TIPPING+

Enabling Positive Tipping Points towards clean-energy transitions in Coal and Carbon Intensive Regions

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D4.2: Assessing the labour market effects of a carbon tax as a tipping intervention in economies undergoing coal phase-out: the cases of Poland and Greece

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Preface

TIPPING+ will provide an empirical in-depth social science understanding of fundamental changes in sociodemographic, geographical, psychological, cultural, political, and economic patterns which give rise to Social-Ecological Tipping Points (SETPs), both positive and negative in relation to socio-energy regional systems. Such empirical and theoretical insights will shed new light on the interdependencies between changes in regional socio-cultural structures and the technological, regulatory and investment-related requirements for embracing (or failing to embrace) low-carbon, clean-energy and competitive development pathways in selected coal and carbon intensive case study regions (CCIRs). The overall goal is to understand why and under which conditions a given social-ecological regional system heavily dependent on coal and carbon-intensive activities may flip into a low-carbon, clean energy development trajectory – or on the contrary may fall into an opposite trajectory with all its negative implications. Towards this goal, main focus of TIPPING+ is the participatory co-production of knowledge on the driving forces and deliberate tipping interventions leading to the emergence of positive tipping points toward clean energy transitions in European CCIRs.

Who We Are

	Participant Name	Short Name	Country	Logo
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3	CIRPA - Università Degli Studi di Roma La Sapienza	UR	IT	
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Executive Summary

Tipping points are considered a moment or a period when the socio-economic system shifts from the preceding development pathway to a qualitatively different state. In this report, we aim to understand the conditions for creating tipping points in the socio-economic system that would bring about a durable regime shift in the energy sector. Precisely, we assess the macroeconomic effects of implementing a carbon tax, using as testbed two European economies at different stages of decarbonisation. We assume that carbon tax implementation may pose a trigger (tipping event) to deliver a tipping point to accelerate decarbonisation and determine whether and in what ways this pathway is followed.

Implementing the dynamic stochastic general equilibrium model (Macroeconomic Mitigation Options model – MEMO), we aim to assess the impact of carbon tax implementation on basic macroeconomic indicators. Our analysis focuses on Poland and Greece – countries maintaining energy-intensive industrial regions, such as Upper Silesia (with hard coal mining and coal-based energy sector) and Megalopolis (with lignite extraction and lignite-based energy sector). Both regions have the coal phase-out dates set up and expect challenges in managing the regional transition process. Therefore, we reflect on the carbon tax implementation's national and regional policy consequences as a tool aiming to bring about tipping towards climate change mitigation.

Our results unsurprisingly confirm a more substantial impact of a carbon tax on GDP and unemployment in the more industrial and carbon-intensive Polish economy. Due to the 'countries' specificities and different decarbonisation stages, carbon tax implementation would strongly affect Poland compared to Greece. In Greece, the effect of carbon tax implementation would be modest and especially affect value-added and employment in market services, as this sector contributes to the Greek economy the most and is highly exposed to changes in energy prices. In Greece, the largest decrease in total employment concerns agriculture, construction and light industry workers. In Poland, it would occur in mining and construction and cause employment losses in the national energy-intensive and advanced industries. As in the discussion about decarbonisation, these industries have not yet received much policy attention so far; they should be considered in further dedicated works.

The carbon tax enables a significant reduction of emissions; however, it requires policy interventions to mitigate the social costs of the transition. Potential value added and employment losses justify the introduction of safety nets and additional support for the profound transformation of the regional economies. The resources collected from the carbon tax should boost the financial transfer for coal and carbon-intensive 'regions' transition. The recycling revenue mechanism of a carbon tax should recognise and address key regional needs in terms of decarbonisation, provide safety nets and retraining programmes for employees at risk, support regional and local SMEs and overall economic diversification to build transformation capacities and make the regions resilient. Through these instruments, we argue that introducing a carbon tax could potentially be the tipping event that could accelerate systemic change towards the desired trajectory. However, it would be tough to reach it under existing socio-political circumstances: the Russian invasion in Ukraine and its consequences on the European energy market. Moreover, such action also requires (1) increasing the current level of climate change awareness, (2) combining narration of decarbonisation and geopolitics (3) providing and communicating efficient support to mitigate such solutions among less affluent people.

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Introduction

Implementing a carbon tax can be treated as a tipping event, which triggers a change in the decarbonisation pathway (tipping point). This event may also cascade into further socio-economic changes ranging from the impact on the GDP to labour market effects. To this end, we assess the potential macroeconomic impacts of implementing a carbon tax using the case study of two European economies at different stages of decarbonisation. We treat the implementation of a carbon tax as a potential tipping event, an exogenous moment which triggers a significant qualitative change in the decarbonisation pathway.

We evaluate the possible consequences of a decision to implement the carbon tax by applying a dynamic stochastic general equilibrium model. We aim to understand the conditions for creating tipping points in the socio-economic system that would challenge a durable regime shift in the energy sector. We focus on the labour market perspective; therefore, we define a stable transition when the positive outcomes of the process outweigh its adverse effects, e.g. employment in the newly developed energy sector is higher than the dismissals from fossil-fuel intensive industries.

Due to the interconnectedness between social and ecological system components, we assume that crossing an ecological tipping point leads to a qualitative change in the social and economic system, characterised by a different set of stabilising positive and negative feedback [1]. We also assume that policy decisions (in this example: introducing carbon tax) may allow transformative change and determine whether and in what ways the transition pathway is followed. Therefore, we assume that carbon price dynamics and emissions reduction are important factors in the energy system development and will determine the stability of particular carbon-intensive states and regions. Until now, a carbon tax was suggested more as a necessary solution to mitigate climate tipping points [2] than the instrument being a trigger to stimulate qualitative change. However, even if such a public intervention does not enable a certain tipping point (rather – a tipping event), it might boost the energy and climate policy efforts and accelerate the decarbonisation pathway [3].

In this deliverable, we aim to answer the following research questions:

(1) Would the macroeconomic effects of introducing carbon tax (a) consolidate the phase of transition and reinforce its irreversibility (positive tipping triggers), or (b) weaken the efforts to reduce emissions due to the social costs of transformation (negative tipping triggers)?

(2) How could the carbon tax introduction affect the value added and labour market outcome in selected sectors of the economy?

We tackle the above research questions by (1) describing possible policy scenarios of introducing carbon taxes from a medium-term perspective; (2) modelling the effects of the carbon tax uptake on the labour market and sectoral developments; (3) translating possible consequences to implications for examined coal and carbon-intensive regions. We also provide insights on questions regarding the labour market and compare these results to the existing research, possible revenue recycling mechanisms, and national/regional context.

Through this study, we plan to illustrate the relevance of the selected economic and resource dimensions to understand cumulative processes, capacities and sociostructural forces in coal and carbon-intensive regions that lead to positive or negative tipping points.

We use the dynamic stochastic general equilibrium model (Macroeconomic Mitigation Options model – MEMO), developed at the Institute for Structural Research [4], [5]. We assess the impact of the carbon tax implementation on basic macroeconomic indicators and long-run determinants of economic growth. We consider two carbon tax scenarios based on the Network for Greening the Financial System outputs generated by state-of-the-art, well-established integrated assessment models (IAMs), namely MESSAGE-GLOBIOM and REMIND-MAgPIE [45]. These simulations were conducted before Russian aggression on Ukraine in February 2022.

We intend to make two key contributions. First, we provide original scenarios for two countries with similar coal phase-out challenges but at different stages of decarbonisation (Greece and Poland). These results can provide helpful insight into the general discussion about decarbonisation consequences. Second, we also reflect on the carbon tax implementation's national and regional policy consequences, which can be a more efficient alternative to accelerate climate mitigation efforts. Thereby, we test carbon tax as a potential tipping event to expedite a positive tipping point, arguing for a stronger public sector agency toward decarbonisation pathways.

The deliverable is structured as follows. Section 2 introduces the concept of tipping points in treating carbon tax implementation as a potential tipping event to adopt an alternative decarbonisation pathway. Section 3 provides information about the MEMO model settings and used data sources. Section 4 presents the results, and Sections 5 and 6 briefly discuss and summarise the findings.

Literature review

1.1. The concept of Tipping Points

The concept of tipping points has its origin in the climate sciences and has been developed by [10] to articulate the prospect of passing thresholds in the climate system or ecosystem [11], [12]. According to this concept, complex systems may undergo abrupt alterations due to accumulating small perturbations [12]. In the environmental context, exceeding critical temperature thresholds may lead to ecological system change that may be difficult to reverse [13]–[15]. Due to the interlinkages between the social and environmental systems, this research approach has been implemented to analyse the pathways of transformation in socio-economic systems to illustrate the changes that are taking place in the broad energy transition.

In the socio-economic literature, climate change-induced tipping points are identified with an abrupt change of a socio-economic system into a new, fundamentally different state [16]. Milkoreit et al. emphasise that at a tipping point, the system triggers a non-linear change process that inevitably leads to a qualitatively different state, which is often irreversible [1]. This process is supported by internal feedback mechanisms, which may either lead to a new stabilised state or further destabilisation [17]. In addition to scientific applications, tipping points have become a popular metaphor for informing the broader public about the effects of climate change and its far-reaching consequences [18], [19]. However, the potential existence of tipping points in socio-economic systems has remained underexplored, whereas they might be highly policy-relevant [16].

In socio-economic systems, the transition to a state where a large majority adopts new technology, behaviour or strategy can be twofold. First, transformation may result from the incremental spread of new patterns. In this case, the new solutions gradually complement the existing system by improving its operation or replacing existing solutions (e.g., replacing fossil fuels with renewable energy sources). The ““transformative-oriented”” policy [20] includes various policy instruments and market mechanisms that can trigger and accelerate the transition process [21]–[23]. Incremental changes in the system landscape may also pressure an existing regime. Thereby a window of opportunity may enable a breakthrough for niche solutions and innovation [24]. Second, transformation can also result from sudden shocks, radically changing the boundary conditions in which the system operates. These shocks may be negative (e.g., soaring prices, supply chain breakdowns) or positive (e.g., disruptive innovation). Such abrupt changes may require an urgent policy response. However, policy change can be implemented slowly and take a long time to fully internalise its results due to adoption of new technologies and behaviours. For example, to reduce the dependency on fossil fuels, society will need to adopt energy-efficient and low-carbon energy technologies, provide new infrastructure and develop new business and behavioural models.

When trying to identify potential or actual positive tipping points in the socio-ecological system of reference, [17] argue that three key moments need to be considered: (1) the building of transformative conditions and capacities for systemic and appropriate, deliberate change, (2) a tipping event, precipitating the system towards a desirable trajectory or basin of attraction, and (3) the qualitative, irreversible, and structural effects derived from such transformation. The key assumption of the energy transition is the positive nature of the tipping points, where changes lead to a more desirable shape of the socio-economic system than the present one. However, such an approach is inconsistent because the transformation assessment is subjective and can be perceived differently in the short and long term. While transformational change may pose opportunities for some stakeholders, it may be disruptive to others, particularly those who depend on the established system [25]. In addition, the distribution of the costs and benefits of transformation can be regionally differentiated and unevenly spread over time. Regions with a high degree of technology dependency, which face the most significant impact on the transition costs in the short term, can benefit from long-term changes due to well-designed policies.

Moreover, the socio-ecological tipping points are difficult to predict. Their occurrence can usually be explained only retrospectively as they designate specific paths or development trajectories [26]. The challenges of tipping points predictions derive from the complexity of the socio-economic system, stakeholders' perception of system dynamics [16] and their ability to impose the pace and course of transition [27]. However, we argue that even if it is impossible to determine future tipping points precisely, the transmission mechanism and potential impacts should be analysed to identify feedback (either positive or negative), develop policy responses, and adopt mitigation measures if required.

1.2. Tipping points and carbon tax: an economic perspective

From the perspective of applied economy, tipping points can be detected as non-linearities or co-occurrence of different trends. As Maier et al. suggested, the tipping point concept has not received attention in this discipline yet, because most economic processes are considered reversible [3]. However, a literature review about advancing state of the art on research on tipping points in economics also suggested immediate carbon tax implementation as a desirable option to accelerate decarbonisation and decrease policy costs in the long run [3], [28]. Following this statement, we assess carbon tax as a trigger (tipping event) to deliver a tipping point.

The general climate policy debate recognised carbon tax as an efficient instrument to reduce emissions and ensure sustainable growth. In principle, the aim of the carbon tax should be to promote fair and sustainable energy consumption patterns and enforce sectors, firms and households to accommodate cleaner energy pathways – or pay more and more in exchange for external costs in the long run. Swedish or Finnish carbon tax is often used as an example of transformative capacity. In these countries, the carbon tax implemented in the early 1990s triggered and accelerated the household heating transition towards cleaner energy carriers [29].

However, there is no consensus about the general impact of a carbon tax on the behaviours of firms operating in different sectors and households. Most of the studies evaluate the ex-ante effects of carbon tax adoption. Recent results for the EU countries using Input-Output models and Household Budget Studies pointed out overall regressive carbon tax levels at the EU level and various national effects of carbon tax implementation on different income groups. In Poland, Romania and Hungary, the carbon tax was considered to be a regressive solution, opposite to Luxembourg (where high-income groups would pay the most), Greece and Cyprus (where the middle-income group would pay the most; more: [30]). A recent exhaustive overview of the distributional impacts of carbon pricing has indicated progressive effects of carbon taxation in developing countries and within general transportation policies, with a still limited discussion about revenue recycling mechanisms [31].

Revenue recycling mechanisms are required to compensate for immediate adverse sectoral effects (e.g., on the labour market) and ensure the economic safety of the most vulnerable households. Carbon tax supporters argue that recycling mechanisms are essential for households, as the most vulnerable ones proportionally lose a larger share of their incomes in the case of excise tax and other typical taxes on energy services [32]. Revenue recycling mechanisms aim to balance benefits and losses and increase political acceptance of carbon taxes [33]. The choice of a particular mechanism should reflect the goals the public administration wants to achieve [34, p. 202]. Popular distributional mechanisms include, e.g. lowering pre-existing taxes (e.g. labour tax cuts), increasing pre-existing social transfers, and introducing differentiated and targeted cash transfers [35], [36].

Recent results on the efficiency of revenue recycling mechanisms are debatable. The first 5-wave panel survey on Canadian and Swiss citizens proved limited effects of current climate rebates on public attitudes regarding carbon pricing [37]. Also, the discrete choice experiment on 6,000 German households indicated that spending carbon tax revenues on green investments "might run the risk of 'preaching to the converted' rather than building societal support with the groups that tend to oppose climate action" [38], p. 11). The reasons may lead to perceiving the carbon tax as an 'additional burden' [39] for society, opposite to the other climate policy instruments such as direct renewable energy support schemes or energy efficiency regulations. However, with each subsequent year, there are more and more critical voices in the EU regarding the existing ETS mechanism from the governments of less wealthy but still carbon-intensive countries in Central and Southern Europe. Such a mechanism is considered to be too expensive compared to obtained reductions [40]. In that way, we see sense to cast an eye on the alternative and assess the consequences of a carbon tax mechanism on selected Central and Eastern Europe and Mediterranean economies. We chose Poland and Greece for further investigations.

Poland and Greece have not been the subject of many empirical studies on carbon tax implementation. For example, relevant analyses for Greece are limited to a couple of old studies which assess the impact of a carbon tax on Greek manufacturing [38] and CO_2-oriented vehicle tax reforms [39]. For Poland, the exemption is a study of the distributional effects of a carbon tax: direct and indirect effects as well as the employment channel, using both macro and microeconomic models for Poland [5]. The authors emphasised different distributional effects of revenue recycling mechanisms dependent on the economic policy target and suggested further studies on countries with the coal industry [5]. Following this hint, we include Greece as a case study country with a more ambitious coal phase-out plan to assess the carbon tax as a potential trigger for the significant qualitative change in the decarbonisation pathway.

Methodology

1.3. Macroeconomic model – MEMO

To assess the macroeconomic effects of implementing a carbon tax, we use the dynamic stochastic general equilibrium model (Macroeconomic mitigations options model – MEMO), developed at the Institute for Structural Research [4], [5]. The model combines two strands of research – input-output and general equilibrium modelling. The model consists of the household sector, which maximises utility from consumption and leisure; the firm sector, which maximises profits; the government sector, which collects various taxes and finances public consumption; and a foreign sector responsible for trade with the rest of the world. The model's main features include the division of the firm into sectors calibrated to the input-output matrix, search and matching on the labour market to the model transition of workers between sectors and endogenous adaptation of technology related to energy use.

The sector structure of the model is calibrated using the 2015's Polish and Greek activity by activity input-output matrix from the Eurostat statistics database, which uses the NACE Rev. 2 statistical classification of economic activities in the European Community. In the model, we distinguish the following sectors: (1) agriculture and forestry, (2) mining and quarrying, (3) light manufacturing, (4) energy-intensive manufacturing, (5) advanced manufacturing, (6) refined petroleum products, (7) energy, (8) construction, (9) transport, (10) market services, and (11) public services.

1.4. Input-Output sector structure and emissions

There are several distinct sets of parameters whose values need to be calculated. The main ones are the parameters governing the firm and production side of the model. These parameters can be further specified as those which govern the value-added[1] structure of the sectors, investment and compensation of employees in each sector, the intermediate use structure, which considers domestically produced and imported goods and a final use structure which also takes into account domestically produced and imported goods. A scheme of the production structure is shown in **Figure 1**. Each firm operates a production function which utilises a nested CES (constant elasticity of substitution) specification to combine the factors of production. In the first stage, the firm combines capital and energy; the second stage consists of adding labour, whereas, in the final stage, this bundle is combined with materials (intermediate use). The material bundle is composed of products of each sector, which are further disaggregated into imported and domestically produced parts. On the use side, the goods produced by each sector are purchased by the household as private consumption, by the government as public consumption, by firms as investment, or

[1] It is defined as the value of output minus the value of purchased inputs.

they can be exported.

To calibrate the firm side of the model, we use the Eurostat database's input-output (I-O) matrix. However, for this study, we have to modify the matrix. In particular, it is necessary to disaggregate some sectors and products shown as a single activity in the IO matrix to model the effects of energy and environmental policies.

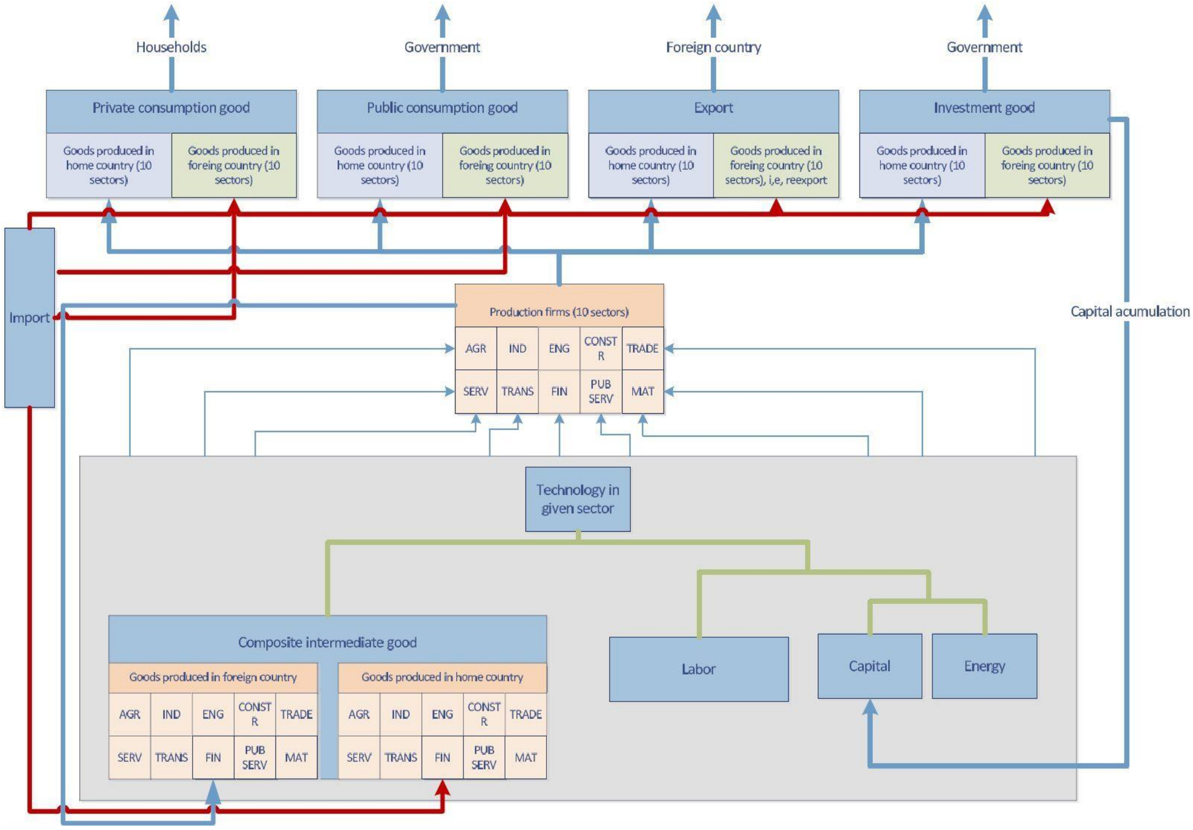

Figure 1: Production process in MEMO model

Source: [4]

Notes: "AGR" agriculture; "IND" industry; ENG "energy"; "CONST" construction; "SERV" market services; "TRANS" transport; "FIN" financial services; "PUB SERV" public services; "MAT" raw materials.

In MEMO, we directly model CO_2 emissions from fossil fuels: coal, oil and gas. The volume of carbon emissions in a particular sector is modelled as a linear function of the use of these fuels, with coefficients set to match sector data regarding emissions. We do not model directly other non-carbon emissions, such as those resulting from industrial processes, waste processing, agriculture or captures in the forestry sector. Such emissions are treated indirectly in the post-processing phase of the modelling exercises. In the case of running a carbon tax simulation, the agents in the model only react to the fossil fuel emissions, which are modelled directly and do not, for example, reduce output in the agriculture sector to cut non-carbon emissions.

1.5. Scenario specifications

Our study is focused on Poland and Greece. As shown in Błąd! Nie można odnaleźć źródła odwołania., Greece had larger GDP per capita than Poland in 2020 while also having much lower emissions per capita in the same year. In this regard, Poland's economy can be considered much more energy-intensive than the Greek economy. This can be mainly attributed to the contribution of the Polish coal and carbon-intensive regions to the national economy. Both countries set different coal exit dates (Poland in 2049; Greece in 2028) and, consequently, are at different stages of the coal phase-out.

Moreover, Poland and Greece experienced different macroeconomic trends and conducted various fiscal and economic policies in the previous decade. After the financial crisis of 2008, Greece implemented a multitude of austerity measures, which significantly increased the unemployment rate and reduced wages (Błąd! Nie można odnaleźć źródła odwołania.). On the contrary, Poland in this period was the only EU Member State that maintained stable economic growth during the previous decade and avoided the economic depression that followed the financial crisis. Considering these similarities and differences, we simulate the potential effects of a carbon tax to assess this instrument as a possible tipping event for the significant qualitative change in their economies.

Table 1. Key macroeconomic and environmental parameters in 2020.

Country	**Population (million)**	**GDP (billion US$)/GDP per capita (US$)**	**Emissions (million tonnes)/Emissions per capita (tonnes)**	**Unemployment rate (%)**	**The annual average wage (US$ PPPs)**
Poland	**38.0**	**594.2/ 15636.8**	**299.6/ 7.9**	**3.2**	**33330**
Greece	**10.7**	**189.4/ 17700.9**	**52.2/ 4.9**	**16.3**	**25630**

Sources: [41], [42]

Both countries maintain carbon-intensive industries in particular regions, such as hard coal mining and coal-based energy sector in Upper Silesia and lignite extraction and lignite-based energy sector in Megalopolis.

Upper Silesia is 'Poland's most urbanised and second most populous region (Area: 12,333 km^2, Population: 4,4 million people, according to the most recent national census results from 2021). Most Upper Silesian inhabitants (76,5%) live in the cities, and the region has the highest population density in the country (357 people per km^2 in 2021, compared to the national average of 122). The centre of the area is the Katowice conurbation developed around mining and other traditional industry branches. Upper Silesia concentrates 90% of domestic hard coal extraction and the vast majority (89%) of total employment in coal mining [43].

Megalopolis is part of the Arcadia regional unit (Area: 4,419 km^2, Population (2011): 86,685 people), which is part of the Peloponnese region (EL65 NUTS-II Code, Area: 15,490 km^2, Population (2011): 577,903 people). According to the most recent census (2011), the municipality of Megalopolis has a population of 10,687 people and covers an area of approximately 722.6 km^2 [44]. Until 1970, Megalopolis retained a rural character. Since then, the Public Power Corporation has begun lignite extraction in the Megalopolis deposit, establishing the region as both an upstream and downstream coal and carbon-intensive region. Megalopolis has become an important energy centre due to the abundance of lignite reserves in the Megalopolis basin subsoil. The dominant activities in Megalopolis are now lignite mining and lignite-based power generation, which employ a significant percentage of the local workforce [45].

We consider two carbon tax scenarios, according to The Central Banks and Supervisors Network for Greening the Financial System (NGFS), which would allow for achieving a CO_2 reduction in line with the 2°Celsius climate mitigation target in Poland and Greece (**Table 2**). The value of the carbon tax originates from integrated assessment model outputs. Tax 1 is calculated based on the MESSAGE-GLOBIOM, and Tax 2 is based on the REMIND-MAgPIE. In the scenarios, the values of carbon taxes are similar in both countries yet yield different results regarding CO_2 emission reduction. We applied a short-term perspective (until 2032) – considering that a 10-year horizon is, on the one hand, a relevant period to observe some specific macroeconomic shifts, and on the other hand, the policy is understandable and viable.

Table 2: The values of the carbon tax in $/tonne of CO_2

Abbreviation	2022	2024	2026	2028	2030	2032
Tax 1	**47.27**	**64.10**	**77.35**	**87.02**	**96.68**	**106.35**
Tax 2	**16.77**	**33.53**	**44.41**	**49.40**	**54.39**	**57.92**

Source: own elaboration based on the MESSAGE-GLOBIOM and REMIND-MAgPIE models [45]

1.6. Limitations of the approach

Even though the MEMO model is considered a well-grounded tool to assess the impact of environmental policy on macroeconomic indicators, we would like to emphasise three important limitations of the approach.

- First, because of the lack of data at the time of this study, we used Input-Output (I-O) tables from 2015. Moreover, because of missing information at the regional level and in national statistical offices, we do not possess regional I-O tables for the Upper Silesia and Megalopolis. In that way, we quantitatively combined insights about decarbonisation challenges at the national level with the regional economic context.
- Second, I-O tables from 2015, as well as the unavailability of macroeconomic data at the stage of preparation of this document, do not allow us to emphasise the implications of the COVID pandemic (2020), the energy price shock caused by

increased global demand after the crisis combined with lower gas supplies and high prices of GHG emission allowances (2021) and the energy crisis stemming from the invasion of Russia to Ukraine (2022), which were undoubtedly important tipping events in the most of the European countries, including Poland and Greece. As a result, the values of carbon taxation considered in the modelling are far higher in reality than expected. If the current situation persists, these findings should be treated instead as a historical exercise, as they provide relevant findings in terms of the structure rather than a scale.

- Third, following García-Muros et al. work, the exact numerical values should be treated with great caution, given that many aspects of the labour market and other details are simplified or beneath the level of model aggregation [36].

Results

Following the overview of questions which need to be addressed by economists in the tipping point debate [3], we decided to focus on the impact of a carbon tax on three main modelling outputs: (1) gross domestic product, (2) unemployment rate and (3) value added and employment in specific sectors in Poland and Greece (**Table 3**).

Table 3: Selected economic variables and questions to address in a debate about tipping points

Economic variables	Questions to be addressed	Research questions
GDP/value-added	How could the level and/or the composition of GDP and value-added develop?	(1) Will the macroeconomic effects of introducing a carbon tax (a) consolidate the phase of transition and reinforce its irreversibility (positive tipping triggers), or (b) weaken the efforts to reduce emissions due to the social costs of transformation (negative tipping triggers)?
Sectoral employment	In which markets/sectors could job losses emerge? In which markets and sectors could job creation emerge	
Competitiveness	Which advantages or disadvantages in terms of competitiveness could a TP generate for industries, sectors, and regions?	
Sectoral Inputs and Outputs	Which shifts in both inputs and outputs could take place across sectors?	(2) How will the carbon tax introduction affect the value added and labour market in selected sectors of the economy?

Source: [3]

Gross Domestic Product and Carbon Emissions

The overall effect of a carbon tax on Polish GDP (**Figure 2**) ranges from -1.8% to -3.2% in 2032. Importantly, this decrease in GDP does not mean a recession, and even after introducing a carbon tax, the Polish GDP will expand in the short run (according to the OECD forecast for Poland)[46]. Moreover, the carbon tax will substantially reduce CO_2 emissions by 30-60% by 2032, depending on the tax rate. These results indicate a reduction between 28.7% and 48.3% in the carbon intensity of the Polish GDP.

Therefore, the introduction of a carbon tax in Poland of even a lower rate (between 16-58 $ per tonne of CO_2) could be considered a tipping event from the aggregate economic effects point of view and the resulting reduction of the carbon intensity of the economy. Alternatively, higher carbon tax levels result in a higher decrease in the

GDP and emissions.

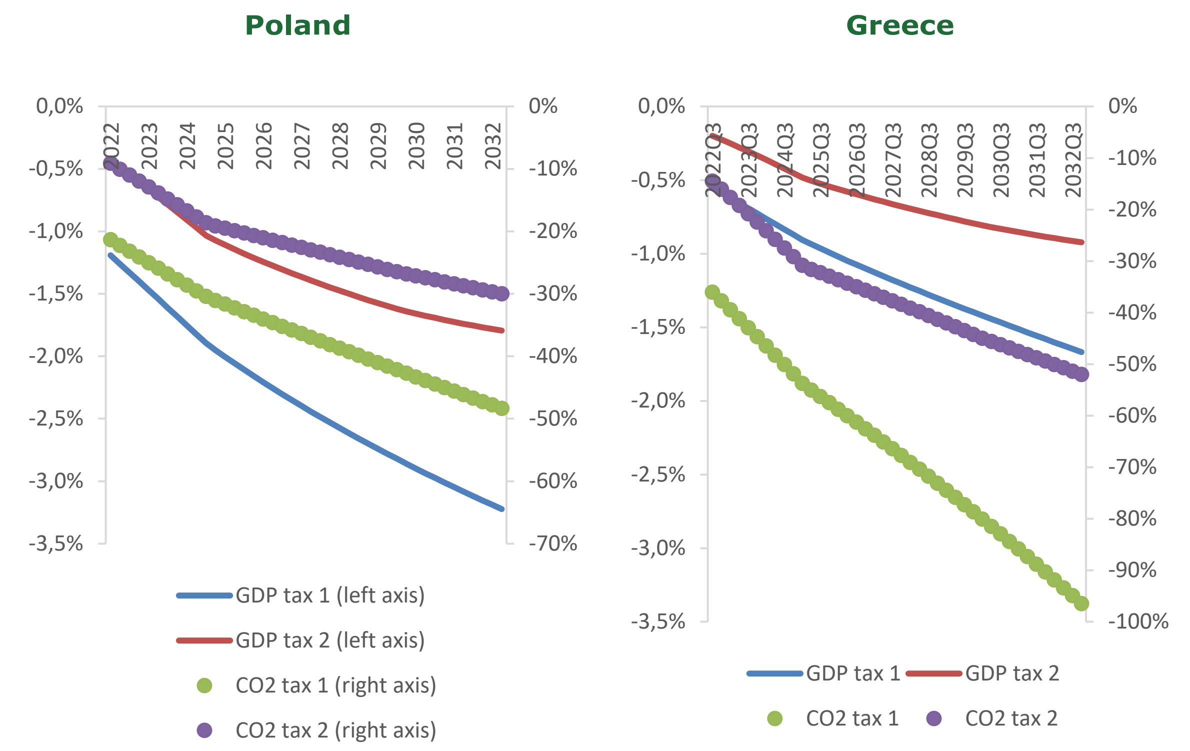

Figure 2: The differences in the GDP and CO_2 emissions if particular carbon tax scenarios are applied in Poland and Greece between 2022 and 2032 (% deviation from no carbon tax scenario)

Source: own elaboration based on the MEMO model

For Greece, introducing a carbon tax yields lower GDP results than Poland (**Figure 2**). The GDP would change by -0.9% to -1.7% by 2032. Notably, even the lower value of carbon tax reduces CO_2 emissions by 40%. If a higher value of carbon tax is implemented, emissions will decrease by more than 60% by 2032. This matches the decarbonisation target of the Greek government. In this case, the results show a drop ranging from 39.5% to 59.3% in the carbon intensity of the Greek GDP.

Overall, achieving the same percentile CO_2 reductions in Greece and Poland would require a higher carbon tax in Poland. In both cases, we evaluate the carbon tax as a positive tipping event that results in a manageable overall impact on the economy in this particular period, and a substantial reduction of CO_2 emissions.

Unemployment and Wages

Poland has one of the most carbon-intensive economies in the EU [47], with about 87,600 people working in coal mining (and 51,200 more in associated industries only in Upper Silesia [48]). Therefore, we estimate the effects of the carbon tax channelled through changes in employment and wage levels (Figure 3). We estimate the unemployment rate to change by 5.4-9.9% by 2032, depending on the tax rate. Higher carbon tax rates result in an increased unemployment rate. These changes would also be channelled through lowered wages (between -4.9% to -9.0% by 2032). Compared to Poland, the labour market effects of the introduction of a carbon tax in Greece are substantially lower due to lower occupation in carbon-intensive industries.

Carbon tax increases the unemployment rate by 2.4-4.3% and causes a wage drop of 1.6-3.6%.

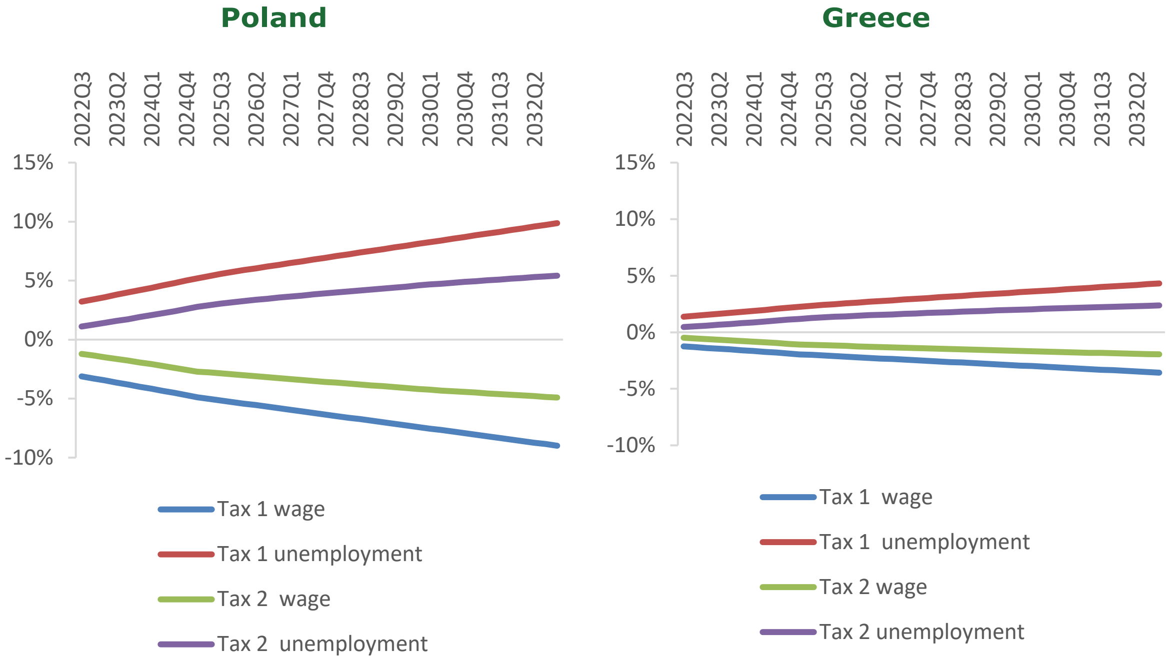

Figure 3: The differences in wages and unemployment rate of particular carbon tax scenarios in Poland and Greece, between 2022 and 2032 (% deviation from no carbon tax scenario)

Source: own elaboration based on the MEMO model

In this way, we note that the adverse effects of the carbon tax on the labour market may affect energy-intensive industries and trigger opposition against the climate policy rather in Poland than in Greece. Therefore, the carbon tax's introduction must be followed by support policies on the labour market.

Sectors: value added and employment

For Poland, implementing a carbon tax would cause different structural shifts than in Greece (**Figure 4**). The services sector would be the most exposed to the aggregate macroeconomic changes induced by the carbon tax in Poland and Greece. This result signals that the service sector is the most exposed to the changes due to a carbon tax as it contributes the most to the Greek GDP and is also highly exposed to the volatility of energy prices. However, we expect a higher level of economic resilience in services compared to the less prepared industry to undergo changes in response to the new market conditions. Therefore, the industry still needs more attention from policymakers. However, in Poland, the contribution of different industries to the value-added decrease is substantially higher than in Greece, mainly because of the relatively high share of mining and quarrying, construction and advanced manufacturing. Among the industry sector in Greece, light manufacturing would primarily lower the added value (as in the case of the services, due to high exposure to price changes and its contribution to the GDP).

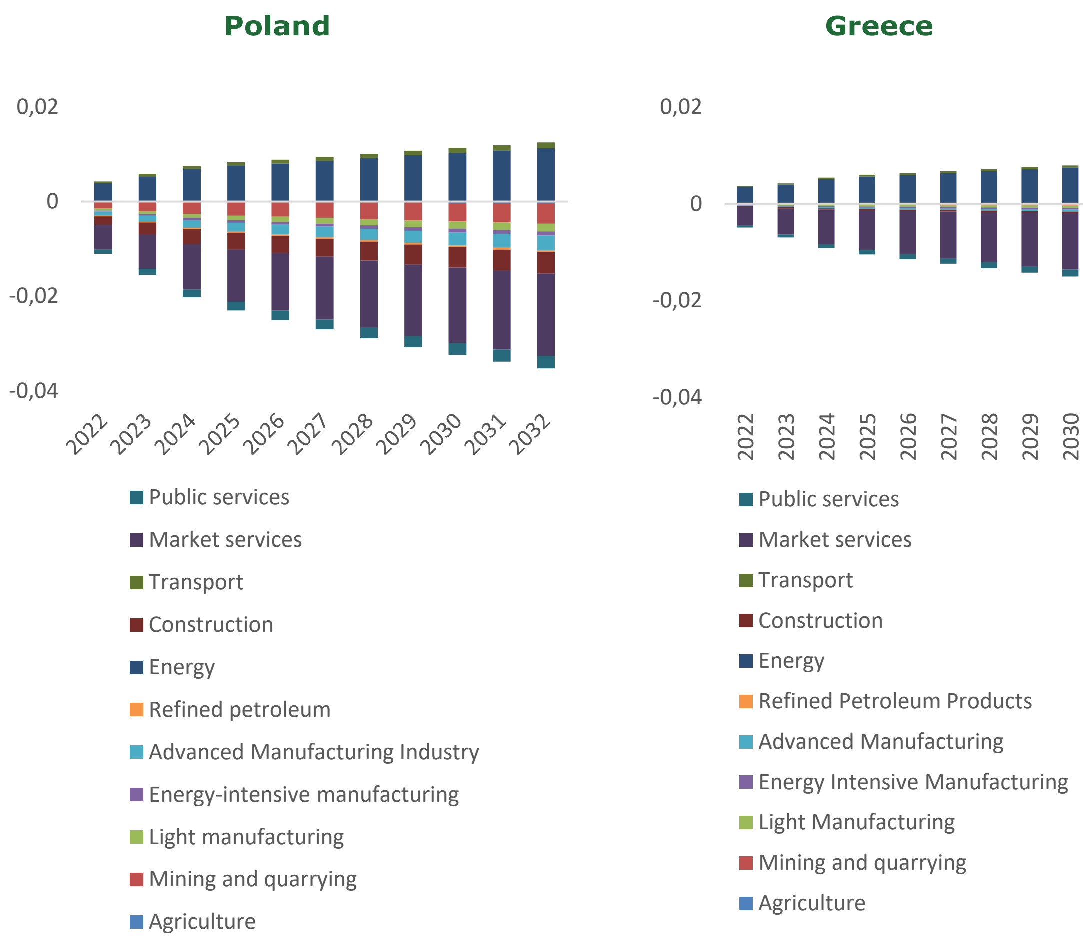

Figure 4: The impact of carbon tax on value added broken by sectors in Poland and Greece

Source: own elaboration based on the MEMO model, MESSAGEix, and Eurostat (2019)

The most severe differences between Poland and Greece are visible in the structure of employment decrease (Figure 5). In Poland, after carbon tax implementation, more than half of the decline in employment would concern industry and construction jobs – especially in mining and energy-intensive activities. It means that these sectors in Poland are particularly vulnerable to the social consequences of decarbonisation. In Greece, the share of the industry section in terms of employment decline is higher than in terms of added value and is considered almost 30% of the total decline (Figure 5). Interestingly, carbon tax implementation will also significantly reduce the number of jobs in agriculture, as in both countries, there is over-employment in this sector.

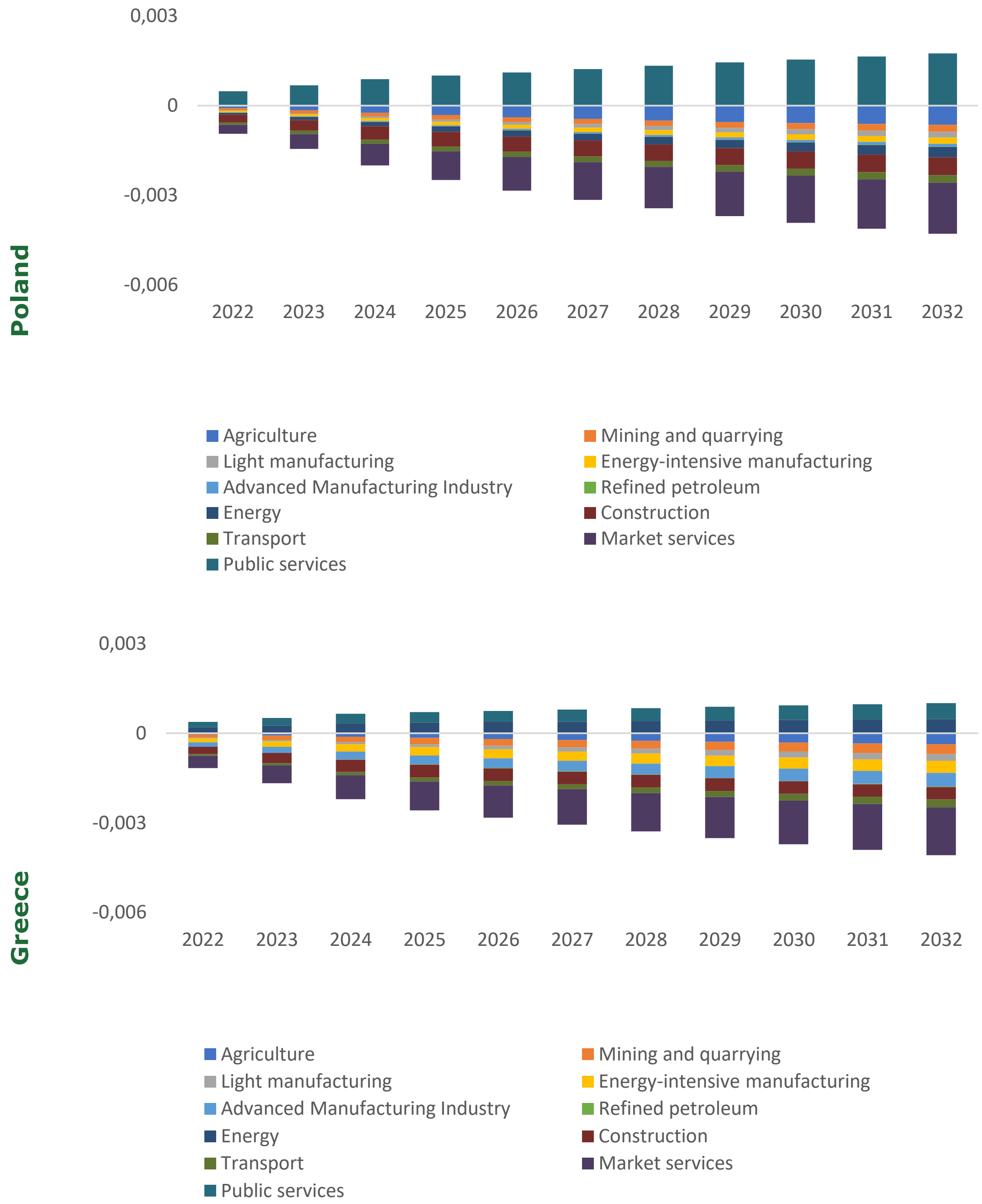

Figure 5: The impact of a carbon tax on employment broken by sectors in Poland and Greece

Source: own elaboration based on the MEMO model, MESSAGEix, and Eurostat (2019)

Discussion

Possible effects of the carbon tax implementation in Poland and Greece

The findings highlight that countries with more carbon-intensive economies, such as Poland, achieve a lower reduction in GDP carbon intensity than countries with less carbon-intensive economies, like Greece, for the same carbon tax levels. This unsurprisingly means that countries with more carbon-intensive economies require higher carbon taxes to follow carbon-intensity trajectories similar to those of less carbon-intensive economies. These results provide a useful policy implication in terms of carbon tax implementation, showing that countries that already implement or are considering implementing this measure should adjust the carbon tax based on the carbon intensity of their GDP and with the implementation of the instrument in other countries. Hence, such actions should eliminate disparities between economic development and the achievement of emission reduction targets along the EU Member States. Besides carbon tax, other forces can be essential to decouple economic growth and carbon emissions—first, the increase in energy efficiency, the result of technological improvements and behavioural changes. Second is the rise of electrification, which is a more efficient way of meeting energy needs in various applications. Third, the increasing use of renewables which have the potential to flatten the primary energy demand curve [49]. Policymakers should also consider the complementarity of these actions with a carbon tax to support achieving climate goals.

Poland and Greece are at different decarbonisation stages, and consequently, a carbon tax would impact Polish added value and employment more. In Greece, the effect of a carbon tax on added value and employment would be less severe and impact the services sector the most.

Adapting carbon tax in Poland would impact employment in the mining and construction sectors. Significantly, the high share of employment in mining contributing to potential employment losses suggests that carbon tax would accelerate coal phase-out and cause structural changes in the mining industry. However, due to demographic and economic trends and favourable institutional arrangements, the future employment outlook of the coal phase-out in Poland is more favourable than it was in the past and easier to manage [50]. In Greece, the carbon tax implementation will affect mostly the services employees, as well as agriculture and construction workers, due to the exposures of these sectors to the price changes and their contributions to the overall employment.

Polish business afraid of energy price hikes started to adopt cleaner energy technologies to maintain competitiveness in the long run and became an agent of change. In 2021, KGHM (Polish iron ore partially state-owned mining company with headquarters in the Lower Silesia – lignite mining region) and Synthos (chemical industry representative from Lesser Poland – located near existing coal mines in Upper Silesia Basin) declared readiness to invest in small modular reactors (SMRs), which means that the private companies could probably adopt the nuclear energy in Poland than the state. Another private lignite mining and energy conglomerate – ZEPAK – switched from lignite-fired power generation to biomass (Eastern Greater Poland: lignite subregion) and started investing in large-scale photovoltaics and hydrogen technologies [51]. Also, state-led energy conglomerates such as ORLEN, PGE, and Tauron announced their carbon neutrality plans before the official Polish Energy Policy publication in 2021. It suggests that even considering possible carbon taxation leads to adopting cleaner technologies in the business sector. In that way, the strategies of both state-led and private companies should also be treated as an early signal for accommodating a cleaner energy pathway in Poland.

In Greece, the recent energy crisis has questioned the energy transition pathway. According to the Greek NECP [52], lignite units were planned to be shut down by 2023, with newly built units proceeding to fuel change by 2028. With this decision, Greece would shut down its only non-renewable, dispatchable generation fleet, which operates with domestic resources. Natural gas would serve as the intermediate fuel towards a RES-dominated energy system. However, with natural gas prices soaring and the fear of a potential lack of fuel, lignite is starting to gain significant market share again, with the Greek Public Power Corporation proceeding to a 50% increase in lignite extraction [53].

Furthermore, to shield citizens from the impact of energy prices, the Greek government launched several subsidy measures targeting the consumers' electricity bills [54]. A RES-dominated system takes years to materialise, especially when supporting measures are diverted from investment-based to limitation-of-damage ones. Therefore, imposing a carbon tax on a country with no alternatives besides renewables could have some impeding effects since it would be an extra burden to the current regime, which is already stressed. However, in the long term, as renewable capacity increases and given the recent lessons learnt from relying almost solely on imported fuel for power generation, a carbon tax could foster faster efforts for decarbonisation.

The carbon tax and immediate and efficient climate policy instruments will disproportionally affect coal and carbon-intensive regions. The sectoral statistics and bottom-up studies allow us to conclude that coal and carbon-intensive regions and their inhabitants may face more substantial consequences than people in other country areas. It is noteworthy that not only coal industry employees will be affected but also those indirectly associated with mining. The studies conducted in Megalopolis and Upper Silesia suggested similar second-tier affected sectors, i.e., manufacturing and trading of basic metals, fabricated metal products, machinery and equipment in coal mining [48,55]. These industries should also be considered in the discussion about decarbonisation, as they probably first face the consequences of decreasing demand for their services and do not possess such safety nets as coal industry workers.

In this way, in terms of scale, we claim that carbon tax adoption would affect Upper Silesia more than it would impact Megalopolis. However, Upper Silesia is economically diversified and possesses the gradual pathway towards coal exit. In addition, in terms of megatrends in labour supply, Upper Silesia seems to be in a relatively stable labour market situation, as the region experiences positive educational and labour market shift [50] and possesses relatively high transformation capacities, such as a dense institutional ecosystem, a clear development vision and favourable economic conditions to prepare for the coal exit. Nevertheless, because of the scale of the coal and carbon-intensive activities, Upper Silesia will require financial support and institutional efforts to shift towards new highly-productive, zero-emission emerging activities such as modern advanced industry, automotive industry or endogenously developed IT services [56]. On the contrary, the economy of Megalopolis is mainly based on the energy, mining, and water supply sector and will undergo an abrupt pathway towards lignite phase-out (Hellenic Statistical Authority, 2019). However, the region's significant solar energy and touristic potential and the opportunity for introducing new models of smart agriculture and livestock can create alternative economic activity options to offset the negative economic consequences of the lignite phase-out [58]. Nevertheless, to diversify its economy, Megalopolis requires further support with a particular focus on improving the funding conditions, legal framework, and administrative procedures. The available funding options under the Just Transition Mechanism could be a unique opportunity for Megalopolis to finance and implement its just transition development plan [59].

Transformative capacities of Polish mining-dependent companies

A network of companies creating supply chains for mining is recognised as an influential contributor to regional and local employment in coal regions. In the areas with the coal industry deeply rooted in the regional culture and economy, it is difficult to disentangle the closure of coal mines, coal-fired energy sources and mining-related industries from the historical experience of the rapid closure of mining [59], [60]. In Upper Silesia, the entire supply chains were a part of the larger mining state-led conglomerate in the past and the socio-economic arguments to prevent business losses and avoid unemployment are vital [61,62]. Consequently, mining-dependent companies are treated as a natural and immanent element of the mining ecosystem.

Mining-dependent companies representing different energy-intensive industries are afraid of the increasing energy and climate policies burden and decreasing demand for their products and services. Some company representatives, including the members of the industry chamber, treat the EU energy and climate policies (e.g. EU-ETS) as a significant threat to their interests and associated local entrepreneurs. Many mining-dependent companies are carbon-intensive (e.g. manufacturers of fabricated metal products, machinery and equipment producers, and metallurgic plants) and experience peaks and valleys in revenues due to energy prices. However, in the long run, they will be forced to reduce and reorient production towards export or change their business offer [43].

The Territorial Just Transition Plan (TJTP) of Upper Silesia recognised the importance of economic goals and supporting mining-dependent companies. Regional authorities responsible for TJTP reserved most funds for economic goals (Figure 6), including smart diversification of mining-dependent activities. The mining-dependent, heavy industry representatives declared to invest in upskilling their employees and expand their offer in such areas as electromobility (electric car/bus charger manufacture), food production, shipbuilding, modern smithies, industrial gears, IT/cybersecurity, scrap processing as well as R&D gas/pollutant measurements [63]. These actions enable local companies to transform into less carbon-intensive production and benefit from the new market niches due to decarbonisation. Implementation of the carbon tax in Poland would probably accelerate these ideas.

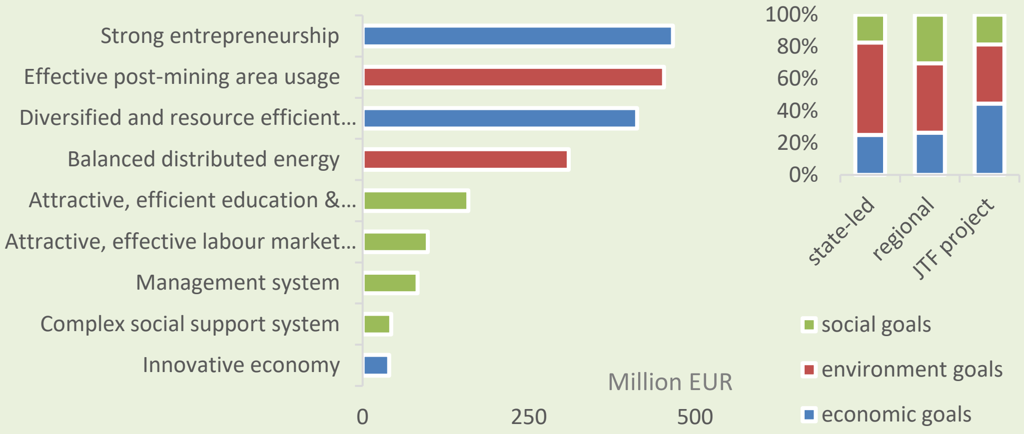

Figure 6: The allocation of TJTP broken by activities and goals (left panel) in comparison to the state-led and regional intervention in 2004-2022 (right panel)

Source: own elaboration based on the government databases and Territorial Just Transition Plan for Upper Silesia

Recycling revenue mechanisms: how can they contribute to the just transition in coal regions and enable positive tipping points?

Existing mining activity compensation funds remain essential financial resources for local municipalities. Mining companies provide extraction or property tax receipts, exceptionally high in municipalities with open lignite pits. Thanks to these incomes, local communes remain resourceful and offer their citizens high-quality services. In that way, they are apprehensive about the uncertain future of the mining companies. In a severe economic crisis or restructuring situation, the mine can be closed and vanish from the local surroundings as an employer and a taxpayer. Understandably, local communes can expect information and compensation for these resources and maintain a similar level of economic prosperity after the coal phase-out.

From 2021, European coal and carbon-intensive regions will receive money from Just Transition Fund. In Poland, these funds will be implemented through regional operational programmes. In a medium-term perspective, the issue here is the amount of these funds and the agency of particular development actors. By introducing top-down strategies, funds and projects instead of locally-received funds, the state or the region also can take control over local development resources. So, implementing a carbon tax as a tool of just transition is also an issue of relevant-policy level and decision, who and in what way will manage and redistribute the available funds.

A future carbon tax should provide a fair redistribution mechanism to enable positive tipping points for regional development. The carbon tax needs to be effective, distributionally progressive and clear [64]. Guiding by these suggestions, the revenues collected from carbon tax should:

- be earmarked and targeted to avoid transferring revenues for purposes other than mitigation and compensation policies.

- boost Territorial Just Transition Plans in coal and carbon-intensive regions and provide long-term, stable, and independent support.
- ensure safety nets and retraining programmes for at-risk employees, support regional and local SMEs to build transformation capacities and make the regions, companies, workers, and citizens resilient.

Under these conditions, adopting a cleaner transition pathway and undertaking efforts to accelerate the coal exit date will be easier, which in Poland is far distant even for mining research institutions [65]. However, the most crucial challenge would be establishing a tangible link between the recycling revenues and current policy to make this mechanism understandable [37]. Even though the macroeconomic consequences of a carbon tax in both countries seem manageable, it would be tough to proceed with this tool under the present unstable socio-economic situation (peak of energy prices, very high inflation rate) and in light of the Russian invasion of Ukraine. In that way, there is a need to strengthen the combing narration of decarbonisation and geopolitics and provide and communicate revenue recycling mechanisms. Then, the carbon tax will help accelerate and adapt new energy policy and technology solutions to break both countries' dependence on fossil fuels finally.

Conclusions

In this deliverable, we assessed the potential medium-term impact of carbon tax adoption on leading macroeconomic indicators in Poland and Greece, applying the DSGE MEMO model. The results confirm general intuitions: more substantial impacts of the carbon tax on GDP and unemployment in more industrial and carbon-intensive economies. However, the results also suggested considerable labour market effects on sectors other than mining: light industry and construction in Greece and energy-intensive and advanced industries in Poland, which have not yet received much policy attention so far, that we found particularly promising for further regional investigations and sector-specific analysis.

Nevertheless, coal and carbon-intensive regions and their inhabitants will be first exposed to the consequences of the decarbonisation process due to the reduction of the activities directly and indirectly related to coal mining and coal-fired power plants. This vulnerability justifies the introduction of shielding mechanisms and smart revenue recycling mechanisms for the profound transformation of the regional economy. Importantly, these changes should aim at a solid diversification to make coal and carbon-intensive regions more resilient to external shocks in terms of the added value generated and the stability of the labour market.

Finally, we cannot arbitrate whether carbon tax implementation would consolidate the transition phase or weaken the efforts due to the social costs of transformation. Modelling is a theoretical process, and as Maier et al. observed [3], many economic processes are reversible. Introducing a carbon tax may pose a tipping event that accelerates the system toward the desired pathway. According to the results, this instrument enables a significant reduction of emissions; however, to generate positive structural effects of such a change, we need to mitigate adverse impacts on carbon-intensive regions, their communities and the labour market. Based on this exercise, it is more reasonable to treat carbon tax instead as an additional political trigger which can prove the agency of a particular narration than the tool which can allow us to determine or ex-ante detect any future tipping point.

It is probably easier to answer how to apply carbon tax and minimise the social costs of transition. We argue that such a mechanism should be implemented in line with tangible and explicable revenue recycling mechanisms. It opens the door for further discussion on how to regionalise such support and maintain the agency of local communities that have managed the exploitation of tributes and taxes. The choice of revenue recycling mechanism should reflect the goals the public administration wants to achieve. What we can recommend here is to uncover distributional trade-offs between competitiveness and inequalities as well as to ensure fair procedures to prepare and communicate such a mechanism.

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Appendix 1: MEMO model structure

Following Antosiewicz et al. (2022), we summarise the main structure of the model. The model assumes a small open economy with four agents: (a) households, (b) firms, (c) government, and (d) the foreign demand sector. These agents interact in three markets: (1) labour, (2) capital, and (3) goods market.

Households

There are many identical households in this economy that conform a representative household that chooses consumption from maximising an inter-temporal CRRA utility function. There is no leisure in the utility function. The usual budget constraint applies. The household uses labour income, firms' profits, the return from previous savings to pay consumption, value added and income taxes, and quadratic search costs in the labour market expressed in terms of consumption goods. The working age population is divided between employed and unemployed workers.

Firms

The model is composed of 12 sectors described in the introduction. It must include raw materials and energy sectors, given the nature of our problem (the macroeconomic effects of a carbon tax). The calibration of the production function and the relations across sectors comes directly from the input-output matrix.

Firms produce a basic sectoral good under monopolistic competition, employing capital, labour, materials and energy as production factors. There are trading firms that purchase this good and sell it to domestic and foreign sectoral markets. The agents that buy this good are (i) (as intermediate demand) producers of basic goods (in each sector); (ii) (sectoral) export firms, which distribute domestic production in foreign markets; and (iii) three types of domestic final goods producers, providing investment, government, and private consumption goods. The final production is traded on the goods market with households, basic producers and the government in accordance with the flows established from the input/output matrix.

$$KLEM_t^s = \left[(1-\theta_{M,t}^s)^{\frac{1}{\epsilon_M^S}} (KLE_t^S)^{\frac{\epsilon_M^S-1}{\epsilon_M^S}} + (\theta_{M,t}^s)^{\frac{1}{\epsilon_M^S}} (M_t^S)^{\frac{\epsilon_M^S-1}{\epsilon_M^S}} \right]^{\frac{\epsilon_M^S}{\epsilon_M^S-1}}$$

$$Y_t^s = e^{\xi_t^Y} \times KLEM_t^s$$

where KLEM is an aggregate production factor that uses capital (K), labour (L), electricity (E) and materials (M). This is constructed using CES aggregator between *K* and *E*, then we add *L*, and finally *M*. Where Y_t^s represents an output of sector s at time t, $\theta_{M,t}^s$ represents the share of materials in the production process of the basic good and ϵ_M^s is the elasticity of substitution between materials and the capital labour-electricity (KLE) composite production factor. ξ_t^Y is an economy-wide productivity shock that we use to calibrate the dynamics properties of the model.

Materials play a key role in the model to estimate CO_2 emissions. Intermediate material used in sector *s*, M_t^s is obtained from a composite of fuels ($FUELS_t^s$) and a composite of all other intermediate inputs.

$$M_t^s = \left[(\theta_{FLS,t}^s)^{\frac{1}{\epsilon_{MF}}} (FUELS_t^s)^{\frac{\epsilon_{MF}-1}{\epsilon_{MF}}} + (\theta_{MO,t}^s)^{\frac{1}{\epsilon_{MF}}} (\theta_{MO,t}^s)^{\frac{\varepsilon_{MF-1}}{\varepsilon_{MF}}} \right]$$

Where $\theta_{FLS,t}^s$ and $\theta_{MO,t}^s$ denote the share of fuels and other material in the intermediate input, with $\theta_{FLS,t}^s + \theta_{MO,t}^s = 1$, while ε_{MF} represents the elasticity of substitution between inputs. In turn, combining materials $M_{i,t}^s$ in a Leontief production function generates the composite MO_t^s, used from all the basic goods sector:

$$M_{i,t}^s = \theta_{i,t}^s MO_t^s$$

where $\theta_{i,t}^s$ (with $\sum_{i\in s} \theta_{i,t}^s$=1) denotes the shares of intermediate good *i* in overall material consumption in sector *s*. Note that this specification allows for the introduction of energy material input into the composite MO For the purpose of calibration, energy only enters in the production of electricity and raw materials, to replicate the high volatility of these two energy inputs observed in the data.

Raw materials intermediate goods (different from fuels, e.g. coal, oil gas, etc.), use raw materials in a Leontief production function. In the case of fuels, a CES aggregator combine all the relevant types of fuels needed for their production.

$$FUELS_t^s = \left[\sum_{k\in FLS} (\theta_{k,t}^s)^{\frac{1}{\epsilon_{FLS}^S}} (M_{k,t}^s)^{\frac{\epsilon_{FLS}^S}{\epsilon_{FLS-1}^S}} \right]^{\frac{\epsilon_{FLS}^S}{\epsilon_{FLS}^S}}$$

Where $\{FLS\}$ is the set of fuels, $M_{k,t}^s$ denotes input of k-th type of fuel, $\theta_{k,t}^s$ is the share of k-th fuel type in fuels intermediate input composite, and ϵ_{FLS}^s denotes the elasticity of substituting between different fuels in sector *s*.

In summary, the set of intermediate sectoral input, $M_{i,t}^s$, is the union of the sets of all intermediate inputs, raw materials different than fuels and fuels. Since, this is a small open economy, $M_{i,t}^s$ is a composite goods produced with inputs made at home ($M_{i,H,t}^s$ and abroad ($M_{i,F,t}^s$, combined according to the Armington aggregator.

The final basic good in sector s, $\overline{Y}_t^s$ is a composite made of intermediate goods produced in the way just described. The final firm produces the final good using the Dixit-Stiglitz aggregator and selling it in a perfectly competitive market.

$$\overline{Y}_t^s = \left(\int_0^1 (Y_t^s(i))^{\frac{p^S}{p^S-1}} di\right)^{\frac{p^S-1}{p^S}}$$

Where parameter p^s sets the markup.

Investment decisions

Firms make capital accumulation decisions in a way which smaximises the profit.

Government

The government collects value added tax, corporate income tax, labour income tax, some specific taxes and CO_2 emission tax. The revenue is spent on public goods, transfers to households and interests on public debt.

External sector

Given the small open economy assumption, the economy is price taker in international markets for exports and imports. There is open capital account, which defines external assets (debt) accumulation.

Crucial aspects of the model

Antosiewicz et al. (2022) highlight two relevant features of the model: the modelling of the CO_2 emissions and the labour market frictions.

CO_2 emissions

Firms and households produce CO2. Firms in sector s produce CO_2^s as a by-product while using intermediate goods.

Formally:

$$CO_2^s = \theta_{H,CO2,t}^s \times Y_t^s + \sum_{j \in T} \theta_{j,CO2,t}^s \times \left(M_{i,H,t}^s + M_{i,F,t}^s\right)$$

where $\theta_{H,CO2,t}^s$ defines the amount of CO2 in sector s by using j-type material produced in home (H) or foreign country (F). The main assumption is that only fuels consumption generates CO2, in other words $\theta_{H,CO2,t}^s \neq$ for $j \in \{FLS\}$. Moreover, chemical processes other than fuel combustion can also produce CO2. We assume that such CO2 emission is proportional to the amount of goods and services produced in a given sector and is controlled by the parameter $\theta_{H,CO2,t}^s$. Similarly, the amount of CO2 emitted by households is equal:

$$CO_2^{CNS} = \sum_{j \in t} \theta_{j,CO2,t}^{CNS} \times M_{j,t}^{CNS}$$

Labour market

Sectoral supply and total demand for labour Wages in the model are sector specific. They are determined in general equilibrium, and hence they react to changes in sectoral demand induced by climate policy. The sectoral demand for labour is determined by the optimisation of representative firms in all sectors. To model labour supply curves at a sectoral level, we assume the existence of an intermediary between representative workers and sectoral firms that allocates workers to different sectors using Constant Elasticity of Substitution technology. In addition, we let the intermediary decide on the total number of vacancies in the economy, which we use to determine the unemployment rate.

The intermediary optimisation problem is given by

$$\max_{\{N_t, n_t, Vac_t\}_{t=0}^{\infty}} V_t^L = \pi_t^L + \lambda_{t+1} V_{t+1}^L$$

Subject to:

$$\pi_t^L = \sum_s w_t^s n_t^s - w_t N_t - v_{Vac} Vac_t$$

$$N_t = \omega_N \left(\sum_S \omega_N^S \left(n_t^S\right)^{\frac{\varepsilon_L - 1}{\varepsilon_L}} \right)^{\frac{\varepsilon_L}{\varepsilon_L - 1}}$$

$$N_t = (1 - \delta_L) N_{t-1} + \Phi_t Vac_t$$

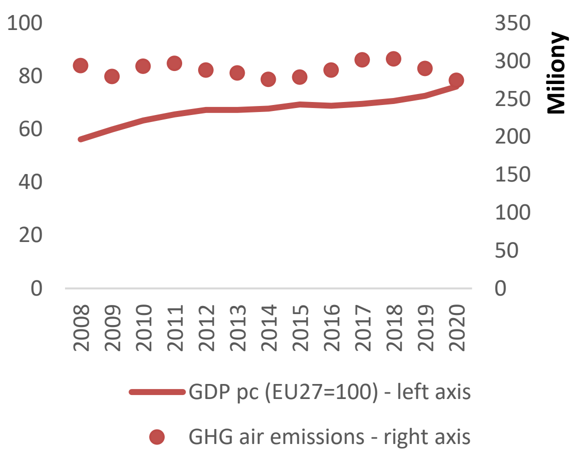
Where V_t^L is the discounted sum of profits, π_t^L is the profit in period t, $\lambda_{t+1}$is the discount factor (determined endogenously based on the interest rate), w_t^s is wage in sector s, n_t^s is the supply of workers in sector s, w_t is the aggregate wage (received by representative worker) and N_t is the total demand for labour, $v_{Vac}$is the cost of having an open vacancy (which could be interpreted as a search cost), Vac_t is the number of open vacancies, ω_N and ω_N^s are parameters calibrated to ensure that number of workers in each sector and total number of workers are the same as in input-output matrices for Poland, ε_L is the elasticity of transformation between sectors, δ_L is a job destruction rate (exogenous in the model) and Φ_t is the probability of filling the vacancy.

The intermediary takes aggregate wage (w_t), sectoral wages) and probability of filling the vacancy (Φ_t)) as given and decides on total demand for labour ($N|t$), its allocation across sectors (i.e. supply of labour at a sectoral level, n_t^s) and a total number of vacancies (Vac_t).

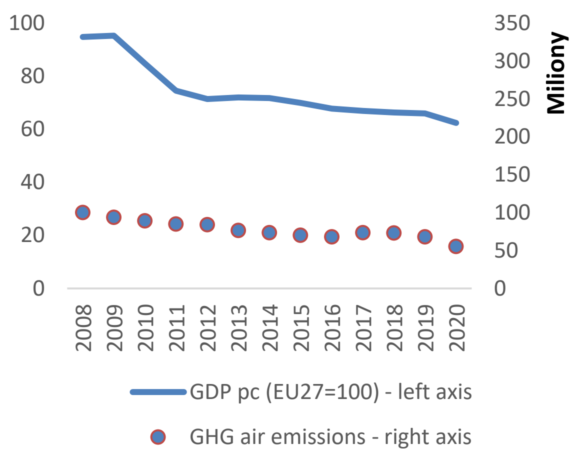
Appendix 2: Descriptive statistics

GDP convergence and emissions between 2009-2020

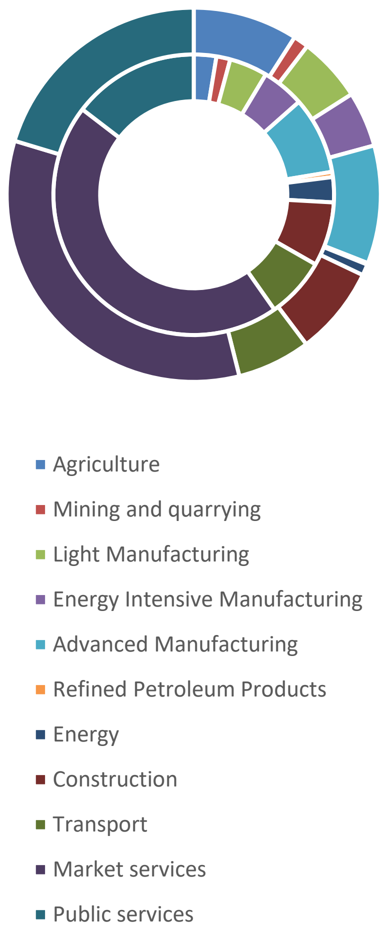
Poland

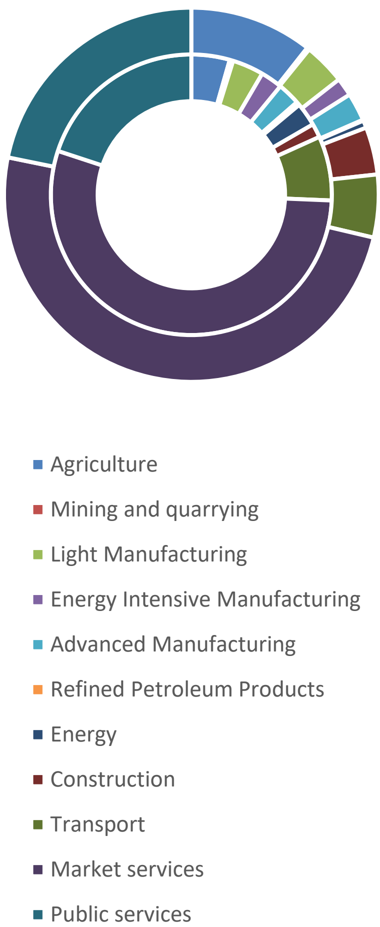


Greece



Value added (inner circle) and employment (outer circle) broken into sectors in 2019





Source: own elaboration based on Eurostat [NAMA_10_PC, ENV_AC_AINAH_R2]