National real GDP increases as national investments grow, which is compensated by lower national private and government consumption. National employment does not change substantially; however, the national real wage level is lower than it would be without this investment, and capital stock is higher than otherwise (Figure 4). The differences in the economic impact, depending on the region of location, are noticeable. However, they stay within a maximum range of 0.025 percentage points for all economic variables analysed.

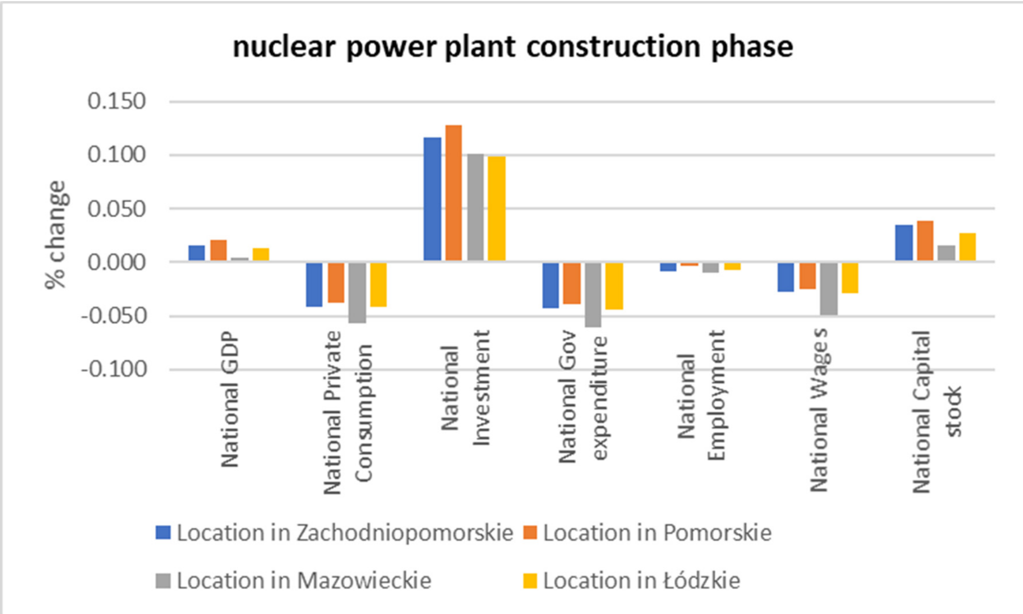

Figure 4. National impact of nuclear plant location in each of the four regions, considering the construction phase in cumulated years 2025–2040.

The most positive impact in the construction phase, from the point of view of the national economy, would be an investment in Pomorskie (real GDP increased by 0.020%), then in Zachodniopomorskie (real GDP increased by 0.016%), followed by Łódzkie (0.012%), with a negligible investment in Mazowieckie (real GDP increased by 0.004%) (see Table 3).

Table 3. Aggregated real impact of regional investment in nuclear power plant on national economy, for the construction phase and the total period. Difference to the base scenario, percent by the end of the simulation period

	Construction Phase 2025–2040				The Whole Policy Simulation 2025–2050			
% Changes in Real Terms	Location: ZachPom	Location: Pomors	Location: Mazow	Location: Łódz	Location: ZachPom	Location: Pomors	Location: Mazow	Location: Łódz
National GDP	0.016	0.020	0.004	0.012	−0.014	0.014	0.086	−0.006
National Private Consumption	−0.041	−0.037	−0.057	−0.042	−0.042	−0.014	0.072	−0.023
National Investment	0.117	0.128	0.101	0.098	0.053	0.067	0.030	0.060
National Gov expenditure	−0.043	−0.039	−0.061	−0.045	−0.012	−0.011	0.047	−0.025
National Exports	0.047	0.048	0.058	0.054	−0.015	0.033	0.119	−0.002
National Imports	−0.012	−0.009	−0.012	−0.009	−0.019	0.005	0.049	−0.001
National Employment	−0.009	−0.004	−0.010	−0.007	−0.015	0.000	0.042	−0.012
National Wages	−0.027	−0.025	−0.050	−0.029	−0.031	−0.011	0.055	−0.004
National Capital stock	0.035	0.038	0.016	0.028	−0.011	0.025	0.113	−0.001

Note: Region abbreviations are ZachPom, Zachodniopomorskie; Pomors, Pomorskie; Mazow, Mazowieckie; Łódz, Łódzkie; all negative values are in red.

If we analyse the whole investment period (construction and exploitation phase together), the picture changes significantly. The most beneficial location of the investment is Mazowieckie. There are also some positive effects in Pomorskie, while investments in Zachodniopomorskie and Łódzkie bring negative effects. The real GDP impact of placing the plant in Zachodniopomorskie or Łódzkie becomes slightly negative (−0.014% in the former and −0.006% in the latter). The most positive impact on real GDP is in Mazowieckie (capital region), due to an increase of 0.086%; the impact is also positive in Pomorskie, although to a lesser extent (increase by 0.014%) (see Table 3).

If the power plant is located in Mazowieckie, then the national economy would benefit from the positive development coming from an increase in all real GDP components (expenditure side), i.e., private consumption would increase by 0.072%, investment by 0.030%, public consumption by 0.047%, and expansion of export by 0.119%, although imports would also increase by 0.049%. National employment would increase by 0.042%, while wages would increase by 0.055%. The economy would end up with higher (compared to baseline) capital stock by 0.113%. On the contrary, if the investment was located in Zachodniopomorskie, the national economy would be worse off. Apart from the increase in the investment itself (by 0.053%), all the main economic indicators would actually decrease: real private consumption by −0.042%, public consumption by −0.012%, national exports by −0.015%, national imports by −0.019%, national employment by −0.015%, and national wages by −0.031%. Even capital stock would be lower than in the counterfactual by −0.011% (see Table 3).

More insights into the economic impact of the investment are provided by the sectoral results (see Table A2 in Appendix A). Clearly, Mazowieckie is the most beneficial nuclear power plant location both from the national and that region's point of view. The total economy, the sum of growing sectors in all 16 regions, is the highest in that case and amounts to 168 sectors. In the national economy, the most prevalent growing sectors, due to that investment, would be the manufacturing, financial, and insurance sectors, as well as the R&D and professional services sectors. Other locations would be much less beneficial from the sectoral output point of view for the national economy. If the investment is placed in Zachodniopomorskie, then only 56 sectors in 16 regions would benefit, and they would mostly be ICT (information and communication technology) services and accommodation and food services. If it is placed in Łódzkie, 57 sectors in the national economy would expand, mainly ICT and professional services. The same investment in Pomorskie would benefit 90 nationwide sectors, again mainly ICT and professional services sectors (Table A2, Appendix A).

4.2. Regional Economic Results

There is clearly a substantial difference in the economic impact of the construction and exploitation periods at the regional level. In the construction phase, all regions where the nuclear power plant is built react similarly, at least in terms of the direction of their economic changes, whereas in the exploitation phase there are huge discrepancies among the reaction of the regions both in direction and magnitude (Figure 4).

In the construction period, between 2025 and 2040, the impact of the nuclear power plant on regional real GDPs follows the investment pattern of an inverted U shape (Figure 5a). The magnitude of the cumulated real GDP change (compared to the baseline) in Zachodniopomorskie is 0.22%, in Pomorskie it is 0.21%, in Mazowieckie it is 0.13%, and in Łódzkie it is 0.14%. The impact on real GDP is consistent with the impact on aggregated employment in regional economies, also demonstrating an inverted U shape (Figure 5b). The cumulated change in Zachodniopomorskie is the highest at 0.35%, similarly to Pomorskie at 0.32%, while the two other regions are lower: in Mazowieckie it is 0.26% and in Łódzkie it is 0.27%. Changes in real wages (Figure 5c), although they naturally follow the shape of changes in aggregated employment, simultaneously reveal the largest ranges in magnitude of all economic variables analysed. The largest increase is experienced by Zachodniopomorskie at 36.7% (compared to baseline), then Pomorskie at 19.5%, Mazowieckie at 4.1%, and Łódzkie at 13.1%. The regional differences in real wages determine the migration (Figure 5d), so in the period 2025–2035 the net migration is positive (compared to the baseline) and cumulatively in Zachodniopomorskie at 7.5%, in Pomorskie at 5.6%, in Mazowieckie at 2.2%, and in Łódzkie at 4.2%. In the second period of the construction phase, 2036–2040, the net migration reverts to negative (meaning it is lower compared to the baseline) in all the regions: in Zachodniopomorskie the net migration was −1%, in Pomorskie it was −1.1%, in Mazowieckie it was −0.3%, and in Łódzkie it was −0.2%.

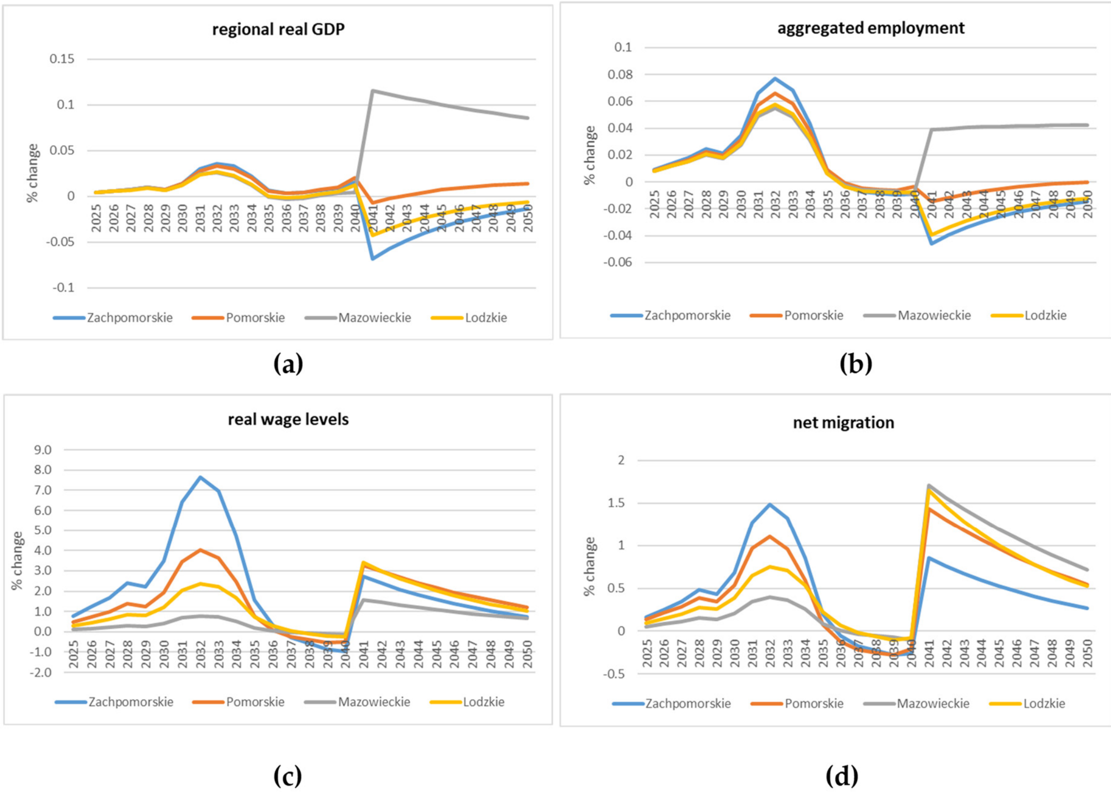

Figure 5. Regional results of building nuclear plants in each region, showing percent changes compared to the baseline in: (**a**) real GDP; (**b**) aggregated employment; (**c**) real wages and (**d**) net migration.

In the exploitation phase, 2041–2050, the economic impact of the investment on regional economies differs in many ways. In terms of real GDP, the impact on Zachodniopomorskie and Łódzkie is even negative, i.e., real GDP is lower in those regions compared to the situation without a nuclear plant by −0.35% and −0.20%, respectively. On the contrary, the impact is the most positive on Mazowieckie if the power plant is built there; thereafter, the real GDP of that region increases by 0.99% (compared to baseline). In cumulative terms (and in most of the years), the impact of such an investment in Pomorskie is also slightly positive, increasing real GDP by 0.061%. The situation in the regional labour market is such that the aggregated employment increases only in Mazowieckie (by 0.41%), whilst in all other regions it declines. Wage increases in the regions are highest in Łódzkie and Pomorskie, followed by Zachodniopomorskie, and are the least in the richest region, Mazowieckie. The wage increase is the highest at the beginning of the exploitation period and then smoothly stabilises in all the regions. In 2041, the net migration reverts to positive (i.e., is higher than the baseline) in all the regions, by the most in Mazowieckie, followed by Łódzkie and then Pomorskie, and by the least in Zachodniopomorskie.

As for regional sectoral results, investing in a nuclear power plant in each location obviously contributes to the expansion of its own energy sector primarily, but also contributes to other sectors in that region. The highest impact on its own energy sector is in Pomorskie, as the energy production in that region would increase by 1.27%; in Łódzkie, the increase would be by 1.12%; in Zachodniopomorskie, the increase would be by 0.95%; and in Mazowieckie, the increase would be by 0.53% (Table A2). In Mazowieckie, this investment would also contribute to the largest expansion of its construction sector (by 0.14%), followed by the trade (0.08%), real estate (0.05%), and public administration (0.05%) sectors.

Investment in Pomorskie would contribute the most to the output growth in the construction (0.76%), trade (0.18%), and public administration (0.13%) sectors. In the case of Łódzkie, the largest expansion would also be in the construction (0.39%), trade (0.16%), and public administration (0.13%) sectors. The investment in Zachodniopomorskie would bring about expansions in only 12 of 19 sectors, and the largest would be similarly in construction (0.96%), trade (0.23%), and public administration (0.15%).

5. Discussion

Our study confirmed that the economic effects of investment in a nuclear power station differ substantially depending on its location. The economic outcomes, both at the national and regional levels, depend on the economic characteristics of the region.

First, the economic impact depends on how big such an investment is for the region in question and its industry structure. If the investment is overwhelming for the regional economy, then the investment has a substantial effect on the region-wide wage increase, which is detrimental to many sectors in the economy (as costs of production increase). This effect can be perceived as a kind of "Dutch disease" (i.e., the apparent causal relationship between an increase in the economic development of a specific sector and a decline in other sectors [70]). Here, we observed the increase in the economic development of the energy sector which results in a decline in other sectors, especially tradable ones. The mechanism is that, as revenues increase in the growing sector, the given nation's currency becomes stronger (appreciates) compared to the currencies of other nations (manifest in an exchange rate) and exports become less competitive and fall. In addition, in smaller economies, investment must be compensated not only by a fall in public expenditures but also private ones. All those mechanisms are especially evident in the case of Zachodniopomorskie. If the nuclear power plant is located there, in the smallest of the four regions, the impact on the wage increase is substantial and much higher compared to the other three (Figure 5c). We also observe that national export falls if the power plant is located here (Table 3, right-hand side). Similarly, many sectors suffer from that investment too, i.e., there are 248 sectors nationwide, and only 56 increase (Table A2). On the contrary, if the investment is in Mazowieckie, the large capital region, then the wage increase is relatively small (Figure 5c), exports increase (Table 3, right-hand side), and the sectoral effects are more evenly transmitted to the rest of the national economy. This is manifested by the highest number of expanding sectors due to investment in this location (Table A2).

The economic outcomes also differ substantially if we examine the construction versus exploitation phase. The former proved to be beneficial for the whole economy and for all regions, as manifested by increases in real GDP and aggregated employment. Since the wage differentials drive migration movements, the increase in real wages in all the regions stimulate an increase in net migration. In the exploitation phase, the outputs of coal- and gas-based power plants are replaced by those of nuclear power plants, i.e., more expensive energy which is repaid many years later.

Our approach and results are very much in line with economic theory. First, the assessment of regionalisation policies is most conveniently conceived of in the context of spatial equilibrium theory [71]. This is because it allows researchers to assess the effects not only of the industries providing public services, but also the cumulative effects on other industries and on public sector finances as well. Most importantly, it allows the assessment of the impacts on total production and with reference to a sensible baseline scenario [71]. This is the precise advantage of our approach where we compare all the changes up to 2050 with respect to the baseline scenario (in which there is not a nuclear power plant). We also have production and trade links among 19 sectors in 16 regions (links among 304 units). Besides, we observe the impact on private and public consumption. In the best location, Mazowieckie, the investment is compensated for not only by a decrease in public consumption but also private consumption (Table 3). Our model has also incorporated rarely seen agglomeration effects, which allowed us to observe the movement not only of the sectoral workers in total but also by age cohorts.

Second, the theory predicts that the most direct effect is in the region of investment and manifested by an increase in labour demand, which in turn increases the real wage level of the destination region [71]. This is exactly what proved to drive our results in four Polish regions where the investment was located. The scale of this effect differed substantially depending on the region's characteristics, from the largest in Zachodniopomorskie to the smallest in Mazowieckie (capital region).

Third, according to the economic theory, the effect of an increase in real wages to individual industries is mixed depending on whether an industry belongs to the tradable or the non-tradable sector. Tradable sectors suffer more than non-tradable industries as they must bear higher costs without much effect on their output prices. On the contrary, the selected location may gain tradable sectors in other regions if the relocation eases some scarcity of resources, such as dwellings [72]. The effect is even worse if the investment has an effect on the appreciation of currency because then the tradable sector also becomes less competitive in foreign markets and its exports decline [71]. We observed this effect in our simulations where among the most suffering sectors were tradable industries not only in the receiving region, mainly agriculture (A), mining and quarrying (B), manufacturing (C), and transport (H), while the ones receiving the most benefits were non-tradable, mainly electricity in receiving regions (D), trade in receiving regions (G), and public administration in receiving regions (O). The impact on other sectors is mixed (Table A2). We also observed a decline in exports if the location is Zachodniopomorskie or Łódzkie (Table 3, right-hand side).

Regarding the international effect of nuclear energy in Poland, we can expect that it would improve the country's standing in the EU, as it would be a contributing measure to the EU's climate policy. The economic effects hinge on the international trade in electricity. However, since Poland is currently net importer of the energy, the nuclear power would increase its self-sufficiency so it would import less energy from the neighbouring countries, especially from Russia. It would also have a chance to turn from net importer to net exporter. On the other hand, Poland will increase the demand for uranium in the region.

It must be stressed that our study concerned purely economic impact because the model we applied is economic. However, we do not imply that economic arguments are the most important for introduction of nuclear plants. We think that, aside from economic concerns, no less important are the environmental, social, spatial, political, military, and many others. The economic impact is especially important because, as this kind of investment involves public money, it needs to be well-justified to the taxpayers. So, the investment should not cause any detrimental effects such as regional imbalances, negative environmental externalities, or societal unease, as they also hinder the development of the whole economy. It seems that in our case, the Dutch disease effect is indeed negative both for the entire economy and the economy of the region involved. It should also be mentioned that two regions—Zachodniopomorskie and Pomorskie—are touristic ones, located at the Baltic Sea, so the negative impact on their tourism would seem unavoidable. Environmental considerations must be taken into account as well, especially concerning the probability of accident and utilisation of the nuclear waste. For these reasons, the alternatives to nuclear energy investments should be also considered. Some analyses for alternatives to nuclear power were carried out in Poland. They showed that investments in a mix of RES would be more beneficial from the strategic point of view. This would also bring a greater increase in innovations, the development of construction and agricultural sectors (also in the field of modernisation of rural areas), and a return from investment that would be ten times faster [73].

All in all, although there is a consensus that all countries, especially heavy polluters, need to look for technologies which are low on greenhouse gas emissions, the controversy still remains as to whether renewable energy (RE) or nuclear energy (NE) should be used. The arguments not only concern safety and environmental issues—obviously RE is superior over NE in that respect—but also are from the point of view of the cost-effectiveness, as state aid is involved. NE is perceived as the most affordable option in the short run [74], but the costs of depreciation and of utilisation increase substantially in the longer run [75]. Meanwhile, costs of RE have been decreasing over the time due to learning effects [76]. The studies comparing RE and NE in the EU showed that supporting the basket of RE technologies is more cost-effective than NE. Following the RE pathway rather than that of NE brings savings of 37.1% in EU28 on average [76]. Still, the countries differ in their approaches. Germany and Japan intend to phase out nuclear power, while other countries such as Bulgaria, France, Romania, Slovakia, and the UK plan to build more nuclear power plants. Poland has declared its intention to "join the club" and invest in nuclear power alongside this latter group of countries.

6. Conclusions

This paper simulated the economic impact, at the national and regional levels, of investing in the first nuclear power plant in Poland. Such an investment would enable the country to become less coal-dependent and get in line with the EU strategy of a climate-neutral economy. The applied spatial recursive dynamic CGE model for Poland (POLTERMDyn) was calibrated until 2050 and included a new feature—agglomeration effects. The simulation assumed building a nuclear power plant worth 17.5 billion EUR in one of the four most probable locations, i.e., Zachodniopomorskie, Pomorskie, Mazowieckie, and Łódzkie. Although the locations were similarly good from a technical point of view (i.e., fulfilling hydro-geological requirements), they were substantially different from an economic point of view. This is due to regional differences in production structure, wage levels, characteristics of labour force, and energy sector. The paper showed that if the investment is too large for the regional economy and its energy sector, it may cause a "Dutch disease" type of effect there. Therefore, Zachodniopomorskie suffered from the investment, while Mazowieckie benefited and was the best from both national and regional perspectives. The construction period was beneficial for all regions, but exploitation was not, when nuclear energy was replacing the traditional sources of energy. Hence, we proved that the location of the nuclear power matters, and hence we advocate that economic criteria should be taken into account among other criteria before the final location decision is made; at the moment, this is not the case.

Further research could extend our paper in four dimensions. First, from a policy perspective, it could add a comparison of our economic impact of one big investment in nuclear power plant with the same amount of investment but in several smaller renewable energy power plants. Second, from a methodological point of view, one could combine our economic CGE model with an energy system model in order to add more energy-specific technical detail to the simulations. Third, for international effects of such investments, one could apply a multi-country CGE model, e.g., GTAP (The Global Trade Analysis Project). Fourth, one could enhance our quantitative analysis over a qualitative one in order to investigate the intraregional distribution of economic consequences of the power plant's location and also confront our results with subjective opinions of inhabitants of specific regions where the investment is to be implemented.

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Appendix A

Table A1. Expert assessment of selected locations of nuclear power plants in Poland (scores in points).

Location: Site	Location: Region	Evaluation criteria 1 Integration into the Electric Grid System	2 Geology, Tectonics and Volcanic Studies	3 Seismology an Seismic Engineering	4 Hydrology (incl. Ground Water, Floods	5 Cooling Water Availability, Intake and Discharge	6 Demography and Land Use	7 Meteorology and Atmospheric Dispersion	8 Study on Flora and Fauna	9 Nuclear Safety and Radiation Protection	10 General Environmental Effect	11 Risks from Man-Made Events	12 Local Infrastructure	13 Cultural and Historical Sites	14 Access and Emergency Response Roads	15 Air, Land and Sea Transportation Patterns	16 Legal Aspects	17 Public Consultations	Total
Żarnowiec	**Pomorskie**	4.7	4	5	3.5	0	5	5	5	3.2	5	3	4.7	5	3	4.5	n.a.	5	65.6
Warta-Klempicz	Wielkopolskie	4.3	4	5	4.5	1	5	3	2	3.4	3	3	4.7	5	3	4	n.a.	5	59.9
Kopań	**Zachodnio-Pomorskie**	2	3	5	3.5	5	5	5	2	2.6	0	3	4.7	5	3	4	n.a.	3	55.8
Nowe Miasto	**Mazowieckie**	2.7	4	5	4.5	1	5	4	5	3.2	5	3	1.9	5	3	3	n.a.	0	55.3
Bełchatów	**Łódzkie**	0.3	2	3	4.5	1	3	3	5	2.8	5	3	4.5	5	5	3	n.a.	3	53.1
Nieszawa	Kujawsko-Pomorskie	1.7	3	5	5	4	4	3	2	1.6	3	1	4.7	5	3	3	n.a.	3	52
Tczew	Pomorskie	4	4	5	1.5	4	3	3	1	2	3	3	4.8	5	5	3.5	n.a.	0	51.8
Choczewo	Pomorskie	2.3	4	5	3.5	5	5	5	2	3.2	0	3	4.5	5	2	1.5	n.a.	0	51
Połaniec	Świętokrzyskie	2	3	4	3	1	5	3	1	3	3	3	4.7	5	3	3	n.a.	3	49.7
Chotcza	Mazowieckie	2	3	5	4.5	1	5	3	5	2.2	5	3	4.4	5	0	1.5	n.a.	0	49.6
Małkinia	Mazowieckie	3.3	5	5	5	1	5	3	0	3.4	0	3	4.4	5	5	1	n.a.	0	49.1
Krzywiec	Zachodnio-Pomorskie	1.3	5	4	4	0	5	3	1	3.2	3	3	4.5	0	5	4	n.a.	3	49
Krzymów	Zachodnio-Pomorskie	1.3	4	5	2	1	5	3	0	2.8	0	3	4.7	5	5	4	n.a.	3	48.8
Kozienice	Mazowieckie	1.7	4	5	5	1	5	3	0	2.8	0	3	4.7	5	5	3	n.a.	0	48.2
Wyszków	Mazowieckie	3	5	5	5	1	3	3	0	2.8	0	3	4.7	5	5	2.5	n.a.	0	48

Table A1. *Cont.*

Location:		**Evaluation criteria**																	
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	
	Location: Region	**Integration into the Electric Grid System**	**Geology, Tectonics and Volcanic Studies**	**Seismology an Seismic Engineering**	**Hydrology (incl. Ground Water, Floods**	**Cooling Water Availability, Intake and Discharge**	**Demography and Land Use**	**Meteorology and Atmospheric Dispersion**	**Study on Flora and Fauna**	**Nuclear Safety and Radiation Protection**	**General Environmental Effect**	**Risks from Man-Made Events**	**Local Infrastructure**	**Cultural and Historical Sites**	**Access and Emergency Response Roads**	**Air, Land and Sea Transportation Patterns**	**Legal Aspects**	**Public Consultations**	**Total**
Pniewo	Zachodnio-Pomorskie	1.3	5	5	2	1	5	3	0	2.8	0	3	4.8	5	3	4	n.a.	3	47.9
Pniewo-Krajnik	Zachodnio-Pomorskie	1.3	5	5	2	1	5	3	0	2.8	0	3	4.8	5	3	4	n.a.	3	47.9
Lubiatowo-Kopalino	Pomorskie	2	3	5	3.5	5	5	5	1	3	0	3	4.7	0	2	2	n.a.	3	47.2
Dębogóra	Zachodnio-Pomorskie	1.3	4	5	4	1	5	3	2	2.6	0	3	4.8	0	3	4.5	n.a.	3	46.2
Stepnica 1	Zachodnio-Pomorskie	1	3	4	2.5	1	5	4	0	3	0	2	4.8	5	3	4	n.a.	3	45.3
Stepnica 2	Zachodnio-Pomorskie	1	3	4	2.5	1	5	4	0	3	0	2	4.8	5	3	4	n.a.	3	45.3
Wiechowo	Zachodnio-Pomorskie	1.3	4	4	4	0	5	3	1	3	3	3	4.4	0	3	3.5	n.a.	3	45.2
Karolewo	Mazowieckie	1.7	4	5	5	4	5	4	3	1.6	0	3	4.5	0	2	2	n.a.	0	44.8
Lisowo	Zachodnio-Pomorskie	1.3	3	4	4	0	5	3	1	3	3	3	4.5	0	3	4	n.a.	3	44.8
Gościeradów	Lubelskie	2.7	3	5	4.5	1	5	3	1	3	0	3	4.4	0	3	2	n.a.	3	43.6
Chełmno	Kujawsko-Pomorskie	2	3	5	5	4	2	3	2	2	3	1	4.7	0	3	2.5	n.a.	0	42.2
Pątnów	Wielkopolskie	1.3	3	5	5	0	3	4	0	2.6	0	3	4.7	0	5	3	n.a.	0	39.6

Source: Based on [77]. Note: The four locations selected for our study are in bold.

Table A2. Impact of the regional investments in nuclear power plants on sectoral outputs in Poland and location regions, simulation for 2025–2050.

NACE 19 Sections:	Impact on Zachpomorskie (% Change)	Impact on the National Economy (in 16 Regions) *	Impact on Pomorskie (% Change)	Impact on the National Economy (in 16 Regions) *	Impact on Mazowieckie (% Change)	Impact on the National Economy (in 16 Regions) *	Impact on Łódzkie (% Change)	Impact on the National Economy (in 16 Regions) *
1. Agriculture (A)	−0.04	0	−0.02	2	0.00	12	−0.02	0
2. MiningQuaring (B)	0.00	1	0.00	7	0.00	12	0.00	2
3. Manufacturing (C.)	−0.02	0	−0.09	3	0.01	16	−0.05	0
4. Electricity&Gas (D)	**0.95**	1	**1.27**	1	**0.53**	1	**1.12**	1
5. Water&Waste (E.)	−0.01	3	−0.01	5	0.00	14	0.00	2
6. Construction (F)	0.96	2	0.76	2	0.14	9	0.39	9
7. Trade (G)	0.23	1	0.18	1	0.08	1	0.16	1
8. Transport (H)	−0.02	0	0.00	3	0.01	6	−0.01	0
9. Accomod&Food (I)	0.02	10	0.01	8	0.01	10	0.00	5
10. ICT (J)	−0.05	14	−0.06	15	−0.01	15	−0.02	14
11. Finance&Insurance (K)	−0.01	6	0.01	7	0.02	16	0.00	2
12. RealEst (L)	0.07	4	0.08	6	0.05	11	0.05	1
13. RandD (R&D from M)	0.00	1	0.00	5	0.00	16	0.00	1
14. Proffes (Rest of M)	0.02	1	−0.02	15	−0.01	15	−0.01	14
15. AdmINSup (N)	0.01	5	0.02	2	0.01	10	0.01	1
16. PubAdm (O)	0.15	2	0.13	2	0.05	1	0.13	1
17. Education (P)	0.12	2	0.12	2	0.04	1	0.11	1
18. Health (Q)	0.13	2	0.11	2	0.04	1	0.11	1
19. All other (R+S+T+U)	0.09	1	0.07	2	0.03	1	0.06	1
Sum of growing sectors**	12	**56**	13	**90**	16	**168**	12	**57**

Note: * The column shows the number of growing industries (out of 19) in all the regions (16); ** The sum shows the total of all 304 (16 × 19) region–industry combinations. All the positive values are in yellow, while negative values are in red. The tradable sectors are equivalent to NACE sections A, B, C, H, I, J, K, M, and N, while non-tradable sectors are equivalent to NACE sections D, E, F, G, L, O, P, Q, and R + S + T + U.

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