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The Macroeconomic Implications of the Clean Energy Transition at Regional and Sectoral level

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For any use or reproduction of elements that are not owned by the European Union, permission may need to be sought directly from the respective rightholders.

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Table Error! No text of specified style in document.**-1 - List of Abbreviations and acronyms**

Abbreviation /Acronym	Description
ARIMAX	Autoregressive Integrated Moving Average with Explanatory Variable
ERR	European Results Regionalisation
EU	European Union
EU27+UK	The 27 Member States of the European Union and the UK
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GVA	Gross Value Added
ILO	International Labour Organization
LCOE	Levelised Cost of Electricity
MW	Megawatts
NRW	North Rhine-Westphalia
NUTS	Nomenclature of Territorial Units for Statistics
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
RES	Renewable Energy Sources
UK	United Kingdom

Executive Summary

The objective of this study is to better understand the macroeconomic impacts of the energy transition below national level, the structural differences that drive differential impacts and the policy actions which can be adopted to address these structural differences and to influence a region's outcome in the clean energy transition. To that end, a literature review, case studies and macroeconomic modelling was carried out.

The wide-scale review of existing literature points to several factors driving the economic impact of the low carbon transition on regions: differences between regions in terms of their economic structure (i.e. the importance of negatively impacted sectors in the regional economy), natural endowments (i.e. the potential for renewable energy generation), conditions of governance (how the transition is managed by policymakers), and the political economy in regions (i.e. local attitudes and vested interests). The literature further highlights several groups of policy levers that can be deployed to manage the low carbon transition in negatively affected regions, including policies to stimulate economic diversification, skills development and retraining, social protection, stakeholder engagement and multi-level governance. Furthermore, the importance of financing for these policies and regional/local governments is highlighted as an important challenge.

The case study review of four regions which have either closed or are in the process of closing coal production facilities (i.e. the Jiu Valley in Romania, North Rhine-Westphalia in Germany, Silesia in Poland, and Asturias in Spain) reveals that restructuring took place because of changing economic and political circumstances (making the coal mines inefficient and uncompetitive), combined with a more climate-oriented policy agenda at national or EU levels. While the four regions are different in many ways, some commonalities can be identified in the impact the transition has exerted on the region's economy. The reliance on coal in the face of changing economic and political circumstances led to – often persistent – lower employment levels, a slow diversification process, emigration, brain drain, labour mismatches and political resistance.

The experience in the four regions further confirms the importance of several of the policy levers identified in the literature review, and experts from the regions emphasise the importance of economic diversification, the importance of social protection, the role of European policy and funding, and the importance of stakeholder engagement. While there is no one-size-fits-all solution and structural reform should build on a region's strengths, early action is key regardless of the region's specificities.

Macroeconomic modelling was undertaken to simulate clean energy transition scenarios for the EU to assess future (2030) economic output and employment impacts for NUTS 2 regions, using the newly developed tools E3ME-ERR and GEM-E3-FIT-R:

- E3ME-ERR, written in Python, is a tool that produces sectoral EU27+UK projections for employment and GVA at the NUTS 2 level. It uses a top-down approach for all economic sectors and a more detailed bottom-up approach for the electricity generation and supply sector.
- GEM-E3-FIT-R, written in GAMS, is an economic model covering both the global economy at the national level and EU27+UK countries at the NUTS2 level distinguishing between 67 sectors of activity. The model calculates both at the country and at the regional level the full set of input-output tables, employment by sector and bilateral trade matrices by product and emissions.

Although the modelling tools used have different specifications, they are both designed to project outcomes by NUTS 2 region based on available data regarding renewable energy potential, competitiveness, demographic change, economic structure and labour markets for each region.

The modelling results suggest that several regions may indeed face negative effects in the absence of further policy action to prevent them, even if the energy transition may be good for the European economy as a whole. The E3ME-ERR model results suggest that the worst hit regions typically see increased employment and GVA in sectors such as construction and manufacturing, yet the these gains are outweighed by losses in GVA and jobs in a) electricity generation and supply activity, and b) mining and quarrying. This is due to high levels of fossil fuel capacity decommissions and thus lower fossil fuel mining and extraction in the scenario compared to the baseline. On the flipside, positive effects in the regions benefiting most in terms of increased 2030 GVA are driven by increased electricity generation and supply output, thanks to a high potential and deployment of renewable capacity within a region. This is often paired with higher service sector activity and employment due to positive indirect and induced employment effects. Similarly, in the GEM-E3-FIT results, the key factor differentiating total 2030 impacts across regions is whether regions contribute to the deployment of RES or whether they produce fossil fuel and fossil-based power generation. Another factor contributing to regional performance is the level of industrialisation, as the renewal of equipment (e.g., more efficient electric appliances, electric vehicles etc.) yields benefits for regions hosting manufacturing industries producing these types of goods.

Detailed region-by-region analysis is required to identify the key structural barriers in each location and customise policy interventions accordingly, yet a comparison of the findings of the literature review, the case studies and the modelling results clearly point to three broad guidelines around which policy action should be designed:

1. **In regions reliant on fossil fuel extraction and electricity generation, early action to diversify the economy is a panacea.** The evidence from the literature, the case studies and the macroeconomic modelling all suggest that regional sectoral composition is a key determinant in determining the overall regional impact on employment and activity in the clean energy transition. Regions with a diverse economy, with already a strong reliance on sectors expected to grow in the low carbon transition, can be expected to perform better and see increased job opportunities in the transition. Excessive reliance in regions on one or several sectors expected to decline in the low carbon transition must therefore be prevented and alternative sources of economic activity sought in order to avoid regions and their inhabitants from becoming 'stranded'. The case study analysis further illustrates that a process of economic diversification can be helped by large scale investment in education and R&D planning to attract investors and retain qualified labour.
2. **Investing in renewable energy generation where the technical potential exists can mitigate some of the job and output losses in fossil fuel related sectors, and thus be an important element of a process of economic diversification.** The literature review and the case studies both point to various regions which have in the past been successful in compensating negative effects from declining coal production by shifting to renewable energy generation. The macroeconomic modelling furthermore indicates that renewable energy generation can be an important driver of economic outcomes in those regions where the technical potential exists and is exploited.
3. **Political buy-in from workers, local communities and stakeholders is key to achieve points 1 and 2, and this can be achieved through social protection, social dialogue, and stakeholder engagement.** The important role local communities' and stakeholders' attitudes can play in driving or resisting a successful transition resonates through both the literature and the case studies. The literature review suggests in this regard that changing the narrative to a positive will ease the necessary process of transition and will reduce political resistance and the negative lock-in effects of resisting change and diversification (Campbell & Coenen, 2017; Heilmann et al., 2020; Sartor, 2018; Zinecker et al., 2018). This is likely to affect the scale and speed of the

transformation in these regions, and thus, the impact on workers and households in the long term. A key observation across all case studies is the need for stakeholder involvement and social dialogue. In each coal region investigated, “citizen support and public acceptance for the transition are vital for success – without this element the transition is likely to fail”. The case studies also find that policies which aim to preserve the status quo and limited or delayed action by governments to implement structural reform measures led to regions facing less coordinated action and reaping less of the benefits that could have been reaped if sufficient plans were made early on.

1. Introduction

As the clean energy transition occurs, replacing fossil fuel technology with low carbon alternatives, new technologies emerge, and structural shifts take place in the economy. The impact of the clean energy transition is not uniform across EU Members States or across regions within Member States because of existing structural differences. Task 6 ('Reflecting the regional and sectoral aspects of the clean energy transition') of the 'Macroeconomics of the Energy Union' project has sought to better understand, both through the application of quantitative models and in-depth case study research, the macroeconomic impacts of the energy transition below national level, the structural differences that drive differential impacts and the policy actions which can be adopted to address these structural differences and to influence a region's outcome in the clean energy transition.

The current report provides a synthesis of the analysis undertaken and is divided into the following sections:

- **Section 2** presents the findings from a wide-scale review of existing literature regarding the economic impacts across the regions of EU27+UK that might occur as a result of the transition to a low carbon Europe.
- **Section 3** presents the key findings from four case studies of localities facing or having faced major restructuring due to the clean energy transition. The synthesis presented focusses on the drivers of change, the main commonalities across the case studies in terms of impacts and the main lessons learned.
- **Section 4** presents projected regional economic output and employment impacts at the NUTS 2 level in a clean energy transition scenario. The projections were made using new extensions to the existing macroeconomic models E3ME and GEM-E3-FIT. The extensions, E3ME-ERR and GEM-E3-FIT-R respectively, were designed as part of this project with the aim to produce consistent results across NUTS 2 regions in the EU through a combination of bottom-up and top-down modelling techniques.
- Finally, by comparing the findings from the different evidence streams (literature review, case studies and modelling), some key policy implications are inferred and presented in **Section 5** of this report.

2. Literature review

This section presents key findings from a review of the available academic and institutional literature that has been carried out. The aim of the literature is to take stock of the available evidence on the key drivers of impact at regional level and the key policy levers at policymaker's disposal to influence this. In Section 2.1, the key drivers of impact are summarised, referring to the structural differences that drive differential outcomes across regions in the clean energy transition. Governance, early and effective policy action in particular, is one of these drivers and Section 2.2 goes into more detail as to the broad policy levers such policy action may consist of.

2.1. The drivers of impact

The literature emphasises several factors driving of the economic impact of the low carbon transition on regions. These are grouped in this review as differences between regions in terms of their economic structure (i.e. the importance of negatively impacted sectors in the regional economy); natural endowments (i.e. the potential for renewable energy regeneration); conditions of governance (how the transition is managed by policymakers; and the political economy in regions (i.e. local attitudes and vested interests). For each of these drivers, we provide an overview of the key issues and conclusions from the literature.

Economic structure

The literature supports the assumption that the existing sectoral composition of a regional economy and how this will influence economic outcomes in the low carbon transition. On the one hand, the transition is expected to be particularly challenging in those regions which specialise in sectors that will face decreasing output and employment. On the other hand, regions with a diverse economy, or with a strong reliance on sectors expected to grow in the low carbon transition, are expected to perform better and see increased employment opportunities. This is supported by case studies of regions that went through an economic transition in the past, which illustrate that coal sector transitions have been associated with prolonged socioeconomic depression and below average economic performance in affected regions (Heilmann et al., 2020). One ex-post review of experiences in old industrial regions in Europe has shown that yet to transform coal regions face similar economic-structural impacts as those faced by old industrial regions due to 'industrial monoculture' (Campbell & Coenen, 2017). The reliance in regions on one or several sectors expected to decline in the low carbon transition therefore poses a considerable risk for these regions. In this respect, Spencer et al. (2018) refer to the concept of 'stranded regions', when workers, regional governments and the regional economy are dependent on one sector (the authors refer to the coal sector in particular) and thus get stranded if no action is taken to manage the transition.

Socioeconomic situation

The literature suggests that the adaptability of a region is partly driven by the existing socioeconomic situation; existing issues of poverty, inequality and education can have a significant bearing on a region's resilience to economic transitions. Grillitsch & Hansen (2019) explored the development of green industries in regions with different attributes and found that regions which have already established strong industrial specialisations typically reinforce this by adapting education and research in that area. This consolidates their pathway and attracts new firms and skilled labour, a phenomenon which the authors call a 'positive lock-in'. However, regions specialised in fossil fuel and energy-intensive industries may also experience a strong lock-in effect by resisting the need to develop new pathways to accumulate new knowledge and diversifying through the application of their current knowledge to new industries ('negative lock-in') (Grillitsch & Hansen, 2019). As such, existing regional socioeconomic inequalities could be deepened in the low carbon transition, a conclusion supported by other studies (Balta-Ozkan et al., 2015).

Reviews of coal mining regions further suggest that coal mining regions tend to already be economically weak with low innovation capabilities (Popp et al., 2018). Markkanen & Anger-Kraavi (2019) synthesised evidence from existing literature on the social impact of climate change mitigation policy and their implications for inequality. One of their key conclusions is that the risk of negative outcomes is greater in those contexts characterised by already high levels of poverty, corruption and economic and social inequalities. The risk in this respect is not only associated with the effects on employment levels in certain regions and communities, but also the effect of potentially higher energy prices and necessary energy efficiency investments on household income should be considered.

Natural endowments

Natural endowments relates to varying resource endowments, spatial configurations and climate conditions between regions; and specifically how these may influence a region's competitiveness in general, as well as how these factors determine a region's potential to generate co-benefits in the low carbon transition. Simply put, depending on natural endowments, some regions are more conducive to the development and deployment of low carbon technologies than others, and thus are better placed to develop this subsector as a source of employment and value added (Balta-Ozkan et al., 2015). Besides natural endowments, better located or more accessible regions can source cheaper intermediate inputs which give them an advantage in local markets (Lecca, et al., 2018). Grillitsch & Hansen (2019) argue in this respect that metropolitan regions are better equipped to benefit from new technologies to facilitate a transition to new greener industries. This is due to their typical closeness to decision makers, the availability of human resources and business services, and a higher likelihood of labour mobility between industries due to multiple industrial specialisations. At a more basic level, differences between rural and urban could further influence a region's pathway in the low carbon transition, through varying energy demand patterns and energy efficiency requirements for the built environment (Balta-Ozkan et al., 2015).

Political economy

It is widely acknowledged in the literature that local networks and vested interests can significantly contribute to the negative lock-in by resisting the need for change and diversification (Campbell & Coenen, 2017; Heilmann et al., 2020; Sartor, 2018; Zinecker et al., 2018). Various reviews of coal mining regions illustrate that in many coal mining regions well-connected incumbent players have considerable influence over political decisions at regional level (Popp et al., 2018) and play a major role enabling or halting the transition (Campbell & Coenen, 2017; Popp et al., 2018; Zinecker et al., 2018). This is likely to affect the scale and speed of the transformation in these regions, and thus the impact on workers and households in the long term. In fact, the idea that the state's ability to overcome vested interests is considered to be crucial for the success of the energy transition. Without the buy-in and commitment from local stakeholders about the need for structural change, it will be hard to steer the regional economy in a certain direction. This challenge may be compounded even further in those regions where local and regional government income heavily relies on tax revenues linked with fossil fuel extraction and markets (OECD, 2019) or where governments have a stake in companies active in fossil fuel industries (Heilmann et al., 2020).

Governance

Institutional quality, policy and strategic planning at local, regional, national and supranational levels can play a role in determining outcomes from the transition. Countries and regions with effective institutions, as well as good coordination between different levels of governance, are likely to perform better in assisting workers, consumers, firms and communities to manage the changes (Green & Gambhir, 2019). A few studies highlight in this respect the differences across countries in Europe related to the way labour market institutions and social dialogue is organised, and how this may change the state's ability to foster consensus-building and commitment across stakeholders (Green & Gambhir, 2019; Popp et al., 2018). Those countries with corporatist structures of interest-group presentation to systematically include trade unions and employer organisations into policymaking processes may be more effective at steering regional and industrial transitions (Finnegan, 2019; Green & Gambhir, 2019; International Labour Organization (ILO), 2018; Stroud et al., 2014).

There is also widespread consensus in the literature that early and effective policy action at various levels of governance can alter the outcomes in regions. The transition to a low carbon economy necessitates policy measures that facilitate the adjustment of households and businesses which could be negatively affected by changes to jobs, energy affordability, and regional competitiveness (OECD, 2018; Newell & Mulvaney, 2013; Green & Gambhir, 2019; Schremmer et al., 2018). Unless this economic transition is carefully and responsibly managed, it is argued, there is a real potential for stranded communities and workers, exacerbating social exclusion of the poorest and most vulnerable, and for stranded assets (Green & Gambhir, 2019; Markkanen & Anger-Kraavi, 2019). Furthermore, while the technical potential for renewable energy production exists in many EU regions in transition, meeting this potential and reaping the added employment benefits relies on the commitment to a framework of climate and energy policies (Kapetaki, et al., 2020; Bódis, et al., 2019). A key variable of the scale of an energy transition on regions is thus the ability of policymakers to purposefully design policies that stimulate the development of alternative economic activities and sources of employment in the region.

2.2. The role of public policy

As the literature review illustrates, multiple variables will interact to determine a region's pathway in the low carbon transition, but there is scope for regional policymakers to manage the transition at regional level. The literature highlights several groups of policy levers that can be deployed to manage the low carbon transition in negatively affected regions. These policy levers can be grouped into policies to stimulate economic diversification, skills development and retraining, social protection, stakeholder engagement and multi-level governance. Besides these, the importance of financing for these policies and regional/local governments is highlighted as an important challenge.

Economic diversification

All studies reviewed stress that efforts need to be made to steer regional economies away from resource extraction through economic diversification and innovation, either drawing on existing sectors or building up new sectors (Campbell & Coenen, 2017; Sartor, 2018). An obvious pathway in this respect is to facilitate investment in renewable energy generation and infrastructure, where the technical potential exists, while discouraging investment in fossil fuel-based activities to avoid stranded assets (Sartor, 2018; Zinecker et al., 2018)

This requires of combination of conventional innovation and industrial policy tools (e.g. smart specialisation strategies), but also particular attention to potential barriers to investment in renewable energy and energy efficiency (Isaksen & Trippl, 2016; OECD, 2019). Reducing barriers to private investment through regulatory simplifications and economic incentives (e.g. grants, low-interest loans, tax incentives), information-based tools (e.g. ecolabels, advice), innovation clustering, green public procurement and support for R&D can all be useful instruments in helping new businesses to emerge, diversify the regional economy and encourage private investment in regional economies.

Speed is of the essence here. The longer regions wait to transform their economies, the higher the economic cost of delaying the process may become. Early anticipation and preparation of the transition are therefore vital to success (Sartor, 2018; Spencer et al., 2018; Zinecker et al., 2018). Reviews of countries where coal extraction is an important sector suggest that these countries have not made much progress in terms of putting the right policies in place, even though the economic profitability of coal power is declining (Heilmann et al., 2020; Spencer et al., 2018).

Skills development, retraining and redeployment

The literature suggests that effective skills and labour market policies are a key ingredient for successfully transitioning to the low carbon economy in regions (Campbell & Coenen, 2017; OECD, 2019; Sartor, 2018). This includes upskilling, retraining and job-search training for displaced workers, but also on-the-job training on environmentally friendly production methods and new technologies for workers. A wide range of instruments are suggested, such as training subsidies and vouchers, training leave allowances, tax incentives, career counselling, placement, reginal worker transfer programmes and personal training accounts.

The objective is to align the skillsets of workers with the needs of a labour market in transitions, particularly to facilitate them to move from declining sectors to growing sectors. Workers currently employed in declining sectors or subsectors may have suitable skills for other sectors. In this respect, it is suggested that an obvious opportunity for those currently employed in coal, for example lies in the renewable energy sector (Green & Gambhir, 2019; Porto, 2012). However, such policies need to be considered in the context of other megatrends affecting skills demand, such as automation and digitalisation, and build on an engagement with regional employers to ensure the skills anticipation is aligned with the needs on the ground (Green & Gambhir, 2019; Sartor, 2018; Vogt-Schilb & Hallegatte, 2017).

Social protection

Social policies can provide a useful policy lever to mitigate the impact of the transition on workers, consumers and firms. This is particularly relevant in the case of job loss and bankruptcy, but also to assist lower income households and poorer communities confronted with higher energy prices and mandatory investments (e.g. retrofitting). The literature in this respect refers to general social protection schemes (e.g. unemployment benefits) already in place, but also ad hoc measures that can be put in place to provide targeted support to those negatively affected by the structural changes. A wide range of options are highlighted: subsidies for relocation costs, redundancy payments, early retirement benefits, employment search costs or training costs, earning subsidies to supplement wages earned from re-employment for workers (Beer, 2015; Green & Gambhir, 2019; Spencer et al., 2018), but also: financial assistance to consumers more widely (e.g. for energy efficient appliances) (Caldecott et al., 2017; Green & Gambhir, 2019), grants and subsidies to companies for restructurings or research and development (Green & Gambhir, 2019; Healy & Barry, 2017; Markkanen & Anger-Kraavi, 2019) and subnational governments in the case of reduced tax revenue (International Labour Organization (ILO), 2018; Sartor, 2018).

Stakeholder engagement

To change the political economy landscape in regions, the literature emphasises the importance of including affected groups and regional stakeholders (e.g. industry, SMEs, trade unions, universities, government, financial institutions) in policy processes and procedures (Campbell & Coenen, 2017; International Labour Organization (ILO), 2018; OECD, 2019; Sartor, 2018; Zinecker et al., 2018). This entails early consultation, continuous two-way communication and social dialogue between workers, government and employers (OECD, 2019; Popp et al., 2018), but also dialogue with groups and stakeholders that are not yet part of formally established processes (OECD, 2019; Zinecker et al., 2018). Of particular importance is involving stakeholders in the articulation of long-term visions and strategies for the region.

Stakeholder engagement is important to generate political and social acceptability of short and long-term transition policies (Heilmann et al., 2020). In particular, stakeholder engagement is important to address the issue of political lock-in where regional power relations and vested interests present barriers a managed transition (Heilmann et al., 2020; OECD, 2019). Understanding the local politics, narratives and power relations within regions, engaging with regional stakeholders and shifting interest-based coalitions thus become important aspects of the policy mix aimed at lifting the barriers to economic transformation. Moreover, strengthening civil society organisations can help attract increased attention to the energy transition at the domestic level (Herpich et al., 2018; OECD, 2019; Sartor, 2018).

Multi-level governance

Various studies underscore the importance of policy coordination and alignment of policy objectives between local, regional, national and supranational levels of governance, in accordance with competencies (Heilmann et al., 2020; OECD, 2019). This is particularly the case in countries with high degrees of regional autonomy (Heilmann et al., 2020).

The need to set and reflect clear low carbon goals into regional development strategies is seen as crucial (Kapetaki, et al., 2020; Bódis, et al., 2019), or in the least making sure that they don’t work against them, as well as channelling the right technical and financial assistance to regional and local government to make sure they can implement the necessary measures. This may also require revising existing allocations of funding across regions, so that resources are targeted to those regions with the highest adjustment costs (Campbell & Coenen, 2017) or with the most ambitious plans (Schremmer et al., 2018).

Reviews of coal mining regions illustrate that clear signals and support from national governments have helped regional governments initiate and implement regional transition strategies (Green & Gambhir, 2019; Popp et al., 2018). They also stress that the involvement of national and European bodies is crucial in coordinating industrial and climate strategies, and in overcoming local party politics and short-term interests. At the same time though, national or European low carbon policies also need to consider regional and local diversity in their policies and addressing the diverging needs and circumstances is crucial. Regions’ vastly different geographic and economic pre-requisites and political economy constellations need to be considered in all levels of planning.

Multi-level governance also relates to policy coordination within and between regions. In this respect, leveraging synergies between local and regional competencies and resources, facilitating the exchange of experience and best practices between regions, and joining forces between local governments and regional governments to apply for financial support are suggested as examples (Heilmann et al., 2020; Popp et al., 2018; Sartor, 2018; Zinecker et al., 2018).

Financing

A recurring theme in these policy prescriptions is the need for financial support (Balta-Ozkan et al., 2015; Caldecott et al., 2017; Green & Gambhir, 2019; Sartor, 2018; Spencer et al., 2018). In this respect, the importance of tax reform and revenue recycling, reallocating fossil fuel subsidies, the establishment of dedicated funds and the importance of financial support from national and supranational levels of governance are cited in the literature. Financial support from these levels of governance can be organised through the establishment of just transition funds, for example. The importance of EU structural and cohesion funds is also highlighted as a key source of funding for regions, in existing examples of regional transitions but also as a potential source of funding for those regions yet to be affected (Balta-Ozkan et al., 2015). In a commitment effort for a fair and equitable transition, the EU has already proposed a Just Transition Mechanism, which includes a Just Transition Fund focusing on regions and sectors affected by the clean energy transition. This should allow Member States to limit their negative exposure to the transition by unlocking investment opportunities that will allow them to focus on economic diversification, reskilling, and upgrading their infrastructure to match the needs of decarbonised power, transport, industry, and building sectors (European Commission, 2020).

3. Case studies

In this section, the key findings from the case studies are presented, focusing on the drivers of change, main commonalities between the cases and lessons learned. The four cases retained for this synthesis report are all regions with a strong historic reliance on coal mining and coal-based electricity generation, therefore providing a sample of regions which have already experienced the effects of the energy transition.

The section starts with a brief description of the four cases, followed by a discussion of the common drivers of change among the four case studies, after which we zoom in on the common impacts. A more detailed description as well as the methodology and a summary of the different impacts per case study[1] can be found in the full case study report. We conclude this section by highlighting several important lessons for regions which are facing major restructuring.

3.1. The regions analysed

The four case studies described here are regions that have either closed or are in the process of closing coal production facilities: the Jiu Valley in Romania, North Rhine-Westphalia in Germany, Silesia in Poland, and Asturias in Spain. All four regions have historically depended economically on coal, and in some cases were even considered to be mono-industrial regions.

Jiu Valley, Romania

The Jiu Valley, located in Hunedoara County (RO423 according to the NUTS 3 nomenclature), is one of Romania's main coal mining regions. In the early 1990s, some 15 mines were operating in the Jiu Valley; today, there are only four mining units left (PwC, 2020). The mines in the region were no longer economically efficient, lacked investments, and required subsidies from the government to survive (Bankwatch, 2019). This, alongside Romania's transition to a market economy and the subsequent demand shock that followed, initiated restructuring efforts in the mining sector (Bruha et al., 2010). As a largely mono-industrial region (80% of the workforce depended on the mining industry), the closure of the mines led to severe economic and social repercussions (Catu, 2018).

Over 1997-1998, more than 20,000 jobs were lost (Bankwatch, 2019). Today, the mining sector employs fewer than 5,000 people but remains the largest employer in the region (PwC, 2020). As a result of a lack of economic opportunities, and an absence of plans to develop new economic sectors, the region witnessed a significant demographic outflow. Unemployment figures are low, but this may be due to economic inactivity and emigration (START, 2020). There has been a low level of economic diversification in the region; however, some sectors such as manufacturing, wood processing, tourism, and commerce are gaining traction (PwC, 2020). The region's GDP was estimated at EUR 457mn or 15% of Hunedoara County's GDP in 2018[2] (PwC, 2020).

All in all, the region lacks competitiveness and has a hard time developing and retaining skilled labour. The transition in the Jiu Valley has been described as weak and unjust. The lack of public policies and integrated efforts addressing economic and social challenges are apparent.

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[1] Including the appropriate references

[2] Calculated by PwC as part of the Strategy for the transition from coal of the Jiu Valley.

North Rhine-Westphalia, Germany

The region of North Rhine-Westphalia (NRW) (NUTS 1 code: DEA) is known for its substantial economy in terms of GDP (Eurostat, 2020a), which is fuelled by large manufacturing and energy-intensive industries. In 2018, the region accounted for 20% of the German GDP maintaining its status as the country's economically largest region (Eurostat, 2020a). NRW's long history of energy-intensive industry operations is based on the proximity of hard coal and lignite deposits in the Ruhr area and the Rhine mining region. The large coal-fired power plants close to these coal mines led to relatively cheap and stable electricity supply to industrial plants (Vallentin, 2016). Especially the Ruhr area (Ruhr metropolitan region) was famous for its hard coal mining and steel industry (Renn & Marschall, 2016).

NRW, and especially the Ruhr area, employed around half a million hard coal mine workers in 1950 and 1960 (Statistik der Kohlenwirtschaft e.V, 2019). However, coal mines and plants have closed due to strong foreign competition leading to cheaper coal prices as well as increased (inter)national pressure to reach energy and climate targets (Renn & Marschall, 2016; Brauers et al., 2018). In 2018, there were no open hard coal mines in the NRW. As such, the hard coal industry has experienced a large reduction in employment over a period of around 60 years. The lignite sector has been smaller and currently employs around 9,000 workers (Alessandrini, et al. 2020). This sector is required to phase-out coal by 2038 (IEA, 2020).

The hard coal phase-out in NRW, in particular the Ruhr area, was relatively successful due to a combination of social policies addressing unemployment and policies to attract new (energy) companies and investments. Moreover, the measures that improved infrastructure, education, research facilities and soft location factors have proven to be important for restructuring the economy. However, the Ruhr area lags in terms of GDP p.c., disposable income, and regional competitiveness compared to the rest of NRW.

Silesia, Poland

The Silesia region (NUTS 2 code: PL22) in Poland has a high dependence on coal. In comparison with the majority of EU Member States, Poland has much larger reserves, and generated 78.3% of its electricity with hard coal and lignite in 2018 (Eurocoal, 2020). The dependence on coal in the country's energy mix is unusually high, although falling over time, and the Silesia region is one of the most coal-intensive regions in the country. The transition away from coal and towards a more diversified economic landscape has been taking place at least since the 1990s, but it is far from complete.

More recent policies, driven by the ambition of the European Union to attain carbon-neutrality by 2050, will accelerate the change. Substantial attention at both national and regional levels has been given to the transition in recent years. Important initiatives include The Government Programme for Silesia, the national strategy for the coal sector, the Silesia Regional Transformation Action Plan, and the Technology Development Programme for Silesia. Importantly, the national government has reached a landmark agreement with the miners' union to phase-out all coal mines by 2049.

Many challenges remain, among them: the need for economic diversification, high levels of air and other pollution, and outwards migration rates. In the case of Silesia, a key need is to diversify the local industrial base (WWF, 2018).

Asturias, Spain

Asturias (NUTS 2 code: ES12) had a booming coal industry (one of the major economic activities in the region), which supported several coal power plants, as well as energy-intensive industries (such as zinc and aluminium), to be developed in the region. However, over the last decades, a series of reform packages were implemented to restructure the coal mining industry in light of the energy transition, having large negative economic impacts.

One of the main effects has been a loss of jobs, going from 100,000 employees in the coal industry in the 1950s to only 2,000 in 2019 (Platform for Coal Regions in Transition, 2020). It has also led to a reduction in economic activity in Asturias, with implications throughout the coal supply and distribution chain, including service activities, notably port infrastructure, transport and logistics. In particular, the negative impact on economic activity and lack of employment opportunities has led to an emigration of young people to other regions of Spain, with more than half of the municipalities seeing their population decrease by at least 20% over the last 20 years.[3]

The transition has been spurred by EU measures, and it is only recently that Asturias decided to focus on the opportunities that the transition can present for the region. Overall, the region has a negative public perception of the transition, as so far there is a history of reduced economic activity and related employment effects. There is still a long way ahead for Asturias to balance the negative impacts and ensure that opportunities are taken advantage of.

3.2. Drivers of change

In the four regions, restructuring took place because of changing economic and political circumstances (making the coal mines inefficient and uncompetitive), combined with a more climate-oriented policy agenda at national or EU levels. Below we describe the key factors driving the change in more detail.

Changing economic circumstances

In several case studies, changing economic circumstances contributed to the transition away from coal. In Germany, mines faced international competition, as the oil crisis of 1973 drove cheap imports of coal and oil into Germany, weakening the economic competitiveness in the NRW region. Meanwhile, in Romania the fall of the Communist regime in 1989 led to a series of political and economic reforms with the aim to transition to a market economy. In such a deteriorated economic climate, the demand for energy dropped (Bruha et al., 2010). While in Romania demand fell due to lower industrial output, in Germany, demand fell due to technological modernisation (i.e. energy efficiency improvements) and shifted towards alternative energy sources (natural gas and renewable energy). In the case of Poland, the restructuring of the coal mining sector also coincided with the fall of Communism but was not necessarily driven by lower energy demand. The change in the political regime opened the mining companies to private investments. However, the state continued to be a majority shareholder in some of the largest mining companies(Szpor, Ziółkowska, 2018). Economic factors, combined with difficult mining conditions, led to the closure of some of the mines in the region.

Changing political circumstances

In the four case studies, changes were partly driven by European and national climate and energy policies. The Union's renewable energy and low carbon aspirations set the scene for a decarbonised European energy sector and made it more difficult to support coal-based energy production, while further strengthening the 'polluter pays' principle. In 2005, the Emissions

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[3] www.ine.es - Cifras oficiales de población resultantes de la revisión del Padrón municipal a 1 de enero. Detalle municipal.

Trading System[4] was launched, setting a cap on the total amount of greenhouse gases (GHGs) that can be emitted by installations covered by the system. In 2009, the first Renewable Energy Directive[5] was adopted, setting binding renewable energy targets for 2020. In 2010, Council Decision no. 787/2010[6] made it clear that uncompetitive mines could no longer be subsidised by national governments. That same year, the Industrial Emissions Directive[7] was adopted, regulating pollutant emissions from industrial installations. More recently, the Energy Union Governance Regulation[8] paved the way for more stringent climate and energy targets, emphasising a diminishing role for coal. This reaffirmed the need to transition away from coal (at a national level) and to redirect energy investments in alternative energy sources. This reiteration of the energy transition at EU and national levels translated into more acceptance in regions like Asturias. As described in the Spanish case study (available in the full case study report), only in the last few years has there been a change with a focus on embracing the opportunities of the energy transition.

Changing social circumstances

The German coal sector faced increased societal pressure to phase out coal. As global pressure for climate action increased, civil society in Germany advocated for change. This prompted Germany to start investing in alternative energy sources (natural gas and renewable energy) (Agora Energiewende and Aurora Energy Research, 2019). Such societal pressures were, however, not identified in other case studies (at least not to the same extent).

In the presence of these drivers of change, the coal mines in these regions faced rising costs and deteriorating infrastructure, which could no longer be compensated by subsidies. New investments in coal infrastructure also became more and more difficult to justify due to the increasing importance of the climate and energy agenda at international, EU, and national levels, and – in one particular case - changes in public opinion.

3.3. Common impacts

While the four regions are different in many ways, some commonalities can be identified in the impact the transition exerted on the region's economy. The reliance on coal in the face of changing economic and political circumstances led to – often persistent - lower employment levels, a slow diversification process, emigration, brain drain, labour mismatches and political resistance.

Lower levels of employment

All four regions experienced a decline in employment compared to their peak. In the Jiu Valley, the mining sector lost over 45,000 jobs; in NRW, around 500,000 jobs in the hard coal mining sector were lost; in Silesia, more than 220,000; and in Asturias, approximately 98,000 (Platform for Coal Regions in Transition, 2020). This led to severe unemployment issues, particularly in the short term. However, in NRW, miners were able to find employment along the value chain

[4] See for more information: https://ec.europa.eu/clima/policies/ets_en

[5] See for more information: https://ec.europa.eu/commission/presscorner/detail/en/MEMO_13_277

[6] See for more information: https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vitgbgiyb2yx

[7] See for more information: https://ec.europa.eu/environment/industry/stationary/ied/legislation.htm

[8] See for more information: https://ec.europa.eu/clima/policies/strategies/progress/governance_en#:~:text=Under%20the%20Governance%20Regulation%2C%20Member,based%20on%20a%20common%20template.&text=Member%20States%20shall%20submit%20their,by%20the%20end%20of%202019.

(e.g. in the steel sector), due to the support and influence of strong mining unions (Oei et al., 2019). Despite many jobs being lost in the four regions, however, the case studies also show positive trends in terms of disposable income. This could be partly explained by the high severance packages and collective dismissal plans offered to the coal industry.

Slow economic diversification

All four regions struggled to create jobs in other sectors; and in some cases, new economic pathways are still being developed (e.g. Jiu Valley, Asturias, Silesia). Some regions have re-oriented towards services more than manufacturing, which is reflected in their GVA (e.g. in NRW), aided by geographical proximity to economically stronger regions.

In Silesia and NRW, structural reform programmes (from 1968 and 1998 onwards in Germany and Poland, respectively) were able to stimulate some economic diversification, while the effects were less present in the Jiu Valley and Asturias, which struggled to develop new sectors of activity. In the case of Silesia, an important, early government initiative was the creation of the Katowice Special Economic Zone in 1996, which served to attract investment in the region.[9]

In more recent years, the regions of Silesia, Asturias and NRW have also invested considerably in innovation to diversify their economic structures. In NRW, several lead sectors were selected for financial support and various research institutes were established. In Silesia, R&D spending increased by 27% between 2014 and 2017 (but remains below the national average on a per capita basis) (Wiatrowski, 2019). In Asturias, the internal expenditure on R&D has almost doubled in the last decade (SADEI, 2020).

Despite these structural reform programmes and investments in innovation, however, industry remains the largest contributor to GVA in most regions and, except for NRW, all regions still lag behind in competitiveness rankings. According to the Regional Competitiveness Index, the Jiu Valley, Asturias, and Silesia are below the EU average in terms of competitiveness (European Commission, 2019).

In terms of energy supply, the four regions are still reliant on the coal-based sector to some degree. Some regions are looking towards new sources of energy (e.g. NRW), while others have not been able to replace coal, thereby becoming importers of energy (e.g. Asturias) (IDEPA, 2016; FAEN, 2018; Platform for Coal Regions in Transition , 2020).

Emigration

Rising emigration is an important effect of the phase-out of coal in all the regions. Many coal regions (e.g. Asturias and Jiu Valley) initially attracted immigrants to meet the demand for labour. However, once the coal mines and plants started closing, the regions could not transform their economies to accommodate the same levels of employment, as outlined above. This effect could be observed in all regions, yet it differed in its extent:

The Jiu Valley's population grew alongside the mining industry. In the 1700s, the region had a population of around 400 people, which grew to almost 23,000 between 1850 and 1900 (Bankwatch and Greenpeace, 2019). The population reached a peak in 1997 (169,911), after which it started to decline. Right after the closure of the first mines in the late 1990s, housing complexes were emptied (NYT, 2019). Migration occurred both within the country (towards other rural regions) and outside of the country (Bankwatch, 2019). Today, the population is close to 135,000 (START, 2020).

In NRW, at the start of the decline of the hard coal sector in the 1950's and 1960's there was considerable emigration due to the closing of the hard coal mines. In the Ruhr area, the

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9 See https://www.invest-ksse.com/ksse-1161#

population reduced by 158,000 from 1977 until 198 (Oei et al., 2019). Two programmes[10] were developed to restore the cultural heritage and to reduce the emigration of people. As a result, total net migration improved, and the population rose by 247,000 people between 1987 and 1995 (Oei et al., 2019).

In Silesia, the population of the province fell by 3% between 2014–2015 and in 2017, it fell by a further 2% (Wiatrowski, 2019). Furthermore, there is a marked difference between expected population outflow among municipalities; in mining municipalities, the decrease in population by 2030 is estimated to be as much as 8.5%, and in non-mining municipalities only 2.7% (WWF, 2018). Moreover, only 41% of the region's population aged over 55 is active in the labour market, which is the lowest participation rate in Poland (nine percentage points below the national average). In the age range of 25–64-yearolds, only 73% of the province's inhabitants are economically active (Wiatrowski, 2019).

Of the 78 municipalities in Asturias, 40 saw their population decrease by at least 20% over the last 20 years (with 6 municipalities experiencing a decrease of over 40%); while only 7 municipalities saw their population increase (where the highest increase was 21%).[11] According to an interviewee, certain towns have seen their population reduce by as much as 50% due to the coal phase-out.

Labour mismatch and brain drain

The 'brain drain'[12] effect, resulting from a lack of economic opportunities, was identified in the regions of Asturias, Jiu Valley and Silesia. In particular the share of young people is declining in these regions, in conjunction with the proportion of economically active people.

In Asturias, the number of university students in the region has declined by around 50% since the mid-nineties (SADEI, 2020). This may also be linked to the emigration of the skilled youth due to high unemployment levels in the region. In the cases of the Silesia and the Jiu Valley, the share of population aged 25-64 with a tertiary education degree has been steadily increasing in recent years (but is still lower than the national average) (Eurostat, 2020b). Strong academic centres in the province of Silesia, including the University of Silesia and the Silesian University of Technology, are an important asset for the region (Wiatrowski, 2019). For both regions it was mentioned, however, that education programmes should be better adjusted to the needs of the labour market (both secondary and tertiary). Moreover, low quality education and a mismatch between training opportunities and labour market needs continue to be a problem for these two regions, where a competence gap can be identified.

In contrast, in the region of NRW, particularly the Ruhr area, investing in education was part of the structural reform programmes. In 1965 the Ruhr area did not have a single university, but due to the structural reform programmes 12 universities and colleges were built in less than 10 years (interview data).

Political resistance

In most case studies, there were/are close political links with the mining companies which resulted in low political support for the phase-out initially. Moreover, both in Jiu Valley and NRW, it was emphasised by the interviewees that mine workers felt that a part of their identity was lost after the closure of the mines. The trade unions are well organised, particularly in

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[10] The programmes were the "Action Programme Ruhr" which focused on technology transfer and innovation, culture and environment, and refurbishment of old industrial sites and the "International Building Exhibition Emscher Park" which aimed to give the Ruhr area a new impulse for an ecological, economic and cultural structural change as a response to the industrial decline of the region.

[11] www.ine.es - Cifras oficiales de población resultantes de la revisión del Padrón municipal a 1 de enero. Detalle municipal.

[12] The emigration of (highly) trained or qualified people from a particular country

NRW and Silesia. In NRW, the trade unions, together with the government and the coal company, agreed that during the phase-out period no miner would become unemployed. In Asturias, the main coal company is state-owned and as such, detailed plans for the closure of mines which included strong social protection measures for the workers were required. In Poland, recently (September 25, 2020) the government and the miners' union reached a landmark agreement to phase out mines by 2049. The agreement still requires approval from the European Commission given that it presupposes the continues financing of coal production until 2049 "in order to ensure the stability of the hard coal mining companies" – a state aid decision.[13]

3.4. Lessons learned

The importance of economic diversification

It is important to develop a holistic strategy to restructure the economy, so that new employment opportunities arrive, and the region can maintain or increase its economic competitiveness. The case study of NRW, particularly the Ruhr area, shows that the more long-term holistic strategy of investing in research and education, infrastructure and lead sectors has paid off in the long run. Although the Ruhr area struggled with creating new jobs and continues to have a lower GDP per capita than the rest of NRW, it has been relatively successful in diversifying its economy. In contrast, the Jiu Valley has not fully transformed its economic structures and continues to suffer from a lack of public policies and integrated action. To bridge the competence gap (see Section 3.3.3), more emphasis needs to be placed on education and R&D to attract investors and retain qualified labour. Moreover, the structural reform strategy should build on the regions' strengths (e.g. tourism in Jiu Valley, energy & energy-intensive industry in NRW and Asturias, and the manufacturing sector in Silesia).

The importance of social protection and inclusion

No one should be left behind – more than a slogan, this message needs to be at the core of the transition. The economic diversification away from coal should be undertaken in a way that is pragmatic but also socially just. Policy makers must acknowledge the real difficulties that citizens of the region face in relation to the transition. The hard coal phase-out in NRW and in particular the Ruhr area was relatively successful, as it managed to protect all the miners from becoming unemployed. Nonetheless, the unemployment rates drastically increased in the region, especially in industries up and down the coal and steel value chain.

The importance of European policy and funding

The European Union's policies and funds play a driving role in the acceleration of the energy transition, and at the same time can play a key role in shaping the response and economic transformation of a region. Notably, in our work we found that EU funds that target regional development[14] or the just transition[15] have proved to be important. They help to ease "the pain" for the stakeholders that are negatively affected, but also assist regions in the development and execution of structural reform plans. Similarly, for some of the regions such as Asturias, EU energy and climate policies have been the main driver for the phasing out of coal mining and coal generated power.

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[13] See:https://www.euractiv.com/section/electricity/news/poland-agrees-to-shut-coal-mines-by-2049/

[14] For instance, the European Regional Development Fund

[15] Just Transition Mechanism and the Initiative for cola regions in transition

The importance of stakeholder engagement

Engaging with local stakeholders is key. In Asturias, the public perception of the transition is negative. So far there has been a history of economic decline (livestock and dairy, then coal mining and now coal power generation) and related employment effects, with no new economic activity filling the gaps. However, to increase public support, all relevant stakeholders have been involved through social dialogue in the process and aimed to reach consensus regarding the way forward. This has mainly changed the political discourse (from maintaining coal as a key element of the local economy to taking advantage of the opportunities from the energy transition) which reinforced political stability. The phase-out in the Jiu Valley, however, has been characterised as lacking engagement with local stakeholders (decisions often being taken top-down), and as 'unjust'. This has been changing, as the community of civil society organisations is very active and promotes an inclusive approach to decision-making. In each coal region, citizen support and public acceptance for the transition are vital for success. Without this element the transition is likely to fail.

The importance of early action

Do not hold on to old economic structures. In the beginning of the decline of the coal industry in NRW, only big companies were active in the coal and mining industry. Mining and steel companies were reluctant to sell their land to companies in other sectors. Moreover, coal and steel companies as well as the government initially did not realise the long-term implications of the coal crisis which resulted in policies (e.g. subsidies) aiming to preserve the status quo and limited action was taken by the government to implement structural reform measures. In particular in the NRW, a distributed system with smaller companies in both the service and manufacturing sectors has proven to be successful. In Asturias, the start of the transition was delayed as the region was keen on maintaining its economic structure and the related competitive edge that coal had brought. It was only when the EU policies required the phase-out of coal that they embraced the transition and its related opportunities. However, in some cases, it is beneficial to build on already existing strengths. For example, in the case of Silesia, due to the high level of specialisation in the region, focus on development of the manufacturing sector should be a priority.

There is no one-size-fits-all solution

Each coal region has its own characteristics, and each phase-out takes place in a different context which means that there is no one-size-fits-all solution. For example, the hard coal phase-out in NRW took around 60 years, whereas other regions have a shorter timeframe for their phase-out. Moreover, the NRW is a relatively wealthy region and is well located. This enabled the region to invest in e.g. education and innovation and to attract many companies due to its favourable geographical location. Such characteristics highly influence the impacts observed across key indicators for each region.

4. Model results

In contrast to the literature review and the case studies, the analysis presented in this section is forward-looking: the future impacts of the clean energy transition as defined in the Task 2 – Low Carbon Baseline are projected for each NUTS 2 region using two separate modelling tools: E3ME-ERR and GEM-E3-FIT-R. From each modelling tool, net/gross output and employment results (at the whole economy level) in 2030 and 2050 are presented as heatmaps. Appendix A and Appendix B includes E3ME-ERR and GEM-E3-FIT-R sectoral heatmaps for all other sectors.

The heatmaps presented in this section also include histograms of the frequency distribution of the relative difference to baseline results for the NUTS 2 regions[16] making up the EU27+UK. These results are summarised in tables focusing on the three NUTS 2 regions with the largest positive impacts, and the three NUTS 2 regions with the largest negative employment and GVA effect compared to the baseline.

4.1. E3ME-ERR

4.1.1. Model description

E3ME-ERR, written in Python, is a tool that produces sectoral EU27+UK projections for employment and GVA at the NUTS 2 level[17]. It uses a top-down approach for all economic sectors, apart from the electricity generation and supply sector, for which a more detailed bottom-up approach was developed. The methodology behind the E3ME-ERR tool is informed by the findings of the literature review carried out in Task 6.1 and summarised in Section 2.1. A full description of the E3ME-ERR tool is available in Appendix A of the Task 6.2 modelling results report. The econometric and data-intensive nature of E3ME also aligns with these findings since the data underpinning the model determines the economic structure and socioeconomic situation of EU27+UK states, two important drivers of economic impact of the low carbon transition on regions.

The top-down regionalisation of national E3ME employment and GVA forecasts uses a dynamic shift-share decomposition analysis with ARIMAX forecasting techniques, as suggested by Mayor et al. (2007). This methodology was adopted to obtain employment and GVA forecasts by sector at the NUTS 2 level based on forecasts produced by the E3ME model and regional Eurostat data. This regionalisation technique allows for the representation of economic sectoral composition in the regional economy, an important driver of the economic impact of the low carbon transition on regions described in Section 2.1. A lack of economic diversification leads to regions with a higher reliance on sectors that are expected to face declines facing prolonged socioeconomic dislocation and below average economic performance (Heilmann et al., 2020). The ARIMAX forecasting technique used captures this by accounting for past behaviour of sectoral employment and GVA. This technique also aligns with E3ME's econometric nature.

The bottom-up approach applied to the electricity generation and supply sectors relies on the regionalisation of national E3ME-FTT power generation capacity results over a projected period. Regional capacity results are then used to estimate electricity generation and supply employment and GVA at the NUTS 2 level by applying employment factors (jobs/MW) and by

[16] 2016 NUTS classification

[17] The 2016 NUTS 2 classification is used.

utilising estimates of regional electricity generation and the Levelised Cost of Electricity (LCOE). The bottom-up approach relies on past regional electricity capacity data as well as the regional technical capacity of certain renewable technologies in the future to allocate future capacity. Therefore, the approach uses the same foundations applied in the top-down approach and developed using the framework summarised in Section 2.1. Regions with a lack of technological diversity, a reliance on technologies that are expected to decline, and lacking natural endowment are expected to face deeper challenges as the EU27+UK transitions to a clean energy system.

Both the top-down and bottom-up regionalisation approaches scale sectoral employment and GVA estimates to E3ME national sectoral results to ensure scenario consistency.

4.1.2. Output results

The heatmap below presents the percentage (%) changes in total (aggregate) regional output with respect to the baseline estimated by E3ME-ERR. The analysis in the following section discusses the regions with the greatest percentage changes from their baseline levels and does not necessarily correspond to the most important ones for disaggregating nationwide impacts (i.e. those where absolute output has changed the most).

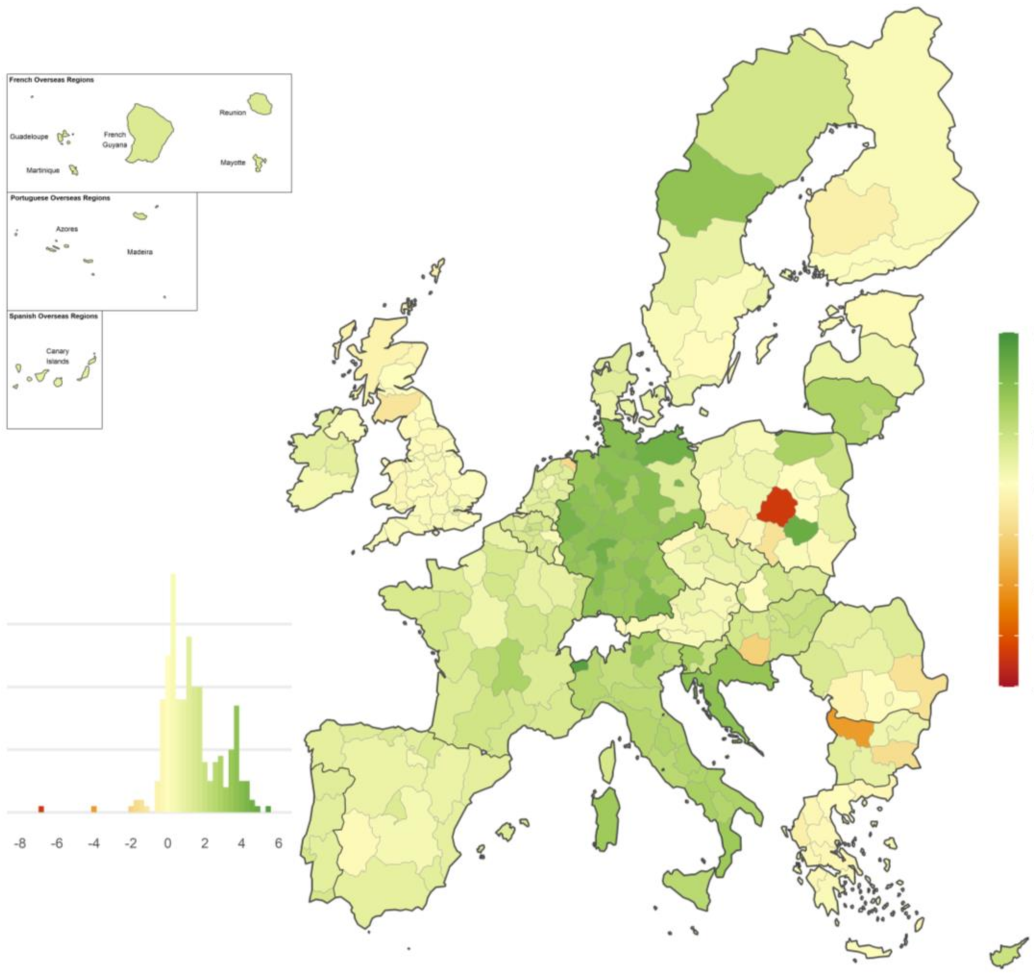

Figure 4.1 – Relative E3ME-ERR 2030 GVA change across all sectors (difference-to-baseline)

All in all, more regions are projected to see higher value added in this scenario (compared to baseline) than see lower value added. The scenario results suggest that the majority of

EU27+UK could expect higher construction and services sector GVA in 2030 from the clean energy transition. Although many regions are projected to see higher agriculture sector GVA, possibly due to increased profits resulting from biofuel production, approximately 13% of NUTS 2 regions show lower agriculture GVA relative to the baseline. Similarly, a third of the NUTS 2 regions show negative manufacturing GVA compared to the baseline with the rest showing positive or zero effects. The hardest hit sectors are the mining and quarrying sector and the electricity generation and supply sector. In these two sectors, more than half of the EU27+UK's regions show a negative GVA effect compared to the baseline. This is due to less mining of fossil fuels and a shift towards renewables. The heatmaps in Appendix B show that 2030 results for these two sectors show the largest negative percentage change from the baseline.

Table 4-1 summarises the regional results by focusing on the three NUTS 2 regions with the largest positive and largest negative GVA effect compared to the 2030 baseline. The table also shows each region's contribution to national 2030 total GVA change relative to the baseline. For all 6 regions summarised, total GVA changes bring about small to moderate changes in national GVA relative to baseline. Figure 4.1 shows that most EU27+UK NUTS 2 regions are projected to see an increase in total GVA relative to the baseline. In fact, the histogram of results is skewed towards positive relative impacts. The range of results is between +5.3% and -6.7% and the few NUTS 2 regions where net negative 2030 GVA impacts are concentrated in Eastern Europe.

Table 4.1 – Task 2 regions with largest and smallest 2030 E3ME-ERR changes in total GVA (difference-to-baseline) and contribution to national change (difference-to-baseline)

Region	%, 2030	%, Contribution to national change[18]
Valle d'Aosta/Vallée d'Aoste (ITC2)	5.3	0.01
Swietokrzyskie (PL72)	4.74	0.11
Mecklenburg-Vorpommern (DE80)	4.62	0.06
⋮	⋮	⋮
Dél-Dunántúl (HU23)	-2.11	-0.13
Severozapaden (BG31)	-3.98	-0.23
Lódzkie (PL71)	-6.72	-0.43

The three regions which are projected to benefit the most in 2030 compared to the baseline are the Italian region of **Valle d'Aosta** (ITC2), the Polish region of **Swietokrzyskie** (PL72), and the German region of **Mecklenburg-Vorpommern** (DE80). In all three regions, increased GVA is driven by the electricity generation and supply sector, as well as an increase in services GVA relative to the baseline. All three regions exhibit higher overall electricity capacity deployment relative to the baseline. In general, E3ME-ERR finds that higher 2030 renewable capacity relative to the baseline in these regions leads to large overall increases in regional GVA.

Negative 2030 GVA effects are most prevalent in the Polish region **Lódzkie** (PL71), the Bulgarian region **Severozapaden** (BG31), and the Hungarian region **Dél-Dunántúl** (HU23). In these regions, a reduction in GVA is driven by reduced activity in the electricity generation

[18] The 'contribution to national change' represents not the share within the % change at national level, but the percentage change attributable to a specific region. In other words, suppose a country is made up of two NUTS 2 regions and the percentage change at national level is 2%, then the sum of the 'contribution to national change' of the two regions equals 2%.

and supply sector as well as lower mining and quarrying activity relative to the baseline. Lower overall electricity generation capacity relative to the baseline in all three regions is driven by a large reduction in coal and nuclear capacity. These reductions are partly offset by increased renewable capacity deployment, yet not to the extent required to offset the large reductions in coal and nuclear capacity, leading to overall decreases in regional GVA relative to the baseline.

With respect to major EU27+UK economies, E3ME-ERR estimates that in Germany, total 2030 GVA impacts range between +1.3% in **Brandenburg** (DE40) and +4.6% in Mecklenburg-Vorpommern (DE80). In Brandenburg, total 2030 GVA in the policy scenario is driven upwards by higher services, manufacturing, and construction GVA which outweighs reductions in 2030 electricity and agriculture GVA relative to baseline while in Mecklenburg-Vorpommern, total 2030 GVA in the scenario is driven upwards by all economic sectors relative to baseline, especially services and electricity generation GVA because of higher renewable capacity relative to baseline. In Spain, total 2030 GVA relative to baseline ranges between -0.2% in **Extremadura** (ES43) and +1.5% in **Comunidad Foral de Navarra** (ES22). In Extremadura, 2030 electricity generation and supply GVA drives down total GVA relative to the baseline due to lower nuclear capacity under a policy scenario while in Comunidad Foral de Navarra, higher 2030 manufacturing GVA is the main driver of higher total regional GVA.

In Italy, 2030 GVA impacts range between +2.2% in **Lombardia** (ITC4) and +5.3% in **Valle d'Aosta** (ITC2). In Lombardia all economic sectors other than electricity generation and supply show higher 2030 GVA relative to baseline. 2030 electricity generation and supply GVA falls due to substantive reductions in gas capacity which outweighs increased renewable capacity relative to baseline. In Valle d’Aosta, all economic sectors other than mining and quarrying show a higher 2030 GVA relative to the baseline. Finally, in France, 2030 GVA impacts range between +0.5% in **Haute-Normandie** (FRD2) and +2.9% in **Auvergne** (FRK1). In Upper Normandie, all economic sectors other than electricity generation and supply show higher 2030 GVA relative to baseline. Although overall 2030 capacity is higher in the baseline, the electricity mix shifts away from nuclear and gas towards solar and onshore wind relative to the baseline. In Auvergne, all economic sectors, especially electricity generation and supply (driven by much higher solar capacity relative to baseline) show higher 2030 GVA.

4.1.3. Employment results

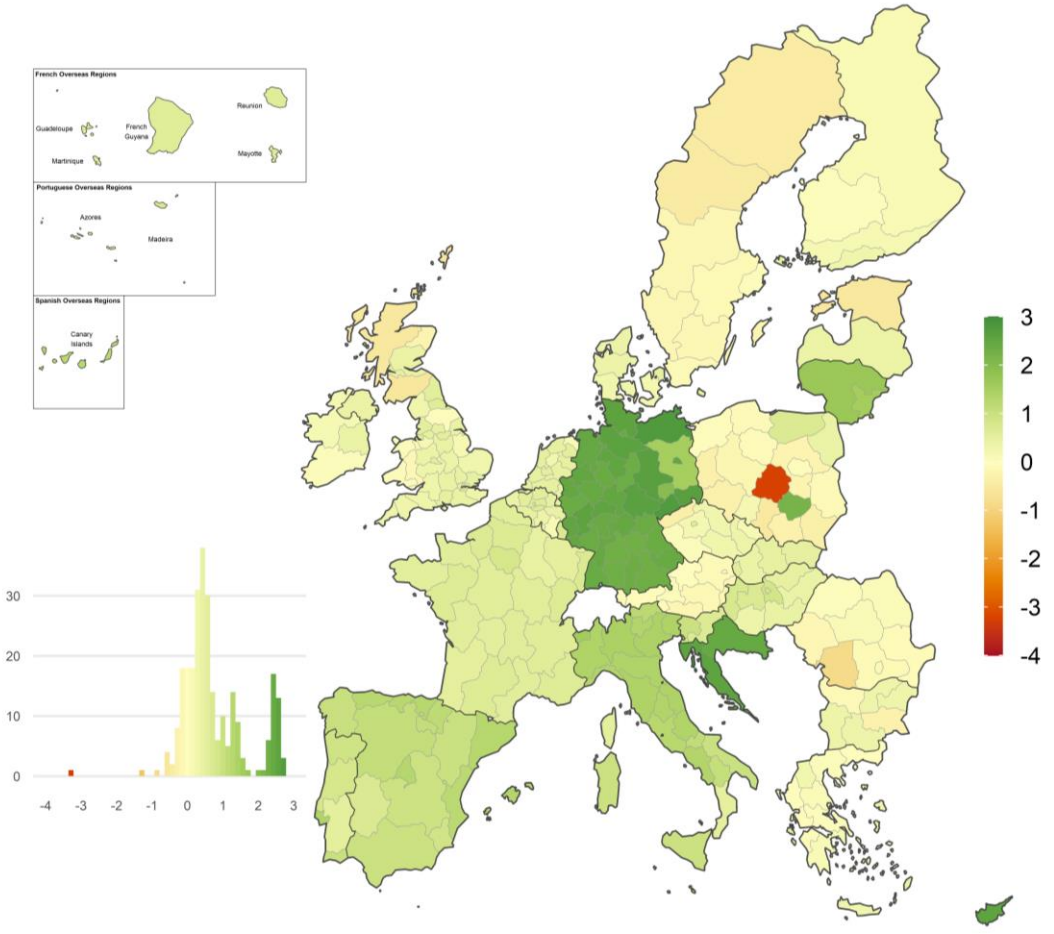

Figure 4.2 – Relative E3ME-ERR 2030 employment change across all sectors (difference-to-baseline)

Similar to the GVA results, the majority of EU27+UK should expect higher **construction** and **services** sector employment in 2030 as a result of the clean energy transition. Although most NUTS 2 regions show positive **manufacturing** employment effects, a third of regions show negative effects relative to the baseline. However, the heatmaps presented in Appendix B show that negative manufacturing effects are small and do not exceed -1% relative to the 2030 baseline, whereas positive effects are concentrated around +2% relative to the baseline.

Other than the electricity generation and supply sector, the scenario results show that most regions are projected to see lower employment levels in **agriculture** and **mining and quarrying** relative to the baseline. By 2030, agriculture employment is -36% below baseline in Luxembourg (LU00), the worst hit region. However, GVA is projected to be marginally higher than baseline in the same region. This indicates that sectoral productivity is expected to increase significantly. 77% of NUTS 2 regions are projected to see lower employment in mining and quarrying. The hardest hit regions are Malta (MT00), showing a -60% reduction relative to the baseline; the North of England (North Yorkshire (UKE2) and South Yorkshire (UKE3)); and a number of Romanian regions.

Table 4-2 shows that the 3 regions with the largest smallest change in total 2030 employment relative to baseline have small to moderate impacts at the national level. In the case of Malta, since it is a single NUTS 2 region Member State, the regional effects is equal to the national effect. Figure 4.2 shows that, in employment terms, for all sectors, Western European regions are projected to fare better than Eastern and Southern European regions in 2030. The range of impacts is between +2.8% and -3.2% relative to the baseline. The histogram presented in Figure 4.2 shows that the majority of EU27+UK NUTS 2 regions can expect a marginally positive employment effect.

Table 4-2 Task 2 regions with largest and smallest 2030 E3ME-ERR changes in total employment (difference-to-baseline) and contribution to national change (difference-to-baseline)

Region	%, 2030	%, Contribution to national change[19]
Mecklenburg-Vorpommern (DE80)	2.78	0.05
Chemnitz (DED4)	2.76	0.04
Sachsen-Anhalt (DEE0)	2.65	0.03
⋮	⋮	⋮
Sud-Vest Oltenia (RO41)	-0.86	-0.08
Malta (MT00)	-1.32	-1.32
Lódzkie (PL71)	-3.22	-0.19

The three regions which are expected to benefit the most in 2030 are in Germany. These regions are: **Mecklenburg-Vorpommern** (DE80), **Chemnitz** (DED4), and **Sachsen-Anhalt** (DEE0). In all three regions, growth in 2030 employment is driven by higher employment levels in services and manufacturing. Mecklenburg-Vorpommern is also one of the regions that exhibited strong positive GVA effects in Section 4.1.2

Negative employment effects are most prevalent in the Polish region **Lódzkie** (PL71), **Malta** (MT00), and the Romanian region **Sud-Vest Oltenia** (RO41). In these three regions, lower employment is driven by a smaller electricity generation and supply sector, and a reduction in mining and quarrying jobs. Agricultural activity also falls significantly in Lódzkie and Malta.

With respect to the major EU27+UK economies, E3ME-ERR estimates that in Germany, total 2030 employment impacts range between +1.5% in **Brandenburg** (DE40) and +2.8% in **Mecklenburg-Vorpommern** (DE80). In Brandenburg, total 2030 employment in the policy scenario is driven by higher services and construction employment, which outweigh lower electricity generation and supply employment relative to the baseline. In Mecklenburg-Vorpommern, total 2030 policy scenario employment is driven upwards by all sectors of the economy other than agriculture, which falls slightly relative to the baseline. In Spain, total 2030 employment relative to baseline ranges between 0.7% in **Extremadura** (ES43) and 1.3% in **Illes Balears** (ES53), due to significant increases in wholesale and retail employment relative to baseline.

In Italy, 2030 employment impacts range between +0.5% in **Calabria** (ITF6) and +1.6% in **Valle d'Aosta** (ITC2). Both regions show higher 2030 services employment outweighing a reduction in agriculture employment relative to the baseline. Finally, in France, 2030 employment impacts range between +0.4% in **Champagne-Ardenne** (FRF2) and +0.8% in **Île de France** (FR10) due to higher 2030 employment in most sectors (in particular services and construction) outweighing small reductions in agriculture and mining and quarrying 2030 employment relative to baseline.

[19] The ‘contribution to national change’ represents not the share within the % change at national level, but the percentage change attributable to a specific region. In other words, suppose a country is made up of two NUTS 2 regions and the percentage change at national level is 2%, then the sum of the ‘contribution to national change’ of the two regions equals 2%.

4.2. GEM-E3-FIT-R

4.2.1. Model description

The GEM-E3-FIT-R, written in GAMS, is an economic model covering both the global economy at the national level and EU27+UK countries at the NUTS2 level distinguishing between 67 sectors of activity. The model calculates both at the country and at the regional level the full set of input-output tables, employment by sector and bilateral trade matrices by product and emissions. A full description of the GEM-E3-FIT-R tool is available in Appendix B of the Task 6.2 modelling results report.

The model follows a two-layer approach; the two layers run sequentially. At the top level, the national economy model, is GEM-E3-FIT; a multi-country, multi-sectoral computable general equilibrium model. The model is a simultaneous system of mixed-complementarity conditions, derived as Kuhn–Tucker conditions of microeconomic optimisation of the agents (i.e., suppliers and consumers) and equilibrium conditions covering all markets for commodities and primary production factors (i.e., labour and capital) simultaneously. The dual variables of the equilibrium conditions determine the prices of commodities and primary production factors. A balance equation acting as a closure of money flows represents the Walras law and, consequently, the model determines all except one of the prices (or a price index), which is the numeraire. The equilibrium runs over time dynamically based on stock-flow relations for capital, labour, and other variables. The optimisation of agents' behaviours includes foresight, which adjusts over time myopically in the standard model version. At the bottom layer is the regional economic model.

The regional economy model down-scales national economic trends; hence the national model subordinates the regional. Activity by sector, hence employment, depends on the location of primary production factors (i.e., capital and labour) which draws on new economic geography theory. The modelling of location choice aims at quantifying agglomeration and dispersion force that influence regional performance.

4.2.2. Output results

The heatmap below presents the percentage (%) changes in total (aggregate) regional output with respect to the baseline estimated by GEM-E3-FIT-R. The analysis in the following section discusses the regions with the greatest percentage changes from their baseline levels and does not necessarily correspond to the most important ones for disaggregating national wide impacts.

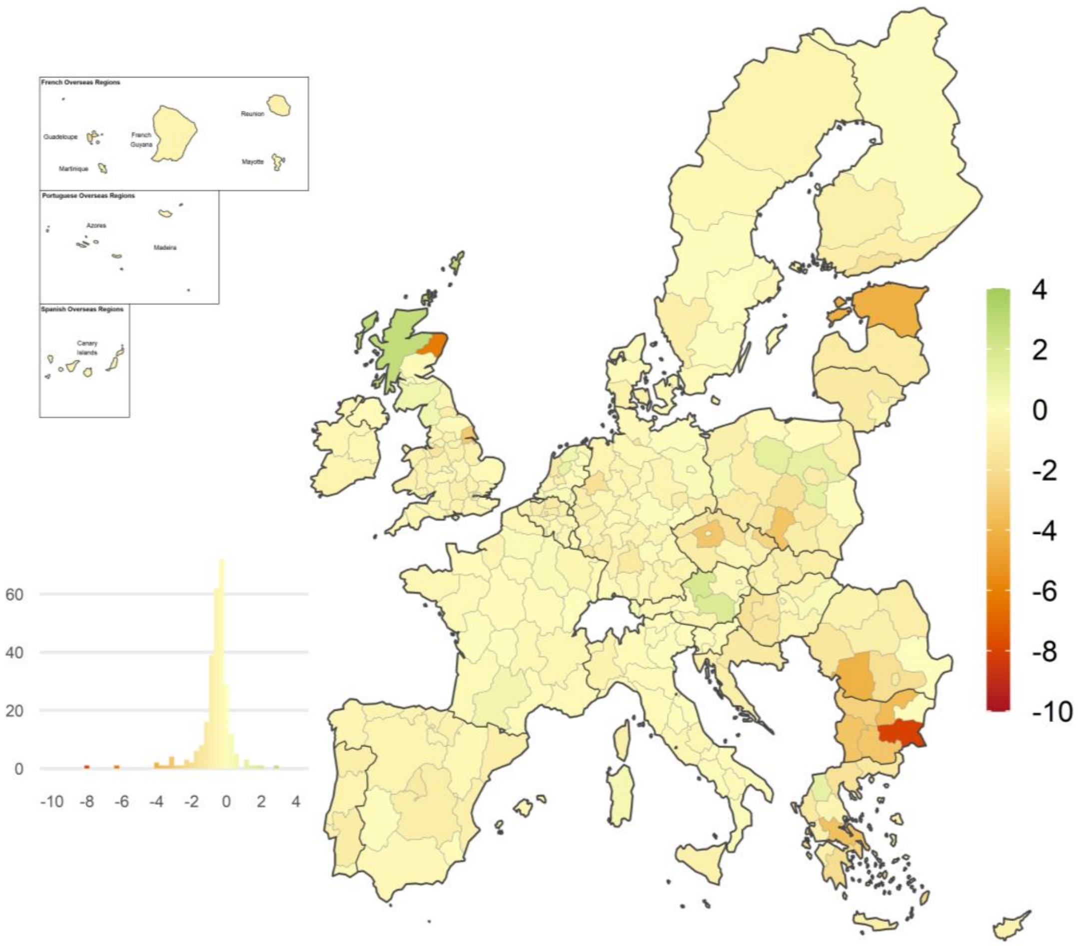

Figure 4.3 Relative GEM-E3-FIT-R 2030 production change across all sectors (difference-to-baseline)

In most sectors of the economy, the clean energy transition implies lower activity compared to the baseline. However, there are sectors such as electricity, agriculture, construction, and manufacturing where numerous regions record higher output levels than in the baseline. The clean energy transition scenario envisages extensive electrification of the economy, while at the same time the commercialisation of clean fuels whose production uses intensively electricity further enhances electricity consumption. In total, 79.4% of regions experience an increase in their electricity sector output.

With respect to manufacturing, the clean energy transition implies higher demand for advanced equipment goods, i.e., products that use energy more efficiently and/or use alternative (non-fossil fuel) inputs. In GEM-E3-FIT-R, the sectors belonging to advanced manufacturing include the batteries for electric vehicles, electric vehicles and other advanced transport equipment, advanced appliances (e.g., heating and cooking appliances), as well as the sectors producing the goods necessary for the deployment of renewables. For those sectors, we observe an increase in their production levels in many NUTS2 regions (approximately 45%). However, traditional manufacturing sectors suffer from competitiveness losses which imply higher substitution of domestically produced goods with cheaper (non-EU) imported products. The overall impact in the manufacturing sector is determined by the relative size of those two categories.

In terms of the agricultural production, 51% of regions are expected to see increased output levels compared to the baseline, with regions in Greece and in Slovakia recording the highest percentage increase in their production in 2030. On the other hand, regions in Ireland and in Croatia record the highest decrease in their production compared to the baseline case. Finally, the construction sector shows increased output levels for 58% of regions in 2030. This effect is associated with the expansion of renewables capacity, as well as with the expansion of the productive capacity of advanced manufacturing industries. Regions in Lithuania, Malta, Italy and France record the highest increase in construction activity while the largest losses are observed in Estonia, Latvia and Finland.

The key factor differentiating the results across regions is whether the regions contribute to the deployment of renewable energy sources (RES) or whether they produce fossil fuels and fossil-based power generation. The range of the results in terms of % changes from baseline are between -7.7% (in Yugoiztochen (BG34)) to +2.8% (in Highlands and Islands (UKM6)). There are 30 regions in 10 countries that record an increase in their overall production levels compared to the baseline in 2030.

Table 4-3 – Task 2 regions with largest and smallest 2030 GEM-E3-FIT-R changes in total production (difference-to-baseline) and contribution to national change (difference-to-baseline)

Region	%, 2030	%, Contribution to national change[20]
Highlands and Islands (UKM6)	2.81	0.02
Oberösterreich (AT31)	1.95	0.4
Steiermark (AT22)	1.69	0.2
⋮	⋮	⋮
Estonia (EE00)	-4.12	-4.1
North Eastern Scotland (UKM5)	-6.17	-0.1
Yugoiztochen (BG34)	-8.03	-1.0

The greatest increases in total regional production are in **Highlands and Islands (UKM6)**, **Oberösterreich (AT31)** and **Steiermark (AT22)**. The two Austrian regions host car manufacturing industries and see an increase their production due to higher demand for electric vehicles while in Highlands and Islands (UKM6) a production increase is driven by changes in the power generation sector, more specifically to the deployment of wind. The increased output of clean energy technologies and energy efficient appliances contributes positively to the region but to a lesser extent.

The three regions that record the largest decrease in their production are **Sud-Vest Oltenia (RO41)**, in **North Eastern Scotland (UKM5)**, and **Yugoiztochen (BG34)**. In Sud-Vest Oltenia (RO41) activity fall is driven by the decreased activity of energy-related and mining industries (which are responsible for 10% of total regional production in 2030) and of the power generation sector (local electricity generation from coal accounts for almost 11% of total national electricity generation). In North Eastern Scotland (UKM5) production is driven by changes in extraction sectors, and more specifically by the reduction in the production of crude oil and gas extraction. In Bulgaria, the largest share of the activity losses is attributed to coal-related activities and to a lesser extent to the manufacturing sector. In 2030, in the baseline case, coal extraction activities account for approximately 13% of total regional production while electricity generation from coal plants accounts for 22% of total electricity generation at the national level.

[20] The 'contribution to national change' represents not the share within the % change at national level, but the percentage change attributable to a specific region. In other words, suppose a country is made up of two NUTS 2 regions and the percentage change at national level is 2%, then the sum of the 'contribution to national change' of the two regions equals 2%.

With respect to major EU27+UK economies, in Germany overall production changes range between -1.8% (Münster (DEA3)) and +0.3% (Brandenburg (DE40)); output changes in Münster are driven by changes in the energy sectors while Brandenburg benefits from the expansion of renewables capacity and changes in overall production are driven by the power generation sector. In Spain, production changes range between -1.1% (Comunidad de Madrid (ES53)) and -0.1% (Extremadura (ES43)); changes in overall production in Comunidad de Madrid are driven by services and energy-related sectors. In Italy, production changes range between -0.7% (Sicilia (ITG1)) and 0.5% (Sardinia (ITG2)) and are mainly influenced by changes in services and energy-related sectors, while construction and transport services record increases in all regions. Finally, in France production changes range from -1.6% (Guadeloupe (FRY1)) to +0.6% (Midi-Pyrénées (FRJ2)) and are mainly driven by the service sectors.

4.2.3. Employment results

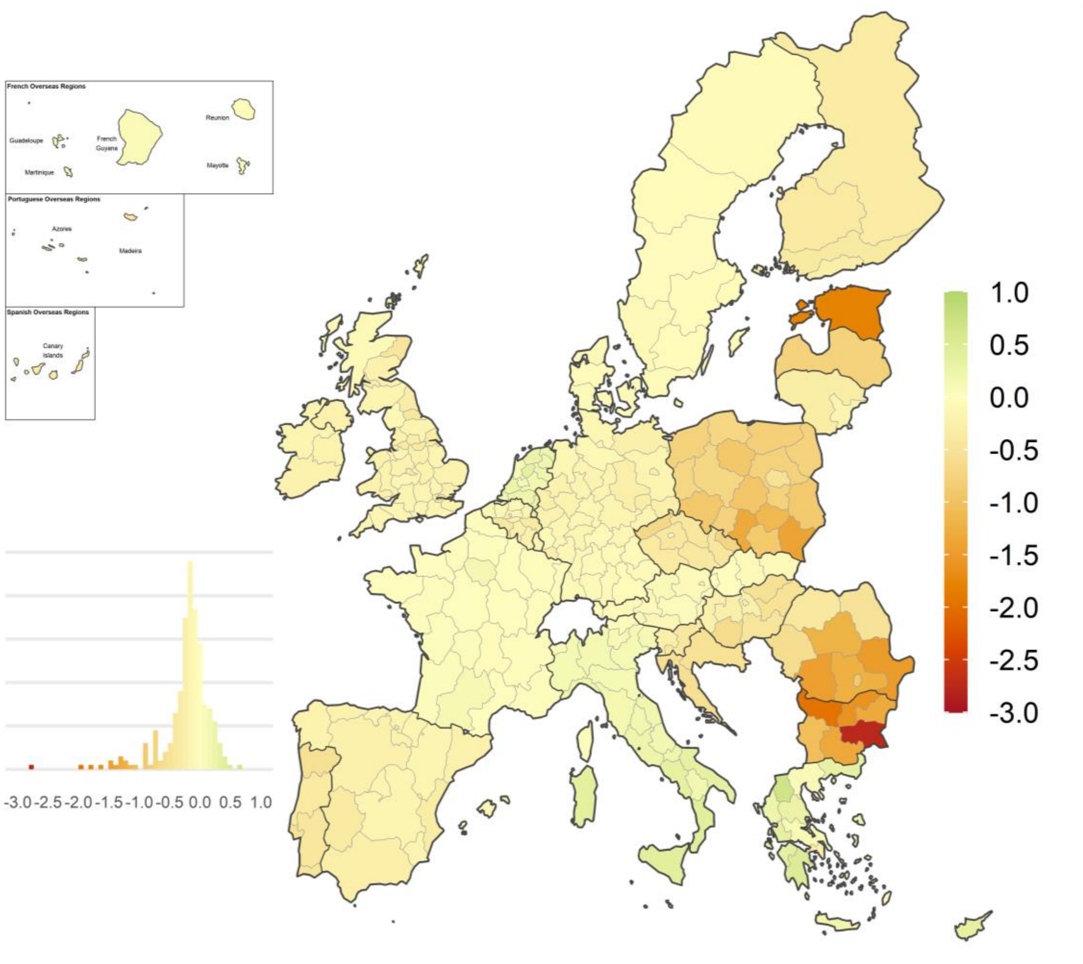

Figure 4.4 – Relative GEM-E3-FIT-R 2030 employment change across all sectors (difference-to-baseline)

For most regions the clean energy transition implies lower sectoral employment. However, compared to the sectoral production, a larger share of regions records higher employment compared to the baseline in 2030. Employment increases in 24% of the regions in the clean energy transition scenario. This effect is associated with the reduction of wages as a response to lower activity and the subsequent substitution of other production inputs with labour (where this is possible according to the substitution possibilities described by the production function of each sector) as well as to the labour intensity of sectors benefiting from the transition (e.g., renewables, advanced manufacturing etc.).

The shift in power generation technologies, away from fossil fuels and towards renewable sources, coupled with the electrification of the economy leads to higher electricity-reemployment in 84% of NUTS2 regions. Regarding manufacturing, labour shifts from traditional manufacturing sectors, where production is reduced due to lower demand stemming either from the increased production costs (i.e., the carbon tax increase either directly affects production costs according to the energy inputs or indirectly according to the energy embodied in intermediate inputs) and the consequent substitution with higher efficiency goods and cheaper imported products. Employment increases in 27% of regions, with the largest increases being observed in Hungary (HU23), France (FRM0), Austria (AT13, AT22, AT31), the Netherlands (NL12, NL33, NL42, NL34), Bulgaria (BG34), Poland (PL22) and Romania (RO41). There is a sectoral shift in regions such as BG34, PL22 and RO41 from away from energy-related (incl. power generation) and extraction activities towards manufacturing. In the baseline, coal-related activities in those regions are responsible for 10%, 5.8% and 2.6% of total employment in 2030 (i.e., they can be characterised as the most coal-intensive regions in their countries).

With respect to agriculture, employment increases in 66% of regions with regions in Greece and Slovakia recording the largest increases; in construction services employment increases in 63.7% of the regions. Finally, with respect to services, employment increases in 11.9% of regions and primarily occur in G-I (wholesale, retail, transport, accommodation, and food services). Noticeably, among the regions with the highest employment gains in the G-I sector, we find coal-intensive regions in Bulgaria, Romania, and Poland, such as BG34, RO41, PL22. This suggest that people that are part of the labour force which is in the baseline engaged in coal activities will be absorbed into the manufacturing and service sectors in the low carbon scenario.

The impact on overall employment is determined by the relative labour intensity of winning and losing sectors as well as from the substitution effect that takes place due to the adjustment of wages. Lower demand for fossil fuels and other products implies lower labour demand with respect to the reference scenario for specific skills. Wages adjust to clear regional markets. The extent to which wages adjust is determined by regional specificities (i.e., a tight labour market implies small adjustment of wages) to reach equilibrium. As labour costs fall, substitution of other (more expensive) production inputs with (cheaper) labour takes place. The range of employment impacts is between -2.7% (in Yugoiztochen (BG34)) and 0.7% (in Dytiki Makedonia (EL53)). It is found that 67 EU27+UK regions (approximately 24% of all regions) record an increase in their overall employment levels compared to the baseline case.

Table 4-4 – Task 2 regions with largest and smallest 2030 GEM-E3-FIT-R changes in total employment (difference-to-baseline) and contribution to national change (difference-to-baseline)

Region	%, 2030	%, Contribution to national change[21]
Dytiki Makedonia (EL53)	0.67	0.01
Peloponnese (EL65)	0.48	0.01
Sicilia (ITG1)	0.41	0.02
⋮	⋮	⋮
Estonia (EE00)	-1.79	-1.8
Severozapaden (BG31)	-1.96	-0.01
Yugoiztochen (BG34)	-2.74	-0.01

The largest increase in employment in terms of % changes from baseline is found for **Peloponnese (EL65) and Western Macedonia (EL53)** in Greece and for **Sicilia (ITG1)** and **Calabria (ITF6)** in Italy. In Peloponnese, employment increases in agriculture, in the production of energy efficient appliances and in the power generation sector (the region has important wind potential, and the penetration of renewables benefits the region). In Western Macedonia, employment increases in the agricultural sector. Peloponnese (EL65) and Western Macedonia (EL53) are the only regions in Greece with coal mines; the share of coal-related employment in total regional employment in the base year is equal to 2% and 21% in EL65 and EL53 respectively. However, in the baseline coal-based power generation is almost phased out in the country by 2030. Coal-related activities are eliminated in EL53 and fall in EL53 (in 2030 the share of employment in coal activities in total employment falls to 0.1%). Hence, the impact on employment from changes in the coal sector in these regions is small in 2030, and changes are driven mainly by developments in clean energy sectors.

In Sicilia (ITG1) and Calabria (ITF6), employment increases in most sectors of the economy except for agricultural activities and traditional manufacturing sectors. The sector contributing most to the increase in regional employment is the construction sector; this increase in construction services is associated with the development of renewables and to the expansion of production capacities of industries related to clean energy technologies and energy efficient appliances.

Bulgaria shows the greatest loss of employment, followed by Estonia. Both countries have significant shares of coal-based electricity production in 2030 (in the baseline); in Bulgaria, the share of electricity produced by coal-fired plants is 31% and in Estonia 42%. In Yugoiztochen (BG34) employment in coal mining and coal-fired power plants accounts for 10.6% of total regional employment in 2030 (the highest in Bulgaria) in the baseline. However, in the clean energy transition scenario coal is phased out (the share of coal-based electricity production falls from 31% to 8%) and the region thus records large employment losses in coal-related activities.

In Severen tsentralen (BG32), the fall in employment is driven by the decreased activity in traditional manufacturing sectors, power generation activities (in the baseline approximately 1% of total employment is related to coal activities) and agriculture. Finally, in Severozapaden (BG31) the employment decrease is linked to decreased electricity production from nuclear.

[21] The 'contribution to national change' represents not the share within the % change at national level, but the percentage change attributable to a specific region. In other words, suppose a country is made up of two NUTS 2 regions and the percentage change at national level is 2%, then the sum of the 'contribution to national change' of the two regions equals 2%.

With respect to major EU27+UK economies, changes are smaller in magnitude. In Germany, employment losses are driven primarily by the loss of jobs in the services sector; Oberbayern (DE21) record the lowest loss in total employment (less than -0.1%); changes in employment are attributed to the service sector while for in most other sectors employment increases. Leipzig (DED5) record the greatest employment losses (-0.3%) as in addition to services, employment falls also in energy sectors and power generation sectors. In Spain, employment losses range between -0.4% (Extremadura (ES43)) and -0.1% (Illes Balears (ES53)); employment changes are driven by changes in services and manufacturing sectors. In Italy, employment gains are seen in all regions; changes range between less than 0.1% (Provincia Autonoma di Bolzano/Bozen (ITH1)) and 0.4% (Sicilia (ITG1) and Calabria (ITF6)). In Provincia Autonoma di Bolzano/Bozen (ITH1) employment losses are recorded in the manufacturing, agriculture, and services sectors. Finally, in France employment changes range from -0.1% (Mayotte (FRY5)) to +0.1% (Île de France (FR10)); changes in Mayotte (FRY5) are driven by the transport sector while changes in Île de France (FR10) are driven by changes in the manufacturing sector.

5. Policy implications

This section of the report presents key policy implications culminating from the results of a detailed evidence review, in-depth case studies, and a quantitative assessment of the regional impacts of a low carbon, clean energy transition scenario in the EU27+UK.

The literature review pointed to various factors determining potential outcomes in an energy transition, but also showed that government at regional and national level have various policy levers available to steer the pathway of a regional economy and, where needed, mitigate its negative effects. Key policy levers identified are a) policies to promote economic diversification, b) skills development, retraining and redeployment, c) providing social protection to those affected, d) engaging with stakeholders to generate political buy-in for change and long-term objectives, e) improving cooperation and aligning strategies for economic transformation horizontally and vertically and f) through national and European government funding, making sure that those regions facing the biggest challenges are supported financially.

The case studies reviewed experiences in several regions which have already undergone, or started to undergo, an energy transition and the economic consequences thereof. The analysis, carried out through a combination of desk research and expert interviews, revealed common impacts, as well as key lessons learned across regions. These lessons confirm the importance of several of the policy levers identified in the literature review, and experts from the regions emphasise the importance of economic diversification, the importance of social protection, the role of European policy and funding, and the importance of stakeholder engagement. While there is no one-size-fits-all solution and structural reform should build on a region's strengths, early action is key regardless of the region's specificities.

The aim of the macroeconomic modelling has been to assess – using newly developed tools – which regions can be expected to benefit economically in the clean energy transition, versus those regions expected to face significant challenges in maintaining the same economic position as they would have in the absence of a clean energy transition. Although the modelling tools used have different specifications, they are designed to project outcomes by NUTS 2 region based on available data around renewable energy potential, competitiveness, demographic changes, economic structure and labour markets for each region. The modelling results suggest that several regions may indeed face negative effects in the absence of further policy action to prevent them.

Region-by-region analysis is required to identify the key structural barriers in each location and customise policy interventions accordingly, yet a comparison of the findings of the literature review, the case studies and the modelling results allows us to identify three broad guidelines around which policy action should be designed:

1. **In those regions reliant on fossil fuel extraction and electricity generation, early action to diversify the economy is a panacea.**

The evidence from the literature, the case studies and the macroeconomic modelling all suggest that regional sectoral composition is a key factor in determining the overall regional impact on employment and activity in the clean energy transition. Regions with a diverse economy, with already a strong reliance on sectors expected to grow in the low carbon transition, are expected to perform better and see increased job opportunities in the transition. In fact, the modelling results indicate that negatively affected regions that historically have large shares of fossil fuel extraction or use activity and employment tend to face a larger total negative effect relative to baseline. Regions which are either positively or neutrally affected tend to still have declining fossil fuel related activity. However, sectors which are expected to remain unchanged or which are expected to grow in a clean energy transition diminish these negative impacts in regions with diverse economies and labour markets. Excessive reliance in regions on one or several sectors expected to decline in the low carbon transition must therefore be prevented and alternative sources of economic activity sought in order to avoid regions and their inhabitants from becoming 'stranded'. The case study analysis further illustrated that a process of economic diversification can be helped by large scale investment in education and R&D planning to attract investors and retain qualified labour. Such actions have at least allowed the Ruhr area in NRW, Germany, to diversify its economy and mitigate the negative impacts brought about by the decline of coal mining, formerly an important sector in the region. In contrast, in the case of Jiu Valley, Romania, early action to develop new sectors and achieve economic diversification was not taken, resulting in persistent and structural issues from which it has been difficult to recover.

2. **Investing in renewable energy generation where the technical potential exists can mitigate some of the job and output losses in fossil fuel related sectors, and thus be an important element of a process of economic diversification.**

A common thread running through the modelled results is that, even if the energy transition may be good for the European economy as a whole, a considerable number of regions will still be negatively affected without further policy action. The E3ME-ERR model results suggest that the worst hit regions typically see increased employment and GVA in sectors such as construction and manufacturing, yet the these gains are outweighed by losses in GVA and jobs in a) electricity generation and supply activity, and b) mining and quarrying. This is due to high levels of fossil fuel capacity decommissions and lower fossil fuel mining and extraction in the scenario compared to the baseline. On the flipside, positive effects in the regions benefiting most in terms of increased 2030 GVA are driven by increased electricity generation and supply output, thanks to a high potential and deployment of renewable capacity within a region. This is often paired with higher service sector activity and employment due to positive indirect and induced employment effects. Similarly, in the GEM-E3-FIT results the key factor differentiating total 2030 impacts across regions is whether regions contribute to the deployment of RES or whether they produce fossil fuel and fossil-based power generation. Another factor contributing to regional performance is the level of industrialisation, as the renewal of equipment (e.g., more efficient electric appliances, electric vehicles etc.) yields benefits for a region hosting manufacturing industries producing this type of goods. The literature review and the case studies both pointed to various regions which have in the past been successful in compensating negative effects from a declining coal production by shifting to renewable energy generation.

3. **Political buy-in from workers, local communities and stakeholders is key to achieve 1 and 2, and this can be achieved through social protection, social dialogue, and stakeholder engagement.**

Although this is not a factor that can be explicitly presented in the modelling tools for the time being, the important role local communities' and stakeholders' attitudes can play in driving or resisting a successful transition resonates through both the literature and the case studies. The literature review suggests in this regard that changing the narrative to a positive will ease the necessary process of transition and will reduce political resistance and the negative lock-in effects of resisting change and diversification (Campbell & Coenen, 2017; Heilmann et al., 2020; Sartor, 2018; Zinecker et al., 2018). This is likely to affect the scale and speed of the transformation in these regions, and thus, the impact on workers and households in the long term. A key observation across all case studies is the need for stakeholder involvement and social dialogue. It was concluded in unambiguous terms that in each coal region investigated, "citizen support and public acceptance for the transition are vital for success – without this element the transition is likely to fail". The case studies also find that policies which aimed to preserve the status quo and limited or delayed action by governments to implement structural reform measures led to regions facing less coordinated action and reaping less of the benefits that could have been achieved if sufficient plans were made early on.

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Appendix A: E3ME-ERR sector maps

All NACE - Regional/Country total

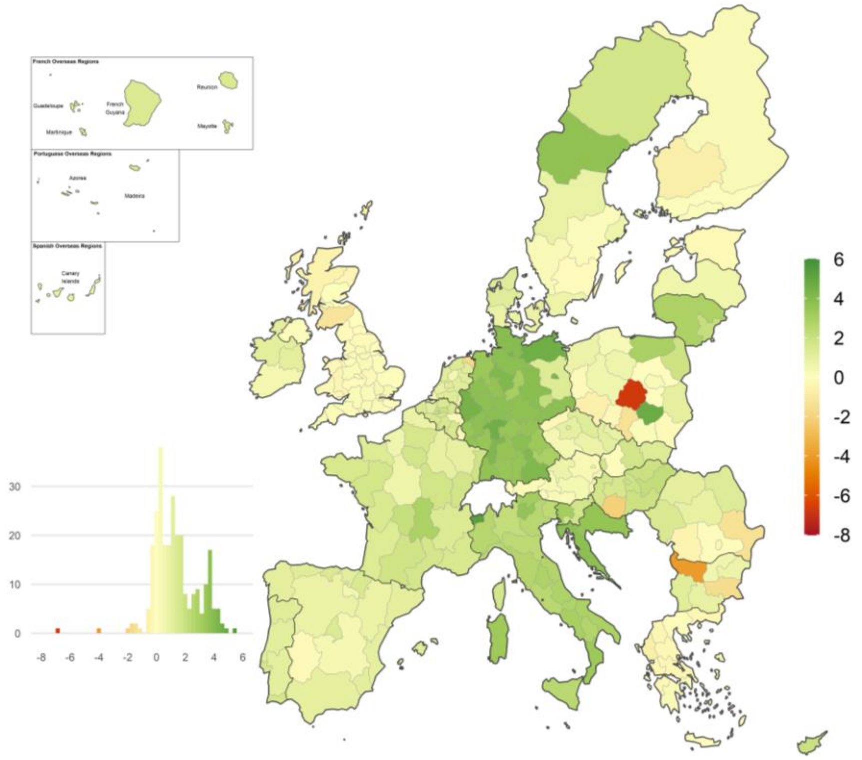


Figure A.1 - Relative E3ME-ERR 2030 GVA change in all sectors (difference-to-baseline)

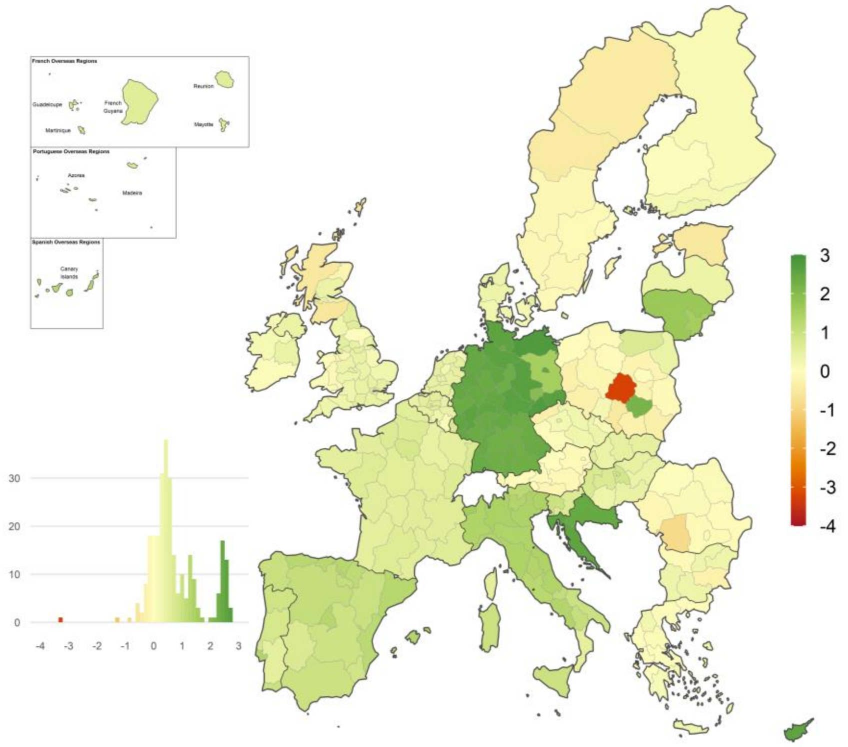


Figure A.2 - Relative E3ME-ERR 2030 employment change in all sectors (difference-to-baseline)

NACE A - Agriculture, forestry, and fishing

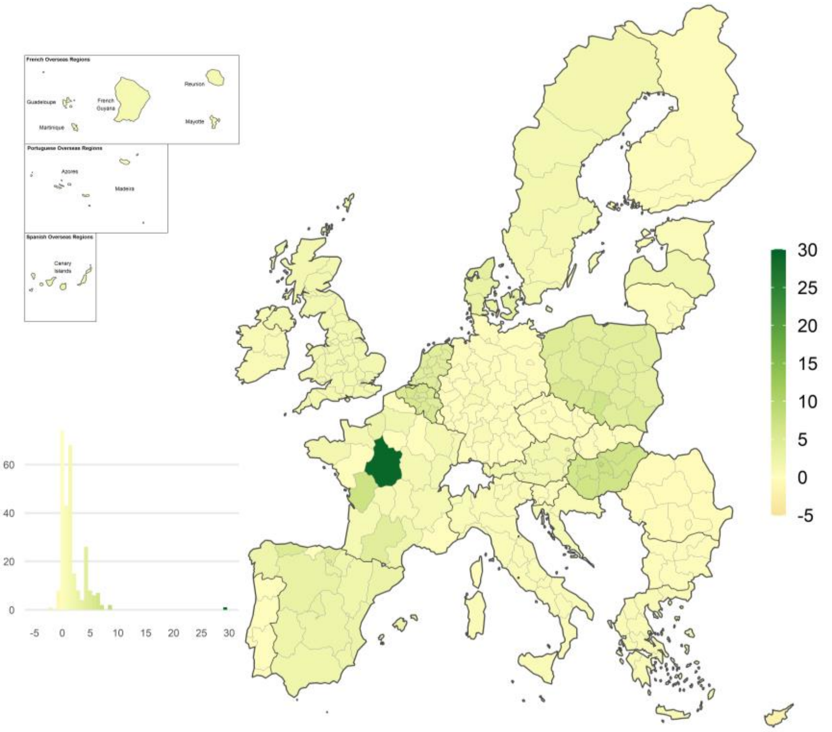


Figure A.3 - Relative E3ME-ERR 2030 GVA change in NACE A (difference-to-baseline)

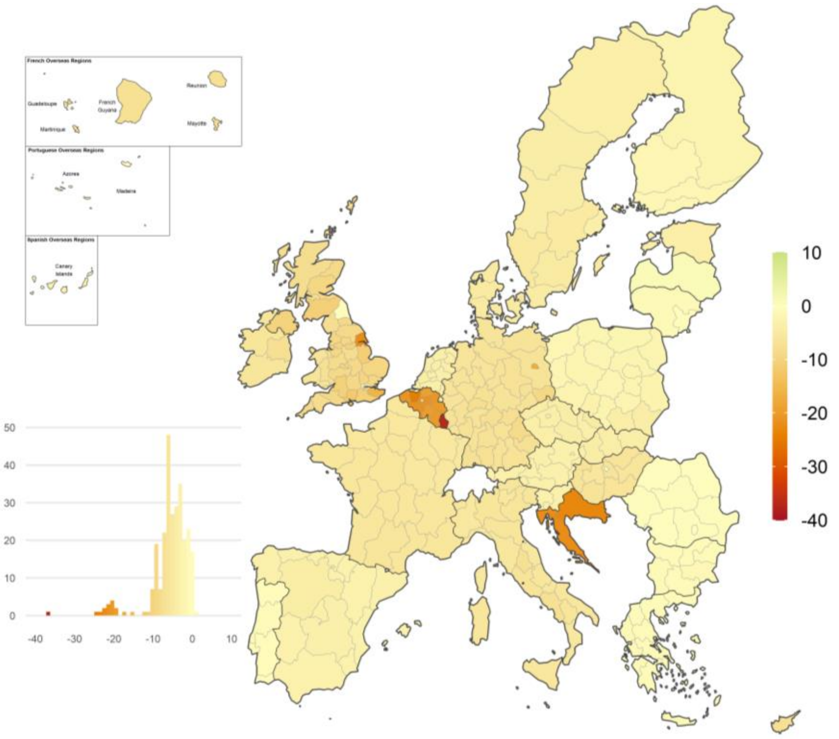


Figure A.4 - Relative E3ME-ERR 2030 employment change in NACE A (difference-to-baseline)

NACE B and E - Mining and quarrying; water supply and sewage

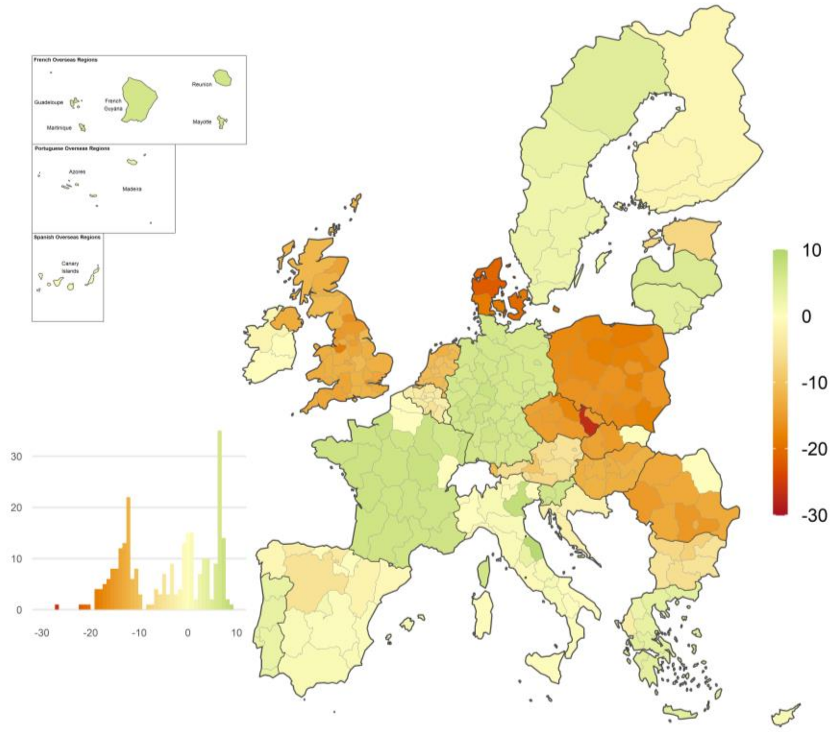


Figure A.5 - Relative E3ME-ERR 2030 GVA change in NACE B and E (difference-to-baseline)

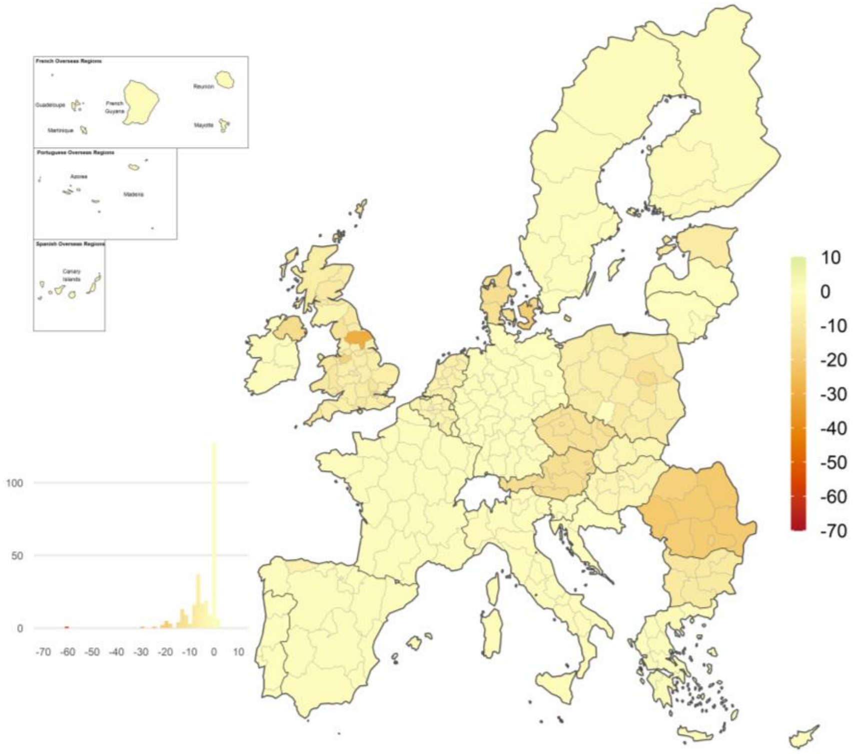


Figure A.6 - Relative E3ME-ERR 2030 employment change in NACE B and E (difference-to-baseline)

NACE C - Manufacturing

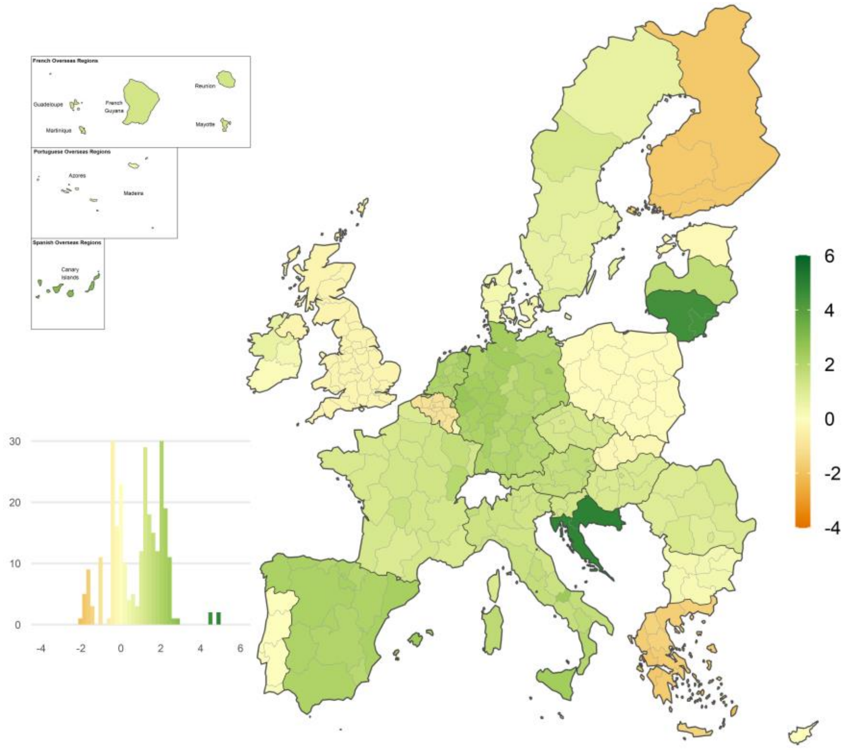


Figure A.7 - Relative E3ME-ERR 2030 GVA change in NACE C (difference-to-baseline)

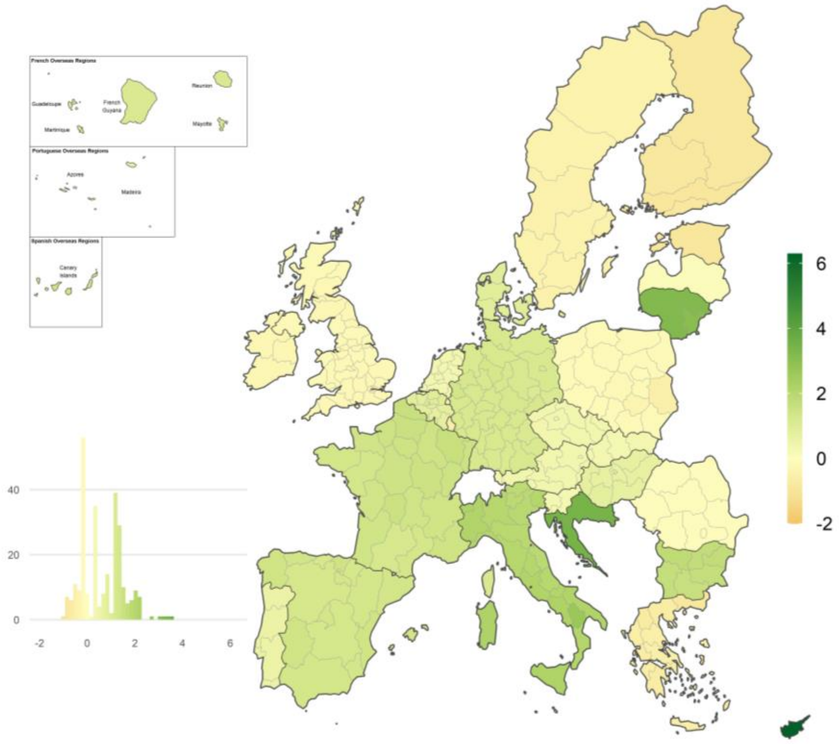


Figure A.8 - Relative E3ME-ERR 2030 employment change in NACE C (difference-to-baseline)

NACE D - Electricity, gas, steam and air conditioning supply

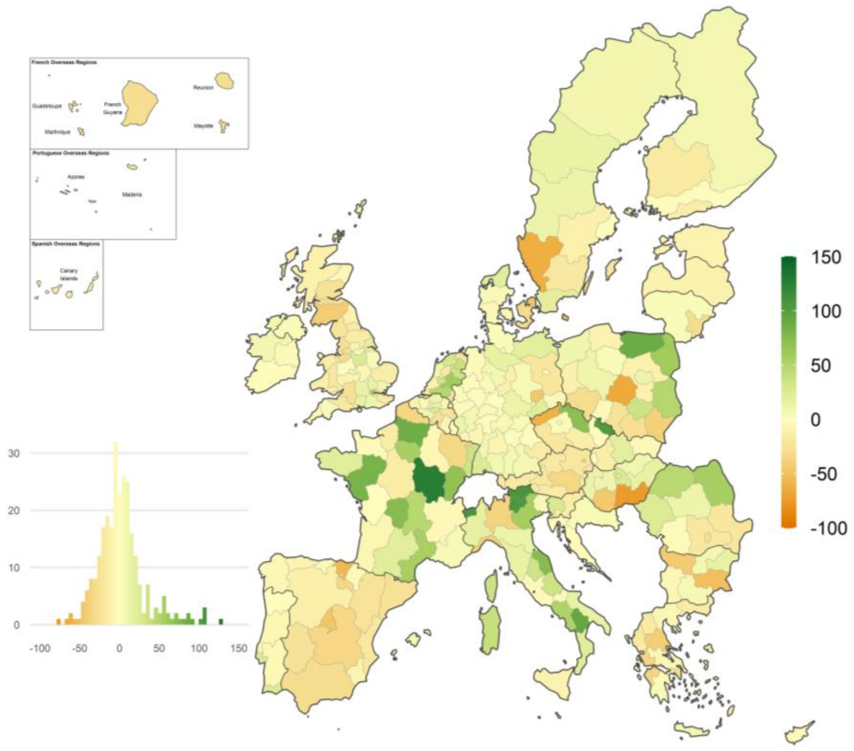


Figure A.9 - Relative E3ME-ERR 2030 GVA change in NACE D (difference-to-baseline)

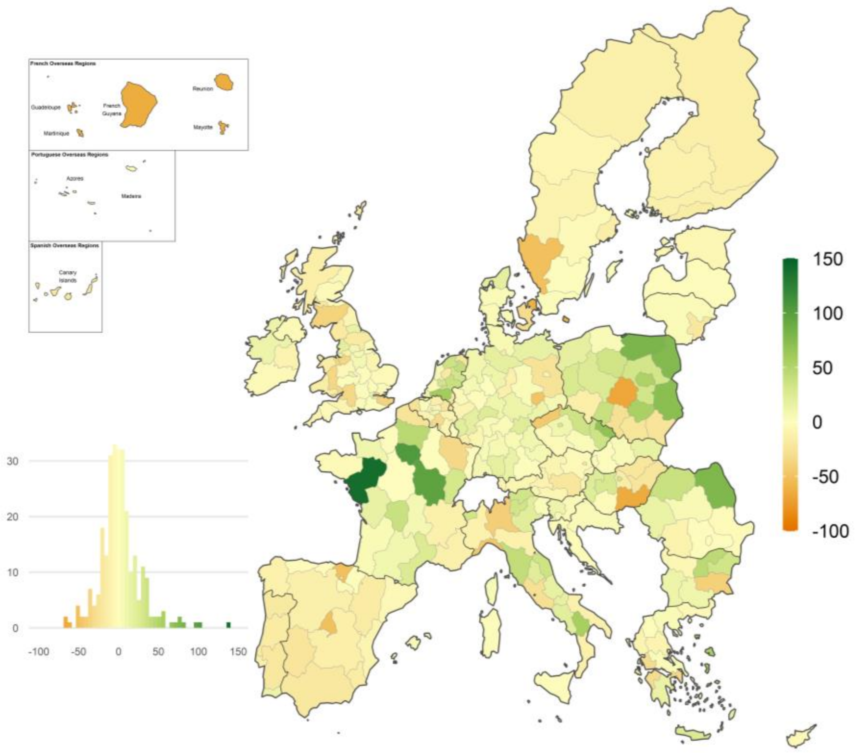


Figure A.10 - Relative E3ME-ERR 2030 employment change in NACE D (difference-to-baseline)

NACE F - Construction

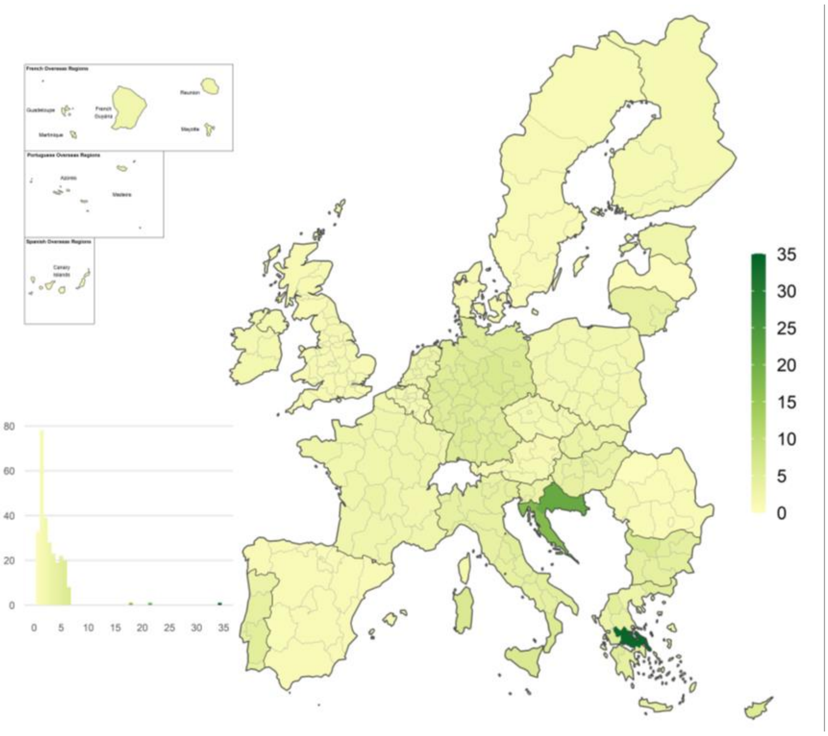


Figure A.11 - Relative E3ME-ERR 2030 GVA change in NACE F (difference-to-baseline)

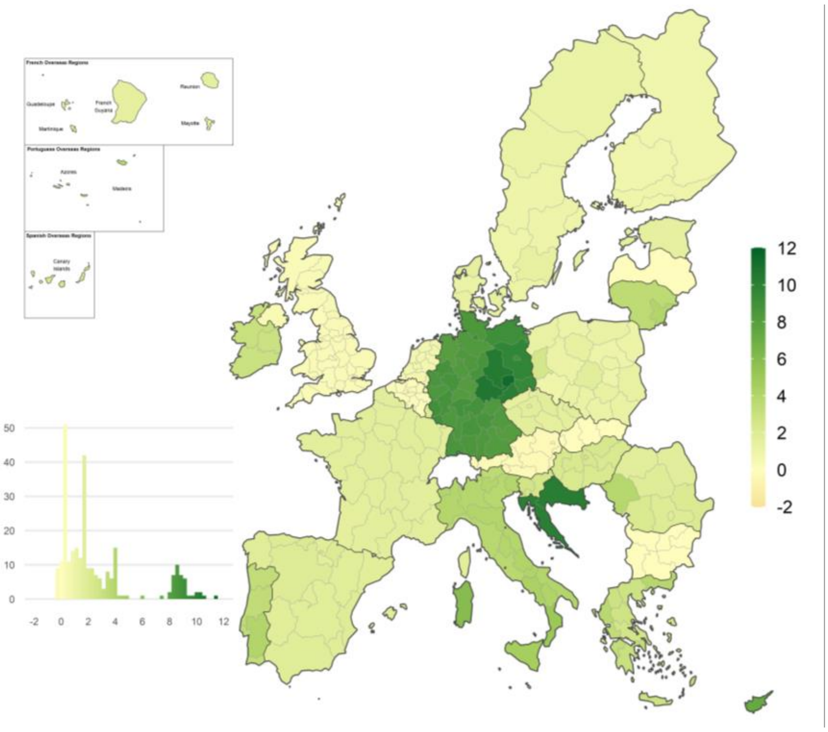


Figure A.12 - Relative E3ME-ERR 2030 employment change NACE F (difference-to-baseline)

NACE G-I - Wholesale and retail trade, transport, accommodation, and food service activities

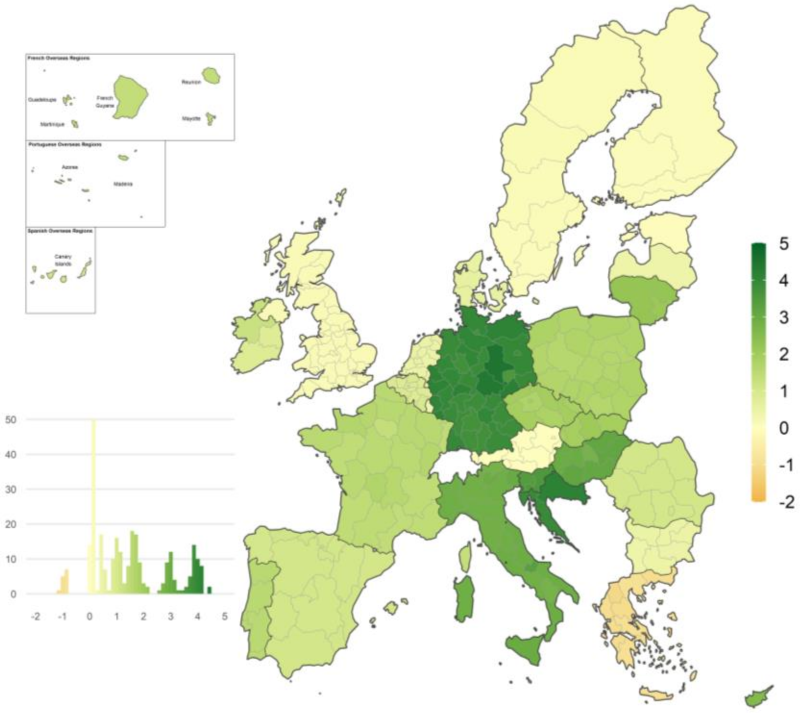


Figure A.13 - Relative E3ME-ERR 2030 GVA change in NACE G-I (difference-to-baseline)

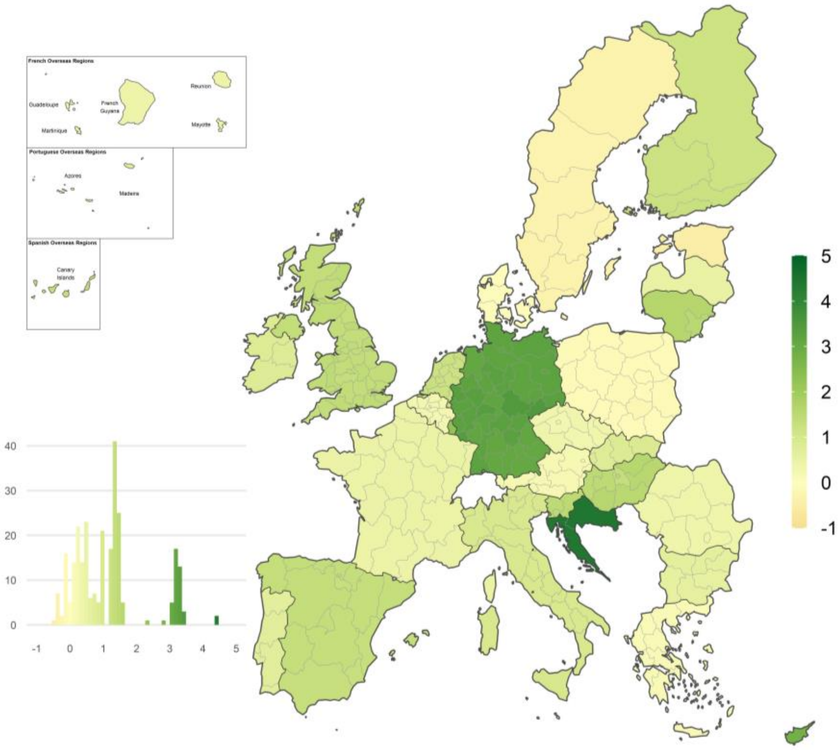


Figure A.14 - Relative E3ME-ERR 2030 employment change NACE G-I (difference-to-baseline)

NACE J - Information and communication

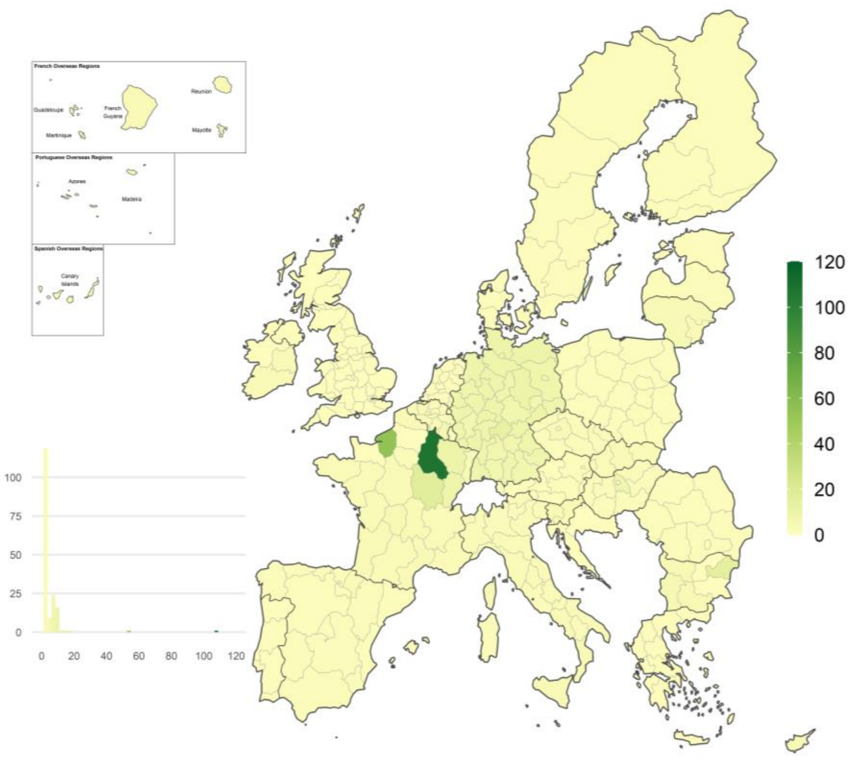


Figure A.15 - Relative E3ME-ERR 2030 GVA change in NACE J (difference-to-baseline)

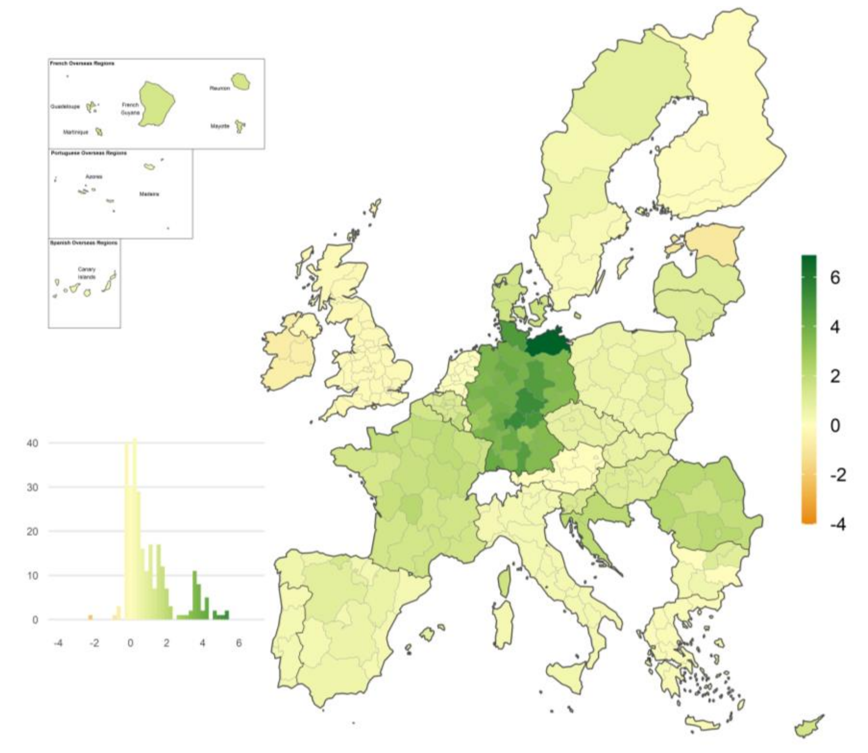


Figure A.16 - Relative E3ME-ERR 2030 employment change NACE J (difference-to-baseline)

NACE K - Financial and insurance activities

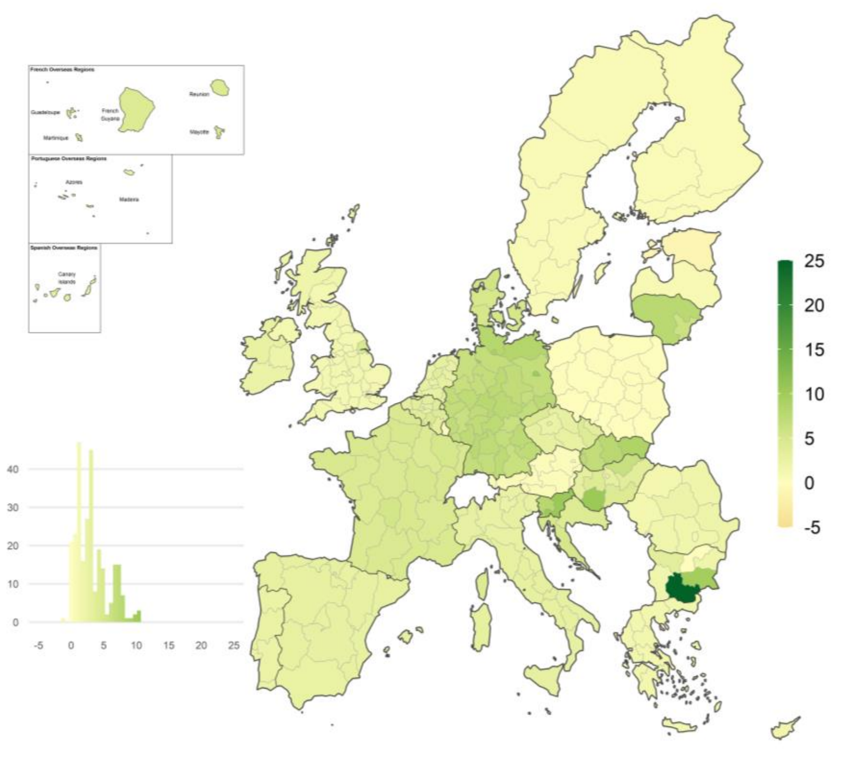


Figure A.17 - Relative E3ME-ERR 2030 GVA change in NACE K (difference-to-baseline)

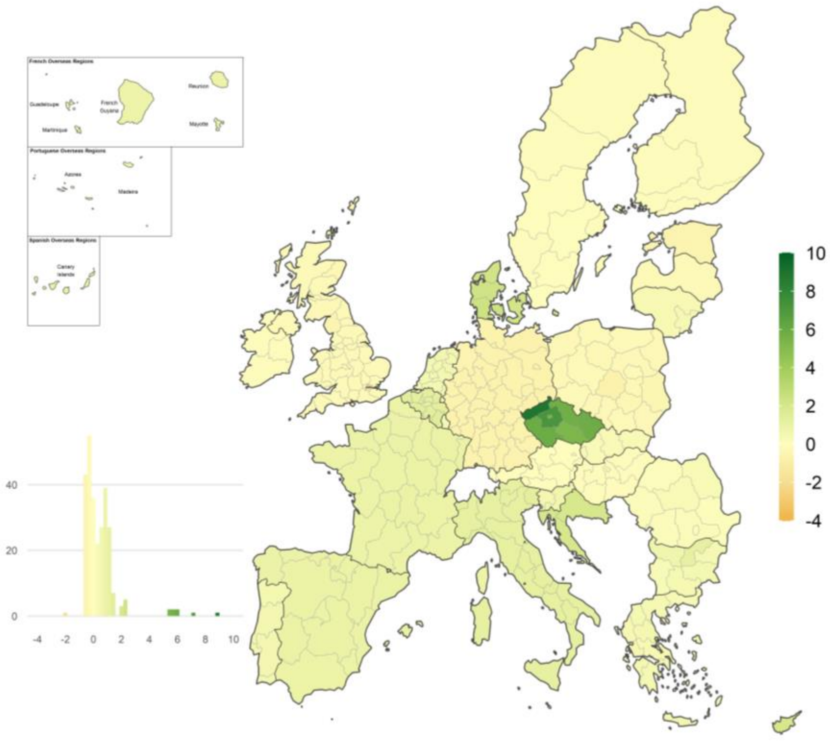


Figure A.18 - Relative E3ME-ERR 2030 employment change NACE K (difference-to-baseline)

NACE L - Real estate activities

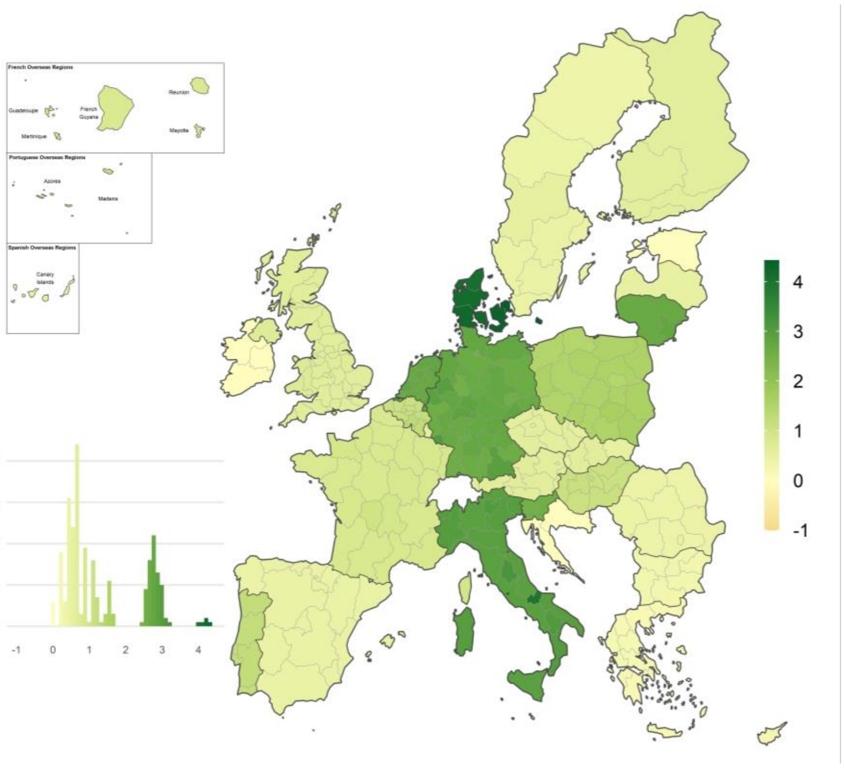


Figure A.19 - Relative E3ME-ERR 2030 GVA change in NACE L (difference-to-baseline)

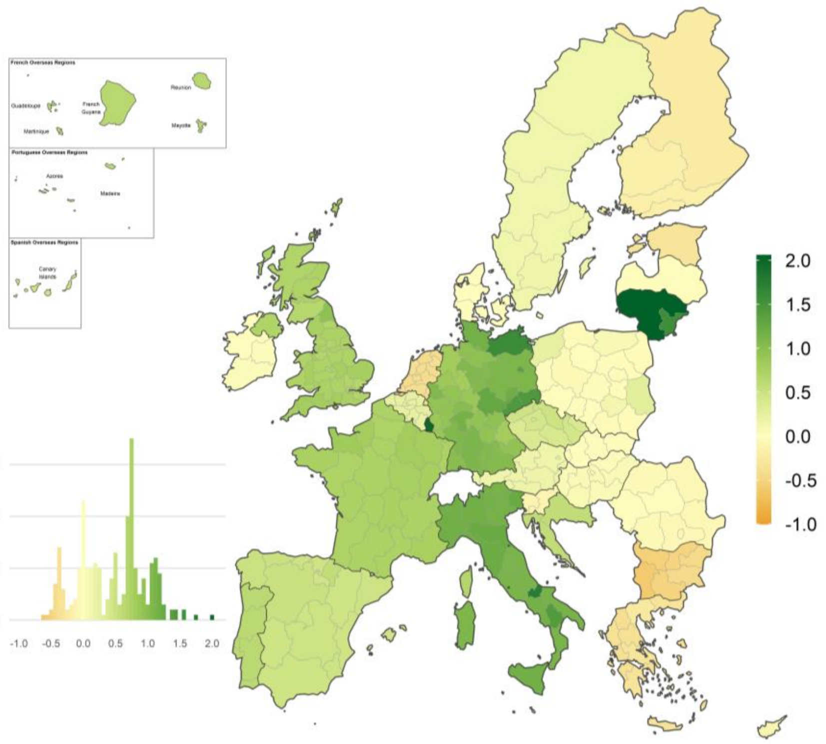


Figure A.20 - Relative E3ME-ERR 2030 employment change NACE L (difference-to-baseline)

NACE M-N - Professional, scientific, and technical activities; administrative and support service activities

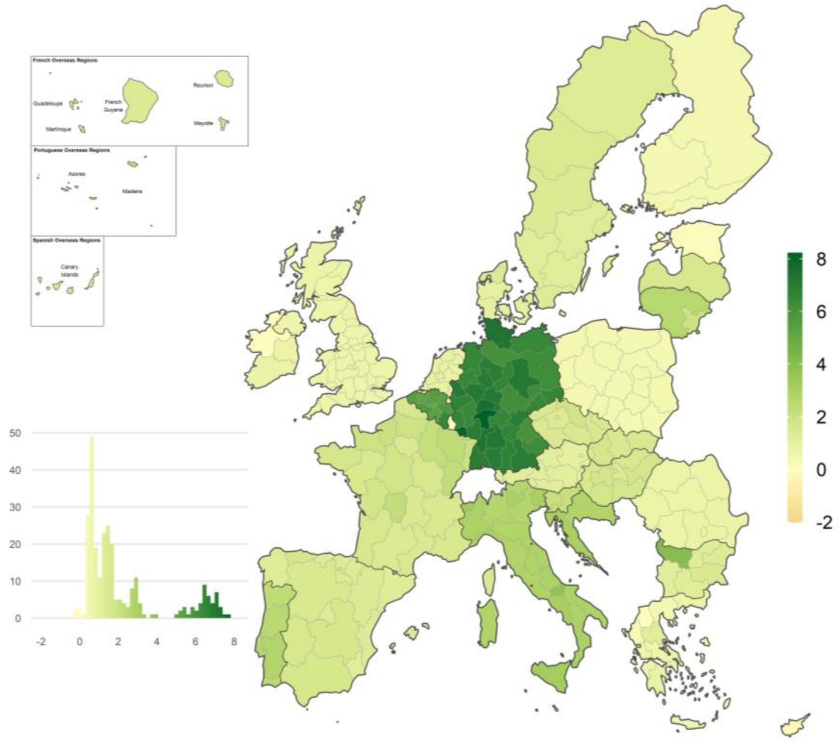


Figure A. 21 - Relative E3ME-ERR 2030 GVA change in NACE M-N (difference-to-baseline)

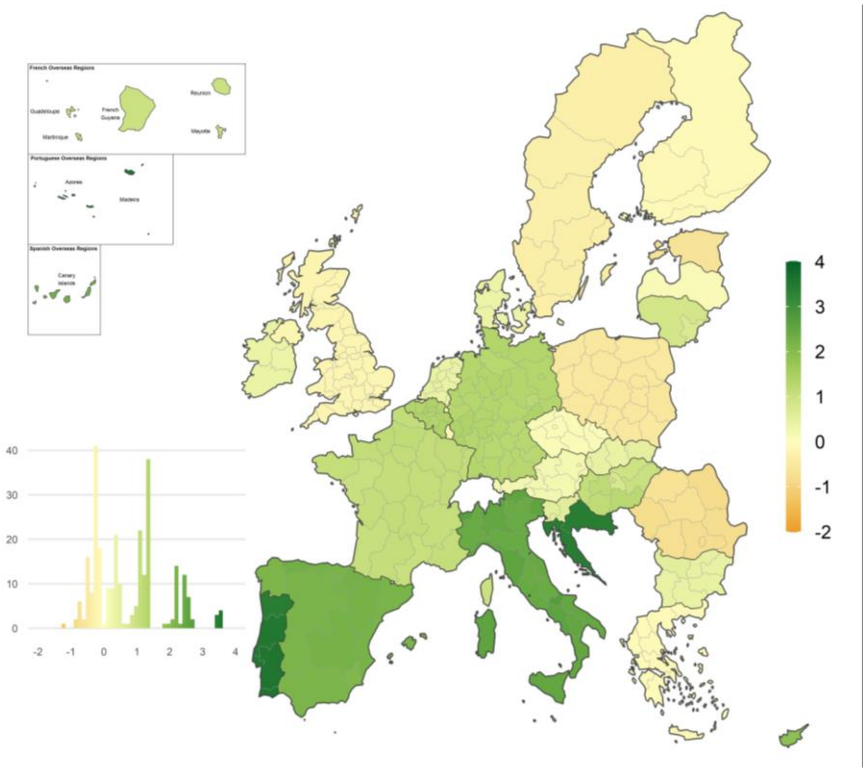


Figure A.22 - Relative E3ME-ERR 2030 employment change NACE M-N (difference-to-baseline)

NACE O-U - Public administration and defence; compulsory social security; education; human health and social work activities; arts, entertainment and recreation, repair of household goods and other services

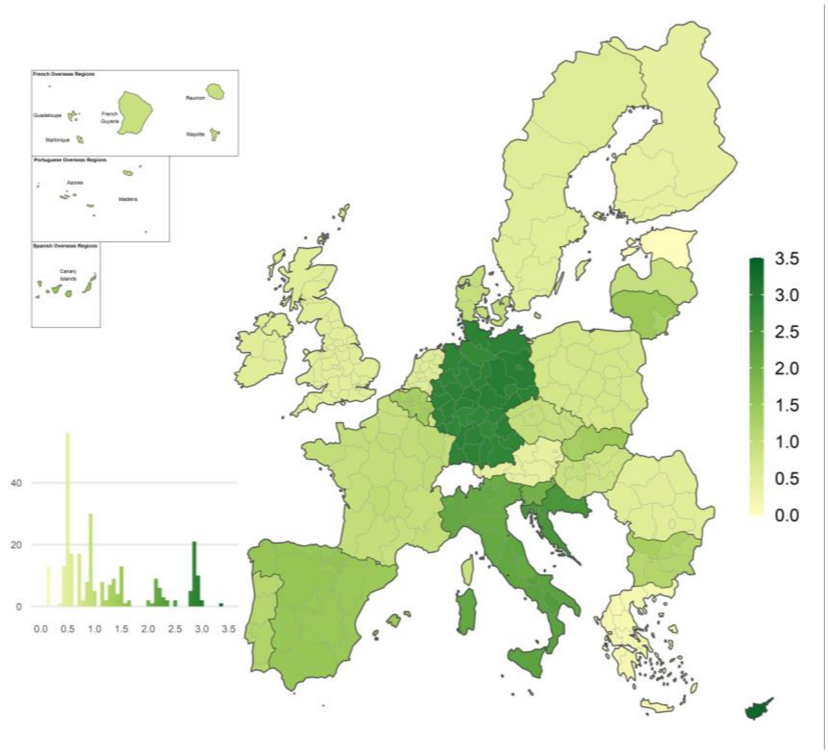


Figure A.23 - Relative E3ME-ERR 2030 GVA change in NACE O-U (difference-to-baseline)

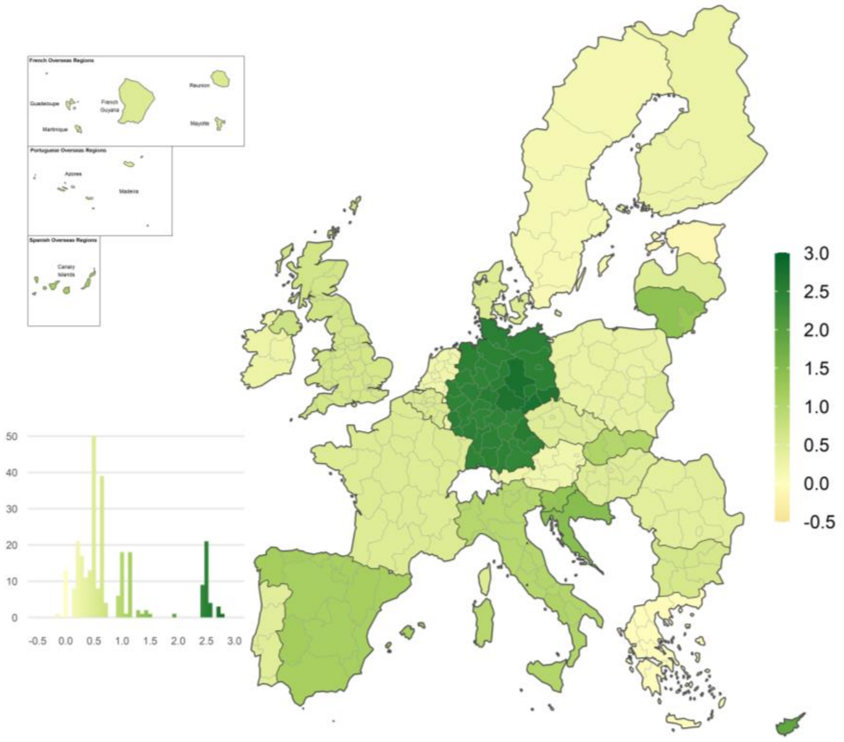


Figure A.24 - Relative E3ME-ERR 2030 employment change NACE O-U (difference-to-baseline)

Appendix B: GEM-E3-FIT-R sector maps

All NACE - Regional/Country total

Figure B.1 - Relative GEM-E3-FIT-R 2030 production change in all sectors (difference-to-baseline)

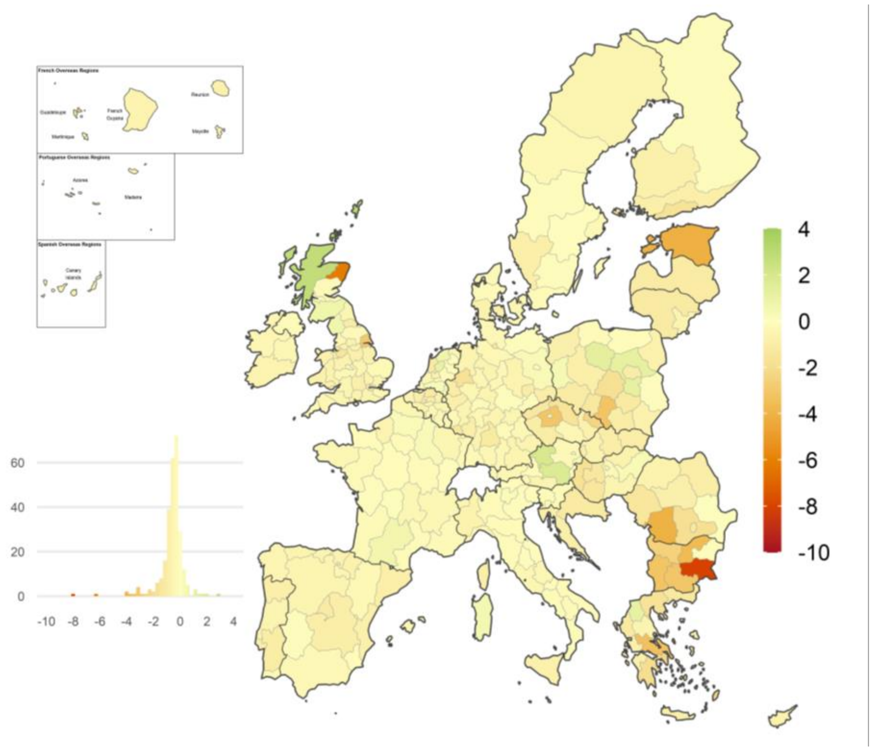
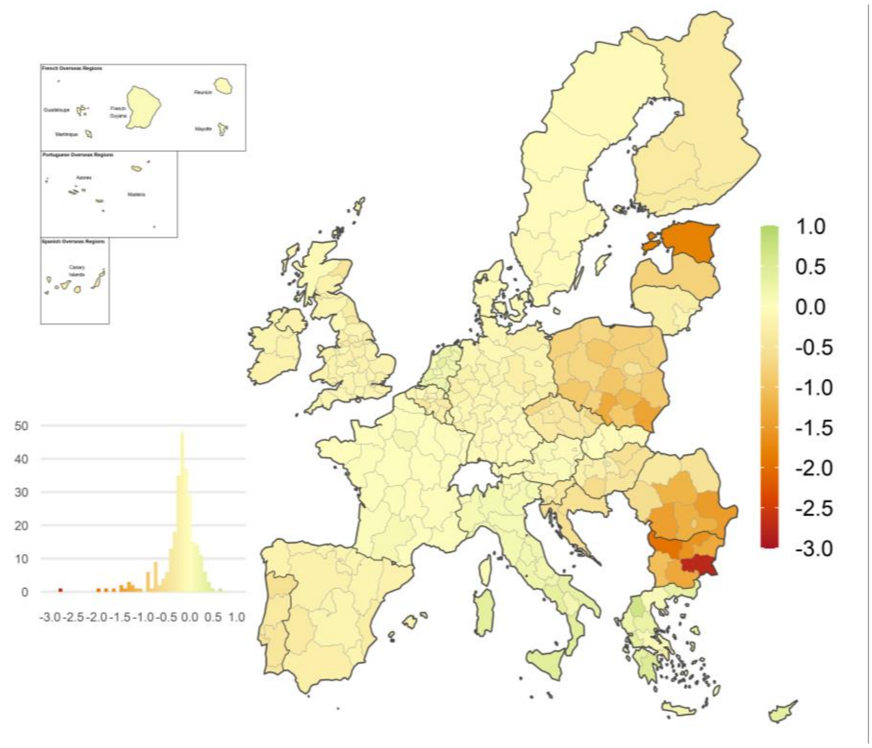


Figure B.2 - Relative GEM-E3-FIT-R 2030 employment change in all sectors (difference-to-baseline)



NACE A - Agriculture, forestry, and fishing

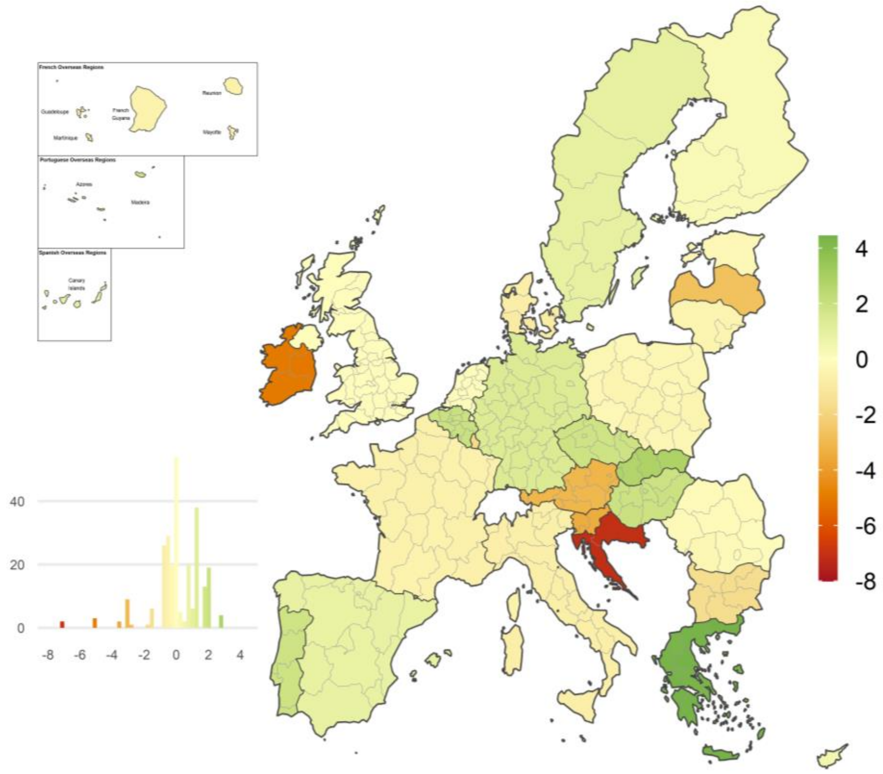


Figure B.3 - Relative GEM-E3-FIT-R 2030 production change in NACE A (difference-to-baseline)

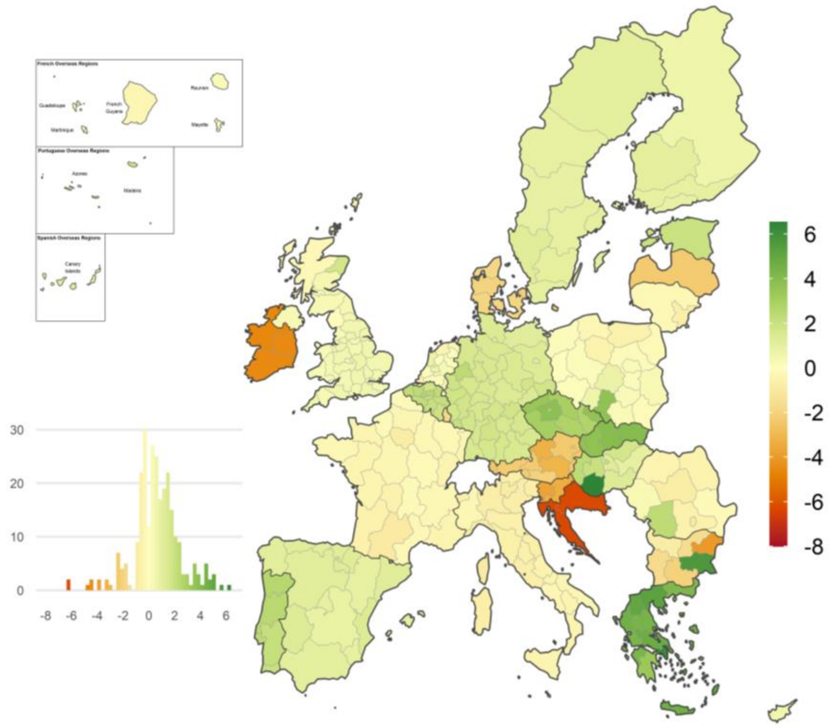


Figure B.4 - Relative GEM-E3-FIT-R 2030 employment change in NACE A (difference-to-baseline)

NACE B and E - Mining and quarrying; water supply and sewage

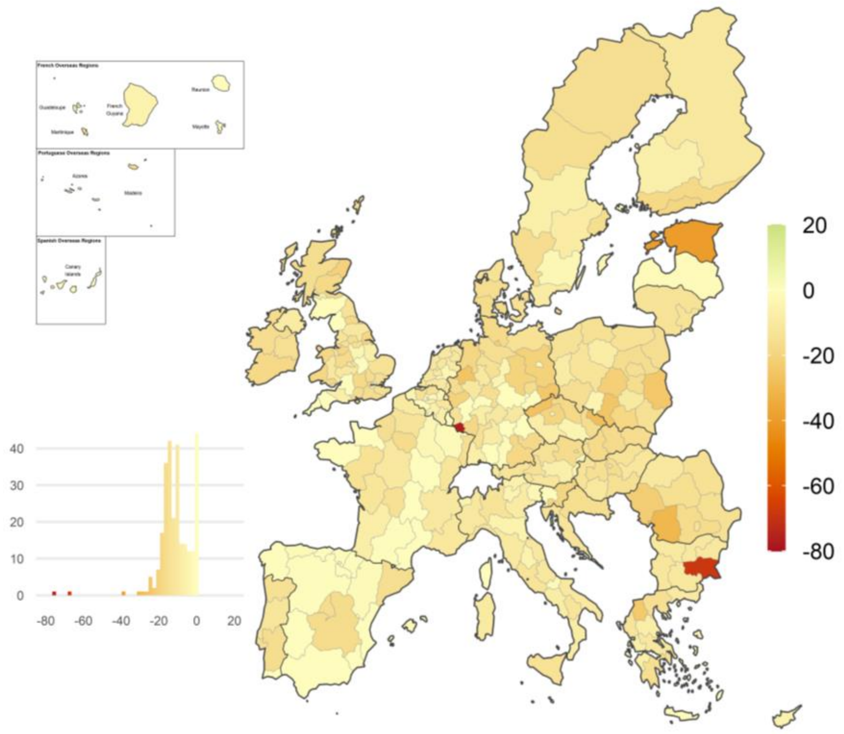


Figure B.5 - Relative GEM-E3-FIT-R 2030 production change in NACE B and E (difference-to-baseline)

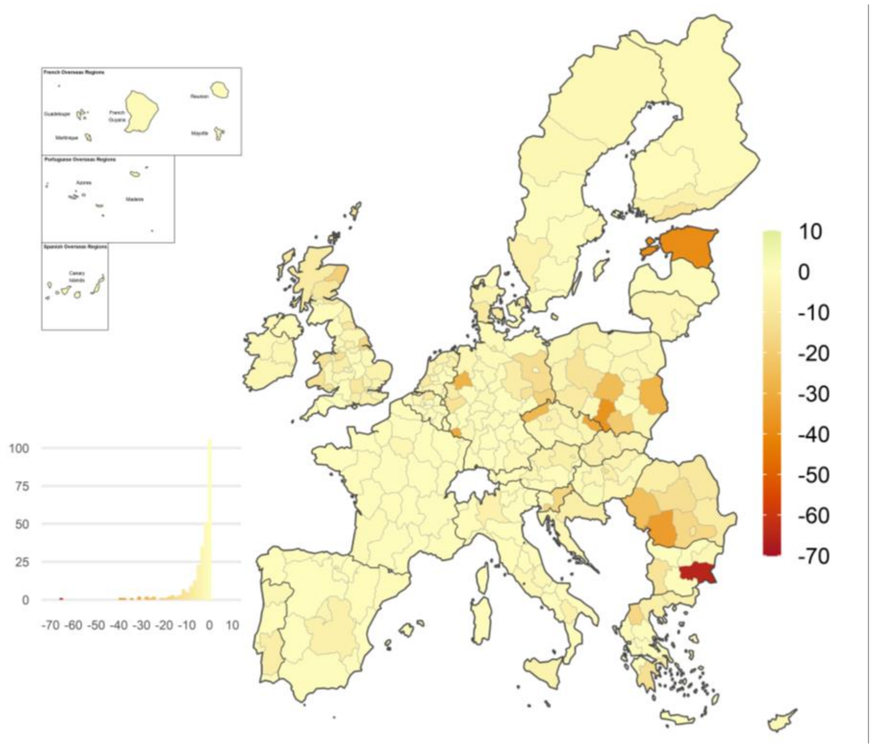


Figure B.6 - Relative GEM-E3-FIT-R 2030 employment change in NACE B and E (difference-to-baseline)

NACE C - Manufacturing

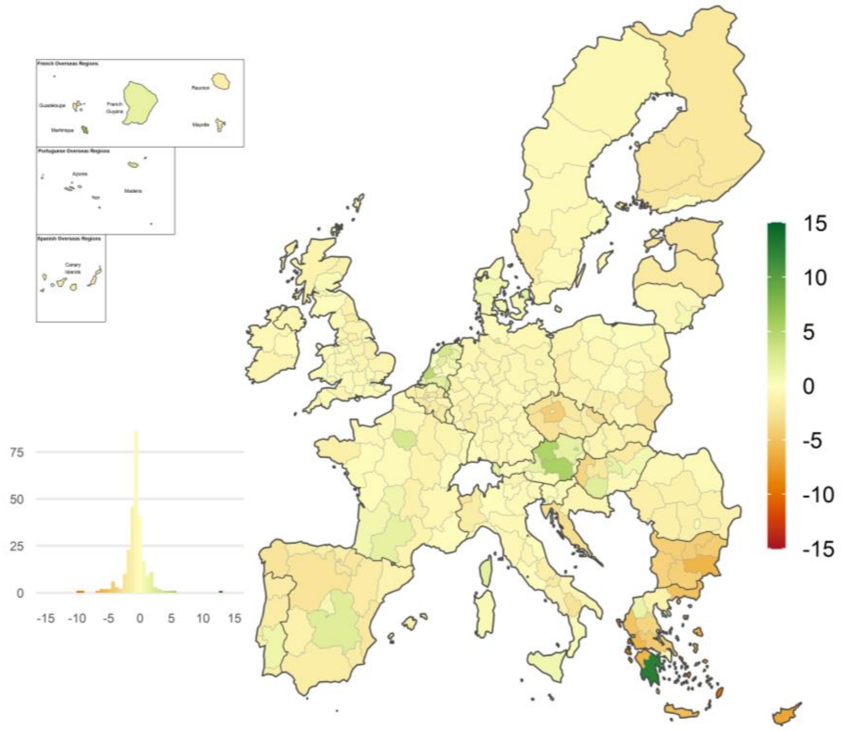


Figure B.7 - Relative GEM-E3-FIT-R 2030 production change in NACE C (difference-to-baseline)

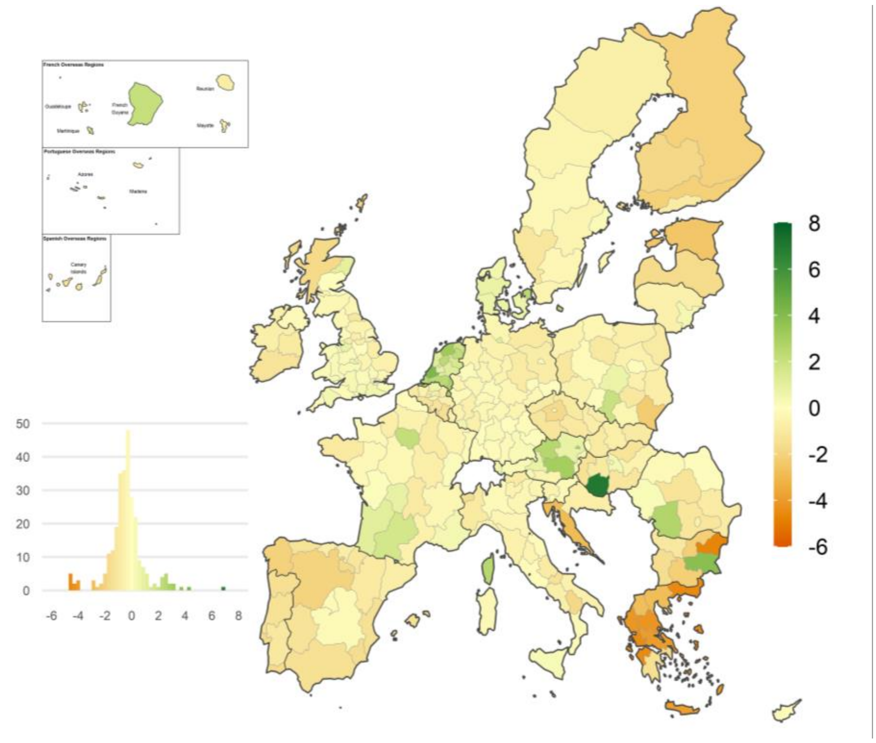


Figure B.8 - Relative GEM-E3-FIT-R 2030 employment change in NACE C (difference-to-baseline)

NACE D - Electricity, gas, steam and air conditioning supply

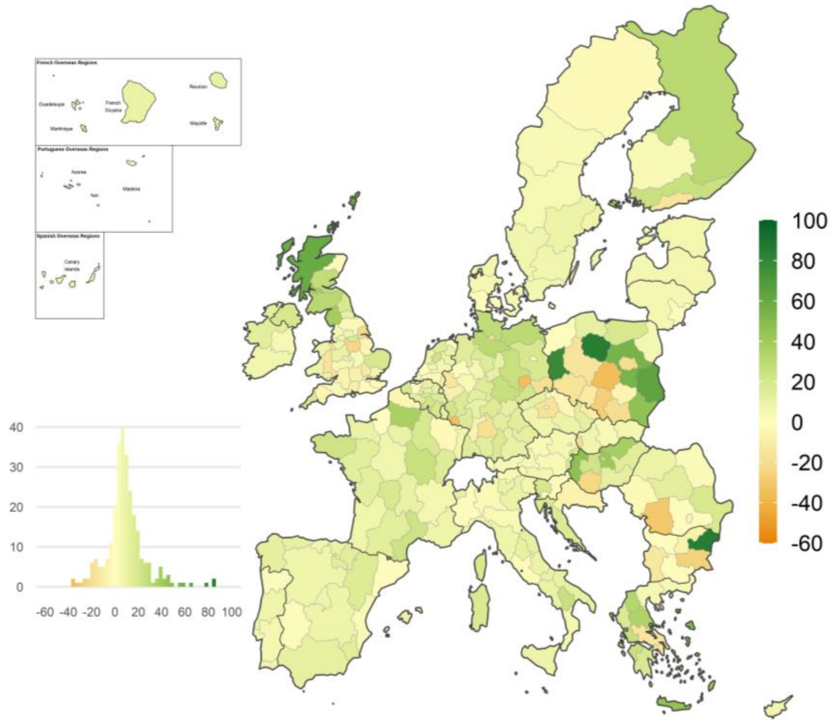


Figure B.9 - Relative GEM-E3-FIT-R 2030 production change in NACE D (difference-to-baseline)

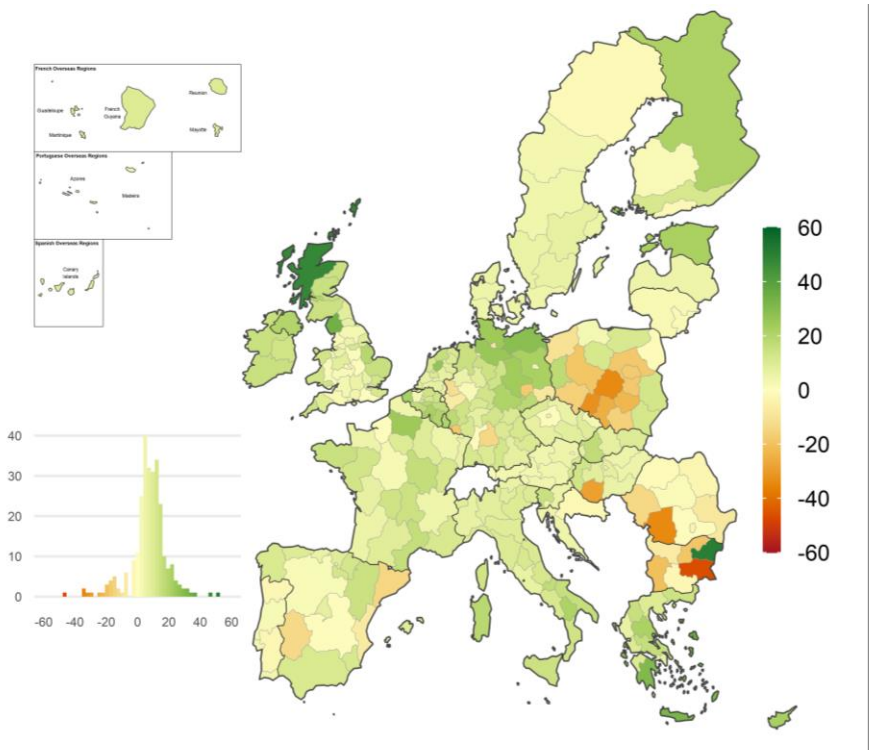


Figure B.10 - Relative GEM-E3-FIT-R 2030 employment change in NACE D (difference-to-baseline)

NACE F - Construction

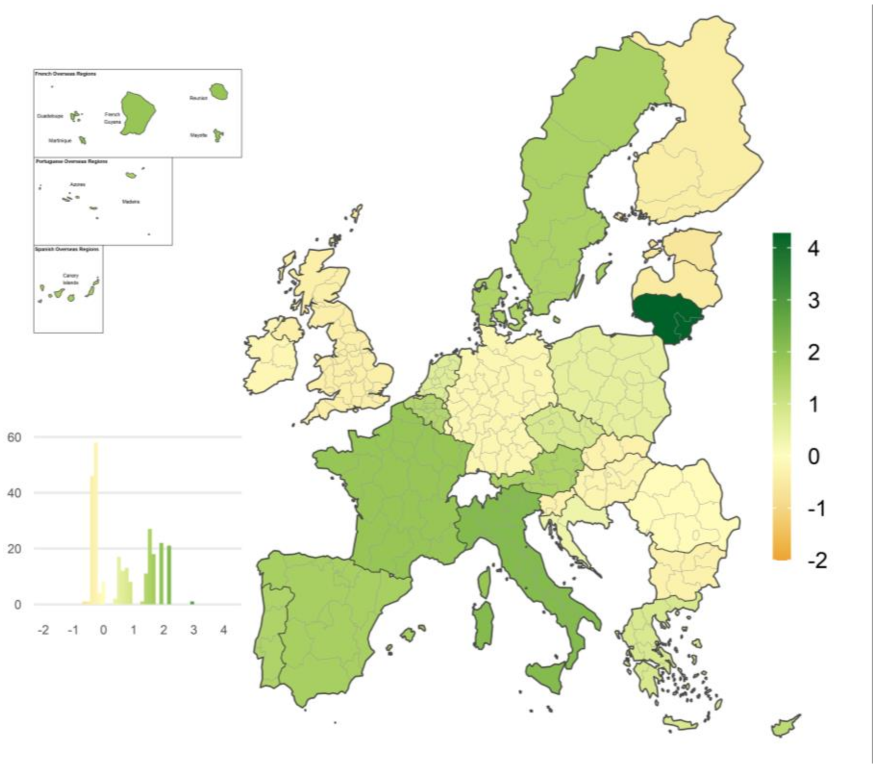


Figure B.11 - Relative GEM-E3-FIT-R 2030 production change in NACE F (difference-to-baseline)

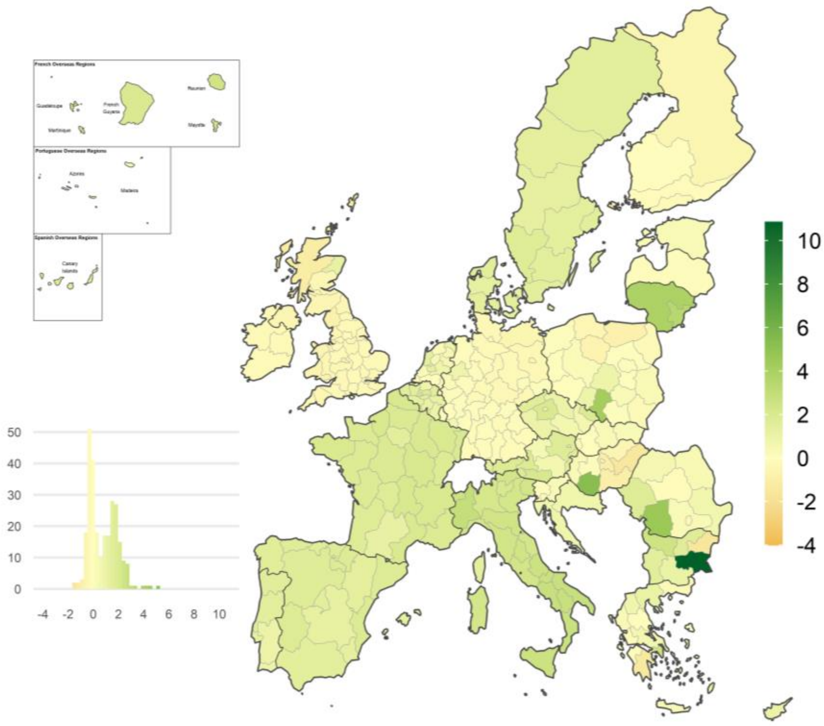


Figure B.12 - Relative GEM-E3-FIT-R 2030 employment change NACE F (difference-to-baseline)

NACE G-I - Wholesale and retail trade, transport, accommodation, and food service activities

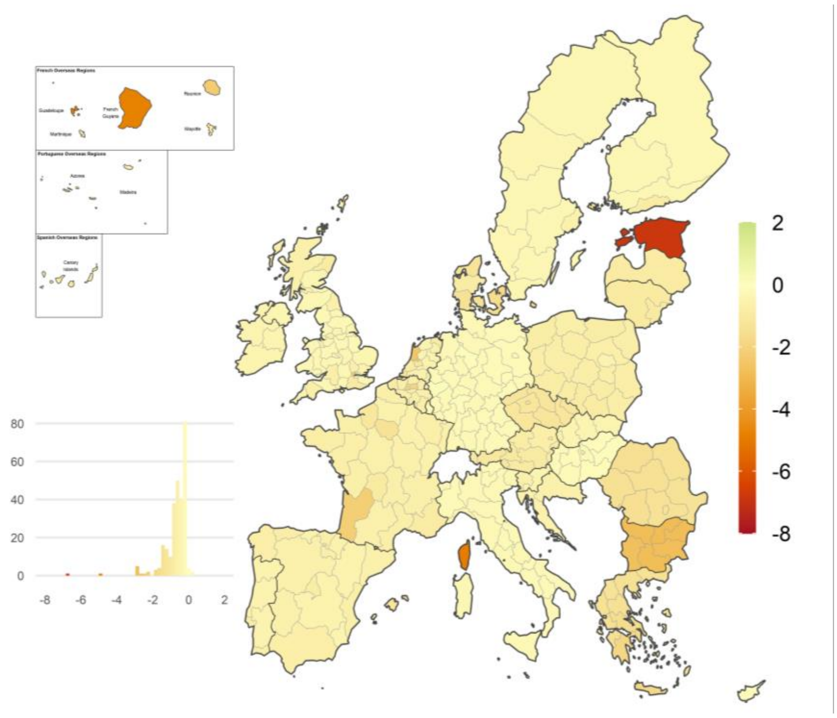


Figure B.13 - Relative GEM-E3-FIT-R 2030 production change in NACE G-I (difference-to-baseline)

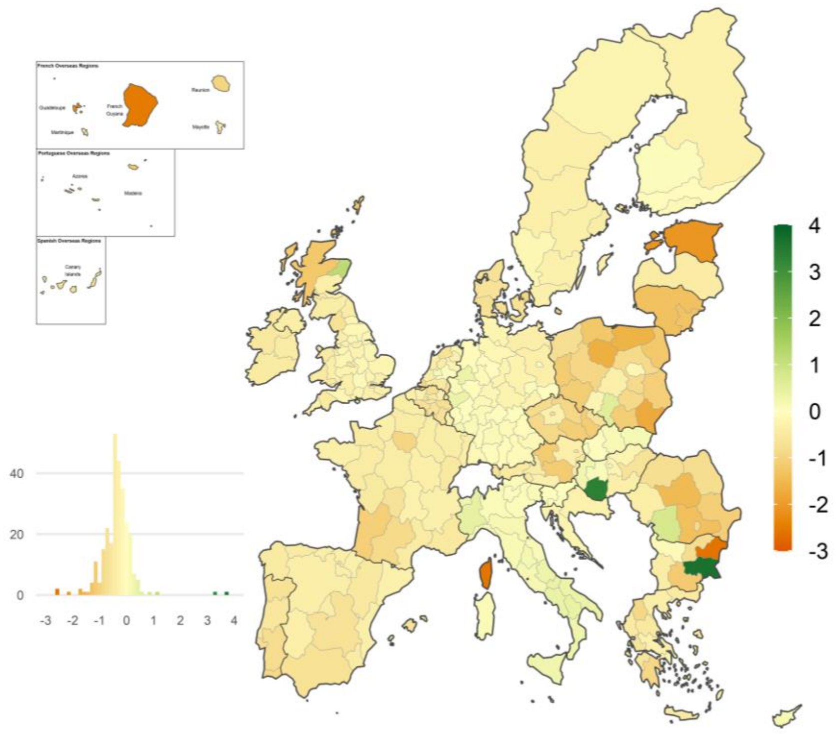


Figure B.14 - Relative GEM-E3-FIT-R 2030 employment change NACE G-I (difference-to-baseline)

NACE J - Information and communication

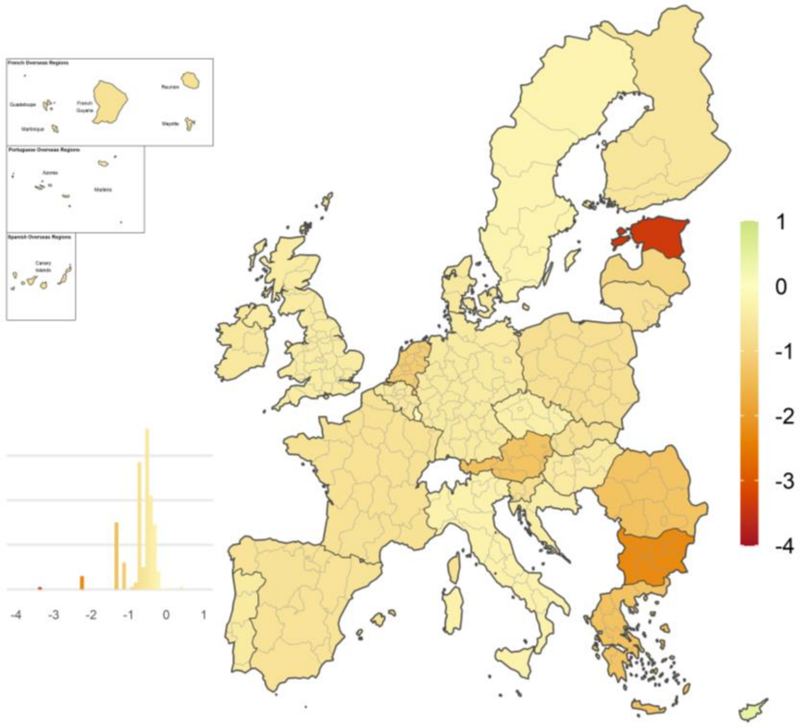


Figure B.15 - Relative GEM-E3-FIT-R 2030 production change in NACE J (difference-to-baseline)

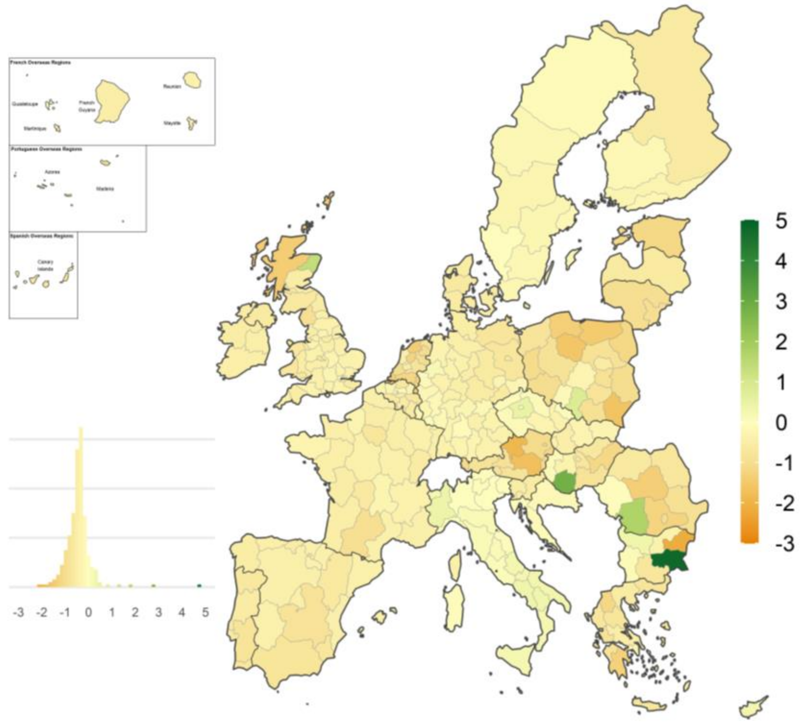


Figure B.16 - Relative GEM-E3-FIT-R 2030 employment change NACE J (difference-to-baseline)

NACE K - Financial and insurance activities

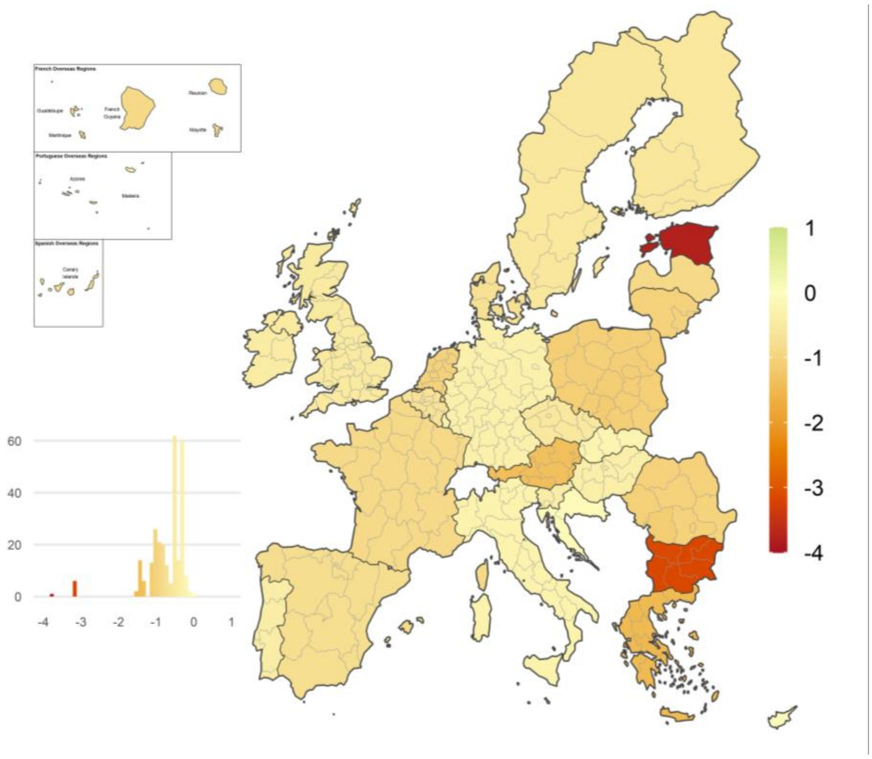


Figure B.17 - Relative GEM-E3-FIT-R 2030 production change in NACE K (difference-to-baseline)

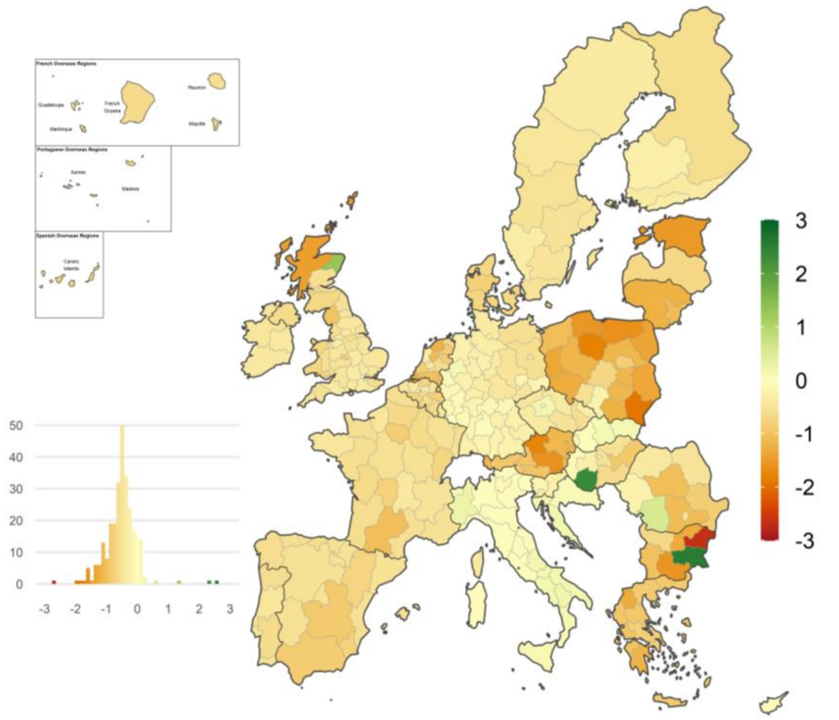


Figure B.18 - Relative GEM-E3-FIT-R 2030 employment change NACE K (difference-to-baseline)

NACE L - Real estate activities

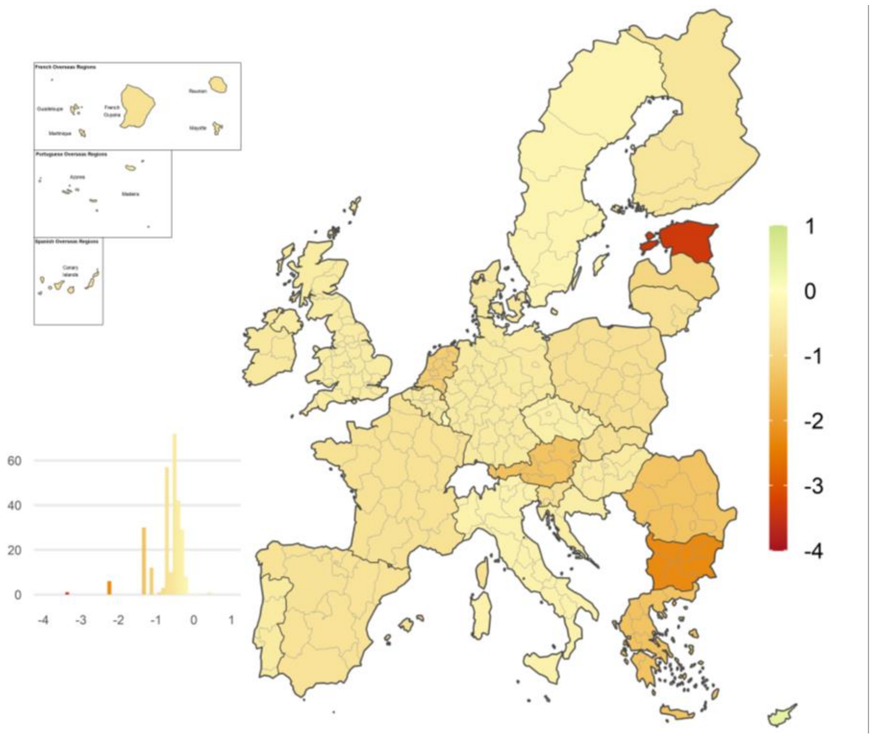


Figure B.19 - Relative GEM-E3-FIT-R 2030 production change in NACE L (difference-to-baseline)

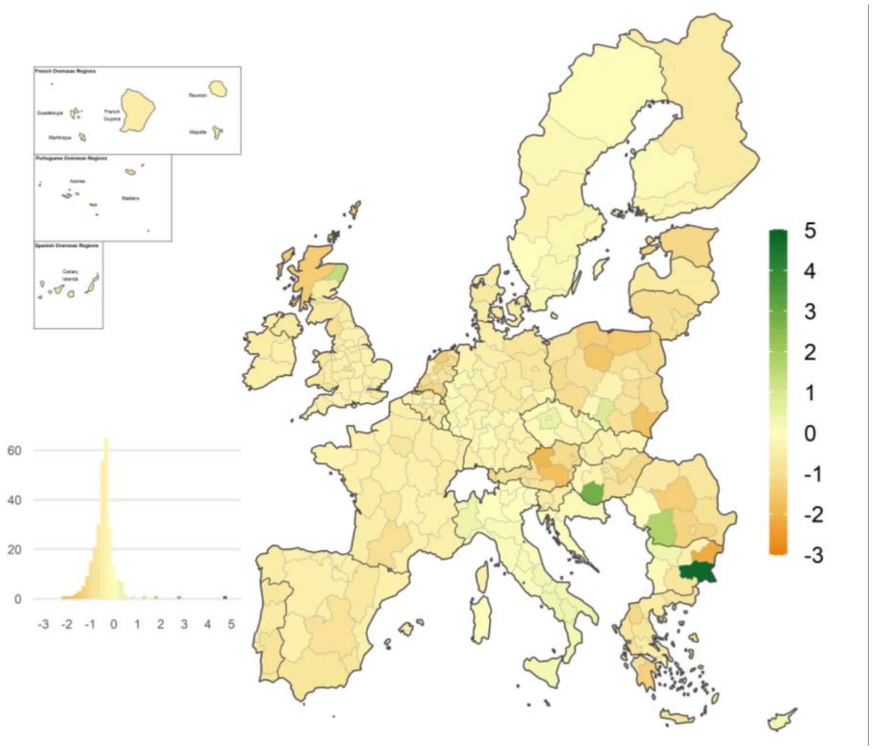


Figure B.20 - Relative GEM-E3-FIT-R 2030 employment change NACE L (difference-to-baseline)

NACE M-N - Professional, scientific, and technical activities; administrative and support service activities

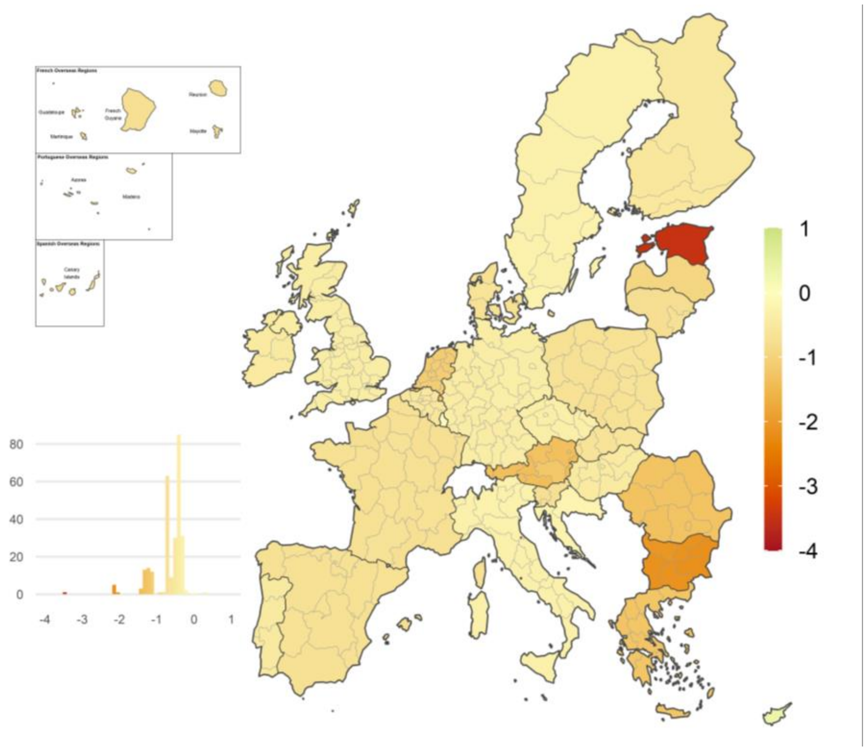


Figure B.21 - Relative GEM-E3-FIT-R 2030 production change in NACE M-N (difference-to-baseline)

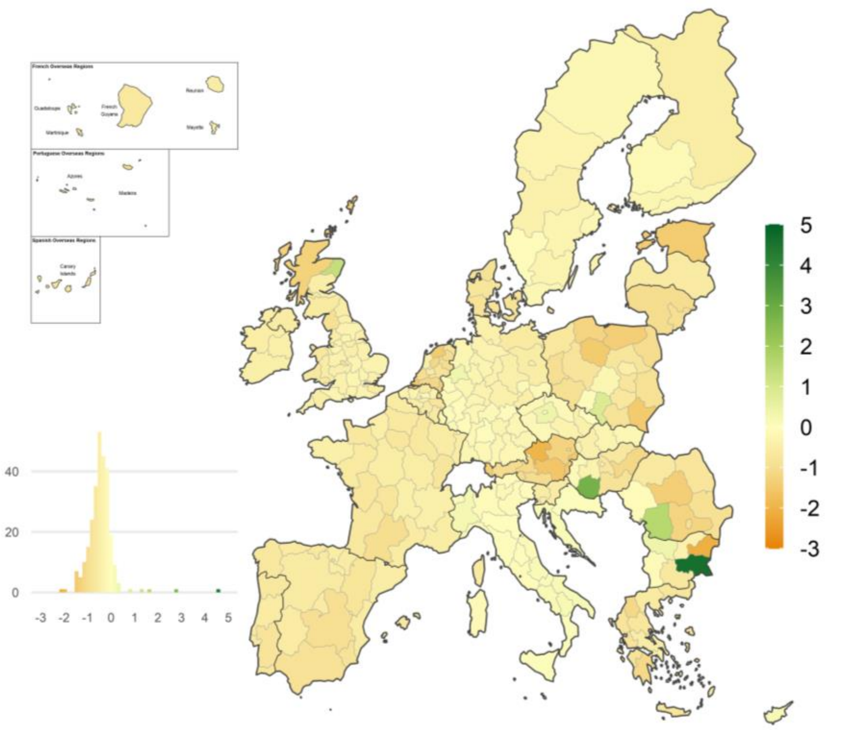


Figure B.22 - Relative GEM-E3-FIT-R 2030 employment change NACE M-N (difference-to-baseline)

NACE O-U - Public administration and defence; compulsory social security; education; human health and social work activities; arts, entertainment and recreation, repair of household goods and other services

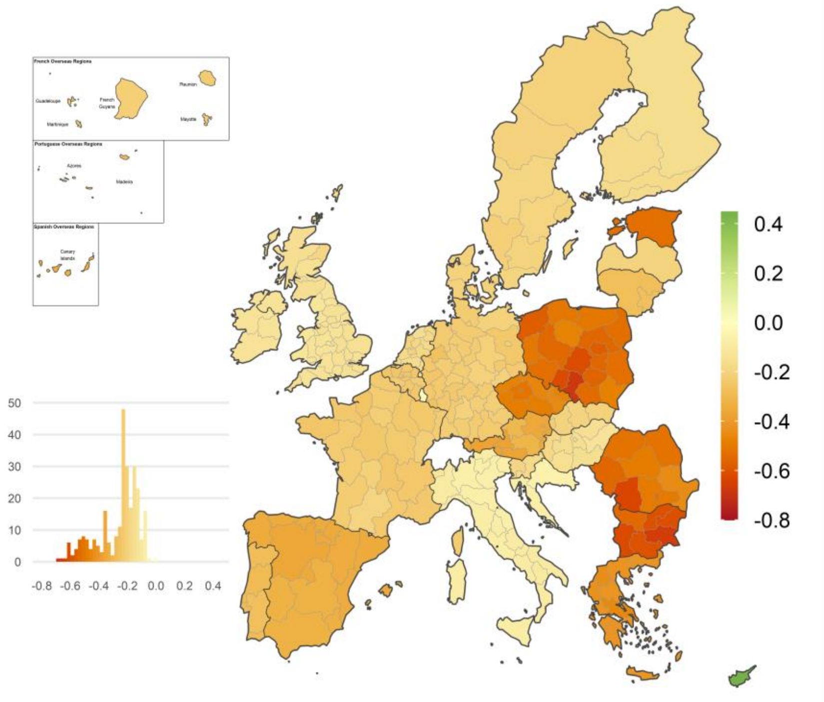


Figure B.23 - Relative GEM-E3-FIT-R 2030 production change in NACE O-U (difference-to-baseline)

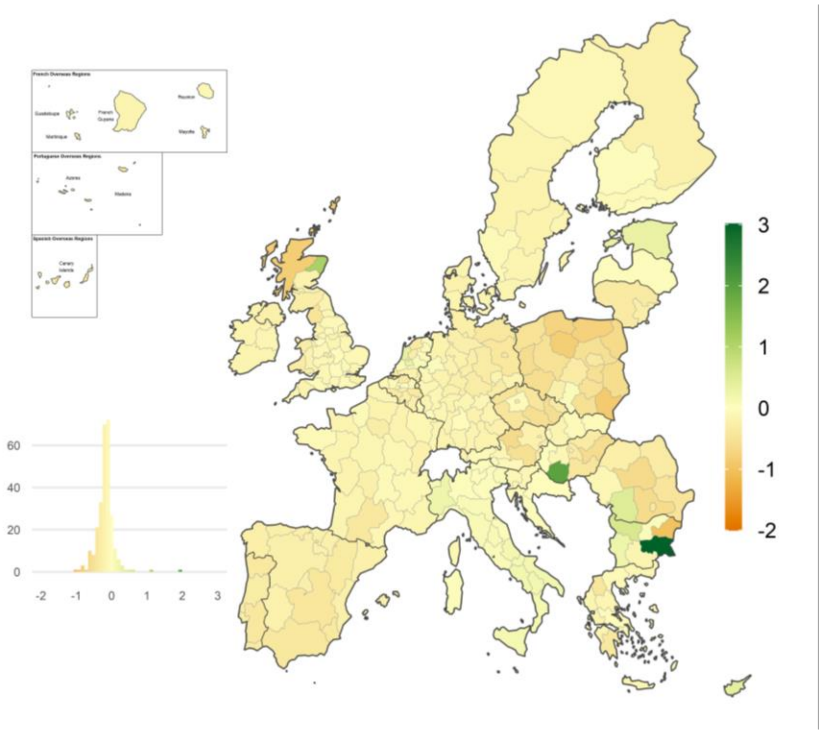


Figure B.24 - Relative GEM-E3-FIT-R 2030 employment change NACE O-U (difference-to-baseline)

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