OECD Regional Development Studies

Regional Industrial Transitions to Climate Neutrality

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Foreword

One hundred and thirty-six countries, covering 83% of global carbon emissions, have committed to net-zero greenhouse gas emission targets in the coming decades, including almost all OECD countries. As the OECD International Programme for Action on Climate (IPAC) has stated, climate risks will only be significantly reduced if net-zero carbon emissions in 2050 are reached. The challenge is turning country commitments and ambitions into actual outcomes and pathways to carbon neutrality.

This report aims to help policy makers fill the gap between targets and required actions in sectors where reaching climate neutrality will be particularly challenging. It goes further by identifying which specific regions will be most affected by the transformations needed in these sectors, including through the prism of socio-economic impacts and related infrastructure needs.

Taking climate action to the regions can help us gain the momentum we need and make the transition just. Many subnational governments and cities have set more ambitious targets than their national governments, highlighting how important they are to scale up action.

Emissions are often concentrated in some regions. As the *OECD Regional Outlook 2021* showed, in most OECD countries, industrial emissions per capita in a few large subnational regions are a high multiple of the national average.

The impact on jobs also differs strongly. The share of jobs in sectors at risk of job loss is twice the national average or more in large subnational regions.

The socio-economic context also differs across regions. Some are better able to undertake needed transformations and deal with them than others, for example because their firms are more technologically advanced or their workers better trained.

This report presents data analysis on all of these dimensions for European regions, reflecting the availability of consistent data for European Union (EU) countries, including from the EU's emission trading system.

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Abbreviations and acronyms

CCS	Carbon capture and storage
CCU	Carbon capture and use
CCUS	Carbon capture, Use and storage
CE	Circular Economy pathway
CSP	Concentrated solar power
EC	European Commission
EFTA	European Free Trade Association
EGD	European Green Deal
EU ETS	European Union Emission Trading System
EU27	27 member countries of the European Union
Eurostat SBS	Eurostat Structural Business Statistics
EUTL	European Union Transaction Log
GHG	Greenhouse gas
IEA	International Energy Agency
KWh	Kilowatt-hour
LNG	Liquified natural gas
LOHC	Liquid organic hydrogen carrier
MENA	Middle East and North Africa
NACE	Nomenclature of Economic Activities. Classification of economic activities at different levels of detail.
NP	New Processes pathway
NUTS	Nomenclature of Territorial Units for Statistics. It refers to the EU system for classification of regions at different levels of detail.
Orbis	Cross-country firm-level database by Bureu Van Dijk
PV	Photovoltaic
RE	Renewable energy
SDS	Sustainable Development Scenario
SES	Structure of Earnings Survey
tCO_2e	Tonnes of carbon dioxide equivalent
TL	Territorial level. It refers to the OECD system for classification of regions at different levels of detail.
TWh	Terawatt-hour
UBA	German Federal Environment Agency

Executive summary

Some of the economic activities that are most difficult to make climate neutral are in manufacturing and these activities are regionally concentrated. Industrial transitions to climate neutrality, therefore, have regional development implications. Since regions differ in their socio-economic conditions, understanding the regional development implications also helps prepare a just transition.

To eliminate greenhouse gas (GHG) emissions, manufacturing requires new forms of production and, in some cases, new energy carriers and raw materials. These in turn require different and more investment, including in infrastructure. The transitions will impact firms and so in turn workers, with some firms contracting (in particular those unable to make the leap) and some expanding. Whilst these may largely balance out at the national level, this is not a given at the subnational level, where the spatial distribution of specific sectors may result in asymmetric impacts.

Preparing for these transformations in those regions most exposed to transformation can help anticipate and manage these challenges whilst also exploiting opportunities. By acting early on the vulnerabilities identified in this report, policy makers can improve regional development opportunities and prevent protracted decline. This report, therefore, identifies key manufacturing sectors requiring particularly far-reaching transformations. It describes how these activities are distributed across European regions, and the related zero-emission-consistent infrastructure needs and socio-economic conditions of the regions most exposed to these transitions.

The biggest emissions and transformation challenges are concentrated in a few key sectors

The key manufacturing sectors with particularly far-reaching transformation challenges identified in this report are:

- coke and oil refining
- chemicals
- basic metals, in particular steel and aluminium
- non-metallic minerals, in particular cement
- paper and pulp
- motor vehicles.

Sectoral transformations have place-based implications. The first four sectors generate the most manufacturing emissions across countries in absolute terms. Together with paper and pulp production, they are also the most energy-intensive relative to value-added. Moreover, refined oil product and coke production is likely to face the biggest relative employment loss, as fossil fuels are phased out. Basic chemicals and metals need to transform their production processes fundamentally, especially if they do not rely on carbon capture and storage (CCS), resulting in substantial demand for hydrogen. CCS is the most likely approach to be used to deal with process emissions in cement production. Primary production of paper and pulp will face increasing competition for biomass. Motor vehicle production generates relatively fewer emissions but is a major employer in many European regions. Moving to electric, lighter and fewer vehicles will have implications for employment and skills.

Reducing energy demand is key to the transition to climate neutrality, as most energy demand needs to be electrified and moved to renewables. In all industries, circular economy practices can reduce pressures on energy and material needs, by sharing equipment (e.g. cars), reusing goods or components (e.g. building components) or improving recycling (e.g. improved plastics sorting) for example. Doing so generates co-benefits for the environment and human health.

Many regions most exposed to the transition are in Central Europe

Some European regions employ up to 11% of workers in the key manufacturing sectors, broadly defined. Regional transformation challenges are likely to be the largest, where both employment shares and emissions per capita are high. These regions will have to decarbonise production assets while at the same time capitalising on opportunities to ensure a just transition. The combination of regional emissions and employment data allows for locating these transformational challenges.

Forty-one European regions are the most exposed to the transition based on their sectoral employment shares and emissions per capita. Many exposed regions are in Central Europe (including the Czech Republic, Germany, Hungary and Poland). Exposed regions in chemicals and oil refining are also in Western Europe (Belgium, Germany and the Netherlands). Northern Europe has exposed regions in paper and pulp and basic metals. Southern Europe includes some exposed regions in vehicle manufacturing (Romania), oil refining (Greece), non-metallic minerals (Italy) and basic metals production (Italy and Spain).

Regions differ in infrastructure needs to make industry climate neutral

The key manufacturing sectors require investments in new infrastructure to accelerate the transition and avoid territorial divergence. Regions have different challenges, however. For example, spatially concentrated electricity and hydrogen demand will require investment for production, transport and storage. Unabated CO_2 emissions need to be transported to storage sites.

Hydrogen and CO_2 are best transported via pipelines which are subject to scale economies. Clustered production sites, such as for the chemicals industry in Belgian and German regions, will face lower costs than dispersed ones. Dispersed production sites may depend more strongly on viable local hydrogen production and CO_2 storage sites.

All sectors identified above depend on freight transport to ship their goods or acquire parts from upstream sectors. Road freight plays an important role, including in access to ports. If the costs of decarbonising road freight are substantial, this will impact firms in landlocked regions the most. Options to substitute rail for road are also regionally unequal. In peripheral European regions, rail network density is lower.

Some regions, their workers and firms are particularly vulnerable to the transitions

Most of the exposed regions are relatively weak on several socio-economic indicators. Gross domestic product (GDP) per capita and wages are up to 38% lower than the national average. The key manufacturing sectors provide a high number of relatively well-paid jobs, which are important for regional economies and development.

In some exposed regions, workers are particularly vulnerable to risks of skills gaps, job and income loss. For example, in regions with high basic metals and vehicle manufacturing, up to three out of four workers in these sectors are in low-skill occupations. Around 90% of exposed regions' workers in coke production and oil refining earn wages higher than the national median.

Regions with less productive firms may also be more vulnerable. Low-productivity firms will find it harder to incorporate technological transformations and finance needed investment. In the chemical sectors, some regions have mainly lagging firms, with average labour productivity 15% lower than leading firms.

1 Regional industrial transitions to climate neutrality: Identifying key sectors

This chapter describes the challenges in moving manufacturing to climate neutrality. It identifies manufacturing sectors subject to the biggest challenges and describes the transformations they require. Manufacturing activities are typically regionally concentrated and the transformations they need to undertake will therefore have implications for regional development. Five sectors – non-metallic minerals (notably cement), basic metals (notably steel), chemicals, oil refining and coke, as well as paper and pulp – stand out in terms of greenhouse gas (GHG) emissions and energy use. Key actions for reaching climate neutrality include reducing energy consumption and moving away from fossil energy use towards electrification. These industries often require high temperatures in their production processes, increasing energy needs and making electrification difficult. Circular economy practices help reach climate neutrality with less pressure on energy and material needs with co-benefits for other environmental outcomes and human health. The motor vehicle industry, which is also included in the analysis, generates few emissions and is not energy intensive but faces challenges from the move to electric, lighter and fewer vehicles the transition is likely to imply.

Introduction

This book is dedicated to the transition of manufacturing to climate neutrality and what this means for the regions at the subnational level, drawing on data from regions across Europe. The motivation is simple: some of the economic activities that are most difficult to make climate neutral are in manufacturing. And these manufacturing activities are typically regionally concentrated. Since the regions differ in their socio-economic conditions, understanding the regional development implications will also help policy makers meet the needs of a just transition.

The transformations will have labour market implications. While most manufacturing sectors will continue to be needed in a climate neutral economy, thus having little impact on aggregate employment, certain sectors may shed employment in some regions. New activities will, by contrast, attract an increasing number of workers. For example, integrating circular economy solutions may result in increased employment (Material Economics, 2019[1]; OECD, 2020[2]). Risks of job loss may not coincide with the spatial distribution of job opportunities. Businesses and workers will need to transform occupations and skills. Impacts on regions will differ according to their socio-economic characteristics. The transformations climate neutrality requires, including access to new, fossil-fuel-free energy sources, zero-carbon transport and related infrastructure, may also shift comparative advantage across regions. Reducing emissions in manufacturing supply chains may also result in some relocation of activity. The labour market implications, therefore, require policy responses for a just transition.

Regional shocks to the industrial base typically widen to affect the production of goods and services in the same or adjacent regions to meet demand from workers in directly affected industries and their families. Loss of employment and value-added is also magnified over time through business clustering and emigration effects. Potential price responses, such as declining regional wages or real estate prices cannot equilibrate these shocks in practice because these price responses may aggravate decline or are too slow to attract activity. This may result in persistent regional crises. The impacts also travel along value chains. Such risks need to be understood and prevented and opportunities seized. Taking into account the move to climate neutrality in manufacturing is therefore central to regional development.

This chapter identifies manufacturing sectors which need to undergo particularly deep transformations and describes these transformations. The following section will describe what transitions to climate neutrality mean for manufacturing, followed by a description of employment implications. This will be followed by a selection of key sectors facing major challenges, the focus of this chapter that concludes with a description of the transformations in the key sectors and their place-based implications.

The second section of this chapter will identify the regions most vulnerable to these transformations. The third will explore infrastructure access conditions required by key manufacturing sectors. The fourth presents data analysis to help identify potential regional socio-economic vulnerabilities in most affected regions, laying the basis for policy action to support a just transition.

Challenges in moving manufacturing to climate neutrality

The manufacturing sector contributes substantially to GHG emissions. The steel and cement sectors alone each generate around 7% of CO_2 emissions and the chemical sector a further 4%, in world economies included in the analysis by the International Energy Agency (IEA, 2020[3]). Heavy industries account for 45% of global GHG emissions (OECD, 2019[4]); (IEA, 2020[3]). In addition to steel, cement and chemicals, heavy industries include other metals, the processing of fossil fuels, for example in oil refining, as well as pulp and paper. These heavy industries account for most manufacturing emissions and will therefore also be referred to as emission-intensive industries below. All of these emissions from heavy industries have been growing significantly faster than overall GHG emissions.

Energy accounts for a relatively large share of production costs in several manufacturing industries. Variations in energy costs in the transition to climate neutrality may affect their competitive position, as manufacturing products are traded in global markets. Manufacturing also heavily depends on heavy-duty road transport for value chain management and market access which itself requires decarbonisation.

Most of the production in emission-intensive manufacturing sectors will need to continue in climate-neutral economies. In addition, outputs in these sectors are important for the infrastructure needs of the transition to climate neutrality, to achieve climate-neutral electricity generation, electrification of energy use, or the decarbonisation of transport and buildings for example (ETC, 2018[5]). However, moving to climate neutrality in these sectors requires technologies that do not exist at full scale in many cases (IEA, 2018[6]; Climate Action Tracker, 2020[7]; Bataille et al., 2018[8]). In these manufacturing sectors, emissions are therefore particularly hard to abate. Fossil fuels have been fundamental to production processes in these industries. In addition to energy-related emissions, process emissions are important in some and arise from chemical processes during the conversion of raw materials to intermediate or final products.

Some decarbonisation methods apply to most forms of manufacturing. These include: decarbonising all energy inputs, increasing energy efficiency and promoting material circularity (Johnson et al., 2021[9]). Two-thirds of industrial direct GHG emissions are from high-temperature process heat, either in the form of steam or hot water (20%) or from the direct firing of various types of furnaces (50%). Space heating contributes 9% (EC, 2018[10]).

Electrification of energy use will play an important role, especially for low to medium heat. Generating high-temperature heat from electricity is challenging and costly. Biomass firing can be an alternative but is climate neutral only if sustainably sourced, limiting supply. Hydrogen produced with renewable electricity in electrolysis ("green hydrogen") or synthetic methane produced from hydrogen can also be used for high heat beyond 1 000 degrees Celsius. These may be used in combination: for example, initial heating with electric heat pumps or some form of solar heating could be boosted with biogas, hydrogen or synthetic methane produced from hydrogen (Bataille et al., 2018[8]).

Electrification of energy needs risks raising electricity demand hugely and resulting in highly regionally concentrated electricity needs (Material Economics, 2019[1]). These electricity needs will need to be mostly met with renewable electricity. To limit economic and environmental costs from large-scale renewables expansion, as well as risks not reaching climate neutrality in the time , reducing energy demand is central to moving to climate neutrality by 2050 (Hickel et al., 2021[11]); (Johnson et al., 2021[9]). Achieving further energy savings in many cases requires the replacement of major parts of production processes, which is often best integrated with other transformations needed for the net-zero emissions target (EC, 2018[10]). The need to reduce energy demand and electrify energy end-use while decarbonising all electricity generation will also impact the types of goods manufacturing produces, such as electric heat pumps instead of natural gas boilers.

Long-lived quasi-fixed capital assets with high sunk cost prevail in emission-intensive sectors, with lifetimes of 30-40 years. Twenty-five years is a typical investment cycle for major refurbishments. New industrial facilities, therefore, need to be climate neutral starting now in some sectors, while refurbishments may need to be net-zero consistent starting in 2025. Investment needs to increase 50%, both to replace some existing capacity and to switch to more capital-intensive, low-CO_2 production routes (Material Economics, 2019[1]).

Twenty-one percent of industrial emissions are process emissions (EC, 2018[10]). In some sectors they are major. Carbon capture, use and storage (CCUS) is essential for some process emission sources in manufacturing because they are difficult to avoid otherwise, as argued below. It may be desirable to limit CCUS to process emissions. Relying on it on a larger scale poses risks, as CCUS has not been deployed at scale yet and its large-scale deployment is subject to uncertainties. Relying on CCUS rather than reducing emissions upfront therefore raises the risk that climate neutrality is not reached. Most CCUS would need to be delivered through carbon capture and storage (CCS). There is limited scope for CO_2 use

(CCU) to support carbon removal. For CCU to result in permanent CO_2 removal, materials produced with captured CO_2 need to be fully controlled and closely linked to the emission source. CCU through direct air capture is highly energy intensive and costly. Due to limitations in the location of available, acceptable and commercially viable storage sites and their costs, CCS for industrial processes can be among the most expensive mitigation options (Sharmina et al., 2021[12]).

The contribution of the circular economy

Reducing demand for raw materials saves energy and other resources and avoids process emissions. This applies especially in the production of basic materials like steel, cement, plastics, paper and pulp which characterises emission-intensive industries. The circular economy is therefore particularly important for industrial transitions to climate neutrality. Without exploring circular economy potentials, switching production to climate-neutral processes alone would result in substantially higher costs and very large demand for clean energy, including for the production of hydrogen (Sun, Lettow and Neuhoff, 2021[13]). Circular economy approaches could reduce CO_2 emissions from 4 major manufacturing sectors (plastics, steel, aluminium and cement) by 56% in developed economies by 2050 (Johnson et al., 2021[9]; Sharmina et al., 2021[12]; Material Economics, 2019[1]). They therefore also reduce the need for CCUS. These approaches include the following:

1. New business models to promote shared use, longer use, repair and reuse, can reduce the demand for industrial output and the materials it requires.
2. Materials recirculation can replace high-emitting raw materials with recycled materials including closed-loop systems, where waste from one process is an input to another.
3. Substitution from high-emitting or hard-to-abate materials to lower-emitting alternatives can achieve significant emissions cuts (EC, 2018[10]; OECD, 2018[14]).

Since the processing of goods and materials for reuse and recycling is likely to be close to where they are consumed, this is likely to also result in employment growth, including from relocation of activity from abroad. While this may also mean that overall emissions to high-income countries rise, at a global level, all other things being equal, emissions should fall.

The circular economy requires exchanging and reprocessing materials or shared-use assets among manufacturing plants or their customers. Reducing transaction costs among agents in the circular economy is therefore important, for example, to ensure the precise composition of materials is known. Digitalisation and industrial symbiosis can contribute as follows:

- Digitalisation can support the circular economy, through improved tracking of product and materials composition. Major opportunities include marking technologies, low-cost sensors and real-time tracking to provide better information on materials composition as well as automation, for example in sorting (Material Economics, 2018[15]). Other opportunities are geolocation technologies to indicate asset locations or blockchain to store information (OECD, 2020[2]). Digital technologies also reduce transaction costs in innovative circular economy business models, such as in the provision of capital goods as a service (Barteková and Börkey, 2022[16]).
- Industrial symbiosis, or closed-loop recycling, as it is sometimes called, involves the use of by-products from one firm as inputs for another. Industrial symbiosis reduces intermediaries and is most common in industries that produce pure and homogeneous materials, such as the chemicals industry. Industrial symbiosis is more meaningful for industrial sites that are closely located to each other (EC, 2018[10]). Some of these relationships may develop organically or are the result of carefully planned industrial parks (OECD, 2019[17]). The partnership of industrial establishments across sectors, sharing infrastructures and their material inputs and outputs (including waste) can also optimise resource use.

Circular economy practices provide key environmental, health and economic benefits in addition to GHG emission reduction (Box 1.1).

Box 1.1. Key environmental, health and economic benefits of the circular economy

Materials extraction and processing, including biomass, fossil fuels, metals and non-metallic minerals account for around 70% of GHG emissions, as well as for substantial water, soil and air pollution and biodiversity loss. Most global environmental impacts of extraction and processing of these key materials are projected to at least double between 2017 and 2060 (OECD, 2019[18]).

Non-metallic minerals, such as sand, gravel and limestone mostly used in construction, and biomass account for the bulk of materials extraction. Although their extraction and processing pollute less per ton than metals, they have important lifecycle environmental impacts, which are magnified by their volume (Wilts et al., 2014[19]). For example, cement and concrete production generate high GHG emissions. It has a significant impact on energy demand, soil acidification and land use (OECD, 2019[18]).

More than 90% of global biodiversity loss and water stress come from resource extraction and processing (EC, 2019[20]), with biomass extraction playing an important role. As discussed below, biomass use is important, especially in the production of paper products but in some countries is also used to generate heat in other sectors. It will gain importance as fossil fuels are phased out. Substituting fossil fuels with sustainably sourced biomass can reduce GHG emissions but does not fully avoid adverse impacts on biodiversity. Plastics production and waste generation roughly doubled between 2000 and 2015, resulting in multiple environmental impacts, including high energy use, pollution from landfill and incineration, and ecosystems from uncontrolled disposals, such as marine litter (OECD, 2018[14]). Metals extraction and processing cause soil acidification, eutrophication of water flows and toxic effects on ecosystems.

In part, environmental degradation associated with material extraction and processing occurs in locations which are distant from the European Union (EU). However, some impacts arise locally, for example from the extraction of construction materials sourced locally. They can also materialise at the point of consumption or disposal. Wherever they arise they often generate adverse health effects on humans. Demand reduction and substitution of key chemicals, for example synthetic fertilisers or solvents and some plastics, could reduce pollution of water and land at the location of use, reduce risks from alterations in the nitrogen cycle (OECD, 2018[21]) as well as provide significant health benefits.

Economic benefits result from the security of resource supply and increase overall employment, especially in resource-importing countries. Security of resource supply improves as the circular economy can reduce material imports and diversify sourcing, especially when raw materials are distant and geographically concentrated.

Source: OECD (2019[18]), *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*, https://dx.doi.org/10.1787/9789264307452-en; Wilts, H. et al. (2014[19]), "Policy mixes for resource efficiency", *POLFREE Policy Options for a Resource-Efficient Economy*, University College London, London; EC (2019[20]), *The European Green Deal*, Communication from the Commission COM(2019) 640 final, European Commission; OECD (2018[14]), *Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses*, https://dx.doi.org/10.1787/9789264301016-en; OECD (2018[21]), *Human Acceleration of the Nitrogen Cycle: Managing Risks and Uncertainty*, https://dx.doi.org/10.1787/9789264307438-en.

Employment consequences

According to Cedefop's European Green Deal (EGD) scenario (Cedefop, 2019[22]), by 2030, most manufacturing will see a redirection of employment toward cleaner production rather than a reduction at the 27 European Union countries (EU27) level, compared to a baseline with previous policies. However, there are some limitations to this analysis. It does not go all the way to climate neutrality, as targeted for 2050, potentially omitting the costliest transformations. It is a partial analysis where wider economic impacts driven by supply chain linkages, changes in consumption patterns and other factors are not systematically considered.

Industrial transitions to climate neutrality will also bring new and different jobs. Assessments of sector-specific transformations of occupations and skills demands in manufacturing are still rare. A broad range of skills, which are not unique to green jobs, will need to support the transition to climate neutrality. Seven out of ten top skills in "the green economy" are generic, while the remaining three are industry-specific. Skill requirements in new activities may be substantially different from those used in declining activities. The share of low-skilled jobs is high in highly polluting sectors, while environmentally friendly activities tend to have a high share of high-skilled jobs.

Table 1.1 shows sectoral manufacturing employment outcomes by 2040 consistent with the IEA Sustainable Development Scenario (SDS). These are closer to the full employment impact of climate neutrality. The SDS shows emission reductions which allow reaching the goals of the Paris Agreement, compared to a baseline that is consistent with policies around 2019. As they are simulated with a computable general equilibrium model, they include in principle supply chain linkages and other national and international market relationships. The processing of fossil fuels, the production of basic metals, chemicals, textiles, electronics, automobiles as well as paper and pulp may suffer employment losses, albeit mostly small ones. However, these are aggregate results for the EU as a whole as well as for other major economies. Secondary iron and steel production by contrast can benefit from circular economy advances.

Some net employment losses in Table 1.1 are likely to be smaller than would be consistent with reaching climate neutrality. The modelled SDS does not fully integrate the ambition to reach net-zero emissions in 2050. Moreover, the SDS assumes the use of CCUS for energy-related emissions in industry, prolonging the use of petroleum, natural gas and coal products for industrial heat and as raw materials as well as possibly employment in related sectors. The manufacturing of motor vehicles includes some diffusion of electric vehicles even in the baseline scenario because of their improving cost competitiveness, which limits the impact of electrification on employment attributed to climate action

The modelling assumes that countries achieve emission reductions in a co-ordinated way. In practice, countries will move towards climate neutrality at different speeds without full co-ordination. EU countries are likely to move ahead of others. Countries with more rapid transitions may not face bigger risks of employment or income losses economywide. Quicker emission reductions initially can, on the contrary, provide more protection against risks of stranded assets. But countries with more rapid transitions are likely to face stronger sectoral employment shifts (OECD, 2017[23]) and, therefore, also larger regional employment shifts. This could in particular generate sectoral employment losses over and above those in Table 1.1. This in particular concerns the manufacturing sectors discussed in this publication. In these sectors, transformation challenges are substantial, emission reductions may result in higher costs and products are mostly internationally tradeable. Policy actions, such as border carbon price adjustment or targeted subsidies, could offset employment losses but would need to be the larger, the bigger the impact of emission reductions on production costs is. Owing to the regional concentration of sectoral manufacturing activity, such policy action will need to be place-based.

Industrial transitions to climate neutrality will also bring new and different jobs. Assessments of sector-specific transformations of occupations and skills demands in manufacturing are still rare. A broad range

of skills, which are not unique to green jobs, will need to support the transition to climate neutrality. Seven out of ten top skills in “the green economy” are generic, while the remaining three are industry-specific (Vasselina, Till Alexander and Saadia, 2020[24]). Skill requirements in new activities may be substantially different from those used in declining activities (Cecere and Mazzanti, 2017[25]). The share of low-skilled jobs is high in highly polluting sectors, while environmentally friendly activities tend to have a high share of high-skilled jobs.

Table 1.1. Employment changes from worldwide emission reductions consistent with the Paris Agreement, by sector, according to the OECD ENV-Linkages model

Deviation of sectoral employment from baseline in 2040, in percentages

Economic sectors	OECD	EU17	EU3+UK	United States	Japan
Petroleum and coal products	-21	-32	-34	-30	-27
Secondary zinc, lead, gold and silver production	-6	-13	-7	-6	-9
Primary aluminium production	-4	-5	-6	-6	-7
Secondary aluminium production	-4	-5	-5	-6	-6
Primary copper production	-4	-5	-5	-6	-6
Primary zinc, lead, gold and silver production	-4	-4	-5	-6	-6
Secondary copper production	-4	-4	-4	-5	-5
Textiles	-4	-5	-4	-3	-4
Electronics	-3	-1	-2	-5	-4
Chemicals, rubber, plastic products	-3	-7	-7	-1	-1
Secondary iron and steel production	3	8	-10	2	3
Non-metallic minerals	-2	-1	-3	-1	-6
Motor vehicles	-2	-2	-2	-1	-3
Paper and pulp production	-2	-1	-2	-3	-4
Primary iron and steel production	-1	4	-5	-1	0

Note: EU17 includes Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Luxembourg, the Netherlands, Poland, Portugal, the Slovak Republic, Slovenia, Spain and Sweden. EU3+UK includes France, Germany, Italy and the United Kingdom.
Source: OECD calculations based on the ENV-Linkages model; OECD (2021[26]), *OECD Regional Outlook 2021: Addressing COVID-19 and Moving to Net Zero Greenhouse Gas Emissions*, https://doi.org/10.1787/17017efe-en; Bibas, R., J. Chateau and E. Lanzi (2021[27]), “Policy scenarios for a transition to a more resource efficient and circular economy”, https://doi.org/10.1787/c1f3c8d0-en.

There are two main types of skills for which green jobs differ from non-green jobs: i) engineering skills used in the design and production of technology; and ii) managerial skills (Vona et al., 2018[28]). Managerial workers, for example, will need to build resource efficiency into business and management practices, incorporate emission reduction scenarios in investment plans or establish carbon footprints in goods procurement. Since the climate transition will require linking activities closely that have so far been separate, such as intermittent electricity generation and use, the complexity of work in some sectors will require cross-, multi- and interdisciplinary skills. Jobs consistent with environmental objectives may be more intensive in non-routine analytical and cognitive skills (Consoli et al., 2016[29]). The gap in terms of skills between green and brown jobs for similar low-skilled occupations appears to be generally small, including in manufacturing (Vona et al., 2018[28]). However, the demand for low-skill occupations is likely to be smaller with the transition.

While carbon capture and storage (CCS) will be an emerging activity, the skill requirements in this industry are not new and can be met using a combination of skills used in the chemicals, oil and gas, process design and engineering construction industries. With some retraining, displaced pipe fitters and designers, leak test technicians and offshore barge operators in the oil and gas industry could be reemployed in CCS (UK Government, 2011[30]).

Key sectors and their transformations with place-based implications

The selection of key manufacturing sectors is based on the following criteria:

- The contribution of sectors to total GHG emissions from manufacturing.
- Transformation challenges from high energy use and low electrification of energy use.
- The extent to which total emissions from each manufacturing sector are covered in the European Emissions Trading System (ETS).
- A significant contribution to employment or employment risks.

GHG emissions are fundamental for the analysis of regional industrial transitions and their regional development implications. The analysis above also suggests that energy consumption and the degree of electrification are indicative of transformation challenges. EU ETS emissions data allow locating the emitting installations geographically.

ETS emissions data provide limited information on the sectoral origin of emissions. The analysis in this publication, therefore, attributes ETS emissions to Nomenclature of Economic Activities (NACE) sectors according to the main activity of businesses owning installations. To this end, ETS data are matched with international non-governmental Orbis business data. The attribution of ETS emissions to NACE sectors allows for estimating the coverage of emissions by ETS. As shown below, GHG emissions data for three- and four-digit NACE sectors allow pinpointing activities which are the most emission-intensive and which will need to undertake the deepest transformations.

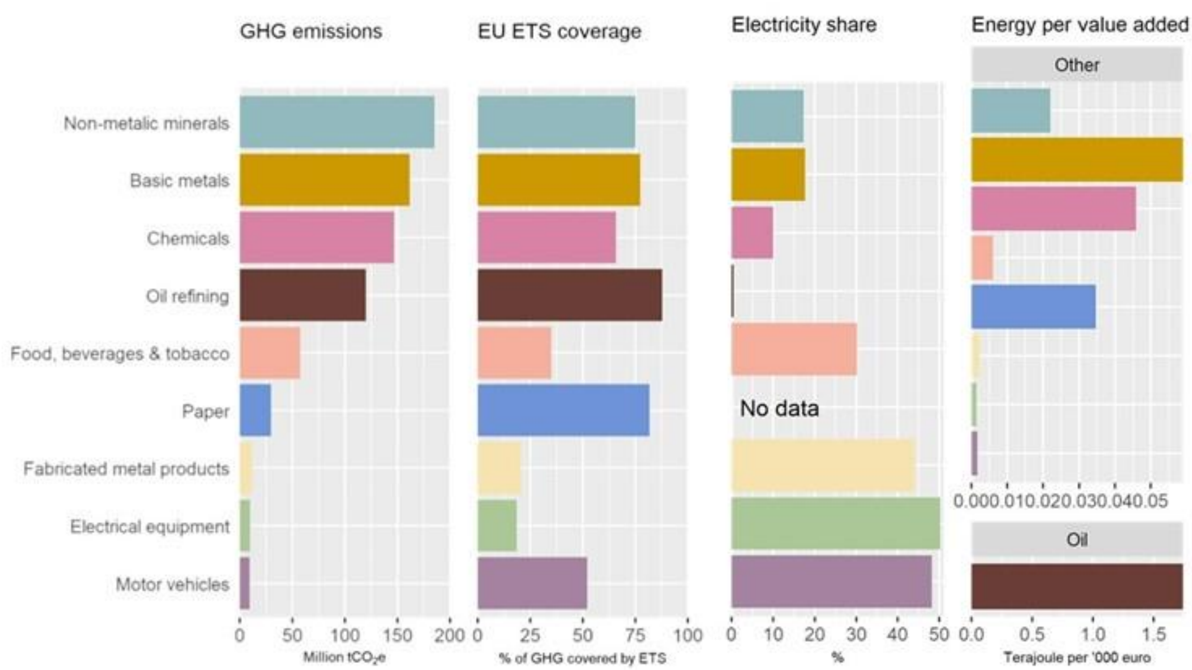
The selected manufacturing sectors are the following: non-metallic mineral products (NACE 23), basic metals (NACE 24), coke and refined petroleum products (NACE 19), chemicals and chemical products (NACE 20), paper and paper products (NACE 17) and motor vehicles (NACE 29).

These six sectors also include most of the sectors with the highest GHG emissions in the EU (Figure 1.1). One exception is the manufacturing of food, beverages and tobacco products (NACE 10-12), where emissions are also high. However, ETS covers only a third of emissions, mostly in the food industry (NACE 10). Emissions in the manufacture of motor vehicles are by contrast relatively low. It also does not stand out in terms of the energy intensity of value-added or the share of electrified energy consumption. However, motor vehicle manufacturing employs the most people among the selected sectors. (Figure 1.2). The production of motor vehicles and chemicals also generates the most value-added (Figure 1.3). Employment is modest in the production of coke and oil refining. However, relative employment losses are likely to be the largest. The selected sectors account for more than 90% of manufacturing GHG emissions. The five selected sectors with high emissions also have the highest energy intensity of value-added and the lowest shares of electrified energy consumption.

With its production of basic materials, the emissions-intensive industry is particularly strongly integrated into the value chains of downstream industries. Addressing the transition to climate neutrality effectively and fairly in the regions where these activities take place is therefore important for activity in downstream sectors. For example, the steel industry employs only 6 million people worldwide but links indirectly to 42 million jobs. The chemical industry provides inputs to over 95% of all manufactured products (ICCA, 2012[31]). Downstream industries, which depend on a particularly large range of inputs from emissions-intensive industries, include the construction of buildings, the manufacturing of motor vehicles, civil engineering, computer electronics and optical as well as, to a lesser extent, electrical equipment (EC, 2018[10]). The prices of the basic materials produced by emissions-intensive industries may become significantly higher than today. Zero-carbon production routes may cost 20-30% more for steel, up to 60% for chemicals and 80% for cement. A more circular economy helps reduce raw materials and energy needs but also modifies value chains.

The attribution of ETS emissions to NACE sectors also allows an assessment of emissions in three- and four-digit NACE sectors, for which no emissions data are available. Emissions in the selected sectors are concentrated in some three-digit subsectors, in particular the production of paper and pulp, refined petroleum products, basic chemicals, cement, basic iron and steel (Figure 1.5). In the analysis of the following chapters, particular attention will be paid to these sectors. They are in some but not all cases the most employment-intensive (Figure 1.4).

Figure 1.1. Emissions, shares of GHG emissions covered by ETS and energy intensities in selected manufacturing sectors

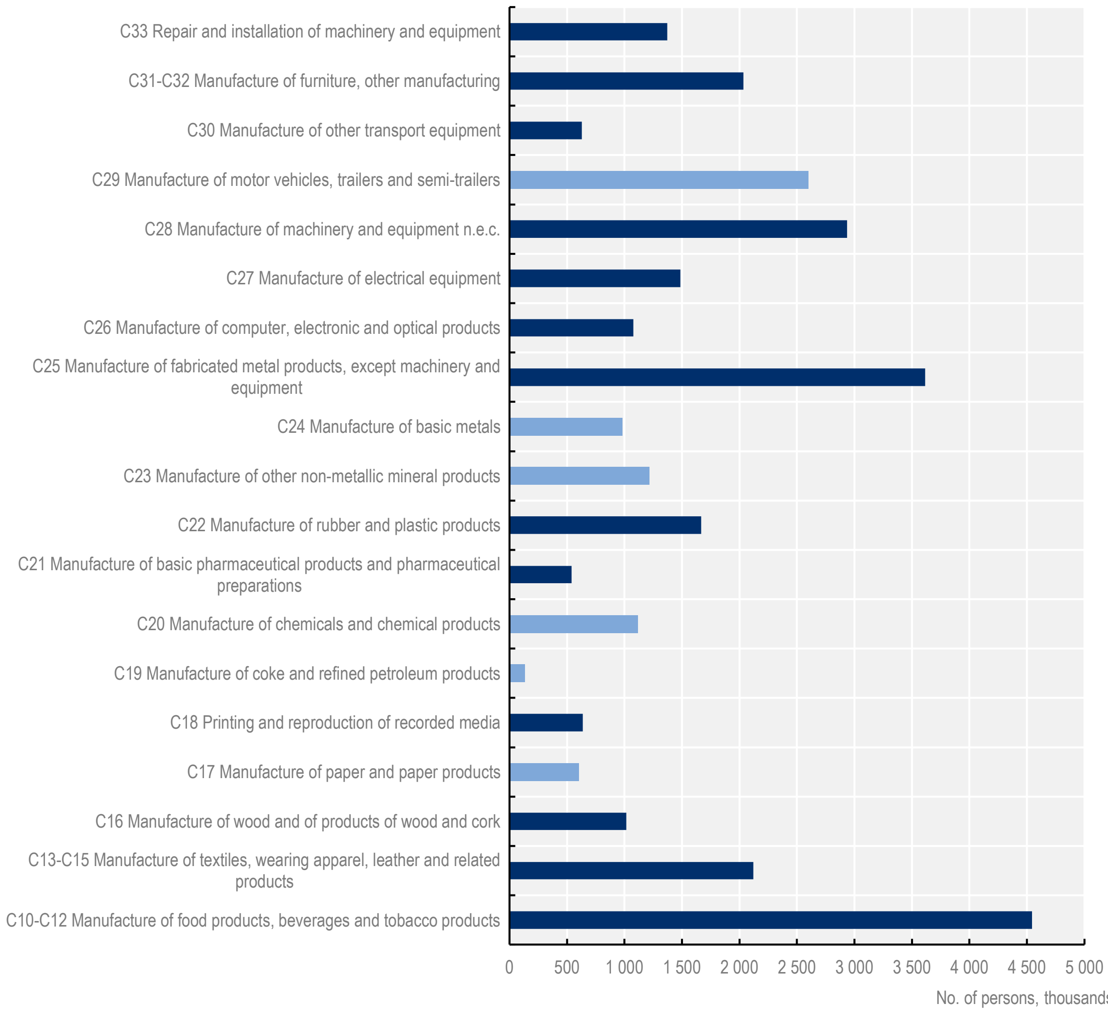


Note: Data for 2019 or latest year available.
Source: Eurostat, matched ETS emissions and Orbis data.

StatLink https://stat.link/wq9o4f

Figure 1.2. Employment across two-digit NACE industries

National accounts employment data in thousands of persons by industry for 2018, EU27

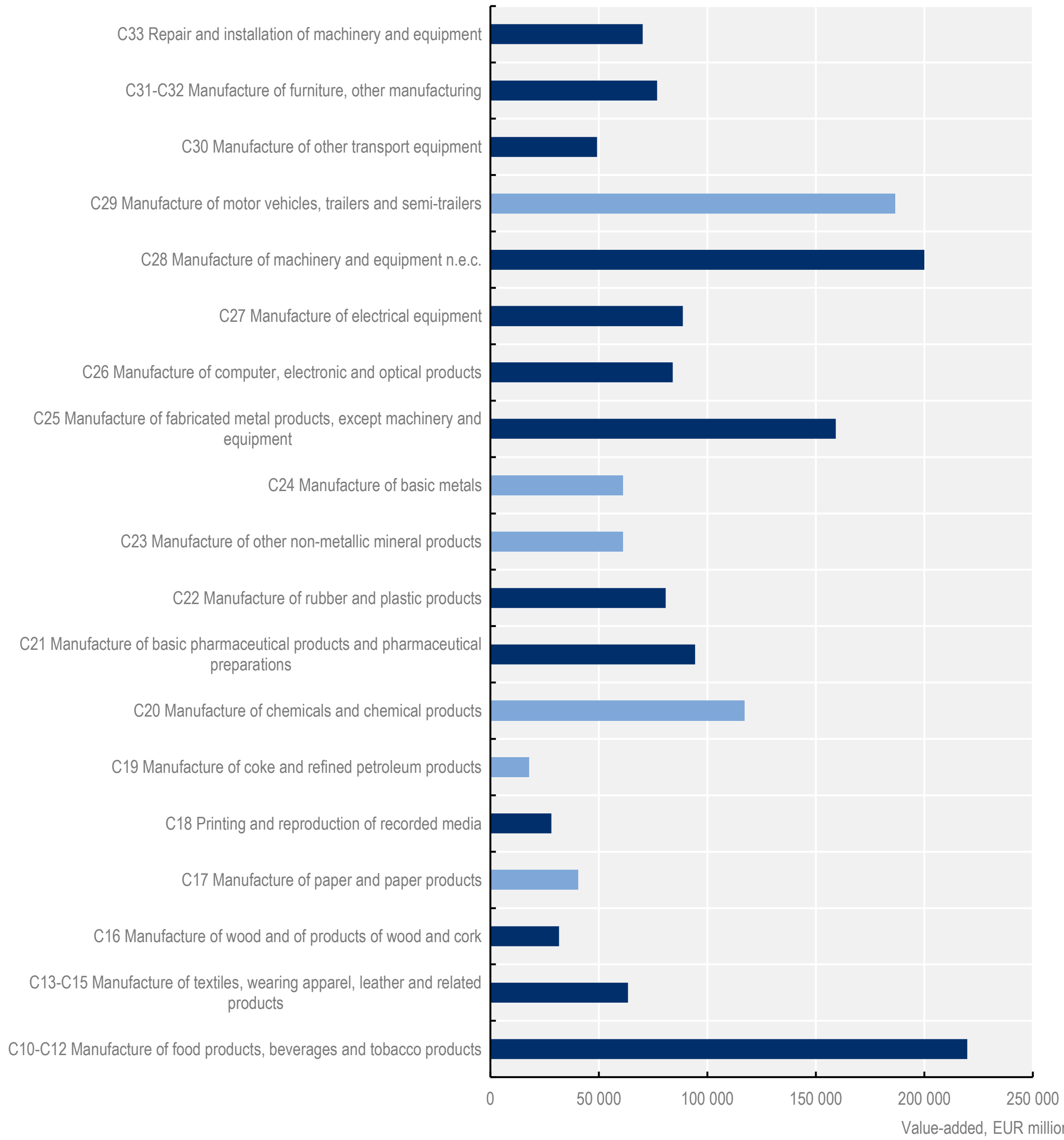


Note: Selected sectors highlighted in fair blue.
Source: Eurostat. Selected sectors are highlighted in fair blue.

StatLink https://stat.link/294sj5

Figure 1.3. Value-added across two-digit NACE industries

National accounts gross value-added data by industry in million euros (current prices) for 2014, EU27

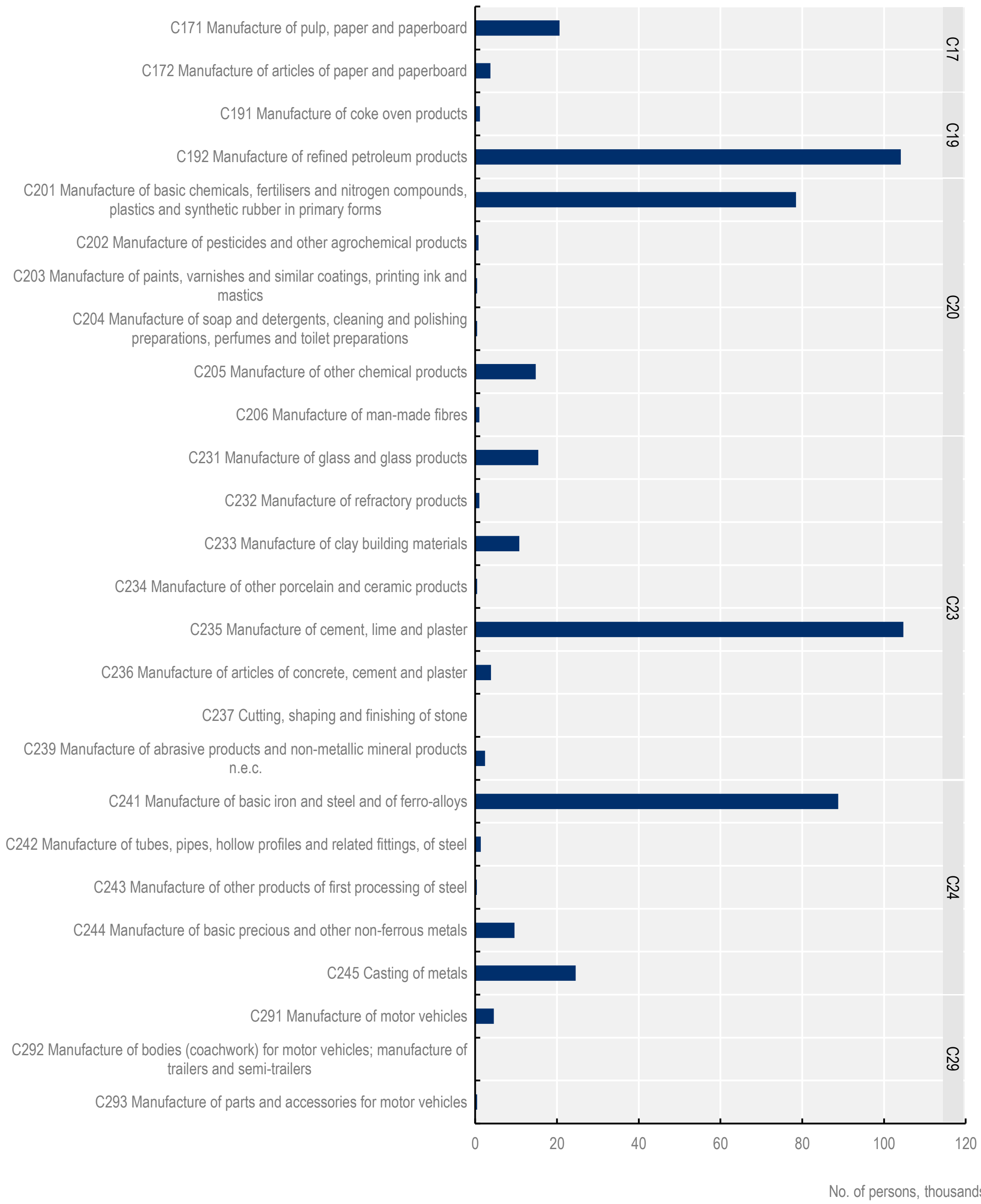


Note: Selected sectors highlighted in fair blue.
Source: Eurostat.

StatLink https://stat.link/ekrfcw

Figure 1.4. Employment across three-digit NACE sectors

SBS employment data in thousands of persons by subsector in key manufacturing sectors for 2018, EU27

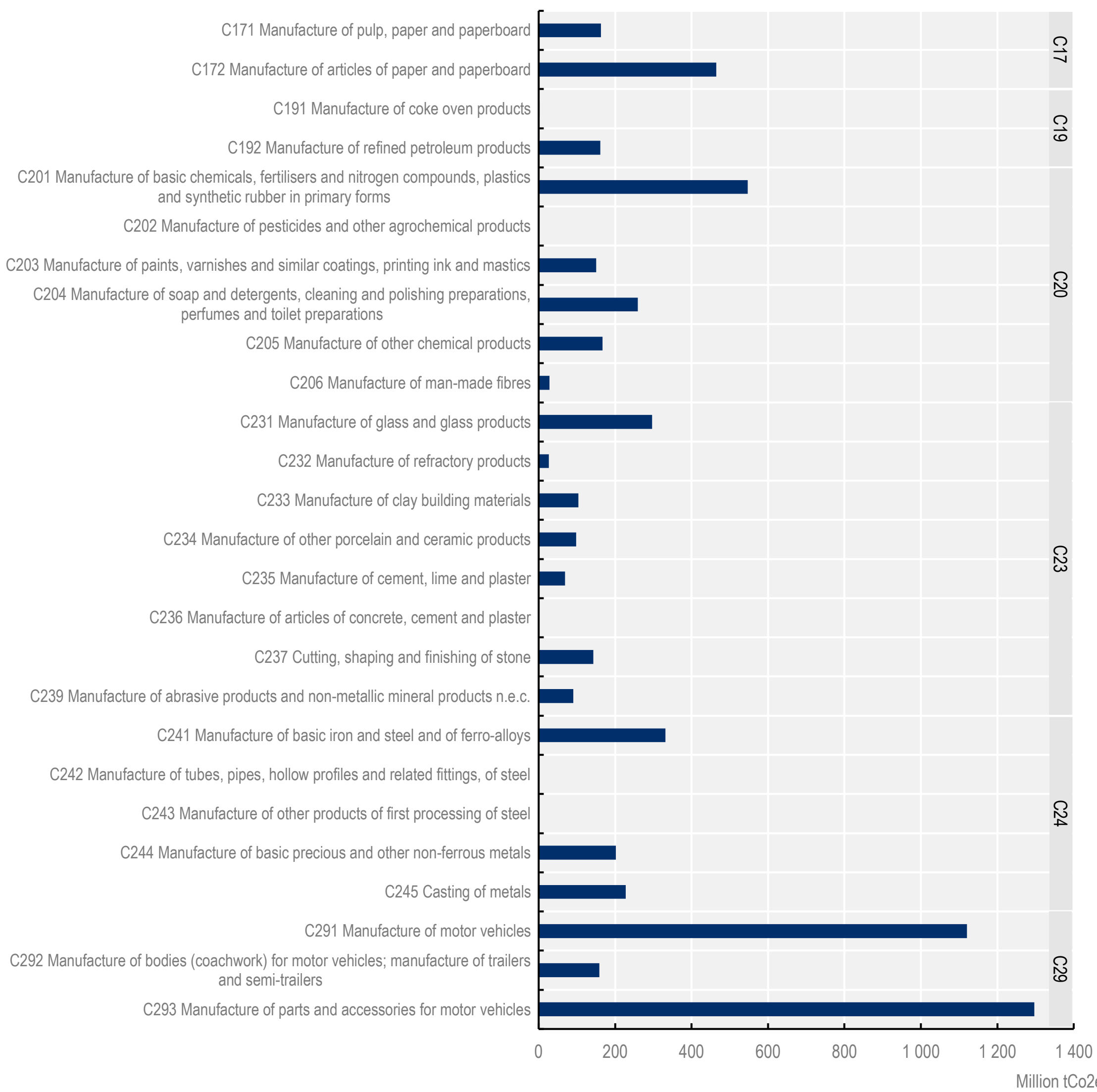


Source: Eurostat.

StatLink https://stat.link/8shdub

Figure 1.5. Emissions in three-digit NACE subsectors of key two-digit manufacturing sectors

Estimations according to company or subsidiary main activity and ETS installations owned by companies for 2019, EU27



Note: Emissions of installations attributed to business sector at the subsidiary level.
Source: Own calculations with EU ETS/ORBIS matched dataset (2019).

StatLink https://stat.link/qkhyem

A large literature describes the transformations in production technologies to get these sectors to climate neutrality, summarised in detail in a forthcoming working paper (Fuentes and Noels, 2023[32]). Some high-level characteristics of these transformations have place-based implications:

- Refined oil production is likely to face the biggest relative employment loss among the chosen sectors because oil and coal product use will need to be phased out. Global demand for oil products will decrease significantly (IEA, 2021[33]) and more quickly so without reliance on CCS for energy-related GHG emissions. According to Cedefop's EGD scenario, direct employment in manufactured fuels in the EU27 will decrease by about 10% already by 2030 (Cedefop, 2021[34]).

- Non-metallic minerals include several activities generating substantial emissions. Cement production stands out; others are glass and other building materials manufacturing. The former is the most likely to require CCS, as technologies to eliminate process emissions are least developed. More than half of emissions from cement production are process emissions (Cao et al., 2020[35]). Other emissions and energy demand reduction levers consistent with net-zero emissions, which need to be used in combination, are improving energy efficiency, switching to alternative fuels, reducing the clinker-to-cement ratio and using alternative binding materials (IEA, 2018[6]).
- Chemicals production can do without CCS. This then reinforces the need to transform basic chemicals production processes more fundamentally and increases the demand for hydrogen. The three main supply-side decarbonisation levers are fuel and feedstock substitution, including biomass, and energy efficiency (Levi and Cullen, 2018[36]). Demand reduction, for example for single-use plastics, is important too. Especially in the near term, mitigation may be achieved through recycling and reuse and more sparing use of nitrogen fertilisers, though the production of plastics and other basic chemicals may still rise worldwide (IEA, 2021[33]). Reduced plastic varieties and additives can boost the value of recycled plastics. Innovative chemical and biochemical recycling can also contribute but requires high energy input.
- Steel production can also do without CCS. This also reinforces the need to transform production processes more fundamentally and increases the demand for hydrogen. The combination of direct reduction and electric arc furnaces has the potential for full decarbonisation, using hydrogen and climate-neutral electricity sources (Wang et al., 2021[37]) (Bataille, 2020[38]). Aluminium smelters are also large electricity consumers (IEA, 2020[3]). Climate-neutral technologies need to reach significant market penetration in the next decade. In steel and aluminium production, secondary production from scrap generates much fewer emissions and is much less energy intensive (Liu and Müller, 2012[39]); (Liu, Bangs and Müller, 2013[40]) but depends on scrap availability. More scrap is available in high-income regions.
- In paper and pulp, the biggest challenge may be rising competition for biomass from other sectors, such as transport (Material Economics, 2020[41]). In addition to biomass being the key raw material, 60% of the energy used in paper and pulp is from bioenergy. Raising the use of recycled paper, combined with renewable electricity use, is likely to be important, which may dissociate production sites from locations with biomass availability. However, combining biomass firing in paper and pulp production with CCS could contribute to net negative emissions, which high-income countries will need beyond 2050.
- In vehicle manufacturing, the challenge is about producing electric vehicles. The transition to climate neutrality will also be facilitated by moving to less car use in high-income countries, notably in urban contexts, as well as to lighter vehicles, as the environmental footprint from the production of zero-emission vehicles is likely to be higher than that of conventional vehicles. A battery accounts for 10-30% of the total life cycle emissions of an electric vehicle (IEA, 2020[42]). The manufacture of an electric motor and related components requires 60-70% less labour than that of a diesel vehicle and 40% less than compared to a petrol car in Germany for example (Bauer et al., 2018[43]). Production operators and equipment technicians are expected to account for 75% of large battery factory workforces and these will require qualification upgrades in advanced manufacturing engineering. Ride-sharing can sharply reduce vehicles in urban contexts.

Most of these industries produce basic materials which are inputs in other manufacturing sectors. Freight transport is the foundation of the supply chain system. Freight transport is also challenging to decarbonise. Access to zero-carbon freight transport modes is therefore also important to move key manufacturing sectors to climate neutrality.

References

Barková, E. and P. Börkey (forthcoming), *Digitalisation and the circular economy*, OECD Publishing, Paris. [44]

Barteková, E. and P. Börkey (2022), "Digitalisation for the transition to a resource efficient and circular economy", *OECD Environment Working Papers*, No. 192, OECD Publishing, Paris, https://doi.org/10.1787/6f6d18e7-en. [16]

Bataille, C. (2020), "Low and zero emissions in the steel and cement industries: Barriers, technologies and policies", *OECD Green Growth Papers*, No. 2020/02, OECD Publishing, Paris, https://doi.org/10.1787/5ccf8e33-en. [38]

Bataille, C. et al. (2018), "A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement", *Journal of Cleaner Production*, Vol. 187, pp. 960-973, https://doi.org/10.1016/j.jclepro.2018.03.107. [8]

Bauer, W. et al. (2018), "Beschäftigung 2030 Auswirkungen von Elektromobilität und Digitalisierung auf die Qualität und Quantität der Beschäftigung bei Volkswagen", Fraunhofer Institut. [43]

Bibas, R., J. Chateau and E. Lanzi (2021), "Policy scenarios for a transition to a more resource efficient and circular economy", *OECD Environment Working Papers*, No. 169, OECD Publishing, Paris, https://doi.org/10.1787/c1f3c8d0-en. [27]

Cao, Z. et al. (2020), "The sponge effect and carbon emission mitigation potentials of the global cement cycle", *Nature Communications*, Vol. 11, p. 3777, https://doi.org/10.1038/s41467-020-17583-w. [35]

Cecere, G. and M. Mazzanti (2017), "Green jobs and eco-innovations in European SMEs", *Resource and Energy Economics*, Vol. 49, pp. 86-98, https://doi.org/10.1016/j.reseneeco.2017.03.003. [25]

Cedefop (2021), *Digital, Greener and More Resilient: Insights from Cedefop's European Skills Forecast*, European Centre for the Development of Vocational Training, Luxembourg, http://data.europa.eu/doi/10.2801/154094. [34]

Cedefop (2019), *Skills for Green Jobs: 2018 Update - European Synthesis Report*, European Centre for the Development of Vocational Training, Luxembourg, http://data.europa.eu/doi/10.2801/750438. [22]

Climate Action Tracker (2020), *Paris Agreement Compatible Sectoral Benchmarks: Elaborating the Decarbonisation Roadmap*, https://climateactiontracker.org/data-portal (accessed on 19 December 2020). [7]

Consoli, D. et al. (2016), "Do green jobs differ from non-green jobs in terms of skills and human capital?", *Research Policy*, Vol. 45/5, pp. 1046-1060, https://doi.org/10.1016/j.respol.2016.02.007. [29]

EC (2019), *The European Green Deal*, Communication from the Commission COM(2019) 640 final, European Commission. [20]

EC (2018), *A Clean Planet for All: A European Long-term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy*, In-depth Analysis in Support of the Commission Communication COM(2018) 773, European Commission, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773 (accessed on 2 March 2021). [10]

ETC (2018), *Mission Possible: Reaching Net-Zero Carbon Emissions from Harder-to-abate Sectors by Mid-century*, Energy Transitions Commission, https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC_MissionPossible_FullReport.pdf (accessed on 19 December 2020). [5]

Fuentes, A. and J. Noels (2023), "Regional Industrial Transitions to Climate Neutrality: Identifying the sectors", *OECD Regional Development Policy Papers*, OECD, Paris. [32]

Hickel, J. et al. (2021), "Urgent need for post-growth climate mitigation scenarios", *Nature Energy*, Vol. 6/8, pp. 766-768, https://doi.org/10.1038/s41560-021-00884-9. [11]

ICCA (2012), *The Global Chemical Industry's Contributions to Sustainable Development and the Green Economy*, International Council of Chemical Associations, Brussels. [31]

IEA (2021), *Net Zero by 2050: A Roadmap for the Global Energy Sector*, OECD Publishing, Paris, https://doi.org/10.1787/c8328405-en. [33]

IEA (2020), *Energy Technology Perspectives 2020*, OECD Publishing, Paris, https://doi.org/10.1787/d07136f0-en. [3]

IEA (2020), *Global EV Outlook 2020: Entering the decade of electric drive?*, OECD Publishing, Paris, https://doi.org/10.1787/d394399e-en. [42]

IEA (2018), *Low-Carbon Transition in the Cement Industry*, IEA Technology Roadmaps, International Energy Agency, Paris, https://doi.org/10.1787/9789264300248-en. [6]

Johnson, O. et al. (2021), "Toward climate-neutral heavy industry: An analysis of industry transition roadmaps", *Applied Sciences*, Vol. 11/12, p. 5375, https://doi.org/10.3390/app11125375. [9]

Levi, P. and J. Cullen (2018), "Mapping global flows of chemicals: From fossil fuel feedstocks to chemical products", *Environmental Science and Technology*, Vol. 52/4, pp. 1725-1734, https://doi.org/10.1021/acs.est.7b04573. [36]

Liu, G., C. Bangs and D. Müller (2013), "Stock dynamics and emission pathways of the global aluminium cycle", *Nature Climate Change*, Vol. 3, pp. 338–342, https://doi.org/10.1038/nclimate1698. [40]

Liu, G. and D. Müller (2012), "Addressing sustainability in the aluminum industry: A critical review of life cycle assessments", *Journal of Cleaner Production*, Vol. 35, pp. 108-117, https://doi.org/10.1016/j.jclepro.2012.05.030. [39]

Material Economics (2020), *A Net-zero Transition for EU Industry: What Does It Mean for the Pulp & Paper Industry?*, https://media.sitra.fi/2020/05/05104241/material-economicspulp-and-paper-in-a-net-zero-transition06-2020.pdf (accessed on 9 July 2021). [41]

Material Economics (2019), *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry*, University of Cambridge Institute for Sustainability Leadership (CISL), https://materialeconomics.com/publications/industrial-transformation-2050. [1]

Material Economics (2018), *Retaining Value in the Swedish Materials System*, Strategic Innovation Program RE:Source, https://circulareconomy.europa.eu/platform/en/main-language/swedish. [15]

OECD (2021), *OECD Regional Outlook 2021: Addressing COVID-19 and Moving to Net Zero Greenhouse Gas Emissions*, OECD Publishing, Paris, https://doi.org/10.1787/17017efe-en. [26]

OECD (2020), *The Circular Economy in Cities and Regions: Synthesis Report*, OECD Urban Studies, OECD Publishing, Paris, https://doi.org/10.1787/10ac6ae4-en. [2]

OECD (2019), *Business Models for the Circular Economy: Opportunities and Challenges for Policy*, OECD Publishing, Paris, https://doi.org/10.1787/g2g9dd62-en. [17]

OECD (2019), *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*, OECD Publishing, Paris, https://doi.org/10.1787/9789264307452-en. [18]

OECD (2019), "Moving to sustainable industrial production", in *Accelerating Climate Action: Refocusing Policies through a Well-being Lens*, OECD Publishing, Paris, https://doi.org/10.1787/75413ccd-en. [4]

OECD (2018), *Human Acceleration of the Nitrogen Cycle: Managing Risks and Uncertainty*, OECD Publishing, Paris, https://doi.org/10.1787/9789264307438-en. [21]

OECD (2018), *Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses*, OECD Publishing, Paris, https://doi.org/10.1787/9789264301016-en. [14]

OECD (2017), *Investing in Climate, Investing in Growth*, OECD Publishing, Paris, https://doi.org/10.1787/9789264273528-en. [23]

Sharmina, M. et al. (2021), "Decarbonising the critical sectors of aviation, shipping, road freight and industry to limit warming to 1.5-2°C", *Climate Policy*, Vol. 21/4, pp. 455-474, https://doi.org/10.1080/14693062.2020.1831430. [12]

Sun, X., F. Lettow and K. Neuhoff (2021), "Climate neutrality requires coordinated measures for high quality recycling", *DIW Weekly Report*, Vol. 6, https://doi.org/10.18723/diw_dwr:2021-26-1. [13]

UK Government (2011), *Skills for a Green Economy: A Report on the Evidence*, Departments for Business, Innovation and Skills, of Energy and Climate Change and for Environment, Food and Rural Affairs, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/32373/11-1315-skills-for-a-green-economy.pdf. [30]

Vasselina, R., L. Till Alexander and Z. Saadia (2020), *Jobs of Tomorrow: Mapping Opportunity in the New Economy*. [24]

Vona, F. et al. (2018), "Environmental regulation and green skills: An empirical exploration", *Journal of the Association of Environmental and Resource Economists*, Vol. 5/4, pp. 713-753, https://doi.org/10.1086/698859. [28]

Wang, P. et al. (2021), “Efficiency stagnation in global steel production urges joint supply- and demand-side mitigation efforts”, *Nature Communications*, Vol. 12/1, pp. 1-11, https://doi.org/10.1038/s41467-021-22245-6. [37]

Wilts, H. et al. (2014), “Policy mixes for resource efficiency”, *POLFREE Policy Options for a Resource-Efficient Economy*, University College London, London. [19]

2 Identifying vulnerable regions

This chapter identifies European regions that are most vulnerable to industrial transitions to climate neutrality in the key manufacturing sectors that will face the biggest transformations. These sectors refine coke and oil, and manufacture chemicals, basic metals, non-metallic minerals, paper and pulp, as well as motor vehicles. The most vulnerable regions are selected using employment shares and per capita emissions in each of the corresponding key manufacturing sectors. Regions with high employment shares and high emissions per capita face the largest transformational challenges in the transition to climate neutrality. They will have to decarbonise production assets and infrastructure whilst also protecting the workers in the key manufacturing sectors to ensure a just transition. The most vulnerable regions, spread throughout all of Europe, with a particular concentration in Central and Northern Europe, will also have to be ready to benefit from the opportunities that arise from the transition. Their distribution varies depending on the key manufacturing sector.

Towards a regionally balanced and just transition in manufacturing

This chapter identifies the regions most vulnerable to the transformation in the key manufacturing sectors in the transition to climate neutrality. The analysis is limited to regions in the 27 European Union (EU) member states (EU27), Iceland, Norway and the United Kingdom (UK), for which emissions data covered by the EU Emission Trading System (ETS) and sectoral regional employment data are available. ETS data and regional sectoral employment data are central to identifying vulnerable regions.

Vulnerable regions are identified by determining their employment and emissions in key manufacturing sectors that will need to undertake particularly profound transformations. The following section explains how the regions are identified in more detail. The chapter will then detail vulnerable regions by key sector. Regions are classified using the Nomenclature of Territorial Units for Statistics (NUTS system), which is the EU's classification regions at different level of details.

Identifying vulnerable regions in the manufacturing's transition to climate neutrality

Most EU economies only provide employment data at the two-digit Nomenclature of Economic Activities (NACE) level across large (NUTS 2) regions. To complement the employment analysis, emissions per capita in each sector across regions (NUTS 2) is used. Sectoral emissions can be computed at the three- and four-digit level as well as for small (NUTS 3) regions. As the analysis below argues, regions with both high employment shares and high emissions per capita in key manufacturing sectors are likely to be the most sensitive to the transition to climate neutrality. In the manufacturing of motor vehicles, emissions data do not serve to locate transformation challenges, as the most challenging transformations relate to the production of zero-emission vehicles rather than to the reduction of production emissions.

The identification of vulnerable regions is based on emissions per capita and shares of sectoral employment in total regional employment to assess the exposure of regional populations and workforces to the transitions sectors require to reach climate neutrality, regardless of size of region. However, the absolute amount of emissions and the total number of workers employed in a specific sector is also of interest to assess vulnerability. This information is therefore also provided below in the identification of vulnerable regions.

The analysis reveals that regions with large employment shares in the key manufacturing sectors identified in Chapter 1 are not always the same as those with high emissions per capita in these sectors. This may occur for several reasons:

- Not all sector employment is to be found at production sites hosting the installations which generate the emissions. Whilst the impact of the carbon-neutral transition is likely to be felt across the firm, workers and locations directly engaged in establishments where the emissions occur are likely to be most vulnerable. They may hold occupations with specific skills that are not always be suited to the new climate-neutral technologies. By contrast, managers and accountants working in other establishments within the firm may find it easier to transfer their skills to other sectors, including those that will benefit from the green transition.
- As demonstrated in the first chapter, there can be significant differences in the emissions intensities of three-digit NACE activities within two-digit activities. There can be significant differences in the distribution of employment across sub-sectors at the three-digit NACE level, with some regions more specialised in sub-sectors with lower emission intensities.
- Regions may also differ in how much they have advanced in adopting less emissions-intensive production. If regions continue to invest in high-emission productions, they will be more at risk of stranded assets, amplifying employment risks. Across regions, industries may also produce with different labour intensities.

Employment data used in the report are sourced from Eurostat structural business statistics (Box 2.1). Emissions data are sourced from the EU ETS. EU ETS data do not identify the NACE sector of origin. One novel contribution of this publication is to attribute regional emissions to the key NACE manufacturing sectors by identifying the companies that own the installations as well as their main sector of activity (Box 2.1).

Box 2.1. Using employment and emissions data to identify vulnerable regions

Employment data

Eurostat structural business statistics (SBS) provide employment data by two-digit NACE sectors for large (NUTS 2) regions according to the geographical location of establishments. The data are from 2018 but if some are missing then data from the latest available year are used. NUTS 2 regions are the same as Territorial Levels (TL) 2 regions, which is the OECD system for classification of regions, except in Belgium, France, Germany and the UK. For these countries, NUTS 2 regions are smaller than TL2 regions, hence allowing for more granular analysis.

Eurostat data are complemented with more granular sectoral (NACE) and geographical (NUTS) data from individual EU countries where available. Some countries provide more detailed regional employment data for employees only.

SBS employment includes employees and the self-employed. Some countries provide more detailed regional employment data for employees only. For example, Sweden provides such data for 5-digit NACE sectors at the NUTS 3 regional level, we assume the distribution of employees and the self-employed across sectors is the same as in the 2-digit sector.

Emissions data

Emissions data and matched regional and firm data are from the European Commission (EC) (2021[1]). Emissions data are from the EU ETS as reported to the EU Transaction Log (EUTL) and provided by the EC Directorate-General for Climate Action. Not all emissions are included in the EU ETS. Inclusion criteria for installations vary. For example, only steel plants with a production capacity of over 2.5 tonnes per hour are included. Hence, when a region employs workers in a manufacturing sector but has no emissions in that sector, it may have installations below the threshold.

Emissions are attributed to large (NUTS 2) and small (NUTS 3) regions based on the location of facilities. They are attributed to two-, three- and four-digit NACE sectors according to the main sector of activity of the company that owns the installation. For this purpose, facility emissions data are matched with Orbis data on businesses. In some cases, the owner's main activity is different from the activity of the installation. Hence, the EU ETS sectoral information is used to complement the sectoral attribution to find the most suitable one. For example, a cement installation owned by a financial holding company is classified as financial services by NACE but cement production in the EU ETS. Relying solely on the EU ETS is not possible as a large part of emissions fall under the ETS activity combustion of fuels, which is the case for many installations in a wide range of manufacturing sectors. ETS activities matched with NACE codes are further described in a forthcoming working paper (Fuentes, Noels and Ventricelli, forthcoming[2]).

Installations are in some instances owned by business whose main activity is in a different sector than the installation. EU ETS provides some sectoral information on installations and is used to completement the NACE sectors in these instances. For example, a financial holding company owns a cement-producing installation as financial services by NACE. ETS information allows to reattribute the installation to cement production. Relying solely on the EU ETS is not possible as the sectoral classification does not follow ETS and ETS attributes many installations to the combustion of fuels, which can refer to many manufacturing NACE sectors.

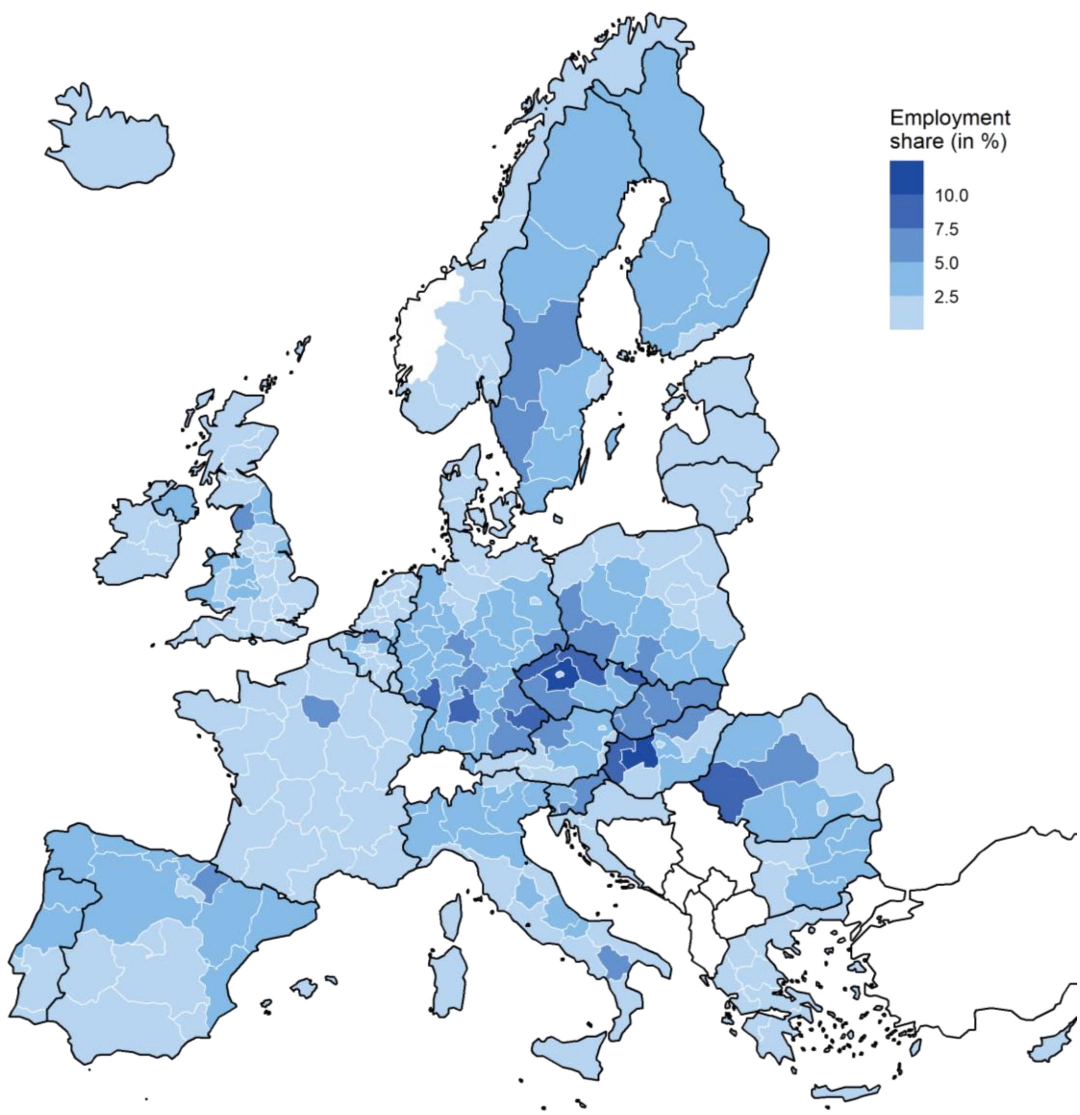
Source: EC (2021[1]), *European Emissions Trading System (ETS) – Calculations on the Regional Employment Impact of ETS Installations*, https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/reg_impact_ets_installations_en.pdf.
Fuentes, A., J. Noels and V. Ventricelli (forthcoming[2]), "Regional Industrial Transitions to Climate Neutrality: Identifying vulnerable regions", *OECD Regional Development Policy Papers*, OECD, Paris.

Regions vulnerable to transformations in the key manufacturing sectors

Employment shares across all key manufacturing sectors are high in Central and Eastern European regions (Figure 2.1). The automobile industry is the biggest employer and therefore dominates this spatial distribution of employment.

Figure 2.1. Regional employment shares in key manufacturing sectors

As a share of total employment, NUTS 2 regions, 2018



Note: The key manufacturing sectors are paper and paper products (NACE 17), coke and refined petroleum products (NACE 19), chemicals and chemical products (NACE 20), non-metallic mineral products (NACE 23), basic metals (NACE 24) and motor vehicles (NACE 29). Regional employment in these sectors is summed. In some regions, missing employment data are assumed to be zero, resulting in an underestimation of employment shares. Areas in white missing data across all sectors.
Source: Own calculations based on Eurostat.

Table 2.1 shows the regions with high employment shares and high emissions per capita in at least one of the key manufacturing sectors. For example, Asturias has high employment shares only in basic metals production as well as higher related emissions per capita. Table 2.2 lists the employment and emissions thresholds that classify regions as vulnerable.

Recognising the importance of a more granular lens, the following sections analyse the vulnerability of regions to the transformations in each key manufacturing sector.

Table 2.1. Employment shares and emissions per capita in key manufacturing sectors for the most vulnerable regions

Large (NUTS 2) regions with high employment shares and emissions per capita in at least one of the key manufacturing sectors, 2018

	Region name	Oil		Chemicals		Basic Metals		Other non-metallic minerals		Paper		Cars
		Employment share	CO_2e/capita	Employment share	CO_2e/capita	Employment share	CO_2e/capita	Employment share	CO_2e/capita	Employment share	CO_2e/capita	Employment share
AT22	Styria	0.00	0.00	0.19	0.00	1.70	2.57	0.76	0.34	0.69	0.68	1.64
AT31	Upper Austria	0.01	0.00	0.98	0.73	1.69	5.56	0.74	0.41	0.47	0.09	1.45
BE21	Antwerp	0.39	3.36	2.37	3.82	0.80	0.02	0.47	0.00	0.25	0.02	0.80
BE23	East Flanders	0.04	0.03	0.95	0.65	0.94	2.96	0.50	0.00	0.56	0.21	1.77
BE34	Luxembourg (Belgium)	0.00	0.00	0.67	0.03	0.09	0.00	0.46	1.48	0.69	0.42	0.24
CZ02	Central Bohemian Region	0.08	0.01	0.83	0.21	0.53	0.04	1.19	0.67	0.38	0.00	7.61
CZ04	Northwest	NA	0.36	1.42	3.68	0.76	0.02	2.32	0.39	0.57	0.31	2.79
CZ05	Northeast	NA	0.02	0.66	0.27	0.66	0.00	1.76	0.38	0.67	0.02	5.89
CZ08	Moravia-Silesia	NA	0.10	0.39	0.00	3.41	2.33	0.49	0.00	0.43	0.01	4.46
DE11	Stuttgart	NA	0.00	0.52	0.00	0.24	0.00	0.26	0.13	0.49	0.05	7.06
DE22	Niederbayern	0.11	0.89	0.39	0.21	0.40	0.00	1.12	0.26	0.23	0.06	5.62
DE91	Braunschweig	0.00	0.00	0.50	0.02	1.25	2.86	0.45	0.24	0.32	0.06	NA
DEA1	Düsseldorf	0.04	0.41	1.71	0.42	1.80	3.42	0.30	0.05	0.21	0.04	0.70
DEA3	Münster	NA	1.40	1.47	1.01	0.30	0.16	0.62	0.95	0.25	0.03	0.70
DEB3	Rheinhessen-Pfalz	NA	0.00	4.75	3.75	0.33	0.00	0.79	0.33	0.34	0.06	1.66
DEC0	Saarland	NA	0.98	0.17	0.00	2.87	6.07	0.64	0.00	0.03	0.00	3.69
DEE0	Sachsen-Anhalt	0.15	1.17	1.62	1.80	0.87	0.10	0.98	1.13	0.33	0.09	0.46
DK05	Northern Jutland	0.00	0.00	0.16	0.00	0.34	0.00	1.01	3.72	0.10	0.00	0.15
EL65	Peloponnese	0.45	3.75	0.05	0.00	0.02	0.00	0.37	0.03	0.11	0.00	0.02
ES12	Asturias	NA	0.02	0.44	0.12	2.28	5.63	0.66	1.20	0.16	0.06	0.22
FI19	Western Finland	0.01	0.00	0.34	0.00	0.61	0.00	0.59	0.00	1.18	0.34	0.53
FI1B	Helsinki-Uusimaa	0.24	1.64	0.67	0.49	0.08	0.00	0.28	0.00	0.28	0.00	0.03
FI1C	Southern Finland	0.11	0.17	0.56	0.11	0.50	0.12	0.86	0.77	1.47	0.96	1.08
FI1D	Eastern and Northern Finland	0.01	0.00	0.31	0.02	1.28	3.67	0.54	0.00	0.52	0.61	0.21
HU21	Central Transdanubia	0.09	0.25	0.62	0.82	2.24	0.80	1.24	0.11	0.67	0.34	5.93
HU22	Western Transdanubia	0.14	0.00	0.12	0.02	0.22	0.00	0.84	0.00	0.17	0.00	7.47
HU31	Northern Hungary	0.49	0.00	1.03	1.38	0.48	0.03	0.62	0.00	0.30	0.00	3.83
ITH4	Friuli-Venezia Giulia	0.01	0.00	0.23	0.00	1.10	1.24	0.70	0.34	0.42	0.39	0.29
ITI2	Umbria	0.02	0.00	0.30	0.00	0.90	0.42	1.07	1.49	0.44	0.02	0.34
NL33	South Holland	0.22	2.37	0.49	0.83	NA	0.01	0.12	0.00	0.08	0.00	0.09
NL34	Zeeland	NA	4.27	1.87	20.52	NA	0.19	0.26	0.39	NA	0.00	0.13
PL22	Silesia	0.17	0.27	0.46	0.01	1.22	1.20	1.07	0.10	0.22	0.01	3.41
PL52	Opole region	0.00	0.00	0.82	1.48	0.41	1.13	1.20	3.61	0.60	0.06	1.72
PL72	Swietokrzyskie	0.01	0.00	0.13	0.00	0.70	0.07	1.77	4.16	0.32	0.00	1.40
RO42	West	0.01	0.00	0.28	0.00	0.29	0.05	0.54	0.32	0.13	0.00	7.36
SE32	Central Norrland	NA	0.00	0.61	0.11	0.58	0.69	0.34	0.00	1.74	0.45	0.13
SE33	Upper Norrland	NA	0.00	0.27	0.00	1.92	2.04	0.17	0.17	0.77	0.12	1.33
SK01	Bratislava Region	NA	3.39	0.18	0.00	0.03	0.00	0.88	1.35	0.06	0.00	5.42
SK02	West Slovakia	NA	0.00	0.67	0.72	0.45	0.00	0.87	0.46	0.24	0.00	3.27
UKD6	Cheshire	0.22	2.03	0.86	0.80	0.12	0.05	0.32	0.00	0.34	0.00	1.37
UKE1	East Yorkshire and Northern Lincolnshire	0.33	3.85	0.97	0.71	1.03	5.47	0.69	0.32	0.37	0.00	0.89

Note: Regions are identified as the most vulnerable regions by having high employment share and high emissions per capita in at least one of the key sectors. Employment shares relate to the key sectors at the two-digit NACE level. The sectors are NACE 19: manufacture of coke and refined petroleum products with an employment share of at least 0.2%; NACE 20: manufacture of chemicals and chemical products with an employment share of at least 1%; NACE 24: manufacture of basic metals with an employment share of at least 1%; NACE 23: manufacture of non-metallic mineral products with an employment share of at least 1%; NACE 17: manufacture of paper and paper products with an employment share of at least 0.65%; NACE 29: manufacture of vehicles, trailers and semi-trailers with an employment share of at least 5%.

Emissions (in CO_2e) per capita relate to the key sectors at the two-, three- or four-digit level. The sectors are NACE 19: manufacture of coke and refined petroleum products with at least 1 tCO_2e/capita; NACE 20: manufacture of chemicals and chemical products with at least 1 tCO_2e/capita; NACE 241: manufacture of basic iron and steel and ferroalloys; NACE 2442: aluminium production with at least 1 tCO_2e/capita combined; NACE 235: manufacture of cement, lime and plaster with at least 1 tCO_2e/capita; and NACE 171: manufacture of pulp, paper and paperboard with at least 0.25 tCO_2e/capita.

Source: Authors' calculations based on Eurostat and EU ETS.

Table 2.2. Thresholds that classify regions as vulnerable

Sector	Employment share (%)	Emissions per capita (tCO_2/capita)
Paper and pulp	0.65	0.25
Coke and refined petroleum	0.20	1.00
Chemicals	1.00	1.00
Non-metallic minerals/cement	1.00	1.00
Basic metals/steel and aluminum	1.00	1.00

Note: For non-metallic minerals, employment shares refer to non-metallic minerals but emissions per capita refer to cement emissions. For basic metals, employment shares refer to basic metals but emissions per capita refer to steel and aluminium emissions.

Regions with employment and emissions in the manufacture of coke and refined petroleum products

Most petroleum refineries will become obsolete as the EU moves towards climate neutrality. Regional employment shares in the manufacture of coke and refined petroleum products are low across the EU. There is little employment in coke production in the EU, so this sector will be referred to as oil refining. No large (NUTS 2) region employs more than 0.5% of workers in this sector. Still, in some regions, it can reach several thousands of workers. One outlier is Île-de-France with over 15 000 employees in 2017, but very low emissions, likely reflecting the presence of headquarters or other managerial functions in the Paris region, with managerial or administrative occupations.

A few large (NUTS 2) regions, spread across West, North and South Europe, have both relatively high employment shares and high emissions per capita in oil refining (Figures 2.2 and 2.3). These regions and their workers will likely be most vulnerable to the gradual phase-out of oil products. Moreover, their employment is concentrated in relatively few establishments. The regions with the highest absolute emissions covered by the EU ETS are in Germany, Italy, the Netherlands and Poland.

Transition risks of moving to climate neutrality are further concentrated in small (NUTS 3) regions (Annex Figure 2.A.1).

Figure 2.2. Regions with high employment shares in oil refining

Regions with employment shares in the manufacture of coke and refined petroleum products exceeding 0.15%, 2018

Nuts ID	Region name	Employment share	Emissions/capita	Employment	Emissions
HU31	Northern Hungary	0.49	0.00	1 916	0
EL65	Peloponnese	0.45	3.75	1 079	2 161 611
BE21	Antwerp	0.39	3.36	3 263	6 210 089
UKE1	East Yorkshire and Northern Lincolnshire	0.33	3.85	1 342	3 586 379
HU12	Pest	0.32	0.00	1 511	0
HR04	Continental Croatia	0.31	0.11	3 491	312 088
FR10	Île-de-France	0.30	0.06	19 244	764 142
DE60	Hamburg	0.30	0.48	3 790	873 772
EL30	Attica	0.29	0.54	5 033	2 012 220
HU33	Southern Great Plain	0.25	0.00	1 180	0
FI1B	Helsinki-Uusimaa	0.24	1.64	2 202	2 709 561
UKD6	Cheshire	0.22	2.03	1 109	1 880 351
NL33	South Holland	0.22	2.37	4 201	8 717 532
HU23	Southern Transdanubia	0.20	0.00	657	0
HR03	Adriatic Croatia	0.20	0.73	1 056	1 004 631
EE00	Estonia	0.20	1.33	1 293	1 751 336
ITC3	Liguria	0.19	0.25	1 277	391 425
BG31	Severozapaden	0.19	0.00	559	3 322
ITG1	Sicily	0.19	1.56	2 815	7 822 051
PT18	Alentejo	0.18	3.31	574	2 359 050
PL22	Silesia	0.17	0.27	3 215	1 235 980
ES42	Castile-La Mancha	0.15	0.73	1 109	1 485 092
DEE0	Sachsen-Anhalt	0.15	1.17	1 497	2 600 136

Note: Emissions in tCO_2e.
Source: Authors' calculations based on Eurostat and EU ETS.

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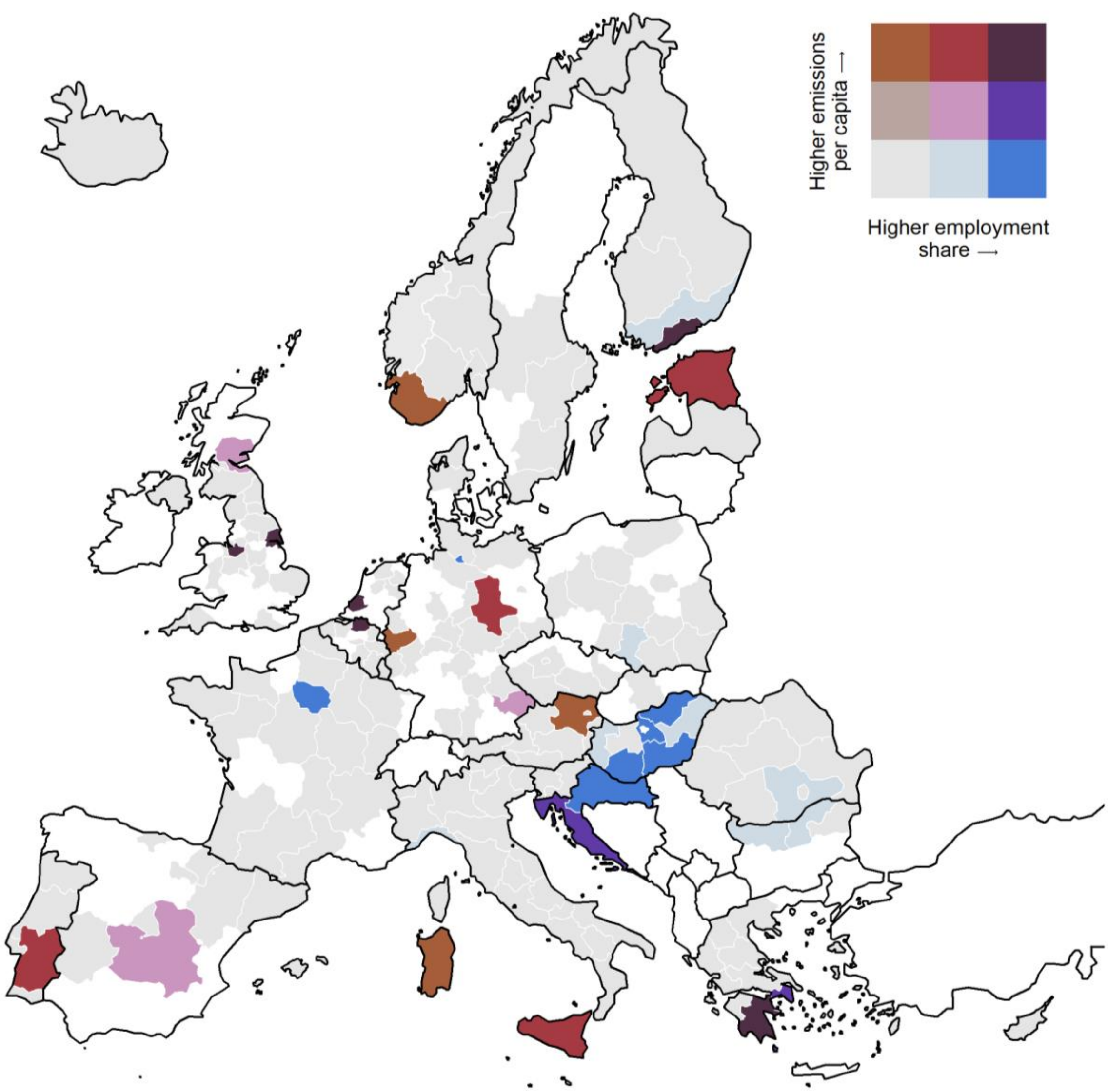
Figure 2.3. Regional employment and emissions in oil refining

Emissions per capita and employment share of manufacture of coke and refined petroleum products, NUTS 2 regions, 2018



Note: Breaks in employment shares are at 0.1% and 0.2%. Breaks in emissions per capita are at 0.5 and 1 tCO_2e/capita. White areas represent missing data. Emissions per capita are calculated as emissions from EU ETS installations of businesses whose main activity is the manufacture of coke and refined petroleum products (NACE 19) divided by the population in NUTS 2 regions. Employment shares are calculated as employment in the manufacture of coke and refined petroleum products (NACE 19) as a share of total employment in NUTS 2 regions.
Source: Author's calculations based on Eurostat and ETS-Orbis.

Regions with employment and emissions in the manufacture of chemicals and chemical products

Regions with high employment shares in the manufacture of chemicals and chemical products are mostly in Central and Western Europe. In some cases, high employment in this sector overlaps with high employment in oil refining as they are often closely related. However, employment is much higher in the chemicals sector. Regions with high levels of employment in this sector employ several tens of thousands of workers. Once again, the Île-de-France region in France is an outlier with over 100 000 workers in this sector in 2018, likely also reflecting a headquarters effect, as Île-de-France has almost 3 000 establishments but only 3 emitting installations in chemical production.

Regions with the highest employment shares are located in Belgium, Germany and the Netherlands (Figure 2.4). Regions with high employment shares and high emissions per capita tend to overlap (Figure 2.5). The most emission-intensive sub-sector is the manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms (NACE 201), where transformation challenges are also likely to be particularly deep.

Figure 2.4. Regions with high employment shares in chemicals

Regions with employment shares in the manufacture of chemicals and chemical products exceeding 1%, 2018

Nuts ID	Region name	Employment share	Emissions/capita	Employment	Emissions
DEB3	Rheinhessen-Pfalz	4.75	3.75	48 224	7 695 111
BE21	Antwerp	2.37	3.82	19 809	7 057 306
NL34	Zeeland	1.87	20.52	3 508	7 845 417
DEA1	Düsseldorf	1.71	0.42	47 949	2 208 716
FR10	Île-de-France	1.63	0.05	105 126	623 516
DEE0	Sachsen-Anhalt	1.62	1.80	16 229	4 008 005
DE71	Darmstadt	1.54	0.02	35 692	75 867
DEA3	Münster	1.47	1.01	19 400	2 652 811
CZ04	Northwest	1.42	3.68	7 247	4 105 686
DE21	Oberbayern	1.35	0.15	39 192	704 259
DEA2	Köln	1.25	0.78	30 611	3 488 582
BE22	Limburg (BE)	1.08	0.46	3 821	405 266
NL42	Limburg (NL)	1.07	0.00	6 281	0
DE92	Hannover	1.04	0.05	11 962	109 269
HU31	Northern Hungary	1.03	1.38	4 021	1 571 453
ES51	Catalonia	1.03	0.38	36 459	2 867 029
BE32	Hainaut	1.00	0.72	4 431	969 843

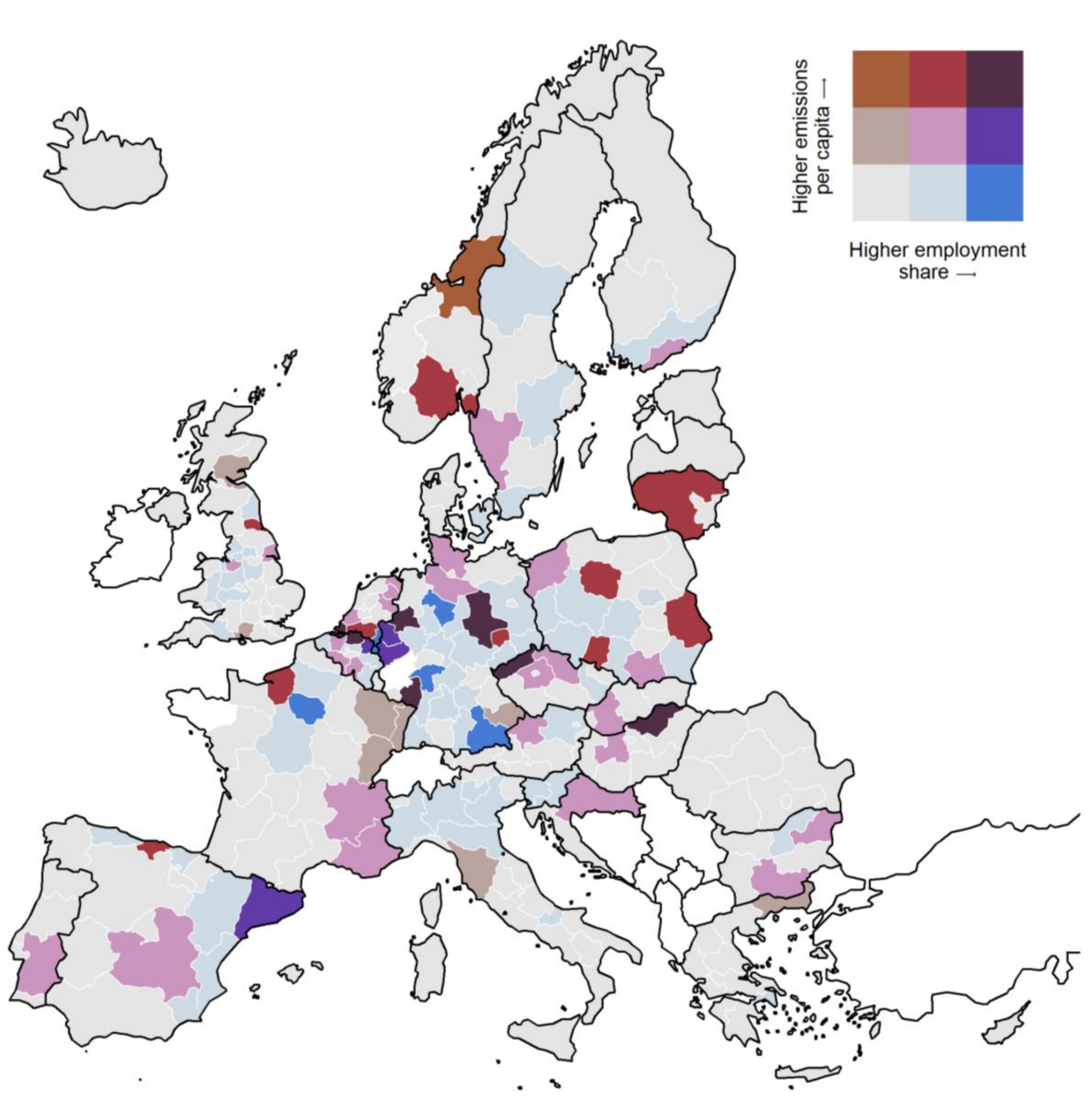
Note: Emissions in tCO_2e.
Source: Authors' calculations based on Eurostat and EU ETS.

StatLink https://stat.link/28cgst

The emissions of the large (NUTS 2) regions with the highest employment shares and the highest level of emissions tend to be concentrated in just one small (NUTS 3) region (Annex Figure 2.A.2).

Figure 2.5. Regional employment and emissions in chemical production

Emissions per capita and employment shares of manufacture of chemicals and chemical products, NUTS 2 regions, 2018



Note: Breaks in employment shares are at 0.4% and 1%. Breaks in emissions per capita are at 0.2 and 1 tCO_2e/capita. White areas are missing data. Emissions per capita are calculated as emissions from EU ETS installations of businesses whose main activity is in the manufacture of chemicals and chemical products (NACE 20) divided by the population in NUTS 2 regions. Employment shares are calculated as employment in the manufacture of chemicals and chemical products (NACE 20) as a share of total employment in NUTS 2 regions.
Source: Author’s calculations based on Eurostat and ETS-Orbis.

Regions with employment and emissions in the manufacture of basic metals

Many regions have thousands or even tens of thousands of workers in basic metals manufacturing, with Arnsberg, Germany, having over 50 000. Two sub-sectors stand out as particularly emissions-intensive and hard to abate, namely the manufacture of basic iron, steel and ferroalloys (NACE 241) and aluminium production (NACE 2442). Therefore, EU ETS emissions related to these two sub-sectors are shown.

Employment shares in the manufacture of basic metals can reach several percentage points. Regional employment shares in basic metals manufacturing exceed 1% in 26 large (NUTS 2) regions. Regions with higher shares are mainly in Central and Northern Europe, especially in the Czech Republic, Sweden and the UK (Figure 2.6).

Thirteen large (NUTS 2) regions have both an employment share in basic metals exceeding 1% and emissions per capita for steel and aluminium over 1 tCO_2e per capita (Figure 2.7). They are spread across Austria, the Czech Republic, Finland, Germany, Italy, Poland, the Slovak Republic, Spain, Sweden and the UK, with a particular concentration in Central and Northern Europe. These regions may find it more challenging to move to climate neutrality as they need to convert current infrastructure, reskill or find employees with skills suitable to the production of green steel and aluminium.

In some large regions with high employment shares, emissions per capita in steel and aluminium production are relatively low, as is the case for Arnsberg. These regions could have jobs in less emission-intensive sub-sectors or employ workers in managerial or administrative tasks rather than in production processes. Conversely, a few large regions have high emissions from steel and aluminium plants but do not stand out on employment shares. Still, they may employ thousands of workers. As Box 2.2 illustrates for Sweden, data at the three-digit NACE level allow for the identification of employment in sectors where transformation challenges are likely to be less deep, such as in the production of tubes and pipes.

Both steel and aluminium production emissions are concentrated within their respective large (NUTS 2) regions. In both cases, large regions with the highest emissions have over 85% of their emissions in just 1 small region (Annex Figures 2.A.3 and 2.A.4).

Figure 2.6. Regions with high employment shares in basic metals

Regions with employment shares in the manufacture of basic metals exceeding 1%, 2018

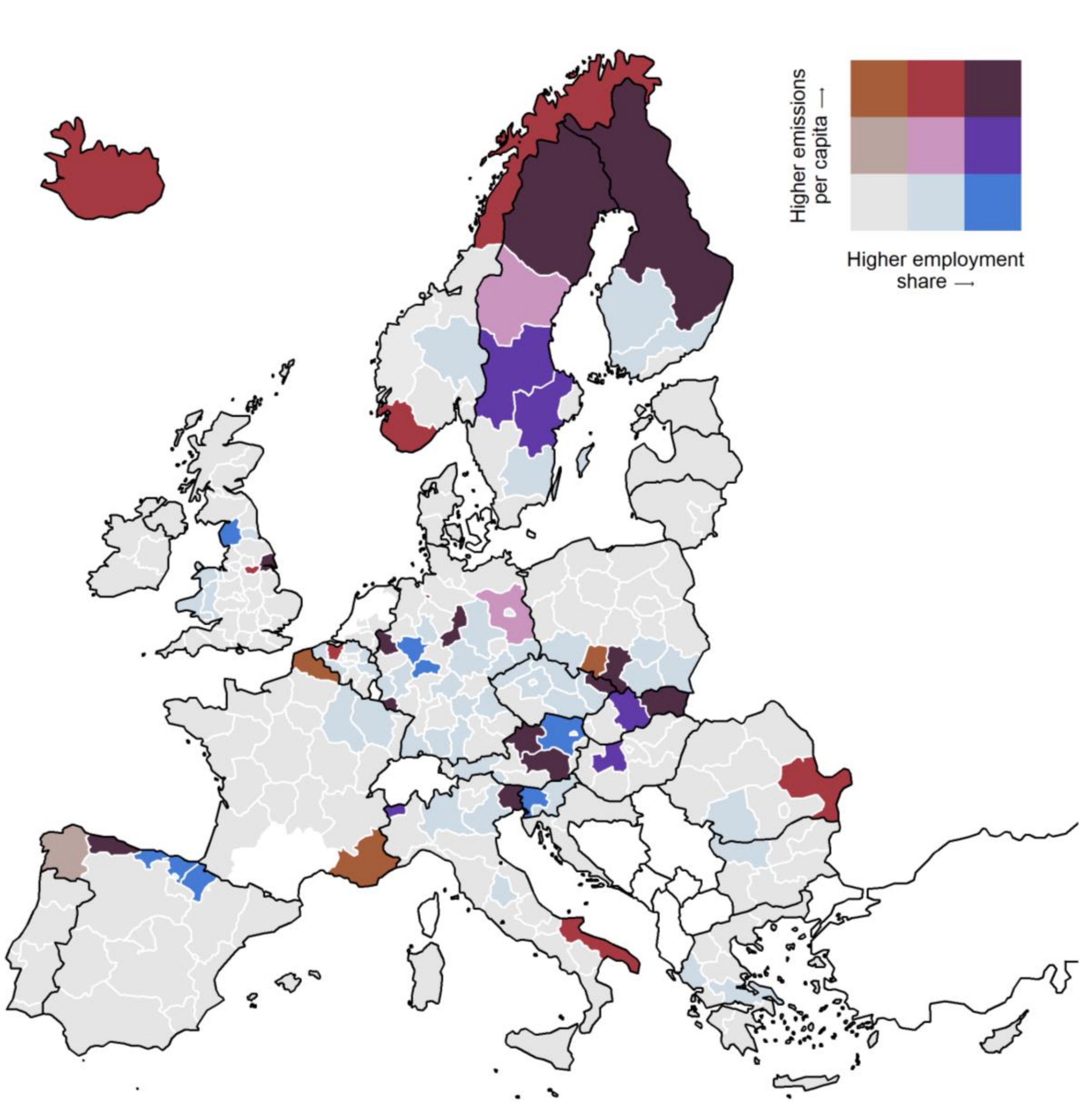
Nuts ID	Region name	Employment share	Emissions/capita	Employment in basic metals	Emissions in steel and aluminium	Emissions ratio
UKD1	Cumbria	4.03	0.00	10 134	0	
SE31	North Middle Sweden	3.68	0.75	14 067	642 166	
CZ08	Moravia-Silesia	3.41	2.33	19 465	2 808 083	
DEC0	Saarland	2.87	6.07	15 323	6 038 045	
DEA5	Arnsberg	2.80	0.16	52 024	565 753	
ES12	Asturias	2.28	5.63	9 000	5 788 321	
HU21	Central Transdanubia	2.24	0.80	10 552	843 977	
SK04	East Slovakia	2.07	3.68	11 856	5 969 066	
ITC2	Aosta Valley	2.06	0.85	1 268	107 236	
SE33	Upper Norrland	1.92	2.04	4 868	1 058 183	
DE72	Gießen	1.87	0.13	9 797	139 981	
DEA1	Düsseldorf	1.80	3.42	50 597	17 782 968	
AT22	Styria	1.70	2.57	10 757	3 191 868	
AT31	Upper Austria	1.69	5.56	13 027	8 188 526	
ES21	Basque Country	1.67	0.28	17 279	598 525	
SE12	East Middle Sweden	1.44	0.91	11 427	1 542 102	
SK03	Central Slovakia	1.38	0.51	7 859	686 339	
FI1D	Eastern and Northern Finland	1.28	3.67	7 071	4 730 587	
DE91	Braunschweig	1.25	2.86	10 419	4 564 932	
PL22	Silesia	1.22	1.20	22 773	5 392 646	
AT12	Lower Austria	1.20	0.00	8 746	0	
ITH4	Friuli-Venezia Giulia	1.10	1.24	6 004	1 502 802	
SI04	Western Slovenia	1.10	0.11	5 933	108 454	
UKE1	East Yorkshire and Northern Lincolnshire	1.03	5.47	4 176	5 093 365	
ES13	Cantabria	1.03	0.41	2 345	238 152	
ES22	Navarra	1.00	0.10	3 067	66 473	

Note: The ratio of emissions represents the combined emissions from the manufacture of basic iron and steel and of ferroalloys (NACE 241) and aluminium production (NACE 2442) as a share of total emissions across all manufacture of basic metals (NACE 24). Niederösterreich has no emissions in NACE 24. Emissions in tCO_2e.
Source: Authors' calculations based on Eurostat and EU ETS .

StatLink https://stat.link/v5uqro

Figure 2.7. Regional employment and emissions in the manufacture of basic metals

Emissions per capita from the manufacture of basic iron and steel and of ferroalloys and aluminium production, and employment shares in the manufacture of basic metals, NUTS 2 regions, 2018



Note: Breaks in employment shares are at 0.5% and 1%. Breaks in emissions per capita are at 0.5 and 1 tCO_2e/capita. White areas have missing data. North Holland has high emissions but does not provide employment data. Emissions per capita are calculated as emissions from EU ETS installations of businesses whose main activity is in the manufacture of basic iron and steel and ferroalloys (NACE 241) and aluminium production (NACE 2442) divided by the population in NUTS 2 regions. Employment shares are calculated as employment in the manufacture of basic metals (NACE 24) as a share of total employment in NUTS 2 regions.
Source: Author's calculations based on Eurostat and ETS-Orbis.

Box 2.2 Basic metals employment in Swedish regions

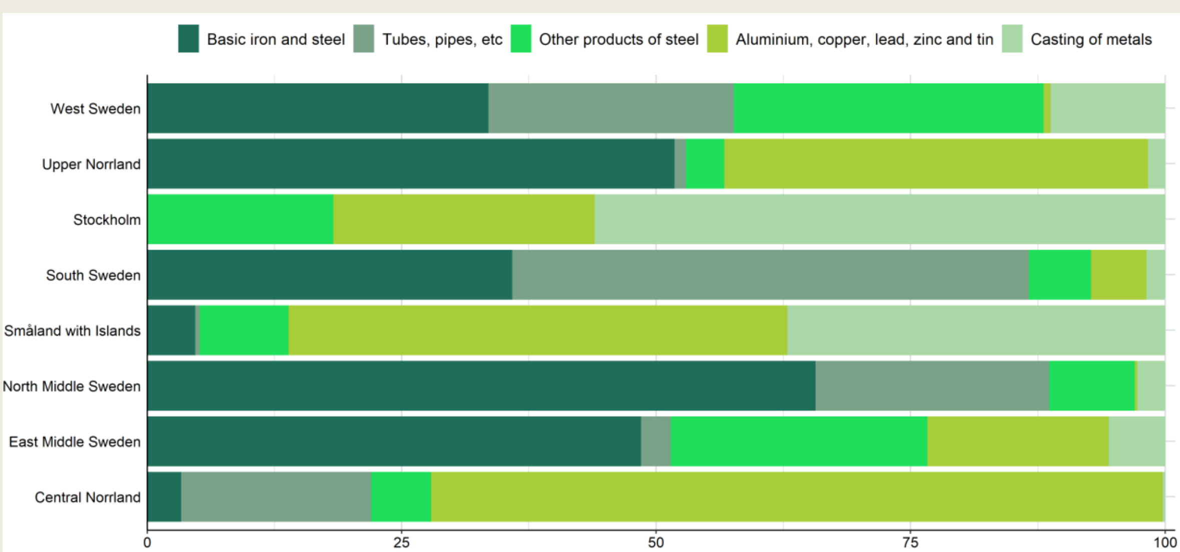
Activities within the manufacturing of basic metals (NACE 24) are affected to different degrees by the transformations to reach climate neutrality, as highlighted in Chapter 1. Workers will therefore also be differently affected depending on which sub-sector they work in. Workers and businesses in the manufacture of basic iron and steel and ferroalloys (NACE 241) and aluminium production (NACE 2442) may be particularly impacted, more so than in the manufacture of other basic metals. Moreover, transformation challenges differ across sub-sectors: indeed, they are not the same in steel and aluminium production. A fine sectoral breakdown for regional employment data, therefore, allows for better identification of regional development challenges. Sweden is one of few countries providing such a breakdown and has vulnerable regions in basic metals production.

The relative importance of employment in these basic metal manufacturing sub-sectors varies substantially across Swedish regions. Moreover, the concentration of EU ETS-related emissions from basic metals in steel production can give an indication of how strongly steel-related employment directly relates to activities generating high emissions.

High emissions from steel or aluminium production do not imply that all workers employed in basic metals are affected. For example, in Upper Norrland, 100% of emissions from basic metals are in steel production but only 52% of employment and in East Middle Sweden, 96% of emissions for only 49% of employment. Hence, the more granular three-digit data allow better identification of the challenges for employment. Emissions data cannot fill this gap.

Figure 2.8. Contribution of three-digit employment to employment in basic metals

Employees in three-digit NACE sub-sectors as a share of employees in the manufacture of basic metals in large (NUTS 2) regions, 2018



Note: The three-digit manufacturing sectors are basic iron and steel and of ferroalloys (NACE 241), tubes, pipes, hollow profiles and related fittings, of steel (NACE 242), other products of first processing of steel (NACE 243), basic precious and other non-ferrous metals (NACE 244) which includes aluminium production and casting of metals (NACE 245)
Source: Swedish Agency for Economic and Regional Growth.

StatLink https://stat.link/ukq24n

Regions with employment and emissions in the manufacture of non-metallic mineral products

The output of the manufacture of non-metallic mineral products is diverse. Cement production has been identified as particularly difficult to move to climate neutrality. Hence, employment in this sub-sector may be more at risk. While employment in cement production cannot be distinguished from other non-metallic mineral production in most countries, emissions from the EU ETS can identify regions producing cement, lime and plaster (NACE 235). Large (NUTS 2) regions with high employment shares in the manufacture of non-metallic mineral products are especially numerous in Central Europe (Figure 2.9). The regions with the highest shares are located in the Czech Republic, Germany, Poland and Portugal. However, high employment shares can also reflect employment in other sub-sectors.

In Italy, employment in cement production can be distinguished from employment in non-metallic minerals (Box 2.3). The example of Italy shows that high cement-related emissions per capita combined with high employment in non-metallic minerals can provide some indication of which regions face more cement-related transformation challenges.

Beyond Italy, there are several large (NUTS 2) regions with employment in non-metallic minerals above 1% and where at least half of emissions in the sector are cement-related. These are located in Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Germany, Hungary and Poland. Many of these large regions have high emissions per capita in cement production (Figure 2.10). Some particularly large (NUTS 2) regions with low emissions per capita and employment shares still stand out for high absolute cement-related emissions and employ thousands of workers, especially in Germany and Spain.

As in other key manufacturing sectors, cement-related activity is further concentrated within small (NUTS 3) regions (Annex Figure 2.A.5). For example, in the large region Opole, Poland, all cement-related emissions are emitted in the small region Opolski. Hence, this Polish community may be especially vulnerable to employment losses.

Figure 2.9. Regions with high employment shares in non-metallic mineral products

Regions with employment shares in the manufacture of other non-metallic mineral products exceeding 1%, 2018

Nuts ID	Region name	Employment share	Emissions/capita	Employment in non-metallic minerals	Emissions in cement	Emissions ratio
PT16	Central Portugal	2.46	0.71	24 672	1 588 032	
CZ04	Northwest	2.32	0.39	11 807	429 958	
DE24	Oberfranken	1.89	0.00	11 259	0	
PL72	Swietokrzyskie	1.77	4.16	8 986	5 130 059	
CZ05	Northeast	1.76	0.38	12 634	567 456	
DE23	Oberpfalz	1.71	0.80	11 160	887 234	
BG33	Severoiztochen	1.49	0.95	6 437	882 410	
ES52	Valencia	1.35	0.40	26 229	1 956 508	
DEB1	Koblenz	1.33	0.00	10 060	0	
PL82	Podkarpacia	1.31	0.00	10 965	4 733	
ITH5	Emilia-Romagna	1.30	0.18	28 080	810 781	
PL71	Lodzkie	1.25	0.63	14 202	1 548 287	
PL51	Lower Silesia	1.25	0.01	15 243	22 497	
HU21	Central Transdanubia	1.24	0.11	5 834	120 377	
PL52	Opole region	1.20	3.61	4 695	3 428 969	
CZ02	Central Bohemian Region	1.19	0.67	7 358	905 923	
PL43	Lubusz	1.18	0.00	4 853	0	
UKG2	Shropshire and Staffordshire	1.16	0.00	8 604	0	
BE22	Limburg (BE)	1.13	0.00	3 996	0	
DE22	Niederbayern	1.12	0.26	7 669	317 966	
DEG0	Thüringen	1.12	0.47	11 714	1 010 775	
AT21	Carinthia	1.09	0.80	2 890	449 914	
ITI2	Umbria	1.07	1.49	3 983	1 314 225	
BE32	Hainaut	1.07	2.03	4 754	2 722 515	
PL22	Silesia	1.07	0.10	19 917	462 000	
BE35	Namur	1.06	0.00	1 868	0	
CZ03	Southwest	1.06	0.00	6 288	0	
AT33	Tyrol	1.03	0.28	4 231	211 612	
SI03	Eastern Slovenia	1.03	0.05	4 954	58 496	
DK05	Northern Jutland	1.01	3.72	2 895	2 190 706	
ITF1	Abruzzo	1.01	0.13	5 270	169 808	

Note: The ratio of emissions represents the combined emissions from the manufacture of cement, lime, and plaster (NACE 235) as a share of total emissions across all manufacture of other non-metallic mineral products (NACE 23). Emissions in tCO_2e.

Source: Authors' calculations based on Eurostat and EU ETS.

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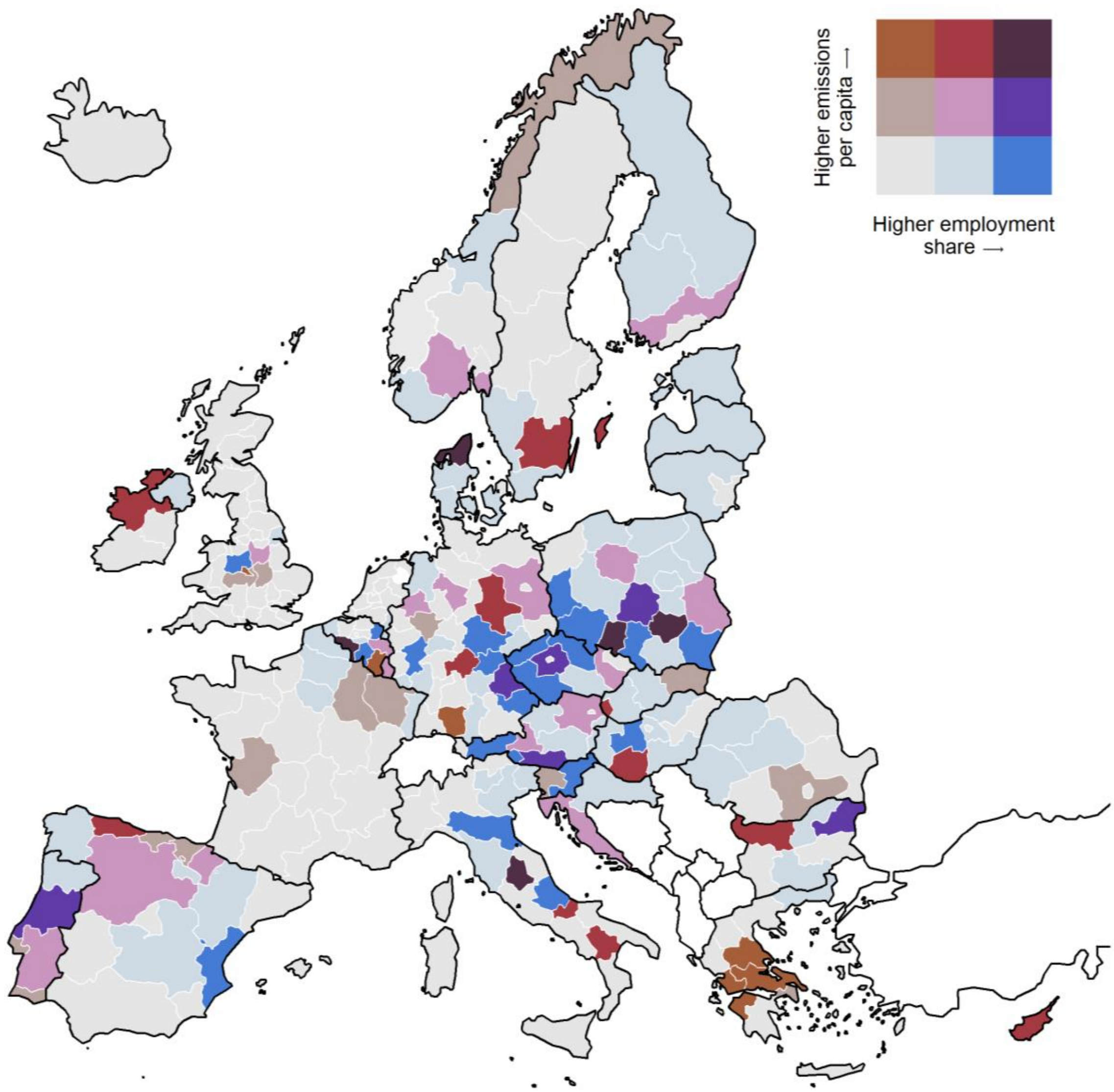
Figure 2.10. Regional employment and emissions in the manufacture of non-metallic mineral products

Emissions per capita from the manufacture of cement, lime and plaster and employment shares of the manufacture of non-metallic mineral products, NUTS 2 regions, 2018



Note: Breaks in employment shares are at 0.5% and 1%. Breaks in emissions per capita are at 0.5 and 1 tCO_2e/capita. White areas have missing data. Emissions per capita are calculated as emissions from EU ETS installations of businesses whose main activity is in the manufacture of cement, lime and plaster (NACE 235) divided by the population in NUTS 2 regions. Employment shares are calculated as employment in the manufacture of non-metallic mineral products (NACE 23) as a share of total employment in NUTS 2 regions.
Source: Author's calculations based on Eurostat and ETS-Orbis.

Box 2.3. The manufacture of cement in Italy

Three-digit data allows for identifying employment in the manufacture of cement, lime and plaster (NACE 235). The only country with data providing a breakdown of employment in non-metallic minerals, including in cement production, and that has high employment shares in the manufacture of other non-metallic mineral products is Italy. It also provides these data at a finer regional breakdown, for NUTS 3 regions.

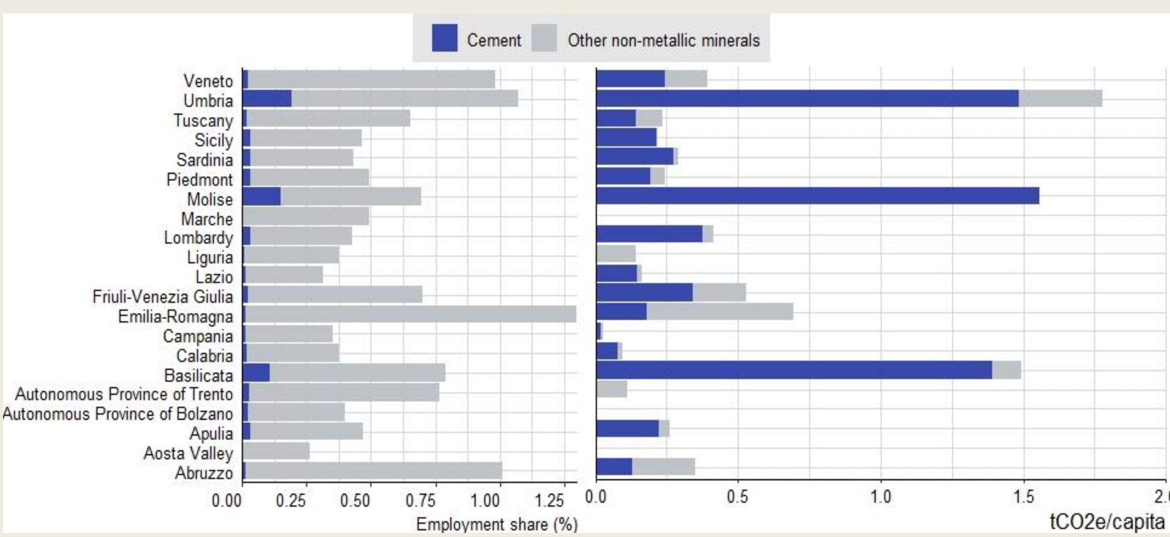
The regions of Abruzzo and Emilia-Romagna have high employment shares in the manufacture of non-metallic mineral products (NACE 23) but not in the manufacture of cement, lime and plaster (Figure 2.11).

Regions with high cement-related emissions and high employment shares in non-metallic mineral products tend to have higher shares of employment in cement production. Figure 2.10 identifies Umbria for its high employment share in non-metallic mineral products and high emissions per capita in cement. In the manufacture of cement, lime and plaster (NACE 235), Umbria has the highest employment share of the Italian regions. The emissions of the manufacture of cement, lime and plaster (NACE 235) represent 84% of regional emissions from the manufacture of non-metallic mineral products (NACE 23).

Employment risks are more concentrated than large (NUTS 2) regions data allow to identify. The small (NUTS 3) region of Perugia, a part of Umbria, employs almost all cement workers of Umbria. It hosts 8 establishments and emits 87% of Umbrian emissions.

Figure 2.11. Contribution of cement within non-metallic mineral products

Contribution of manufacture of cement, lime and plaster to employment shares and emissions per capita in the manufacture of non-metallic mineral products, large (NUTS 2) regions, 2018



Source: Italian National Institute of Statistics, Eurostat and ETS-Orbis.

StatLink https://stat.link/47x2a9

Regions with employment and emissions in the manufacture of paper and paper products

Among the key sectors, emissions are relatively low in the manufacture of paper and paper products. Even so, the transformations needed are still great in the manufacture of pulp, paper and paperboard (NACE 171), which is the most emissions intensive. Therefore, emissions from this sub-sector are considered.

While employment shares exceed 1% in only a few large (NUTS 2) regions, regional employment can still reach thousands of workers (Figure 2.12). Large regions with higher employment shares in the manufacture of paper and paper products are mostly in Northern Europe. Swedish regions lead the sector. Their high employment shares rely on a relatively small number of establishments.

Figure 2.12. Regions with high employment shares in paper

Regions with employment shares in the manufacture of paper and paper products exceeding 0.65%, 2018

Nuts ID	Region name	Employment share	Emissions/capita	Employment in paper paper products	Emissions in paper and pulp	Emission ratio
SE31	North Middle Sweden	2.02	0.22	7 723	187 191	
SE32	Central Norrland	1.74	0.45	3 105	169 161	
FI1C	Southern Finland	1.47	0.96	7 483	1 116 447	
FI19	Western Finland	1.18	0.34	7 357	469 470	
PL61	Kuyavian-Pomerania	1.11	0.05	9 664	112 943	
FRF1	Alsace	1.09	0.13	8 516	251 624	
DEB2	Trier	1.01	0.00	2 644	0	
SE21	Småland with Islands	0.92	0.04	3 963	30 371	
PL43	Lubusz	0.83	0.22	3 422	220 993	
DEB1	Koblenz	0.81	0.17	6 134	260 965	
SE33	Upper Norrland	0.77	0.12	1 965	62 686	
HU12	Pest	0.75	0.00	3 549	0	
ES22	Navarra	0.75	0.21	2 291	137 460	
PL41	Greater Poland	0.72	0.01	11 573	48 513	
AT34	Vorarlberg	0.69	0.06	1 372	23 889	
BE34	Luxembourg (Belgium)	0.69	0.42	683	119 393	
AT22	Styria	0.69	0.68	4 353	837 297	
SE23	West Sweden	0.69	0.07	7 080	139 249	
HU21	Central Transdanubia	0.67	0.34	3 155	355 311	
CZ05	Northeast	0.67	0.02	4 800	36 887	
SE12	East Middle Sweden	0.66	0.07	5 264	120 203	

Note: The ratio of emissions represents the combined emissions from the manufacture of pulp, paper, and paperboard (NACE 171) as a share of total emissions across all manufacture of paper and paper products (NACE 17). Trier and Pest have no emissions in NACE 17. Emissions in tCO_2e.

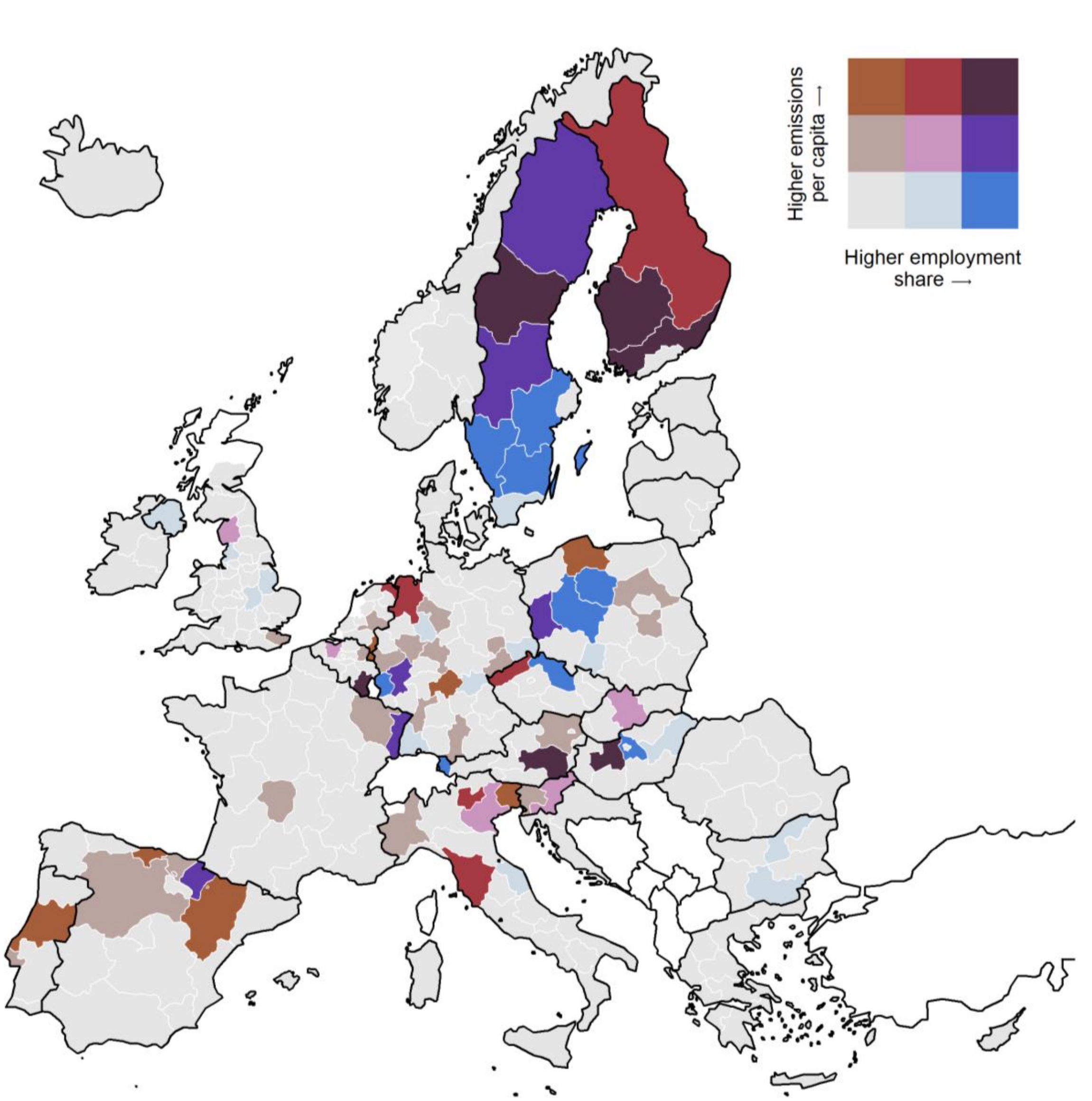
Source: Authors' calculations based on Eurostat and EU ETS.

StatLink https://stat.link/h7u0b1

Regions with high employment shares and high emissions per capita are mainly located in Finland and Sweden (Figure 2.13). Few other sectors have such consistent overlap in regions scoring high on both. Finnish regions also have among the highest absolute emissions.

Figure 2.13. Regional employment and emissions in the manufacture of paper and paper products

Emissions per capita from the manufacture of pulp, paper and paperboard and employment shares of the manufacture of paper and paper products, NUTS 2 regions, 2018



Note: Breaks in employment shares are at 0.5% and 0.65%. Breaks in emissions per capita are at 0.1 and 0.25 tCO_2e/capita. White areas have missing data. Emissions per capita are calculated as emissions from EU ETS installations of businesses whose main activity is in the manufacture of pulp, paper and paperboard (NACE 171) divided by the population in NUTS 2 regions. Employment shares are calculated as employment in the manufacture of paper and paper products (NACE 17) as a share of total employment in NUTS 2 regions.
Source: Author's calculations based on Eurostat and ETS-Orbis.

Box 2.4. Manufacturing of paper and paper products in Swedish regions

Figure 2.13 shows that Swedish regions have very high employment shares and some also have high emissions per capita in the manufacture of paper and paper products (NACE 17). Two Swedish regions, North Middle Sweden and Central Norrland, lead on employment shares. However, emissions in these Swedish regions are low. This may be due to Sweden's reliance on biomass as 41% of energy use in industry comes from bioenergy and the pulp and paper industry accounts for more than 50% of industrial energy use (Swedish Energy Agency, 2021[3]). Following the rules of the EU ETS, the burning of biomass is considered carbon neutral as it is assumed that emissions have been saved during the growth phase and will be compensated by the growth of new biomass (Transport & Environment, 2015[4]). They may nevertheless face some transition risks from competing demands on biomass.

Using three-digit employment data illustrates that most of the employment in Sweden's most vulnerable regions is concentrated in the manufacture of pulp, paper and paperboard (NACE 171), which is likely to be more vulnerable to the transition to climate neutrality than the production of paper products (NACE172). This sub-sector accounts for 92% of North Middle Sweden's and 97% of Central Norrland's employment in the manufacture of paper and paper products. Similarly, the sub-sector represents 85% and 100% respectively of regional emissions in the manufacture of paper and paper products. In the case of Central Norrland, transition risk is further concentrated in Västernorrland as 100% of employment in the three-digit sub-sector is in this small (NUTS 3) region.

Note: As described in Box 2.1, the three-digit employment data refer to employees only.
Source: Swedish Agency for Economic and Regional Growth, Eurostat and ETS-Orbis (2018); Swedish Energy Agency (2021[3]), *Energy in Sweden 2021 - An Overview*, https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=198022; Transport & Environment (2015[4]), *Reasons to Change the Zero-rated Criteria for Biomass in the EU ETS*, https://www.transportenvironment.org/wp-content/uploads/2021/07/2015%2001%20biomass%20ets_rating_FINAL.pdf.

Regions with employment and emissions in the manufacture of motor vehicles, trailers and semi-trailers

Regional employment shares in the manufacturing of motor vehicles, trailers and semi-trailers (NACE 29) across the EU are the highest among the key sectors. Almost a third of EU large (NUTS 2) regions have a regional employment share greater than 1% in this sector, indicating that a great share of regions and their workers will be at risk.

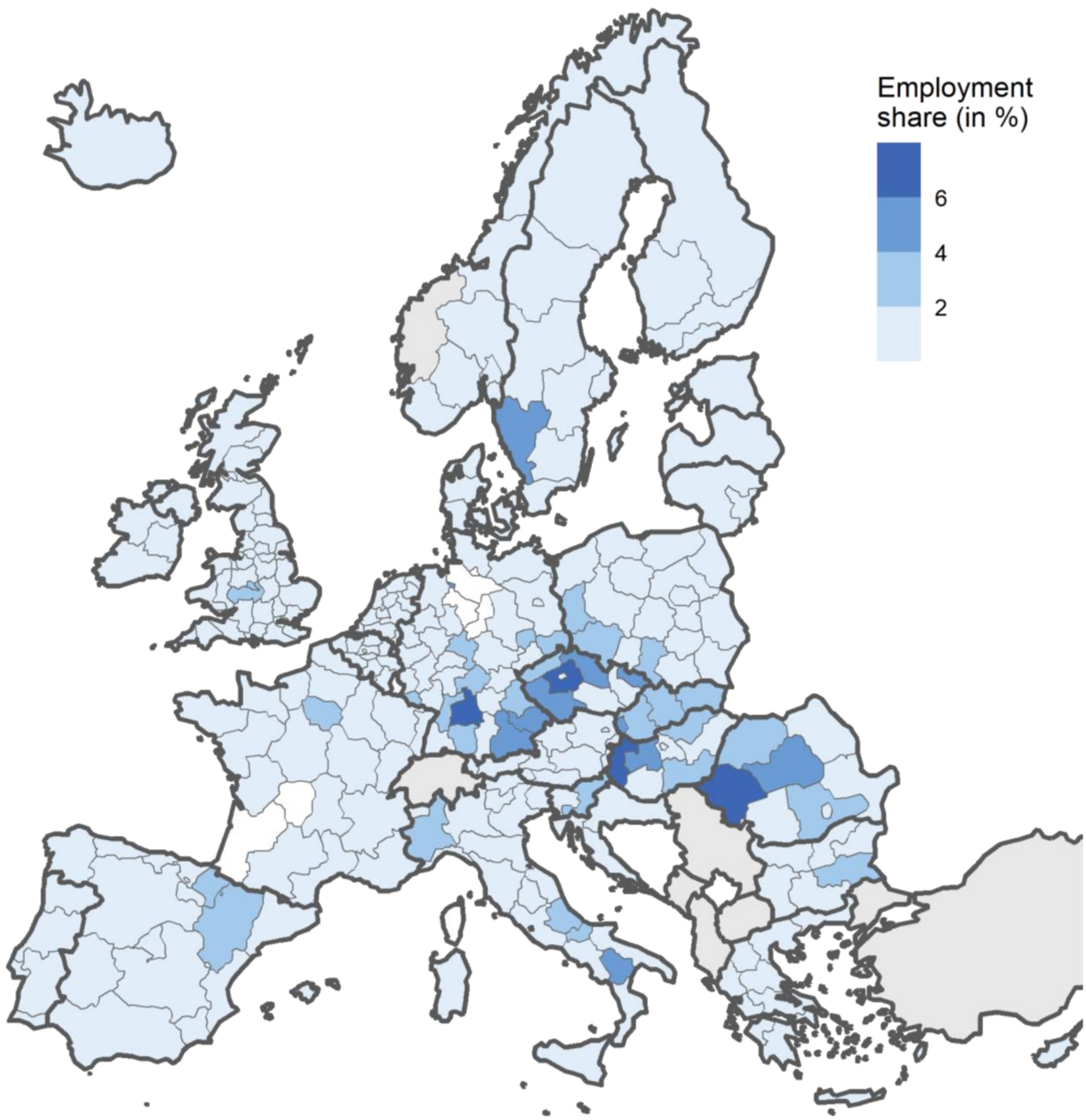
The regions that have high employment shares are mainly concentrated in Central and Eastern Europe (Figure 2.14). Four large regions, employing over 300 000 workers combined, in the Czech Republic, Germany, Hungary and Romania have regional employment shares greater than 7%. Regions with the highest employment shares in the EU do not report data for three-digit vehicle manufacturing sub-sectors. Box 2.5 focuses on Romania, where more than half of large (NUTS 2) regions have employment shares above the EU average.

Some large (NUTS 2) regions are more dependent on fewer establishments. For example, while the Central Bohemian region in the Czech Republic has a similar number of workers compared to West Romania, it has more than double the number of establishments. Central Bohemia may be better able to absorb firm-specific employment shocks when a single establishment closes.

Transformation challenges in this sector do not mainly relate to emissions, so emissions are not shown. Moreover, only 52% of sectoral emissions are represented in the EU ETS, as many installations fall below the threshold to be included in the EU ETS. Île-de-France, France, and Stuttgart, Germany, have the highest and second-highest absolute employment respectively. There may be a stronger headquarters effect in Paris, where workers may have more transferable skills.

Figure 2.14. Regional employment shares in the manufacture of motor vehicles, trailers and semi-trailers

Employment in the manufacture of motor vehicles, trailers and semi-trailers as a share of total employment in NUTS 2 regions, 2018



Note: White areas have missing data.
Source: Eurostat.

Box 2.5. Manufacture of motor vehicles, trailers and semi-trailers in Romania

Romanian regions with employment shares above the EU average in the manufacture of motor vehicles, trailers and semi-trailers are the West (7.36%), the Centre (4.78%), South-Muntenia (3.19%), the North-West (2.18%) and South-West Oltenia (1.65%).

Most employment in Romanian regions is concentrated in the manufacture of parts and accessories for motor vehicles (NACE 293), which will be affected by the transition to producing electric vehicles. The employment shares in the West (5.62%), the Centre (3.49%), South-Muntenia (2.27%) and the North-West (1.62%) are particularly large.

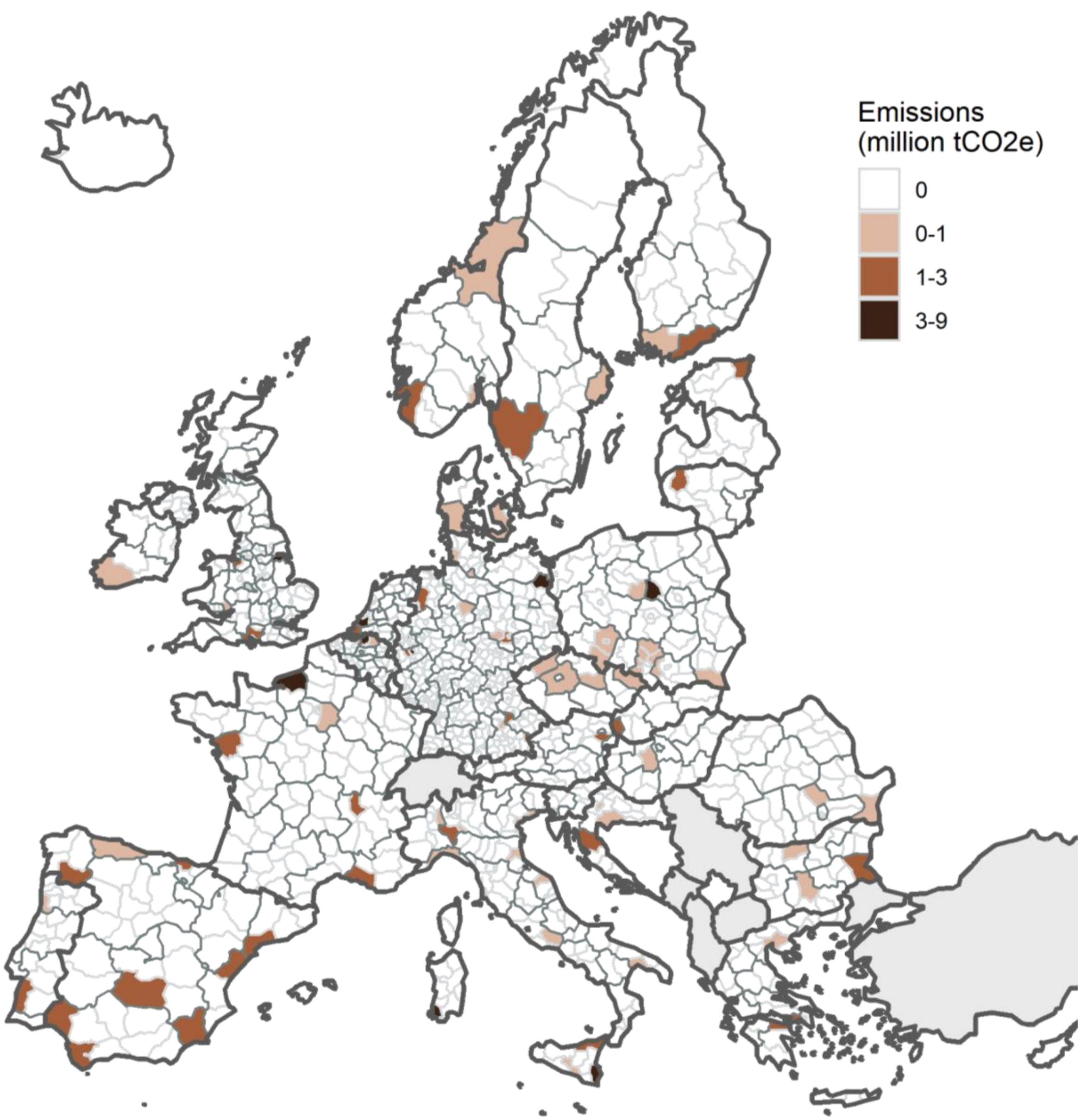
The NUTS 3 regional breakdown can further identify the regions with high employment and that may face greater risks. This would be especially useful for the Czech Republic, Germany and Hungary. In Romania, four NUTS 3 regions employ over 10 000 people in the manufacture of parts and accessories for motor vehicles. They are Timis in West, Arges in South-Muntenia, and Brasov and Sibiu in the Centre.

Note: There is no emissions data available for any Romanian regions in this sector on the ETS database.
Source: Romanian Ministry of Public Works, Development and Administration and Eurostat (2018).

Annex 2.A.

Annex Figure 2.A.1. Regional emissions in coke and petroleum

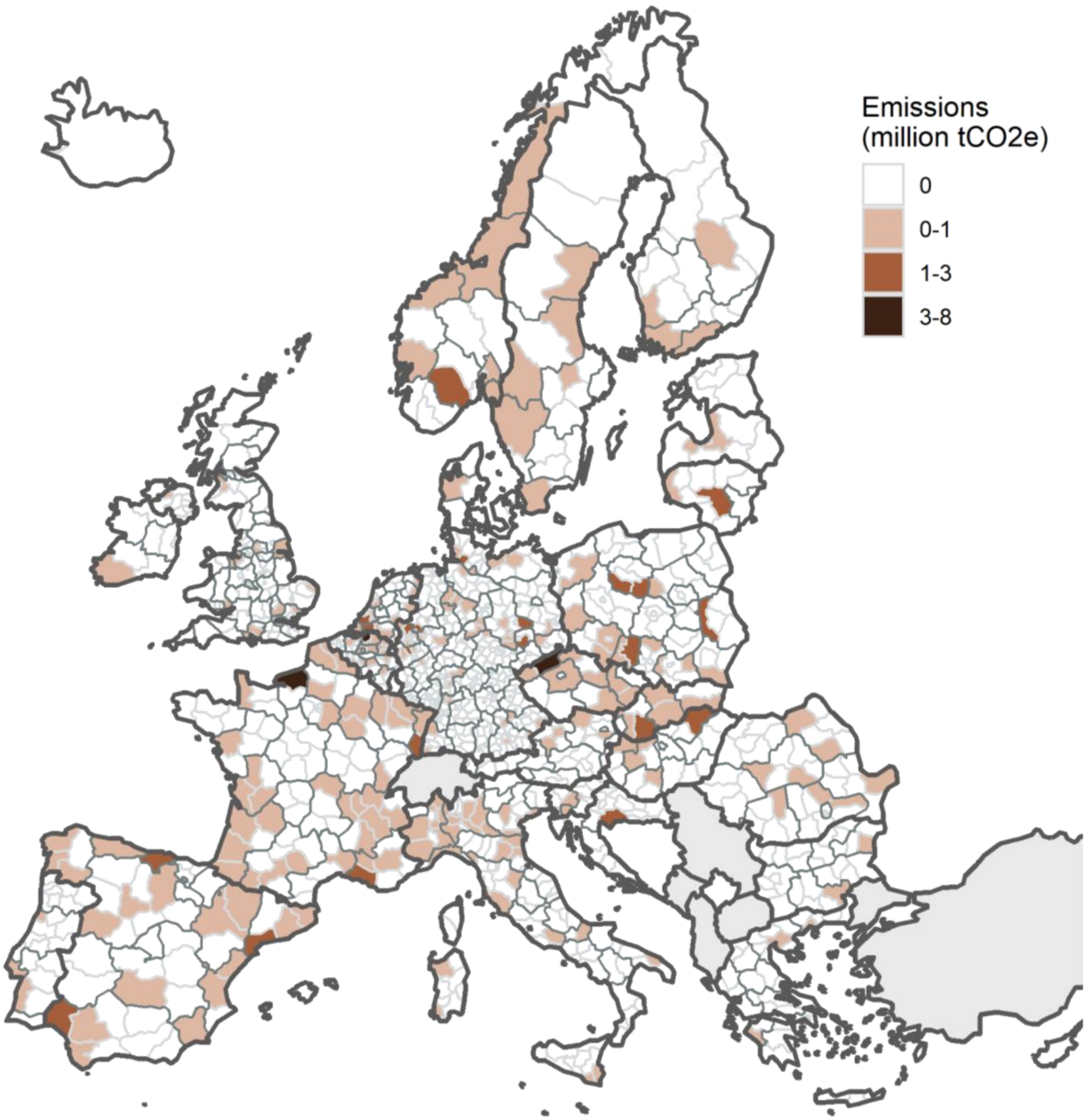
Emissions from EU ETS installations of businesses whose main activity is in the manufacture of coke and refined petroleum products (NACE 19), NUTS 3 regions, 2018



Source: Authors' calculations based on ETS-Orbis and Eurostat.

Annex Figure 2.A.2. Regional emissions in chemicals

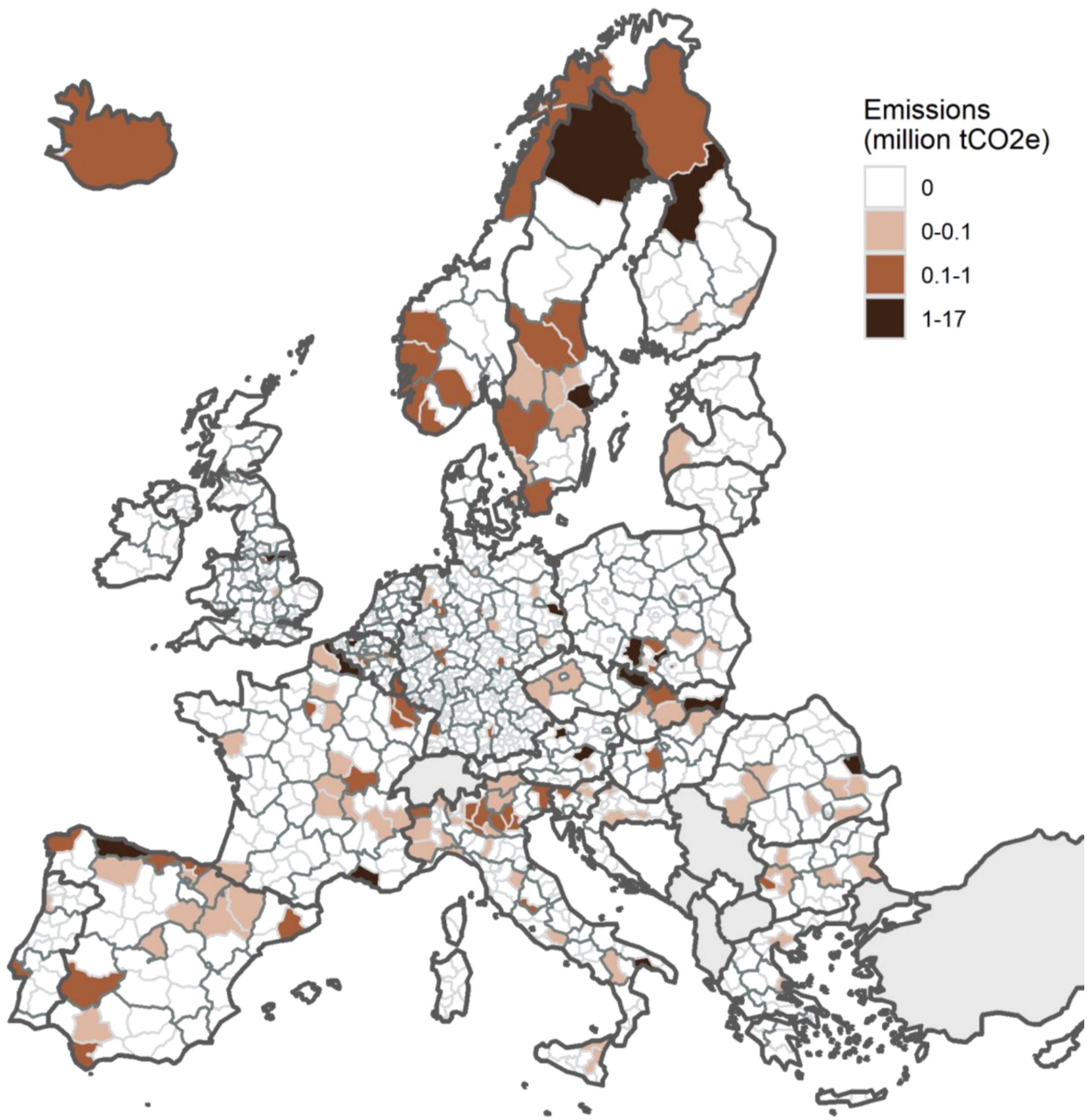
Emissions from EU ETS installations of businesses whose main activity is in the manufacture of chemicals and chemical products (NACE 20), NUTS 3 regions, 2018



Source: Authors' calculations based on ETS-Orbis and Eurostat.

Annex Figure 2.A.3. Regions with high-emitting steel production installations

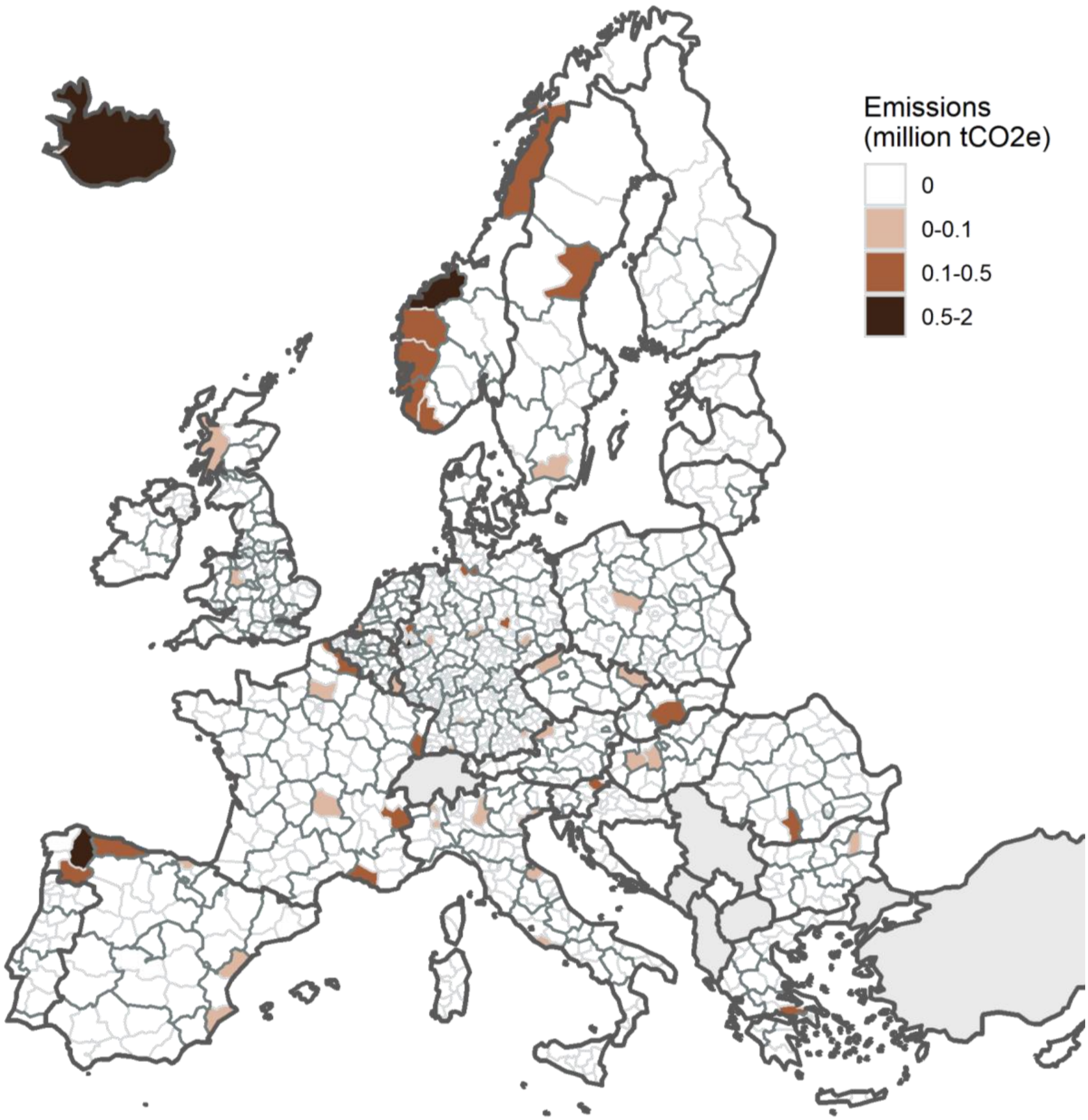
Emissions from EU ETS installations of businesses whose main activity is in the manufacture of basic iron and steel and ferroalloys (NACE 241), NUTS 3 regions, 2018



Source: Authors' calculations based on ETS-Orbis and Eurostat.

Annex Figure 2.A.4. Regions with high-emitting aluminium production installations

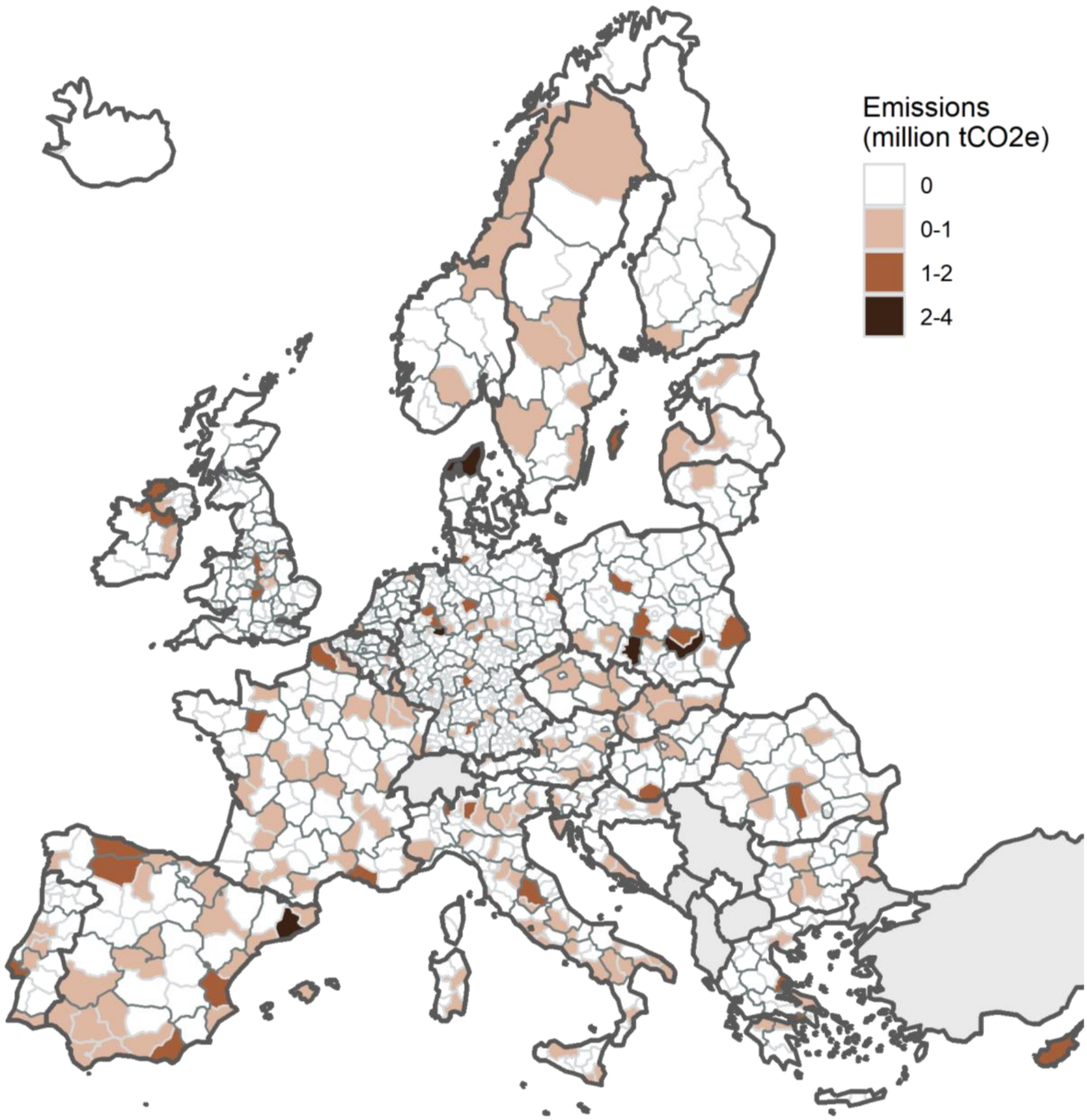
Emissions from EU ETS installations of businesses whose main activity is in the manufacture of aluminium (NACE 2442), NUTS 3 regions, 2018



Source: Authors' calculations based on ETS-Orbis and Eurostat.

Annex Figure 2.A.5. Regions with high-emitting cement production installations

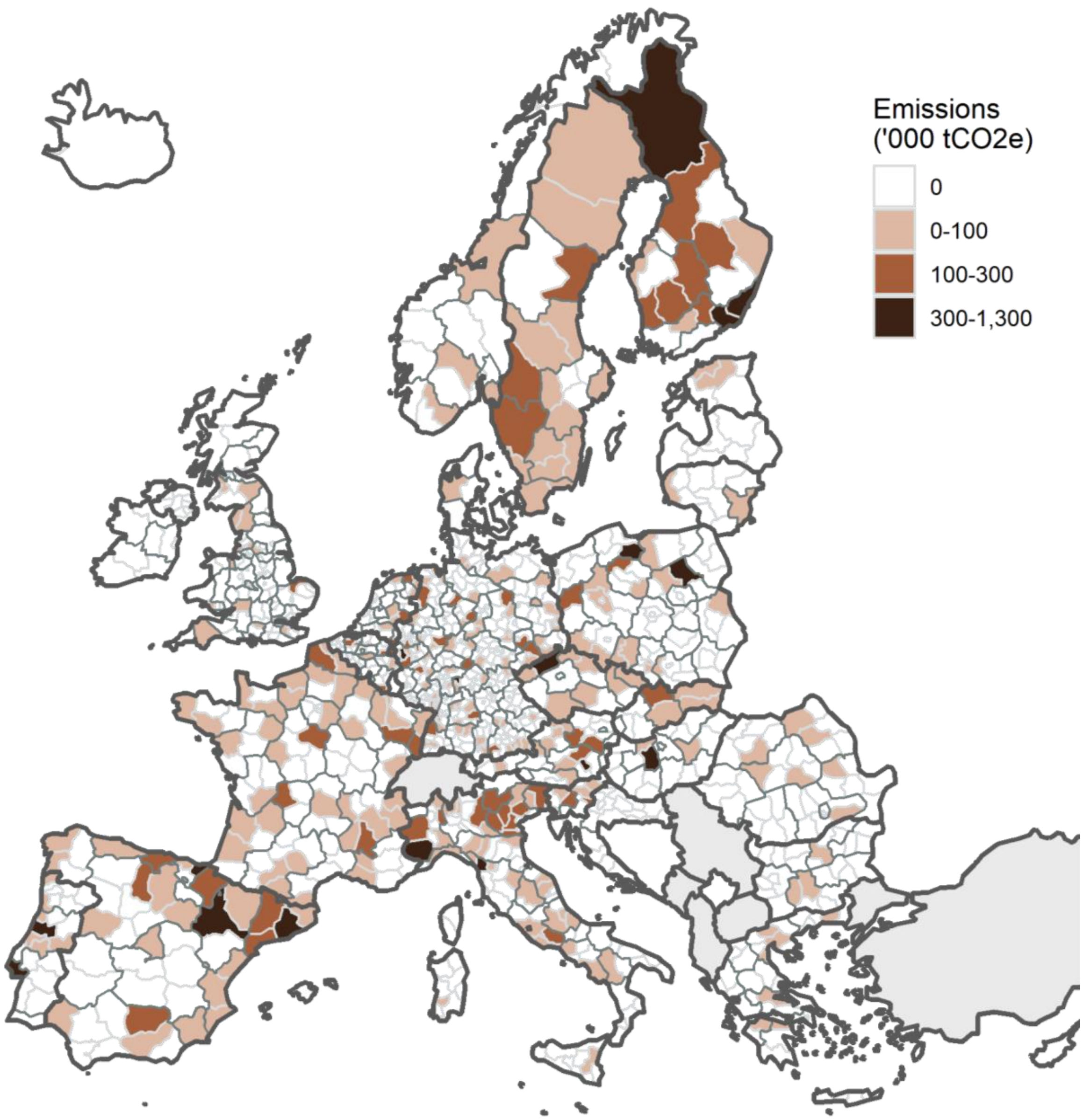
Emissions from EU ETS installations of businesses whose main activity is in the manufacture of cement, lime and plaster (NACE 235), NUTS 3 regions, 2018



Source: Authors' calculations based on ETS-Orbis and Eurostat.

Annex Figure 2.A.6. Regional emissions in paper

Emissions from EU ETS installations of businesses whose main activity is in the manufacture of pulp, paper and paperboard (NACE 171), NUTS 3 regions, 2018



Source: Authors' calculations based on ETS-Orbis and Eurostat.

References

EC (2021), *European Emissions Trading System (ETS) – Calculations on the Regional Employment Impact of ETS Installations*, Publications Office of the European Union, European Commission, https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/reg_impact_ets_installations_en.pdf. [1]

Fuentes, A., J. Noels and V. Ventricelli (forthcoming), "Regional Industrial Transitions to Climate Neutrality: Identifying vulnerable regions"*, OECD Regional Development Policy Papers*, OECD, Paris. [2]

Swedish Energy Agency (2021), *Energy in Sweden 2021 - An Overview*, https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=198022. [3]

Transport & Environment (2015), *Reasons to Change the Zero-rated Criteria for Biomass in the EU ETS*, BirdLife, European Environmental Bureau and Transport & Environment, https://www.transportenvironment.org/wp-content/uploads/2021/07/2015%2001%20biomass%20ets_rating_FINAL.pdf. [4]

3 Identifying regional access to hydrogen, carbon capture and storage, and climate-neutral freight

Making the key manufacturing sectors described in Chapter 1 climate neutral requires infrastructure. This chapter shows how access conditions and costs may differ across regions. Both hydrogen, needed for chemicals and steel production, and captured CO_2 emissions, most generally needed for cement production, are best transported via pipelines. Pipelines are subject to scale economies: clustered production sites will face lower costs. The first hydrogen transport network will therefore likely be laid out in Northwest Europe. In some regions, local renewable electricity production potential will not be sufficient or too costly to produce the needed hydrogen and will require imports. Good connection to ports also matters: hydrogen or hydrogen-derived products may also be shipped. Moreover, transport to and from ports plays an important role to provide the basic materials key industries produce to downstream industries. Any costs from decarbonising road transport could impact transport costs in inland production locations the most.

Hydrogen, CO_2 capture and storage (CCS) and zero-carbon road freight transport are important to reach climate neutrality in key manufacturing sectors. This chapter investigates access conditions to needed infrastructure and related costs. As shown below, access conditions and infrastructure costs can differ substantially across regions. The chapter analyses these issues for European regions, mostly in European Union (EU) countries.

The first section starts with scenario projections for electricity, hydrogen and CCS needs for emissions and energy-intensive manufacturing sectors in a climate-neutral economy in 2050. It provides the quantitative basis for the analysis in the following sections and explains underlying assumptions. The following sections investigate the regional determinants of supply and demand of hydrogen and CCS respectively. The final section provides an analysis of regional aspects of decarbonising road freight for the key manufacturing sectors, drawing on modelling results to describe the potential regional impact of carbon taxes on road freight.

Scenarios for electricity, hydrogen and CCS use in a climate-neutral economy

The analysis of this section presents projections of electricity, hydrogen and CCS use in the chemicals, steel and cement industries in regions of the European Union and the United Kingdom according to scenarios in which these industries contribute to reaching climate neutrality in 2050. These scenarios are based on the study *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry "Industrial Transformation 2050"* (Material Economics, 2019[1]). This report distinguishes three pathway scenarios to decarbonise energy-intensive industries, in particular comprising steel, chemicals (including ammonia production) and cement by 2050. The resulting hydrogen, energy and CCS demands differ (Figure 3.1).

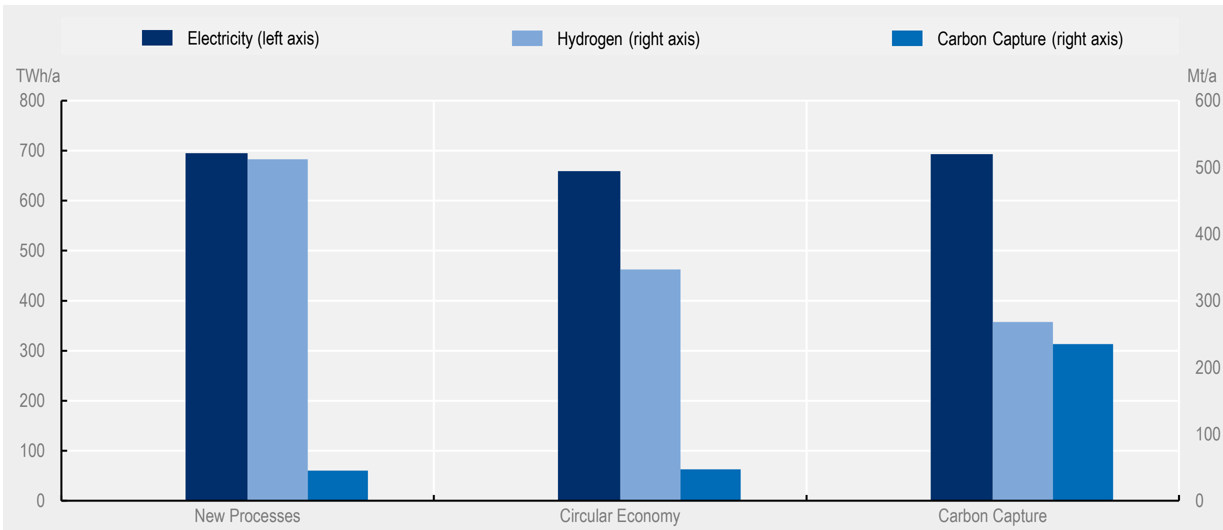
- One pathway with a strong shift to innovative production processes (called New Processes, NP).
- The Circular Economy (CE) pathway, relying mainly on circular economy practices to reduce emissions.
- The Carbon Capture and Storage (CS) pathway, using carbon capture and storage to a greater extent than the other pathways.

The three pathway scenarios – New Processes (NP), Circular Economy (CE) and Carbon Capture and Storage (CS) – all use CCS but to a different extent. The CS pathway focuses mainly on CCS to reach climate neutrality in the 3 manufacturing sectors. Efficiency improvements and other new technologies are used less than in NP (Material Economics, 2019[1]). In the NP and CE pathway scenarios, production processes are electrified directly or indirectly, including with the use of green hydrogen, sharply reducing the need for CCS.

The analysis of regional CCS demand in the following section is based on the CS scenario pathway which implies the largest CCS demand, allowing to point out the largest potential infrastructure needs. The precautionary principle may however argue in favour of limiting reliance on CCS to those activities where it may be unavoidable. CCS has not yet been deployed at scale. Relying on it may imply the risk that emission reductions will not be made if deployment at scale is not forthcoming. The precautionary principle has become embedded in EU environmental protection (Science for Environment Policy, 2017[2]). CCS is most likely to be unavoidable for emissions in cement production, consistent with the analysis in the first chapter. The emission locations from cement production and the challenges in CCS deployment can also be identified in the analysis below and are described in more detail in a forthcoming working paper (Fuentes Hutfilter et al., 2023[3]).

Figure 3.1. The circular economy can damp energy and hydrogen demand from new production processes while limiting reliance on carbon capture

Demand for hydrogen, electricity and carbon capture in emissions and energy-intensive industries: steel, chemicals (including ammonia production) and cement according to three scenarios



Note: The horizontal axis shows three different pathway scenarios to reach climate neutrality by 2050 in steel, chemicals (including ammonia) and cement production. The vertical axes show the amount of electricity (left-hand axis), hydrogen and carbon capture (both right-hand axis) required by each scenario. Carbon capture can include carbon capture and use (CCU) as well as storage.
Source: Material Economics (2019[1]), *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry*, https://materialeconomics.com/publications/industrial-transformation-2050.

StatLink https://stat.link/zavl9t

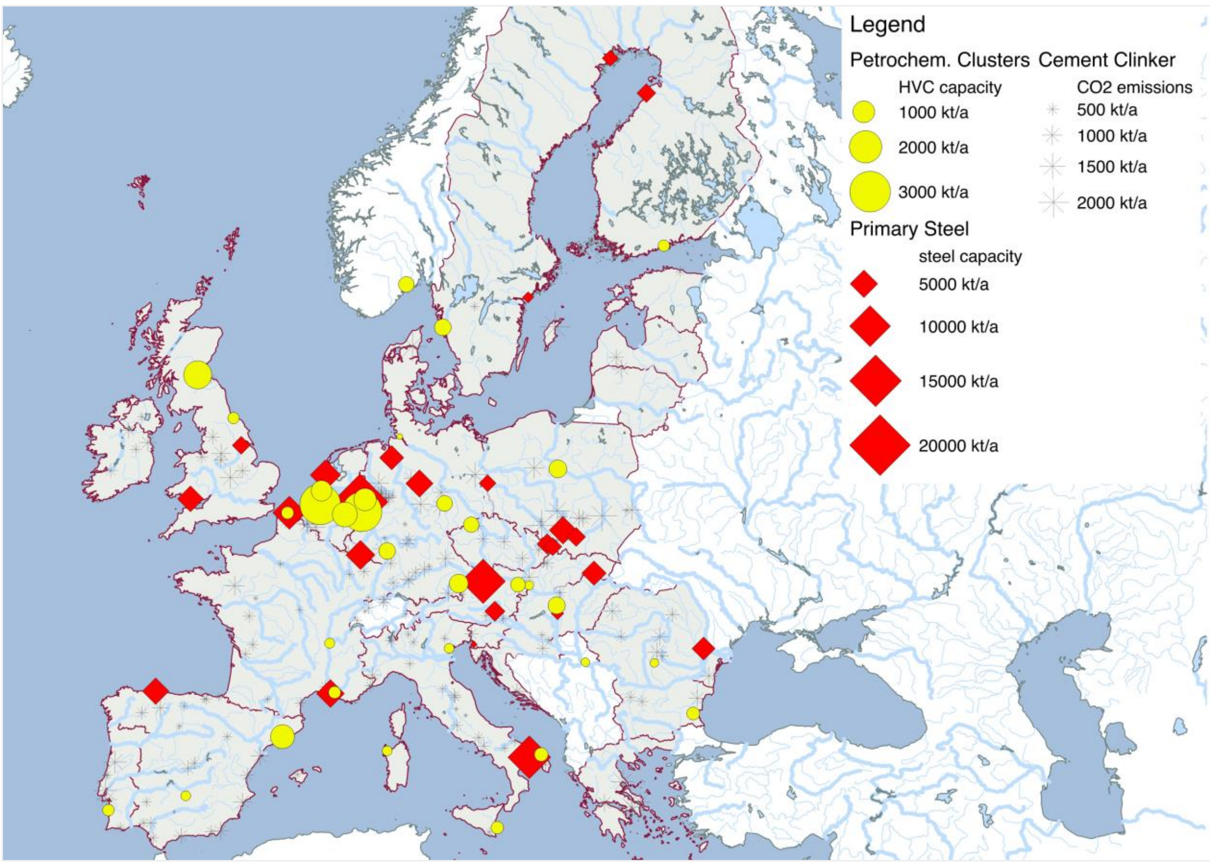
CCS is sometimes classified as an unsustainable technology, such as by the German Federal Environment Agency (UBA). Due to the lack of experience regarding possible negative effects on the environment and health, as well as the violation of intergenerational justice in the case of intensive use of limited CO_2 storage capacity, the UBA recommends the use of CCS only as a transitional technology (Viebahn et al., 2018[4]). A major topic is a legal framework for the export and offshore storage of CO_2 (Benrath, 2021[5]).

The analysis of hydrogen demand below is based on the NP scenario pathway, which implies the largest hydrogen requirements of the three scenario pathways. Again, this allows to identify the largest related infrastructure needs. To ensure consistency with reaching climate neutrality, only “green” hydrogen, produced with renewable energy, is considered. Only hydrogen production from zero-carbon electricity production is consistent with climate neutrality. Most expansion of zero-carbon electricity production will be from renewables, as illustrated, for example, in the International Energy Agency (IEA) sustainable development scenario.

Today’s industrial production sites and their relative production volumes are assumed to remain constant in the assessment of the spatial distribution of hydrogen and CCS demand. Shifts in locations in the transition to climate neutrality are hence not taken into account. Such shifts may however arise as a regional comparative advantage may change, possibly as a result of differences in access to needed infrastructure. While the largest production sites of basic chemicals are geographically concentrated, steel and especially cement production are more dispersed (Figure 3.2). More dispersed production sites may result in stronger regional development challenges for matching supply and demand for CCS and hydrogen, as discussed below. This is because, for both CCS and hydrogen, new infrastructures are subject to economies of scale. The unit cost for industrial use of new infrastructures will be lower if demand in a given location is high.

Figure 3.2. Petrochemicals, steel and cement production is spread across Europe

Production capacities in petrochemical and primary steel production in kilotonnes per annum (kt/a) and CO_2 emissions in kt/a



Note: Petrochemical production capacity refers to high-value chemicals (HVC).
Source: Wuppertal Institute (2019[6]), *Project INFRA-NEEDS - Infrastructure Needs of an EU Industrial Transformation towards Deep Decarbonisation*, https://wupperinst.org/en/p/wi/p/s/pd/818.

Regional determinants for supply and demand of CCS

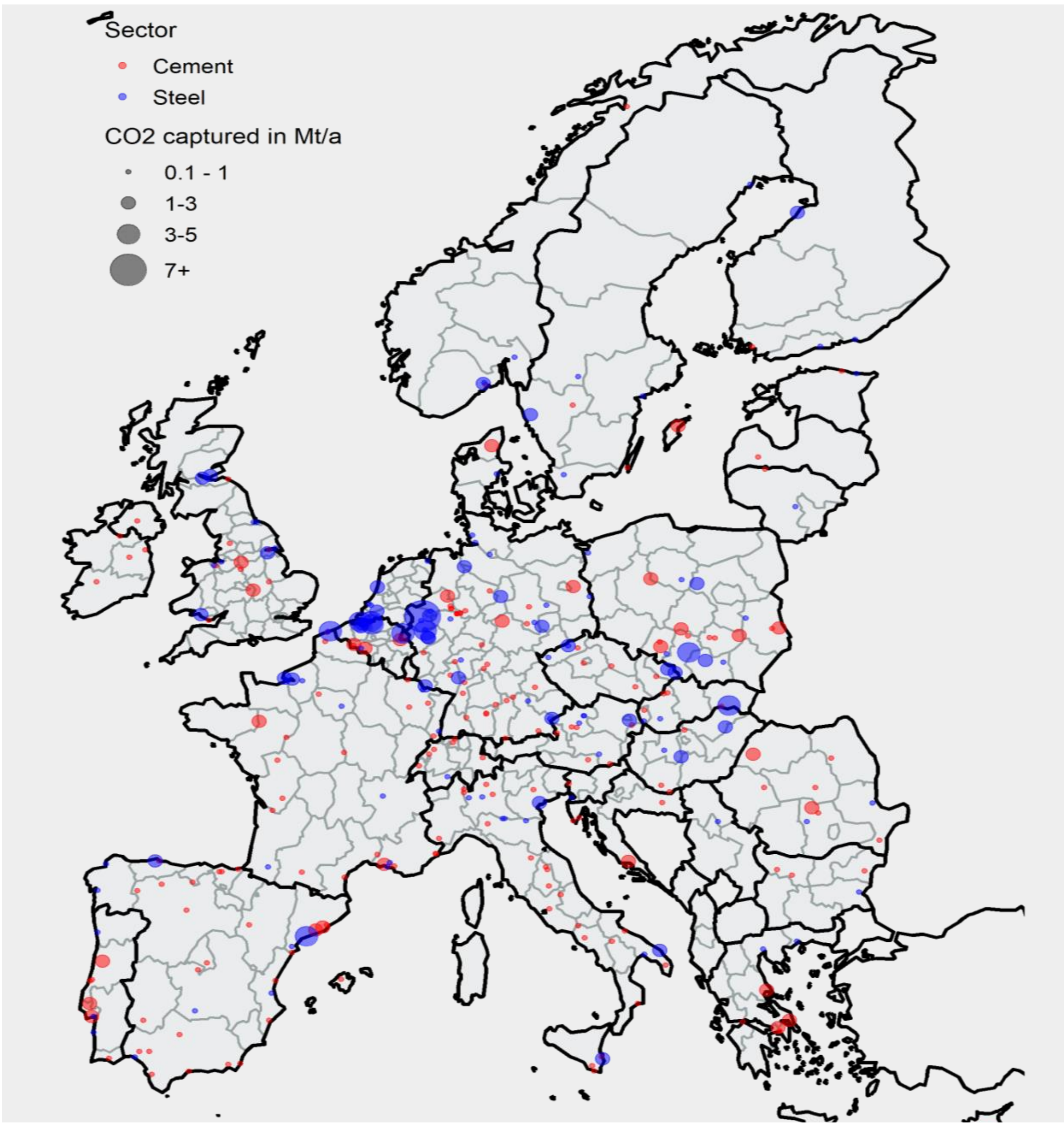
European storage potentials seem to be sufficient on aggregate to meet potential CCS demand. But taking into account constraints from economic and geologic reasons as well as public acceptance, realistic storage sites may often be distant from the location of emissions needing storage. An immense transport effort is needed even if both on- and offshore storage is used. As this section will argue, in most European countries, offshore CCS may have the biggest chance of realisation, due to restrictions, risks and public acceptance issues with potential onshore sites.

Determining industrial CCS demand and its locations

Figure 3.3 shows the distribution of CO_2 emission sources to be captured and stored in 2050 following the CS scenario pathway illustrated in Figure 3.1 and established industrial sites. A major challenge is to develop a sensible infrastructure for small amounts of CO_2 emissions from each of the many dispersed production facilities. The cement sites are spread across Europe in small-scale production units, posing particular challenges for connecting them to CO_2 transport pipelines, as argued below. Since CCS is likely to require new transport infrastructure and infrastructure is subject to economies of scale, quantity reduction results in a higher cost per unit of CO_2.

Figure 3.3. Industrial CO_2 emissions that may be addressed with CCS

2050, million tonnes per year



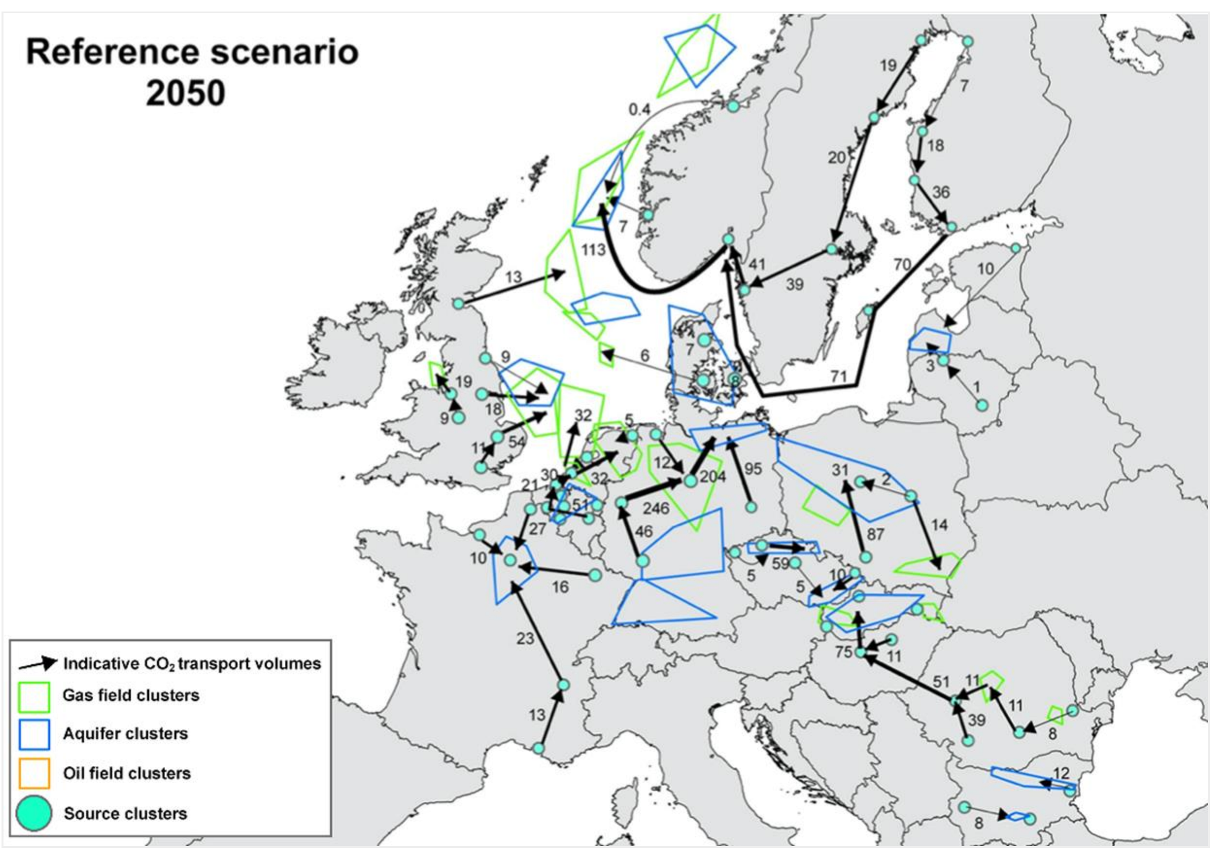
Source: Material Economics (2019[1]), *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry*, https://materialeconomics.com/publications/industrial-transformation-2050.

Carbon capture, storage and transport supply

Social acceptance of CO_2 storage might be rather low, especially for onshore storage. This is reflected, for example, in the German legal situation. The Act on the Demonstration of the Permanent Storage of Carbon Dioxide (*Kohlendioxid-Speicherungsgesetz*) limits storage in Germany and leaves it up to each regional government to prohibit the storage of CO_2 completely, which already occurs in some regions. Depleted oil and natural gas fields, mostly offshore, have an additional advantage, as old infrastructure can often be used (e.g. pipelines or oil rigs). As discussed in more detail in a forthcoming working paper (Fuentes Hutfilter et al., 2023[3]), saline aquifer storage sites, which are the main storage sites onshore, may be subject to more uncertainty with respect to storage capacity and therefore economic viability, as well as with respect to other local risks, such as the re-emergence of stored emissions.

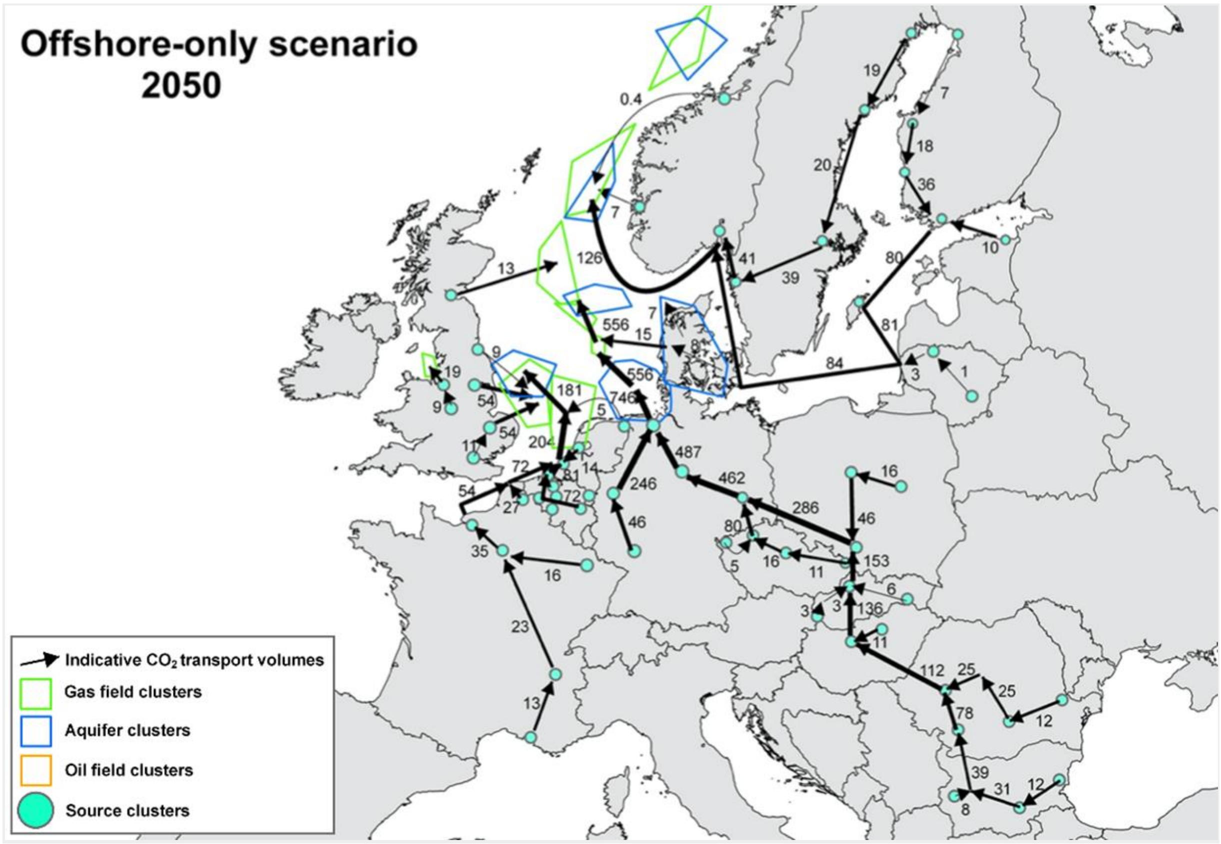
The matching of captured CO_2 to storage sites is primarily a transport problem. Planning and building this infrastructure are time-consuming and costly. No matter which geological storage options are actually used in the future, the captured CO_2 will have to be transported over long distances. Figures 3.4 and 3.5 illustrate what a European CO_2-pipeline-infrastructure solution could roughly look like for the year 2050 in a “reference scenario” with onshore and offshore storage (Figure 3.4) as well as an “offshore-only scenario” (Figure 3.5). No study appears to exist to date to show how the industrial emission sources illustrated above could be linked to potential CCS sites. Therefore, instead, the two scenarios shown in Figures 3.4 and 3.5 were designed for CO_2 emissions from power generation (Neele et al., 2011[7]).

Figure 3.4. CO_2 to be transported and geological storage options in the reference scenario in 2050



Source: Neele, F. et al. (2011[7]), *Towards a Transport Infrastructure for Large-scale CCS in Europe*, http://www.co2europipe.eu/.

Figure 3.5. CO_2 to be transported and geological storage options in the offshore-only scenario in 2050



Source: Neele, F. et al. (2011[7]) , *Towards a Transport Infrastructure for Large-scale CCS in Europe*, TNO, http://www.co2europipe.eu/.

From today's perspective, power generation should not be decarbonised with CCS, given the available low-cost zero-emission electricity generation. Even so, the scenarios shown in Figures 3.4 and 3.5 are illustrative, as the challenges industrial production locations face to be connected to a CO_2 pipeline transport infrastructure system may be broadly similar. The scenarios are ten years old but the broad locations of storage sites identified at the time remain broadly valid today. The pipeline infrastructure in the reference scenario with 21 800 km as well as in the offshore-only scenario with 32 000 km suggests that an immense transport effort is necessary in either case. Moreover, existing natural gas pipelines are more difficult to repurpose for CO_2 transport than for hydrogen transport as discussed in the aforementioned forthcoming draft working paper. CO_2 transportation is therefore likely to require new infrastructure.

As argued above, it may be prudent to limit CCS for industrial emissions to process emissions in cement, which is likely to be the most dependent on CCS. As discussed in Chapter 1, doing away with CCS in the steel and chemicals sectors raises the demand for hydrogen and the depth of the transformation of production processes, requiring more focus on avoiding stranded assets. If CCS is limited to process emissions in cement, only between 31 and 35 $MtCO_2/a$ process-related emissions would have to be taken into account (Material Economics, 2019[1]). Even so, transportation needs would still be largely owing to the geographical spread of cement production, as process-related emissions will occur at every site unless production sites are closed. Owing to scale economies, limiting CCS to cement production is therefore likely to reduce transportation costs much less than proportionally to the reduction in demand for CCS.

As Figures 3.4 and 3.5 illustrate, transport costs may vary considerably across regions, especially in an offshore-only scenario. In regions where transport costs for CCS may be particularly high, the economic pressure to do without CCS may be strongest, which may in turn reinforce the need to integrate new industrial processes and related investment and technology needs. However, these regions may not be the most advanced technologically and their businesses may not have the strongest capacity to invest in these new technologies.

Determinants of pipeline transport costs

Table 3.1 illustrates the economies of scale from pipeline deployment. For example, the investment costs for an 18-inch-wide pipeline and a distance of 500 km are higher in absolute terms (EUR 1 002 per metre) compared to a 12-inch pipeline (EUR 884 per metre). In unit terms, however, investment costs of a larger pipeline are significantly lower, as the transport capacity may be more than twice as high. Regions with a high density of industrial point sources (e.g. Northwestern Europe), which may also be economically more developed, benefit from more potential to reduce unit costs. Higher unit costs in less economically developed regions could be a source of territorial divergence.

Table 3.1. Investment costs for CO_2 pipelines, in EUR/metre

Inner diameter in inches	100 km distance	250 km distance	500 km distance	1 000 km distance
48	4 559	3 195	2 749	2 516
40	3 666	2 504	2 130	1 888
36	3 299	2 221	1 787	1 652
30	2 455	1 698	1 451	1 327
28	2 316	1 586	1 363	1 227
24	2 100	1 405	1 174	1 062
18	1 879	1 222	1 002	888
12	1 699	1 085	884	775

Source: Kjärstad, J. et al. (2016[8]), "Ship transport - A low cost and low risk CO_2 transport option in the Nordic countries", *International Journal of Greenhouse Gas Control*, Vol. 54/5, pp. 168-184.

In regions with high industrial density in key future CCS transport network locations and with good access to offshore sites, industrial sites and their owners may pursue collective strategies to develop pipeline infrastructure to access such sites. There may be pressure to include more emissions in CCS in such regions to benefit from scale economies, though small and more distant emitting plants may still be left out. In regions with poor access to offshore sites and low industrial density, it is particularly important to explore distributed onshore sites (Fuentes Hutfilter et al., 2023[3]).

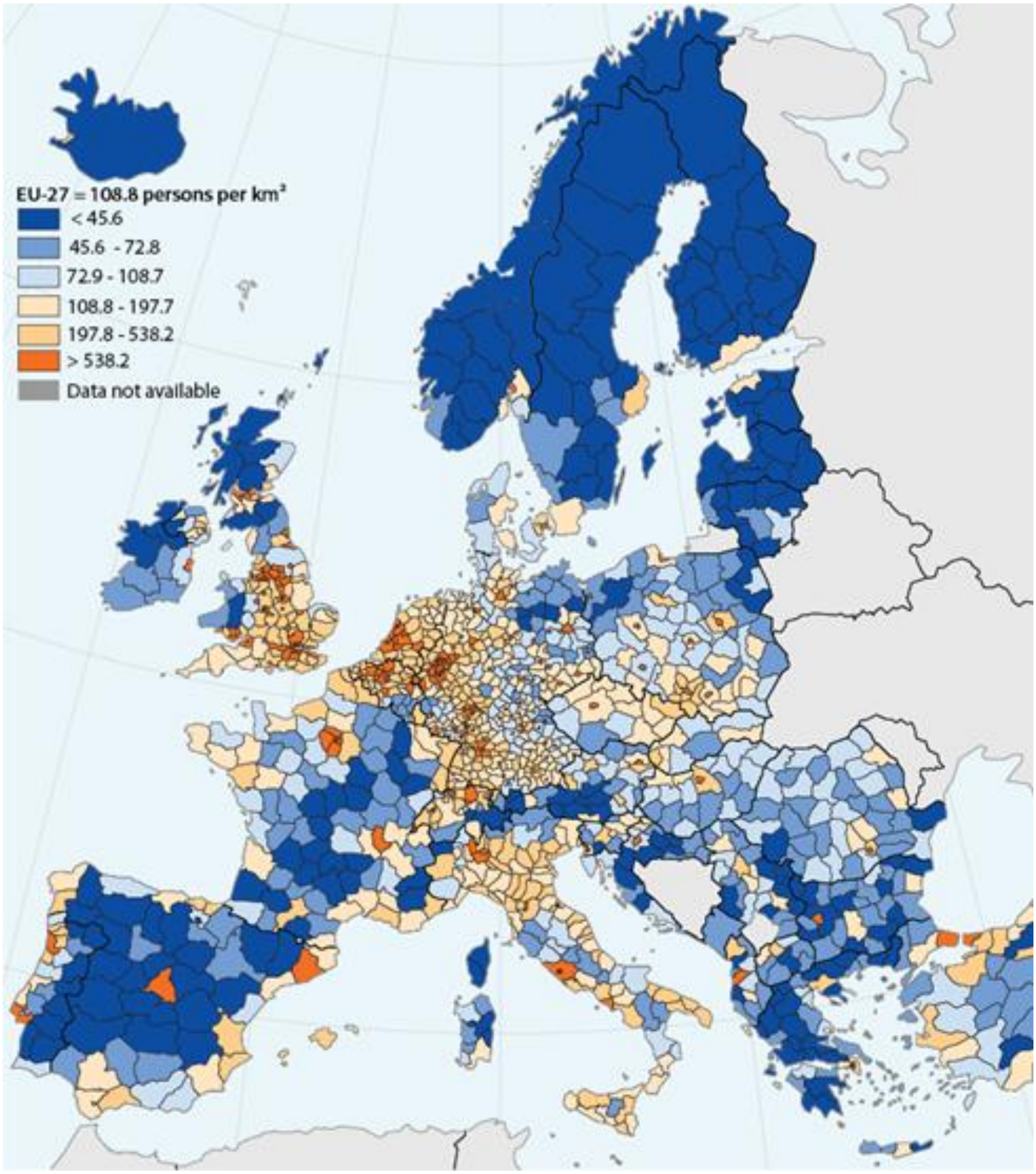
The terrain to be crossed and the distance have a major influence on the cost. Land that is difficult to cross, including densely populated or mountainous areas, may need to be bypassed and, if crossed, mountainous areas may require more energy for pumping (Kjärstad et al., 2016[8]; IEAGHG, 2013[9]). The following terrain factors for cost have been estimated, for a given distance:

- 1.2 for flat terrain.
- 1.5 for hilly terrain.
- 2 for densely populated areas, wetlands and nature reserves.

These three terrain factors that raise transport costs are unequally distributed across regions (Figures 3.6 and 3.7).

Figure 3.6. Population density raises pipeline costs

Population density across European regions



Source: EC (n.d.[10]), “Using CO_2 instead of storing it: carbon capture and use (CCU)”, European Commission.

Figure 3.7. Wetlands raise pipeline costs

Wetlands locations across European countries

Source: (European Environment Agency, 2000[11]) Wetland concentration in Europe https://www.eea.europa.eu/data-and-maps/figures/wetland-concentration-in-europe-2000.

CCU may be an alternative to CCS. CCU is particularly useful when CO_2 capture and CO_2 use occur at the same site. This is usually only the case for integrated applications in the chemical industry, although this can be very specific to the site. Therefore, an individual assessment for each site is required. Cement and lime plants, in contrast, are often spatially distributed and usually do not have a direct potential user on site. They would have to look for a buyer in the surrounding region. Climate neutrality would also require that local supply and demand of CO_2 match very closely quantitatively.

Only CO_2-absorbing products that have very long product life cycles of at least several decades and do not ultimately release the CO_2 themselves contribute to decarbonisation. It has not yet become clear which products can satisfy these conditions. One example is to blow the captured CO_2 into greenhouses in order to achieve better plant growth. The decisive factor would in this example be how the biomass is subsequently used. CO_2 capture can entail a considerable additional expenditure on electricity and process heat (about 30%) and CO_2 capture only achieves capture rates of 80-90%, depending on the technology (Samadi et al., 2018[12]).

Regional determinants for supply and demand of hydrogen

As this section will argue, even though European renewable generation potentials might be sufficient to meet electricity and green hydrogen demand, including from industry, if fully exploited, hydrogen imports play an important role because of their potentially low cost. Hence, the proximity to well-suited renewable generation potentials and hydrogen transport infrastructures such as ports and repurposed natural gas grid pipelines is important.

Determinants for industrial hydrogen demand

Hydrogen can be used for the climate-neutral production of steel as well as chemicals. Among the three pathways considered above (Material Economics, 2019[1]), the lowest hydrogen demand is in the Carbon Capture and Storage (CS) pathway, which includes the least transformations in production technologies. The Circular Economy (CE) pathway results in slightly higher hydrogen demand. The New Processes (NP) pathway implies by far the highest demand for hydrogen (Figure 3.1). In the following, this pathway is chosen – as previously explained – to illustrate hydrogen demand implications.

Figure 3.8 shows the resulting spatially resolved hydrogen demand in the year 2050, assuming a development according to the NP pathway (ENTSO-E, 2014[13]) assuming the current production sites are maintained until 2050.

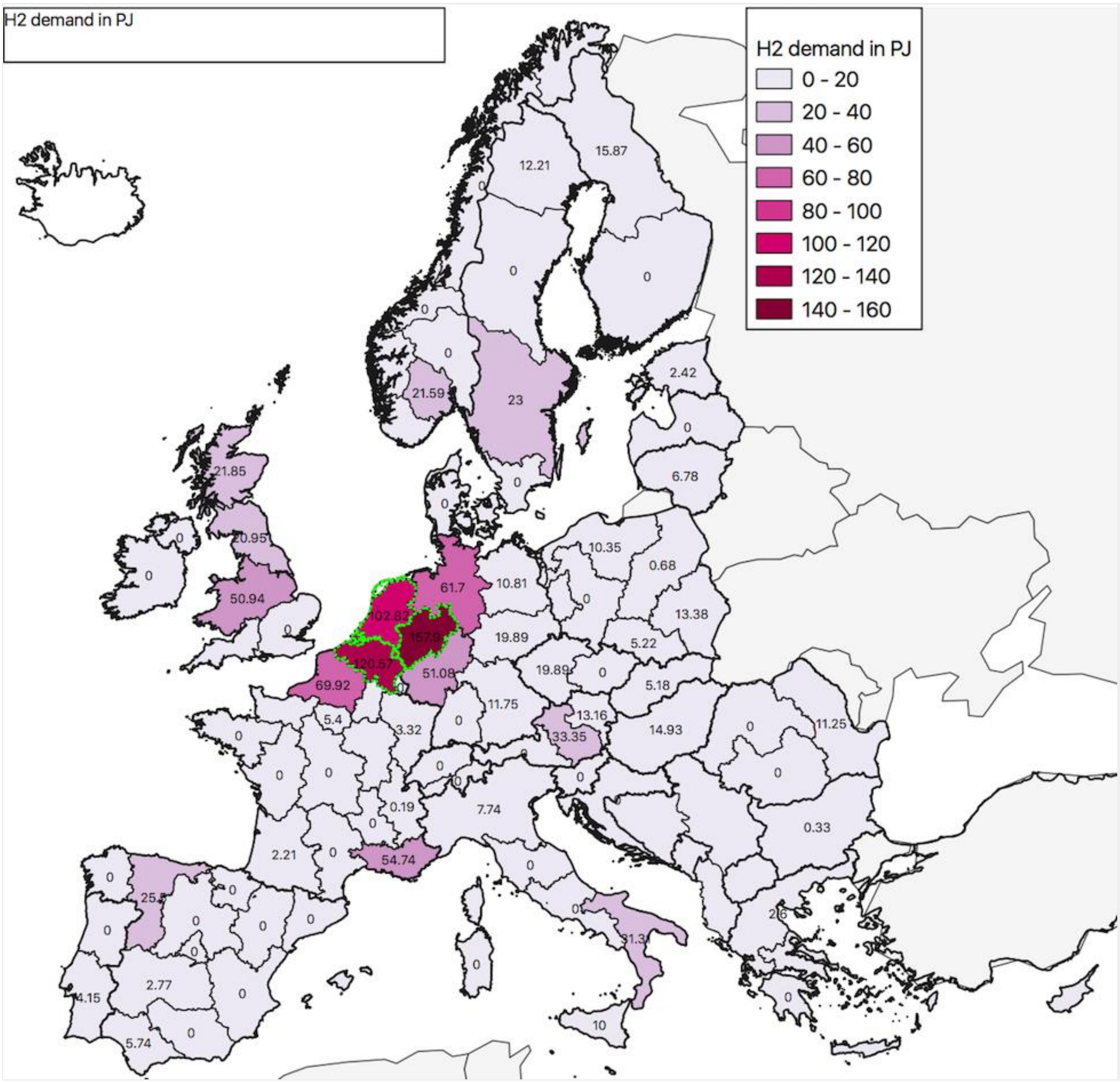
There will be some regions with highly concentrated industrial hydrogen demand. Hydrogen demand from non-industrial sectors such as transportation must, in addition, also be considered for future infrastructure.

Determinants of hydrogen supply

Green hydrogen is produced using renewable electricity in electrolysis. Renewable energy (RE) sources are essentially solar (photovoltaic, PV, or concentrated solar power, CSP), wind power (on- and offshore) and electricity generation from hydropower. Well-suited hydrogen production sites are locations with steady, strong wind speed and solar irradiation. In addition, the technical electricity generation potential is determined by the properties of the land: residential areas may be suitable for rooftop PV but not for wind power generation; agricultural activity, forests or mountains also influence which and how many renewable power plants can be built. The combination of weather conditions and the installable capacity (available places) is referred to as the technical generation potential. In addition, nuclear electricity could also be attractive. But scenarios for reaching climate neutrality by 2050 generally posit that most of the large-scale increase in zero-carbon electricity generation must come from renewables and electricity is typically generated at the lowest cost from renewable sources.

The estimates of the technical potential differ widely across studies. For example, in the study used below the potential is estimated at 6.900 TWh (ENTSO-E, 2014[14]). Figure 3.9 shows renewable electricity generation and the technical potential of RE generation from wind on and off shore, solar PV and CSP based on ENTSO-E data (ENTSO-E, 2014[14]) for European countries. Offshore potentials are allocated to the neighbouring land clusters. LBST (LBST, 2017[15]) estimates about double the potential (14 000 TWh).

Figure 3.8. Spatial distribution of hydrogen demand for decarbonising chemicals and steel production

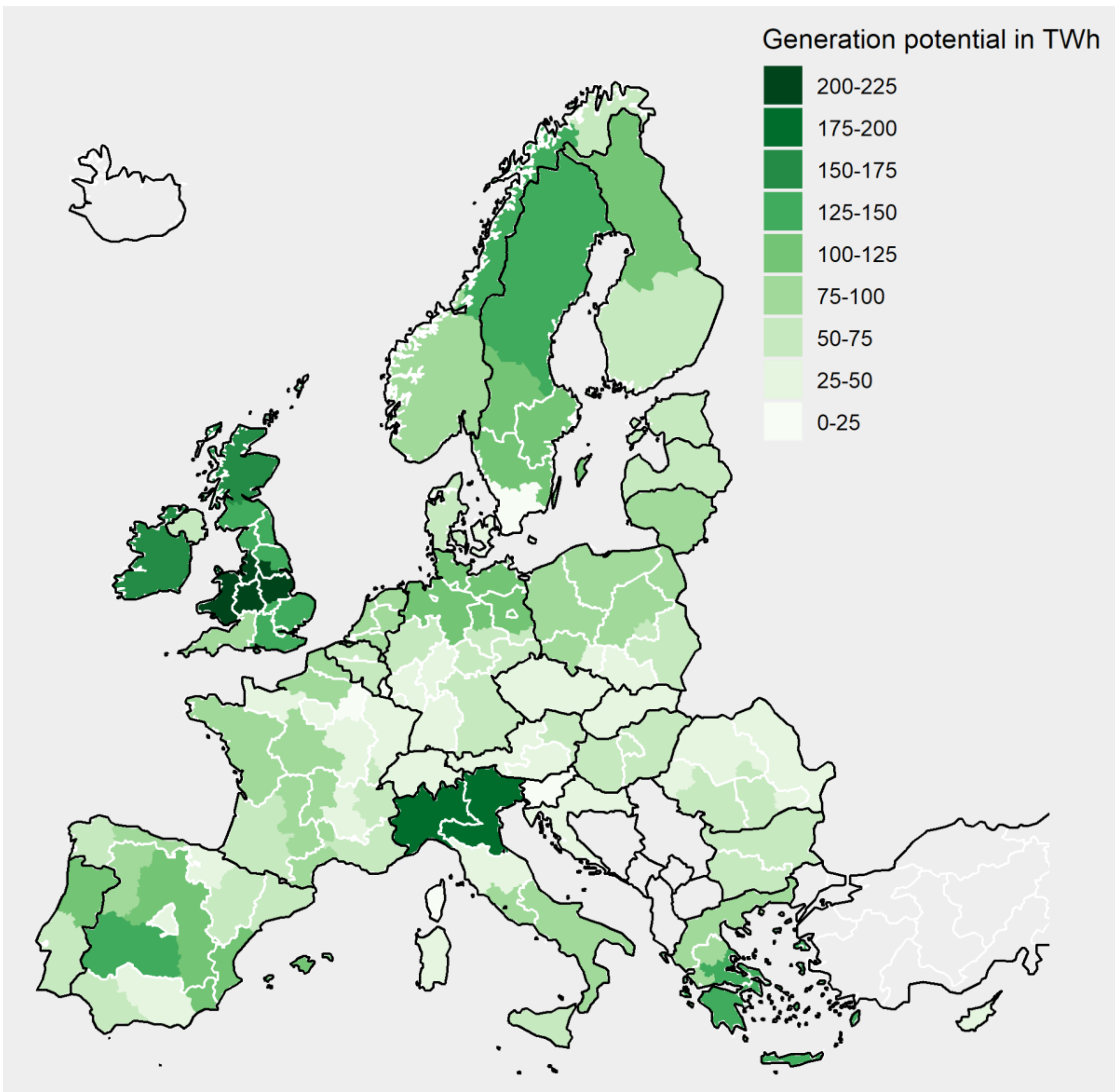


Source: (2014[13]); (ENTSO-E, 2014[14]) Wuppertal Institute calculations.

The potential of RE in Europe could be technically sufficient to meet demand including from climate-neutral industry. However, this would require exploiting the technical potentials to a large extent, including where it may be costly to do so, for example because wind or solar conditions are not optimal. Economic optimisation implies the import of hydrogen or hydrogen-based products, from the Middle East and North Africa (MENA) region for example (IEA, 2019[16]; Forschungszentrum Jülich, 2020[17]). Chile may also offer strong potential. Aiming for independence from foreign supply can lead to accepting the additional costs of local production. Some regions may be forced to be independent because their access to imported hydrogen is difficult.

For green hydrogen, the more uniform the electricity supply, the better the utilisation of electrolysis plants' capacity. CSP is attractive due to its thermal storage but its potentials are limited within the EU. This makes offshore wind generation suitable but often expensive, as shown below. Green hydrogen can also be produced with renewable electricity from distant locations and transported via a sufficiently developed electricity grid. Electrolysers with low-capacity utilisation owing to intermittent wind or solar power can also add value to climate-neutral energy systems as a flexibility instrument, running in times of surplus electricity generation and perhaps providing hydrogen for backup power plants. This option may become more viable as the capital cost of electrolysers falls. The determinants for the availability of green hydrogen can be summarised with spatial proximity to generation potentials, suitable electricity and gas grid nodes, hydrogen transport routes or hubs, and the density of hydrogen demand.

Figure 3.9. Renewable electricity technical potential from wind and solar vary across regions

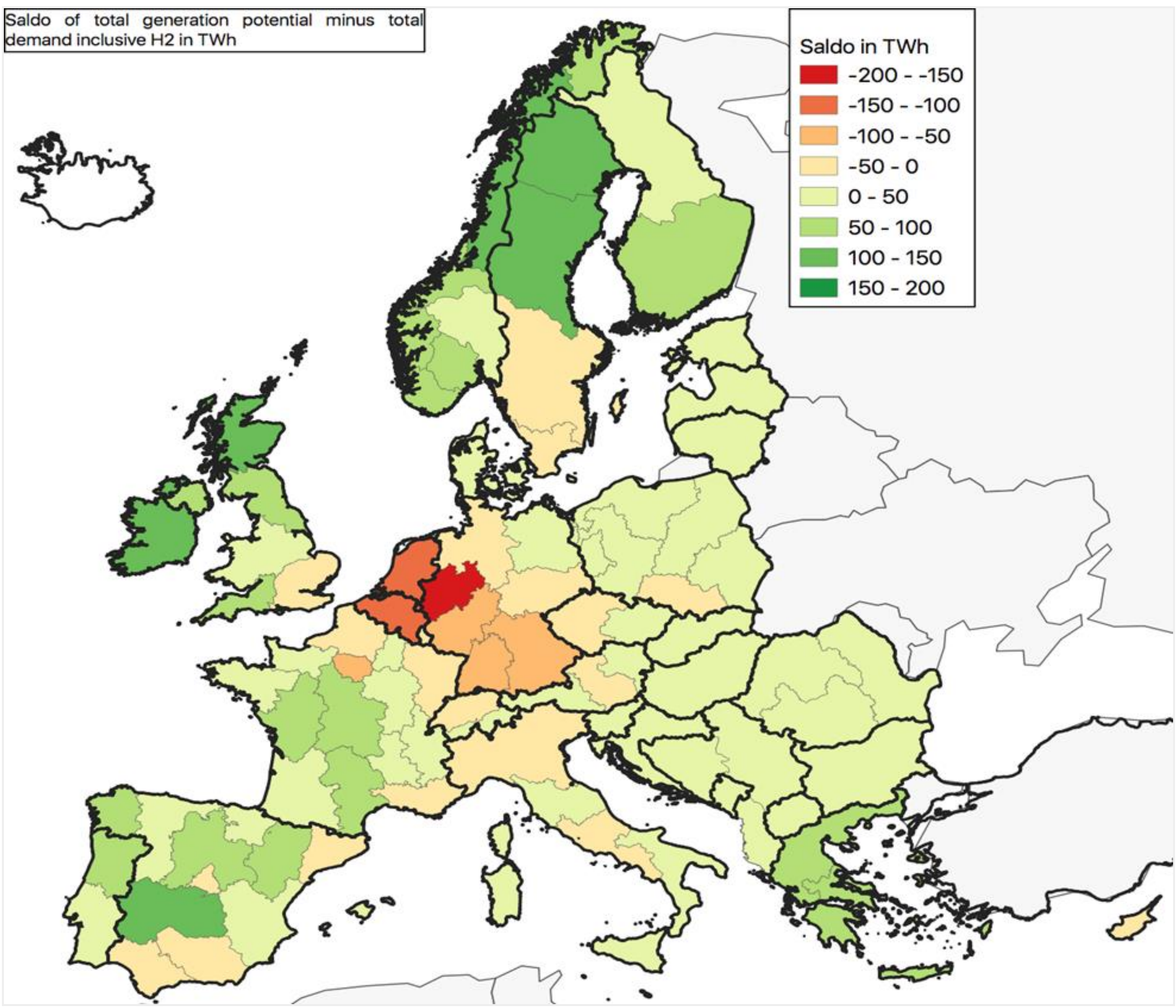


Note: Includes existing renewable electricity generation, including from other sources than wind or solar, and solar and wind technical potential.
Source: (2014[13]). (ENTSO-E, 2014[14])

Figure 3.10 shows the balance of renewable electricity generation potential and the demand for electricity in each region, including the demand for electricity to produce hydrogen for industrial needs. Red colours indicate that, in the respective region, electricity consumption is higher than the generation potential, and green colours show that excess generation could be achieved if the full generation potential were exploited.

This overview shows that technical RE potentials in southern and northern Europe could be sufficient to meet the demands on a yearly basis without taking into account diurnal or seasonal fluctuations. But especially in Northwestern Europe, the demand is significantly higher than generation potentials. This will result in hydrogen imports. Imports may be more widespread than the map suggests owing to lower renewable electricity production costs outside Europe.

Figure 3.10. Balance of generation potential and projected total electricity demand in Europe



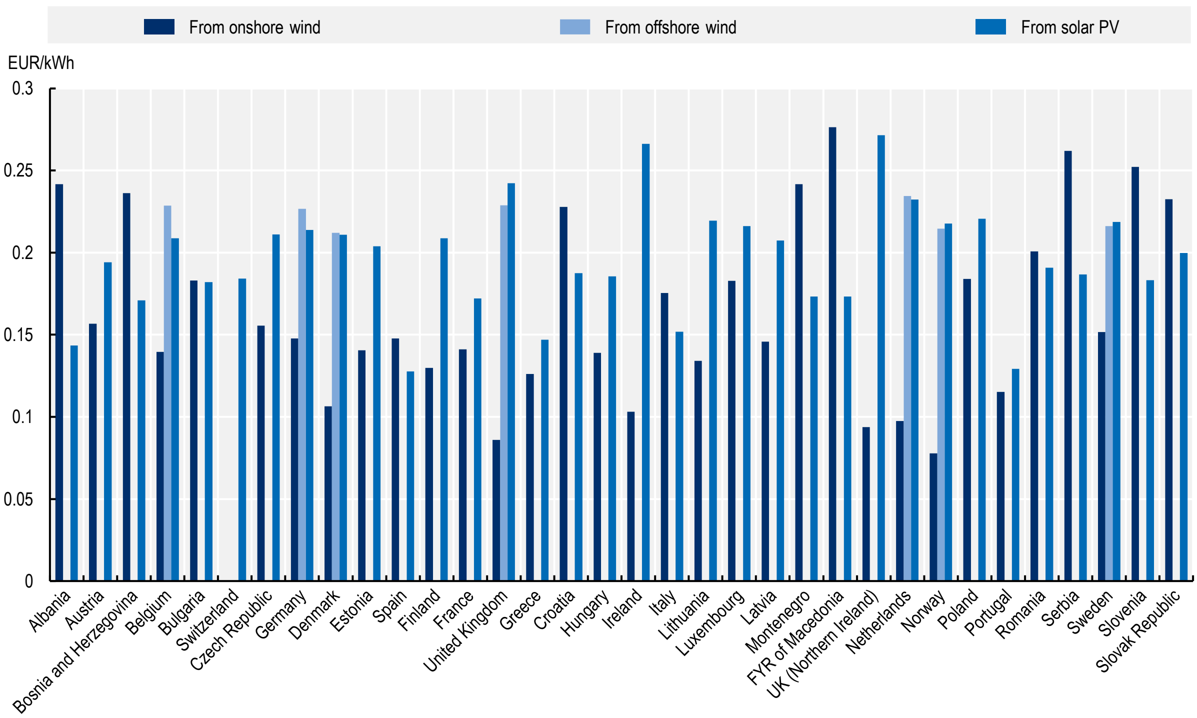
Source: (2014[13]); (ENTSO-E, 2014[14]) and Wuppertal Institute calculations.

Regional hydrogen production costs

While many regions may have sufficient technical potential for renewable electricity to cover their energy needs, including those needed to meet hydrogen production for industry, costs may be relatively high in some. Figure 3.11 shows hydrogen production costs across European countries. These are calculated assuming that electrolysers use electricity from either onshore or offshore wind or solar photovoltaics (PV) directly. Higher renewable yields lead to a better capacity utilisation of the electrolyser and thereby lower costs. Even higher full load hours can be achieved when combining wind and solar plants (Agora Verkehrswende/Agora Energiewende/Frontier Economics, 2018[18]).

Offshore wind is a rather expensive source of hydrogen: despite the high full load hours, the assumed high costs and low lifetimes of offshore wind plants lead to hydrogen costs between EUR 0.21 and 0.23/kWh.

Figure 3.11. Regional costs for producing hydrogen from onshore wind or PV in Europe in 2030



Source: Data supplied by Wuppertal Institute.

StatLink https://stat.link/e0yrf6

There is a broad range of estimated import costs as a meta-analysis on hydrogen import costs to European countries reveals (Merten et al., 2020[19]), taking several studies with a focus on imports from northern Africa into account, and showing a range between 0.080 EUR/KWh (8 Ct/kWh) and 0.2 EUR/KWh (19.6 Ct/kWh). Some regions in Europe could produce hydrogen within the range of import prices. Other work (Merten et al., 2020[19]) has compared the cost of domestic production with the cost of imports.

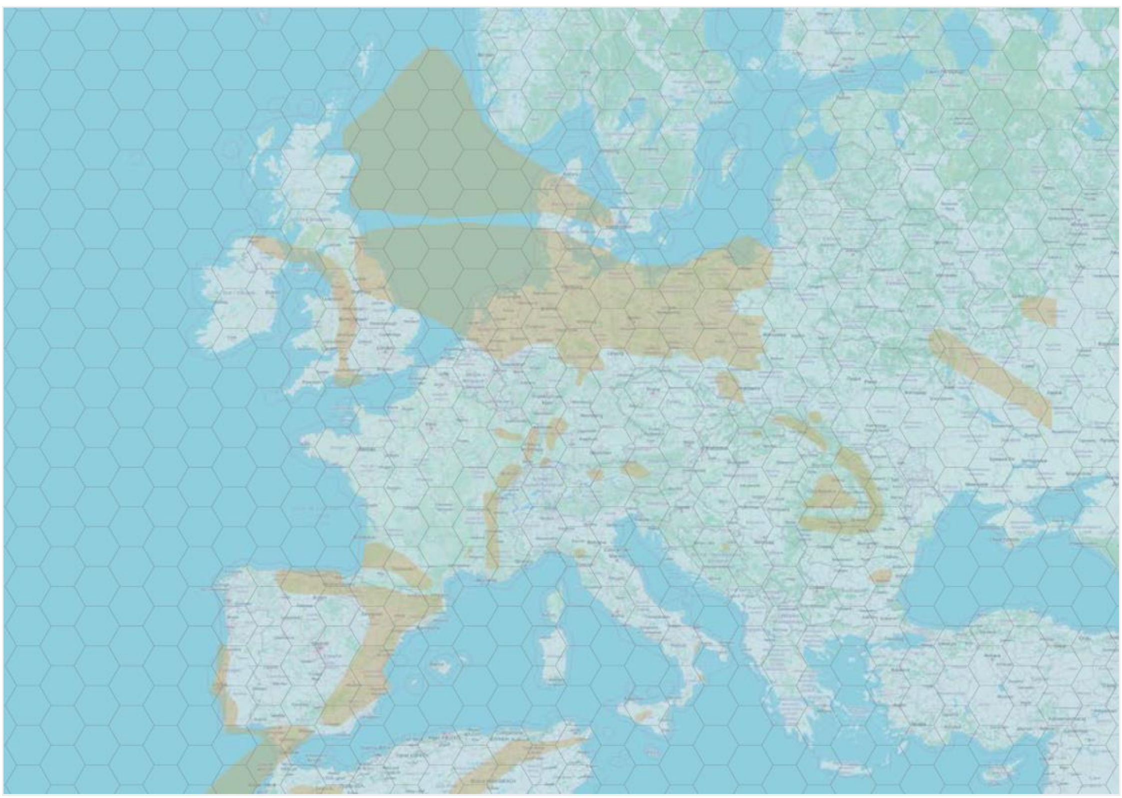
Hydrogen storage and electricity transmission capacity

The local availability of hydrogen storage and the transmission capacity of the electricity grid also have an impact on hydrogen availability and its cost. Seasonal storage in salt caverns is not possible everywhere (Figure 3.12) but is important for the overall energy system to manage fluctuations in hydrogen demand and intermittent renewable electricity supply. Sites with seasonal storage potential may be among the first sites to be connected to a future hydrogen grid. The spatial proximity to suitable salt caverns is therefore a regional advantage to provide an early connection to the hydrogen network.

For remote sites without good access to sufficient renewable generation and to a hydrogen infrastructure, it may be cheaper to use or reinforce the electricity grid for transporting the energy there, especially if they are located in difficult terrain and produce hydrogen from this electricity.

One effect of the decarbonisation of industry is that electricity demand concentration is intensified with implications for electricity transmission. Decarbonisation will lead to a shift in energy use from fossil fuels to electricity and hydrogen produced with renewable electricity. As a result, regions with much industrial production will experience a much stronger increase in electricity demand than regions with low industrial production.

Figure 3.12. Salt strata in Europe indicating possible seasonal hydrogen storage sites



Note: Orange shading indicates salt strata.
Source: Agora Energiewende/AFRY Management Consulting (2021[20]), *No Regret Hydrogen - Charting Early Steps for H_2 Infrastructure in Europe*, https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_02_EU_H2Grid/A-EW_203_No-regret-hydrogen_WEB.pdf.

Hydrogen transport

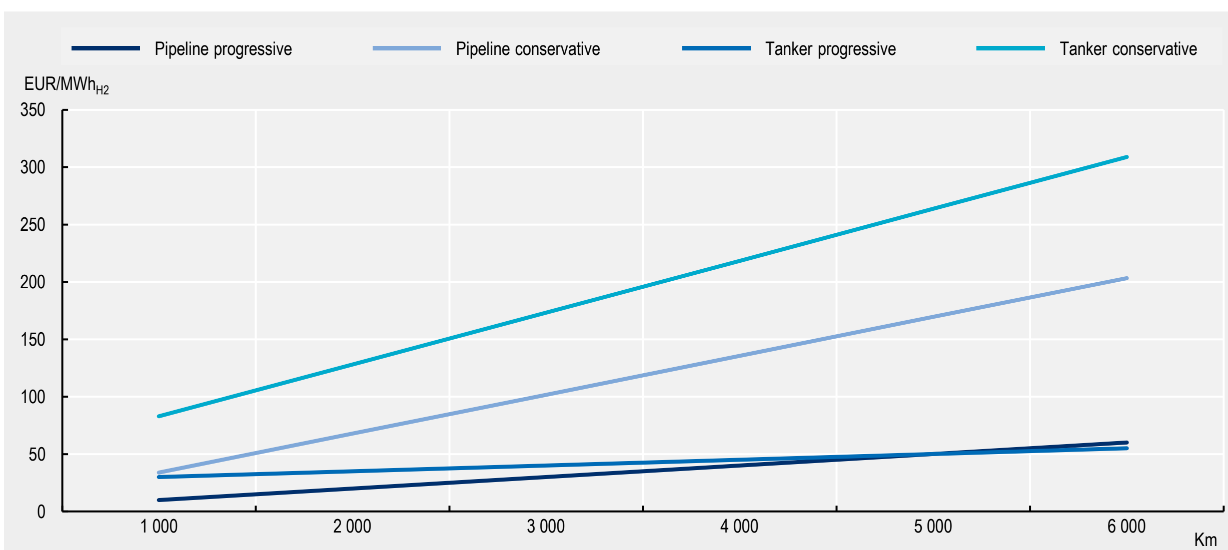
Hydrogen can be transported in various forms: as a gas in pipelines, as a compressed gas or cryogenic liquid in tankers or by train or truck. An important determinant for hydrogen availability is therefore access to the corresponding infrastructure. In principle, trucks can reach almost any site but, like trains, they are not economic for large quantities of hydrogen and their operation requires energy. Port locations offer the best access to the “world market” for hydrogen: since distances for transport by ship are of less relevance, hydrogen can also be landed here from distant world regions. Pipelines enable the transport of large quantities of hydrogen onshore over long distances but are cost-intensive to provide if newly built over long distances. Larger clusters of consumers can be connected via pipelines but the associated additional costs are high for small consumers. A very important alternative to the construction of new hydrogen pipelines is the repurposing of existing natural gas pipelines. These have to be retooled for that purpose since natural gas and hydrogen have different chemical features.[1] Natural gas pipelines offer the great advantage of an interconnected network that is well developed, especially in industrial locations with a high demand density.

There are different alternatives to transporting pure hydrogen gas: liquid organic hydrogen carriers (LOHCs) are chemical substances which are easily storable and can absorb and release hydrogen through chemical reactions. They are suitable for transport by tanker, train, truck or pipeline. LOHCs are liquid even at ambient pressure and temperature (IEA, 2019[16]). The advantage of this transport method is that the energy density is several hundred times higher; however, LOHCs require additional energy input. Transport of hydrogen-derived ammonia is also an option; ammonia is especially suitable for transport by ship. The energy density is about twice as high as LOHCs (4.25 kWh/l). After transport, hydrogen can be recovered or the ammonia can be used in downstream chemical production. Another indirect form of transporting hydrogen is to import iron produced with hydrogen without emissions (see Chapter 1): it could be produced in RE-strong regions, be transported to the steel plant and avoid hydrogen use there. The transport of direct-reduced iron might be a solution for steel sites without sufficient access to renewable hydrogen.

Costs for long-distance hydrogen transport

The different forms of transport have different implications for European regions. The costs for pipeline transport increase significantly with distance than the costs for transport by ship (Figure 3.13).

Figure 3.13. Relationship between transport distance on transport costs for hydrogen



Note: "Progressive" refers to low-end estimates of costs, "conservative" to high-end estimates of cost.
Source: Merten, F. et al. (2020[19]), "Policy brief – Infrastructure needs of an EU industrial transformation towards deep decarbonisation, based on research project funded by EIT Climate-KIC. Task ID: TC_2.11.1_190229_P259-1B".

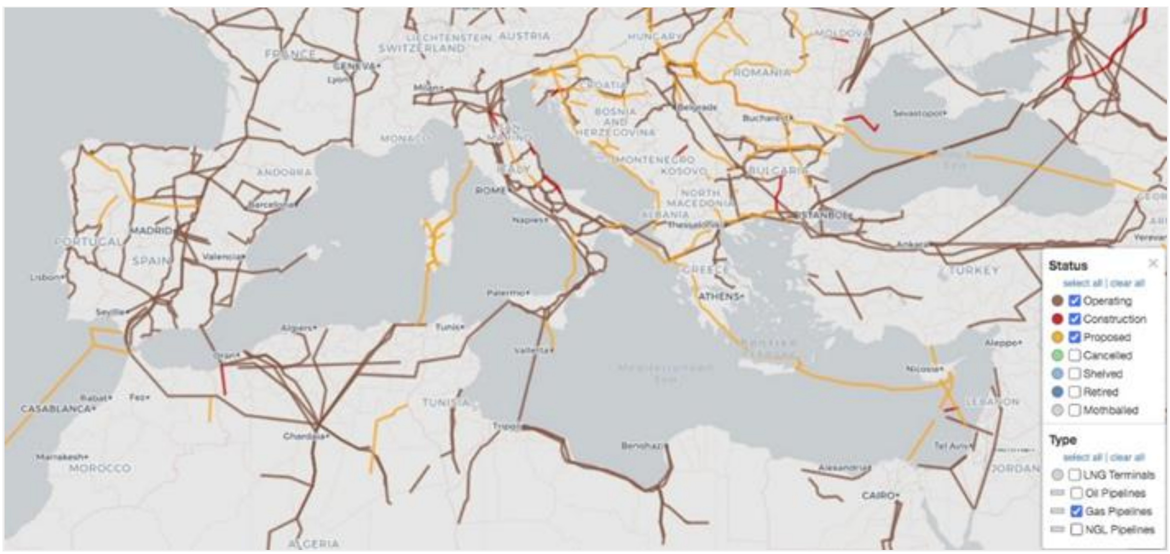
StatLink https://stat.link/ikolsr

Regions that are close to potential hydrogen-producing regions, such as MENA, and benefit from mostly land-based connections can take advantage of lower-cost pipeline transport, such as Southwestern Europe via Algeria and Morocco. Natural gas pipelines could be repurposed for hydrogen (Figure 3.14).

The costs for hydrogen transport by ship are less distance-dependent but the proximity to a suitable port and the existence of the corresponding infrastructure is an advantage. Especially ports which today serve as natural gas hubs could also play an important role for hydrogen in the future. Even though existing liquefied natural gas (LNG) terminals may not easily be repurposed for hydrogen, they are entry points to the natural gas grid.

LOHCs and ammonia have lower transport costs than gaseous or liquid hydrogen due to higher energy density and easier handling but require additional infrastructure for coupling and decoupling them to hydrogen. Hydrogen transport per ship may be around two to three times cheaper when using ammonia than transporting liquid hydrogen (EC, 2021[21]). The IEA (2019[16]) sees both ammonia and LOHCs to be much cheaper than hydrogen transportation.

Figure 3.14. Existing and planned natural gas pipelines connecting Europe and MENA



Source: Global Gas & Oil Network (2020[22]), *Global Fossil Infrastructure Tracker*, http://ggon.org/fossil-tracker/.

Repurposing natural gas pipelines is typically the lowest-cost option. The capital cost of repurposing existing pipelines is about 10-25 % of the cost of building new hydrogen pipelines (Wang et al., 2020[23]) . The European gas grid infrastructure will offer good connection conditions for many industrial locations in the longer term but, in the medium term, its pipelines will still mostly be required for natural gas: 82 % of the German natural gas pipeline network, for example, may be technically suitable for conversion but, depending on different availability scenarios, only 13-46% of the necessary hydrogen pipelines may be available before 2030, though this varies with the ambition of climate action and geopolitical developments. Northwestern Europe may have an early-mover advantage. It has a double infrastructure, with gas pipelines becoming obsolete for gas by 2030. They can first be repurposed for hydrogen without compromising the gas supply.

New pipelines will also need to be built, for example, to serve industrial plants that have not used gas but may require hydrogen, such as in steel production. The terrain has a major influence on the costs of new pipelines. Even though the absolute numbers may differ, the principles for CO_2 pipeline construction outlined above also apply to hydrogen pipelines. Repurposing existing pipelines reduces the impact of terrain on cost.

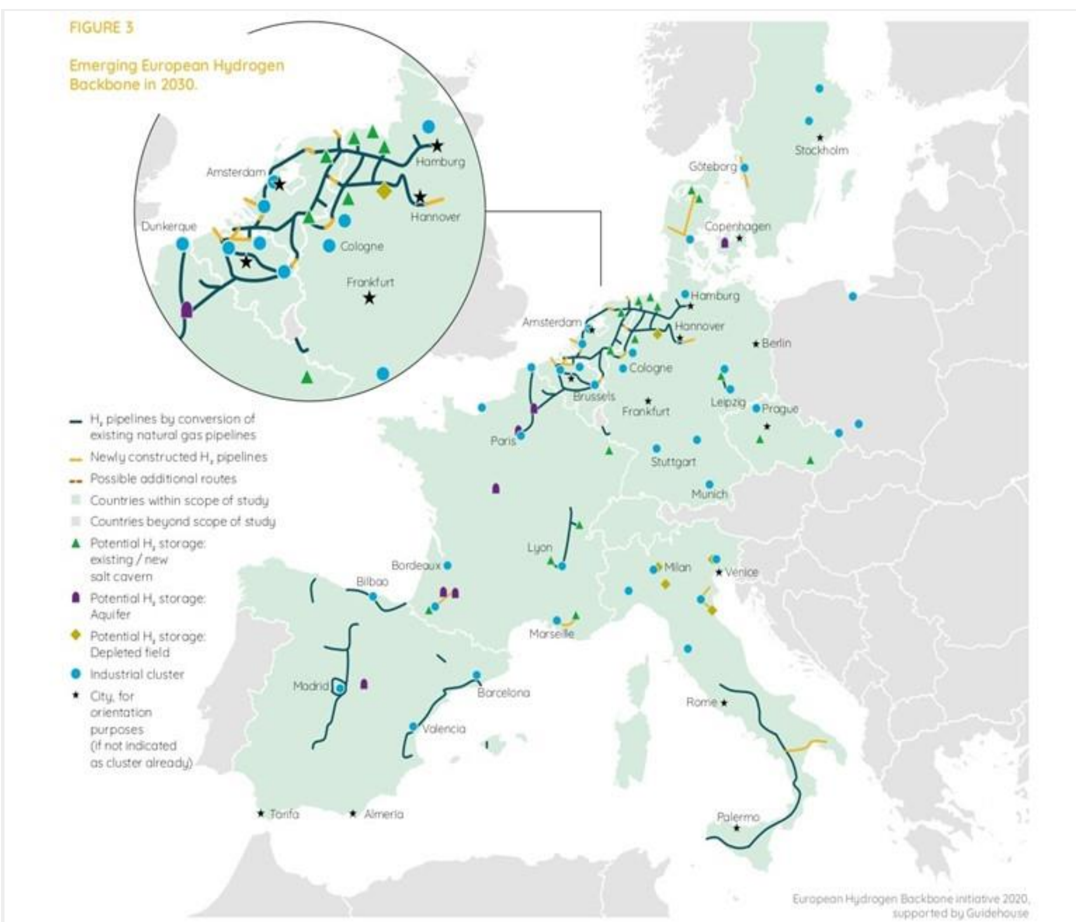
As in the case of CO_2 pipelines, scale economies apply. The amount of hydrogen demanded in a region has an influence on the transport cost: larger pipelines have lower costs per unit if used at full capacity. As a result, hydrogen consumers in an area of high overall hydrogen consumption have a cost advantage.

In summary, locations with a high density of industrial consumers and close to the coast have advantages over spatially distributed hydrogen demand in areas that are more difficult to access via existing pipelines. Coastal industrial clusters host important opportunities for establishing hydrogen infrastructure (IEA, 2019[16]).

Examples of building up a hydrogen transport infrastructure

The local availability of hydrogen, regional demand and the spatial characteristics and storage potentials need to be taken into account when hydrogen infrastructure is developed. A look at such existing plans can indicate which locations can benefit from the development of the infrastructure at an early stage and which are likely to be connected only in the long term. There are a few proposals for establishing a hydrogen infrastructure for some European countries in Western Europe (Figures 3.15 and 3.16) (Agora Energiewende/AFRY Management Consulting, 2021[20]). They all begin with connecting initial locations where hydrogen demand is particularly high, notably chemical production clusters in Northwestern Europe until 2030 and, from there, building a growing network that will eventually connect all European regions. They rely to a large extent on existing natural gas pipelines.

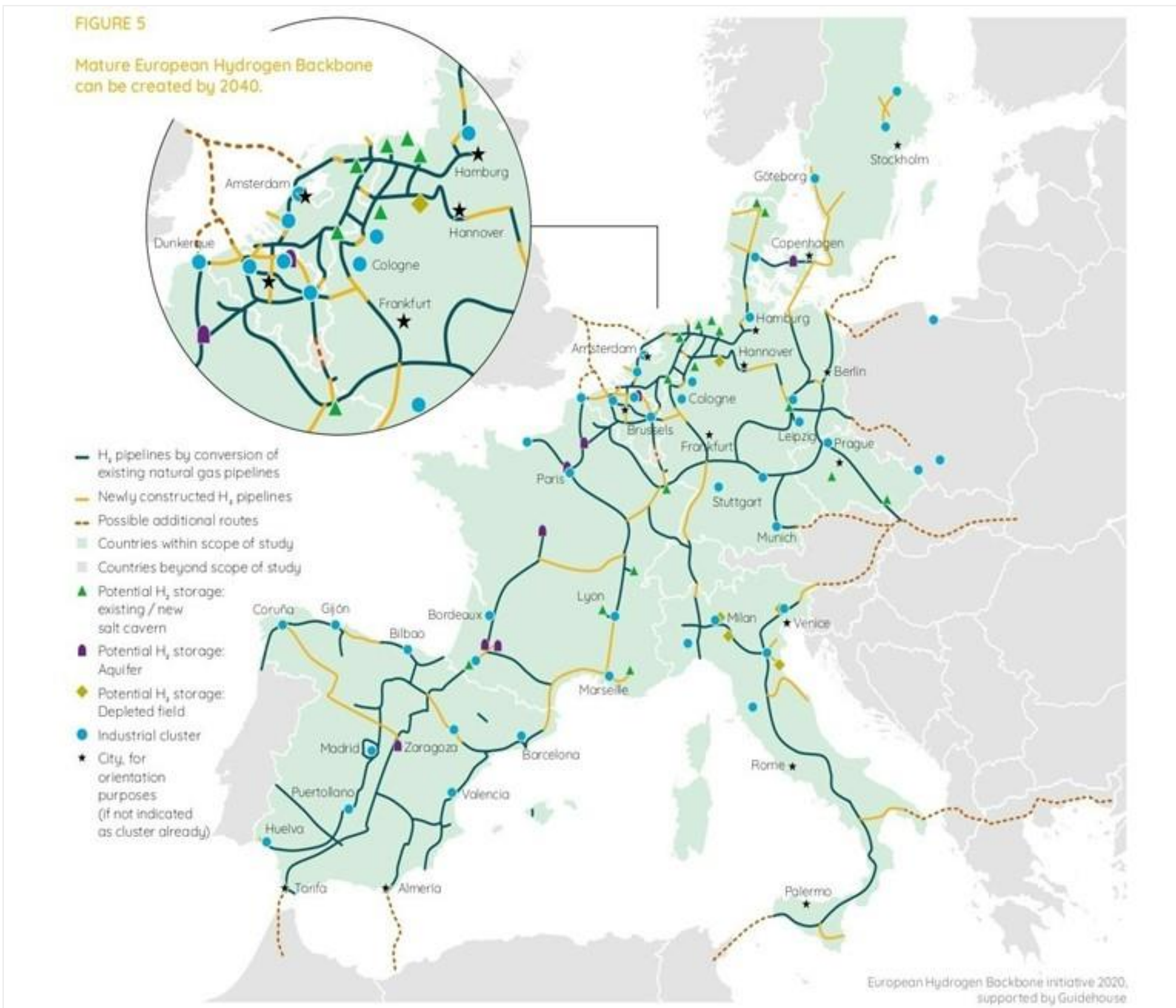
Figure 3.15. Possible development of a hydrogen network in 2030



Source: Wang, A. et al. (2020[23]), *European Hydrogen Backbone - How a Dedicated Hydrogen Infrastructure Can Be Created*, Guidehouse.

They illustrate regional development challenges that result from hydrogen use in climate-neutral industry. Regions with industrial clusters may be able to build needed infrastructure first and at a lower cost, reflecting economies of scale and pre-existing infrastructure. Policy makers will need to consider how to integrate these regional development challenges into spatially balanced policies to reach climate neutrality. One option may be to require more demanding, earlier steps towards climate neutrality in regions with industrial clusters which will be first served with hydrogen.

Figure 3.16. Possible development of a hydrogen network in 2050



Source: Wang, A. et al. (2020[23]), *European Hydrogen Backbone - How a Dedicated Hydrogen Infrastructure Can Be Created*, Guidehouse.

The total investment until 2040 may amount to between EUR 27 and 64 billion for the full capital cost of building and retrofitting, and operational expenditures may amount to between EUR 1.6 and 3.5 billion per year.

Regional challenges in road freight

Decarbonisation in road freight is less advanced than in passenger transport, as zero-carbon technologies to be deployed at scale have not yet been chosen for freight. CO_2 emissions from heavy-duty transport vehicles account for approximately one-quarter of total CO_2 emissions from transport and almost 5% of total 27 European Union member states and the UK greenhouse gas emissions. Deployment of such technologies is a near-term priority to move road freight towards net-zero emissions. One important impact of transport decarbonisation policies is on transport costs (Halim, Smith and Englert, 2019[24]). As the first chapter has shown, road transport plays a dominant role in the transport of output of key sectors, especially in intra-EU transport. Freight transport is particularly important for these sectors because the key sectors produce essential materials and goods.

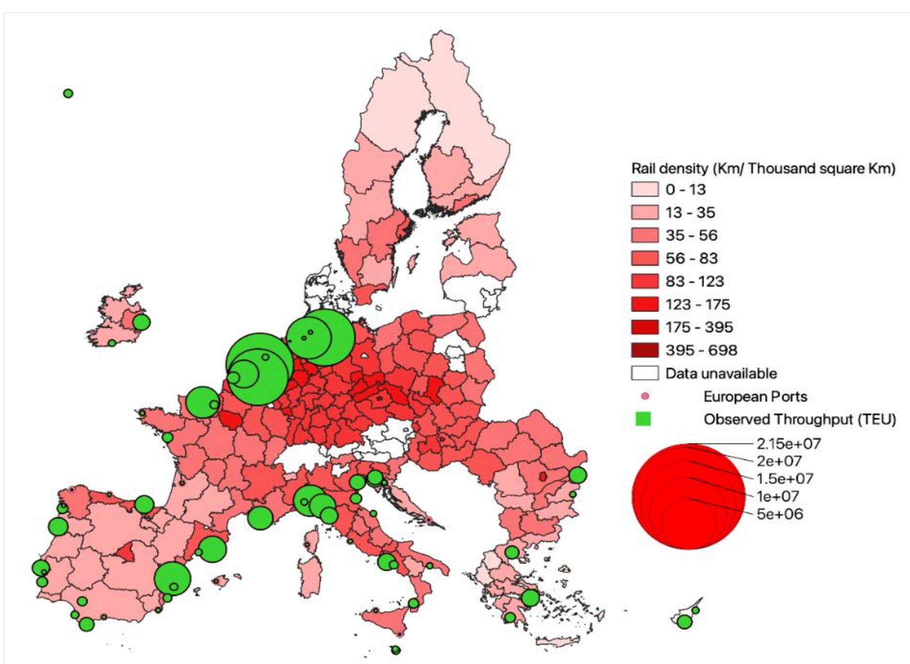
If decarbonisation of freight raises transport costs, higher transportation costs can fall back on the manufacturing industries that rely heavily on road transport and their value chains, notably for industries producing basic materials. This increase in road transport costs may trigger a shift to cheaper modes of transport, such as railways or waterways – if these modes are available in the region. Railways and inland waterways could increase their share of freight to ease the transition to climate-neutral road transport. For example, the EU aims to shift 50% of medium-distance freight journeys to rail by 2050.

The impact of decarbonising freight will vary between European regions, due to different dependencies on road freight across manufacturing sectors and regions. Regions that depend heavily on road freight may see higher increases in transport costs than those which do not (Wilmsmeier, Hoffmann and Sanchez, 2006[25]). Firms may relocate their manufacturing facilities to regions that offer lower transport costs.

Regions with a higher density of the rail network that connects the regions to their major trade partners, including via maritime ports, may see lower increases in transport and logistics costs. Port-hinterland infrastructure strongly determines international-trade related transport costs going through ports (Wilmsmeier, Hoffmann and Sanchez, 2006[25]). Hinterland transport costs, on average, constitute 80% of the total transport cost of intermodal shipment, while it covers only 10% of the total transport distance (Notteboom and Rodrigue, 2012[26]).

In the EU, regions differ in the density of their rail networks and therefore in their ability to substitute rail for road (Figure 3.17). Regions in the periphery of the EU, in particular in far northern regions, in Southwest and Southeast Europe have low rail densities, especially in regions which do not have maritime ports or capital cities in their proximity.

Figure 3.17. Rail network density and maritime port throughput across EU regions



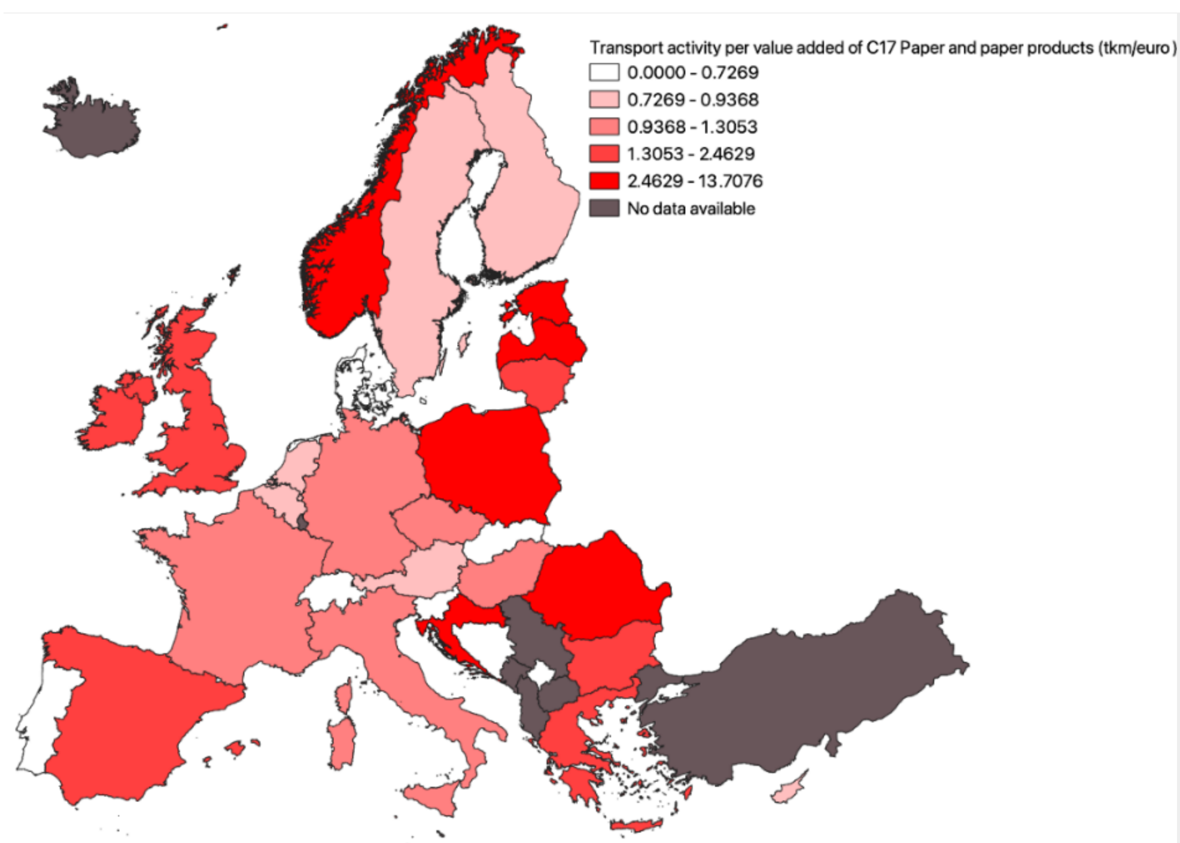
Source: Eurostat and Equitable Maritime Consulting.

Across the key manufacturing sectors identified in the first chapter, paper and pulp (NACE 17) and non-metallic mineral products (NACE 23) tend to be the most intensive in road freight use to transport their output, as measured by road freight tonne-kilometres invoiced by businesses producing goods in this sector relative to value-added.

The dependency on road transport measured in this way also varies across countries. Regional data for road freight use are not available. Indeed, as Figures 3.18 and 3.19 show, road freight dependence of both these sectors tends to be particularly strong in Southern and Central Eastern Europe. Some of these countries, such as the Czech Republic, also stand out for their long distance to maritime ports and high shares of employment in non-metallic minerals production. As shown in the following section, regions with these characteristics may suffer substantially higher increases in transport costs, if the decarbonisation of road freight turns out to be costly and substitution by rail is not readily available. By contrast, regions with strong paper and pulp production in Finland and Sweden appear to be less road freight dependent. In the non-metallic minerals industry, some regions with high-emission activity and employment in Poland, as shown in Chapter 2, appear to be in countries with relatively strong road freight dependence. A forthcoming working paper illustrates road freight dependence for the other key manufacturing industries (Fuentes Hutfilter et al., 2023[3]).

Figure 3.18. Road freight intensity in paper and pulp production

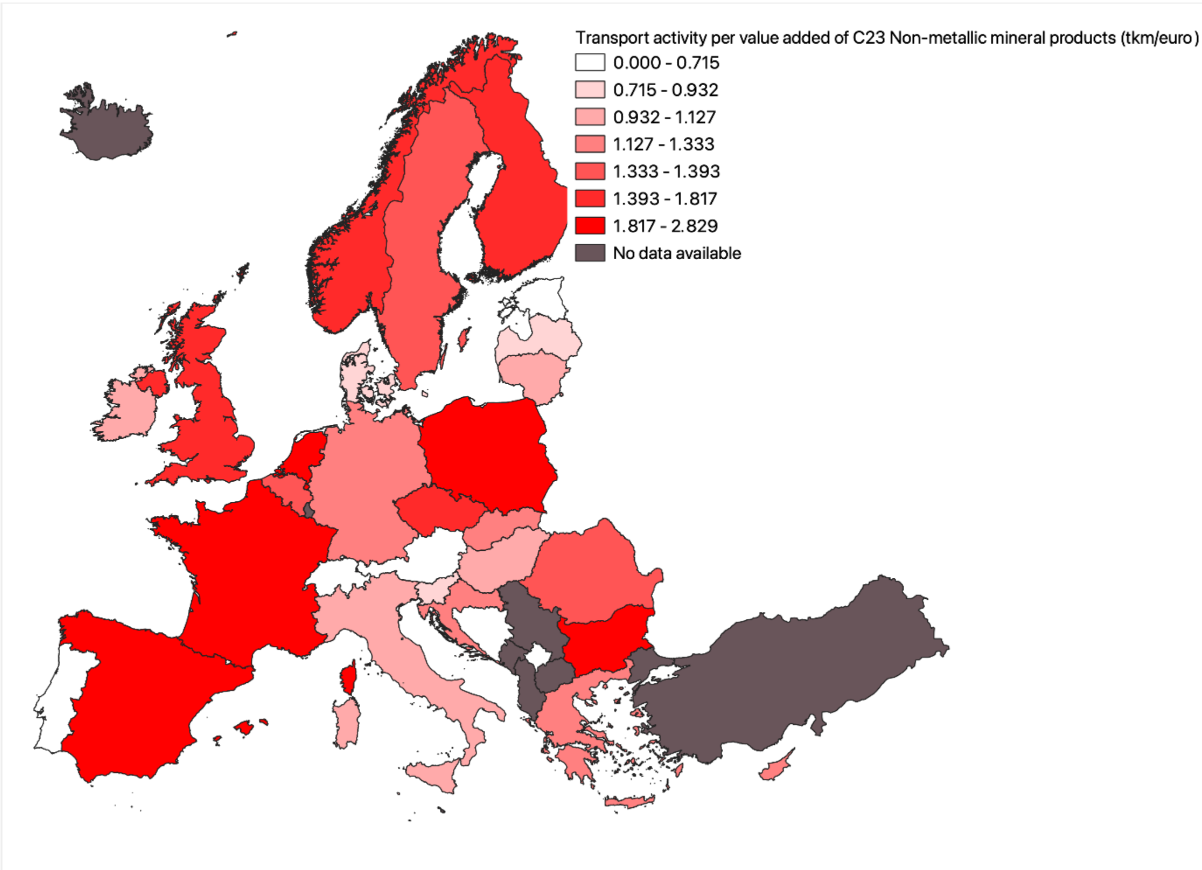
Tonne-kilometres of output transported on roads relative to value-added



Note: Tonne-kilometres refer to road transport services invoiced by businesses in the respective countries.
Source: Eurostat and Equitable Maritime Consulting.

Figure 3.19. Road freight intensity in non-metallic minerals production

Tonne-kilometres of output transported on roads relative to value-added



Note: Tonne-kilometres refer to road transport services invoiced by businesses in the respective countries.
Source: Eurostat and Equitable Maritime Consulting.

Impact of road freight carbon taxes on freight transport costs in selected EU regions

This section illustrates the potential impacts of road freight carbon taxes on transport costs for selected commodities produced by key manufacturing sectors in selected European regions, drawing on one example region. The analysis highlights the importance of road freight, especially in regions distant from maritime ports. A fuller analysis with a range of different regions is contained in a forthcoming working paper (Fuentes Hutfilter et al., 2023[3]). Road emerges as the cheapest land-based freight transport mode in all examples. The transport model optimes transport modes and routes, minimising transport cost, between a key sector-producing region and a major export destination. Modelled costs include fuel costs, transport tolls and taxes, operating and capital costs of transport equipment as well as labour costs and other time-related costs. However, for simplicity, no behavioural response is assumed in response to the carbon tax increase, for example from the substitution of road by rail or from fuel-saving. The Annex to this chapter contains a more detailed description.

The carbon tax increases considered include an increase of 50% and 100% in fuel costs respectively. Based on the assumption that, on average, a heavy duty vehicle (HDV) consumes 3.45 L/100 km, a 50% and 100% increase in the fuel price is approximately equivalent to a carbon tax of 58 USD/tonne CO_2 and 116 USD/tonne respectively. A carbon price of EUR 60 (66.70 USD/ tonne) per tonne of CO_2 would be consistent with a scenario of slow decarbonisation by 2060, and a carbon price of EUR 120

(133.40 USD/tonne) per tonne of CO_2 is a central estimate of the carbon price needed to decarbonise by 2050 (OECD, 2021[27]). However, the German Environmental Protection Agency estimates that the social damage per CO_2 tonne released is EUR 180 in 2016, implying that the assumed fuel prices may still be too low to include all costs (OECD, 2021[27]).

The modelling results suggest that land-locked regions supplying or receiving basic materials produced by key industries may face substantial freight cost increases from carbon taxes on road freight. This is shown in the example of cement exports from Krakow, Poland, below. Cost impacts may be lower if the cost of introducing zero-emission road freight technologies or the shift to rail can be achieved at a lower cost than the assumed carbon prices.

Export of cement from Krakow to Los Angeles, United States

For destinations that are geographically far away, intermodal maritime transport is the main mode. There are several alternative routes to ship goods through 2 ports: the port of Gdansk (344 km) and the port of Szczecin (407 km). The transport from Krakow to both ports is mainly carried out using road freight (Figure 3.20, Panel A).

From Table 3.2, it is apparent that hinterland transport costs represent the highest fraction of total transport costs. Under the baseline scenario, road transport from Krakow to major Polish ports constitutes 68-70% of transport costs to Los Angeles. The application of carbon tax on road transport will amplify the costs of hinterland transport to USD 52/tonne (low scenario) and USD 60/tonne (high scenario). In comparison to hinterland transport, maritime transport costs are a lot lower. This is due to the economy of scale offered by large ships that serve the Poland-US route (Figure 3.20, Panel B). Improving hinterland transport infrastructure to make it climate neutral is most important. For instance, improving the availability of rail could help to attain this objective.

Table 3.2. Breakdown of intermodal maritime transport costs from Krakow to Los Angeles

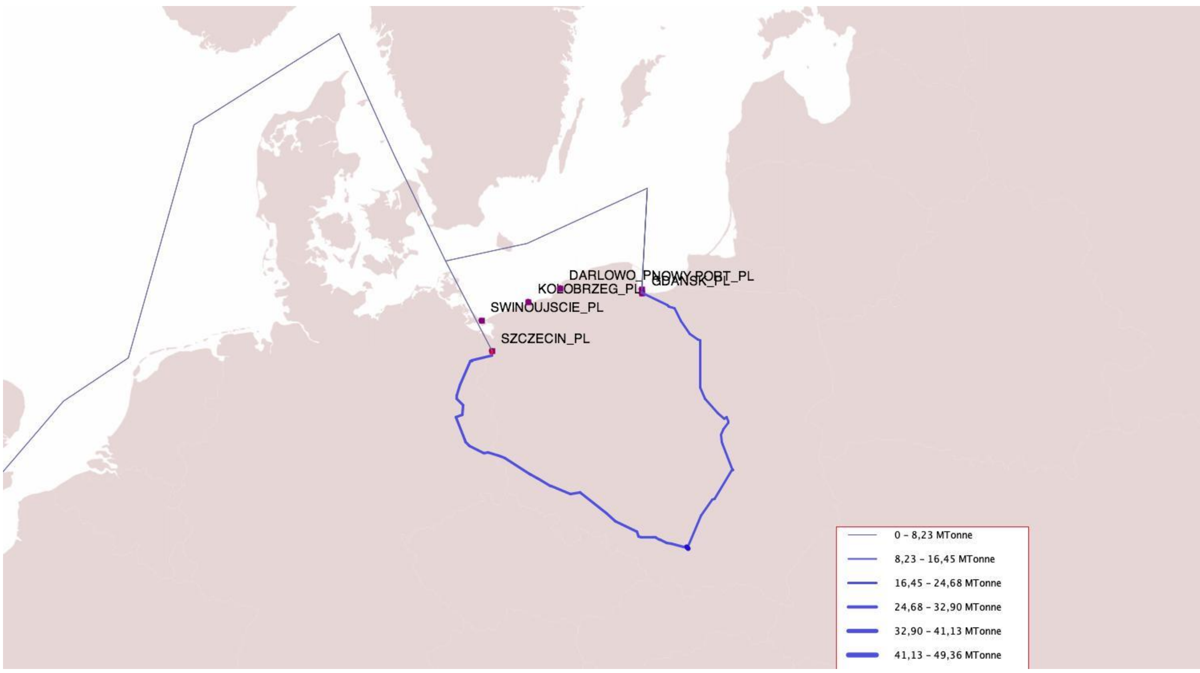
USD per tonne unless indicated otherwise

Hinterland connection	Scenario	Road freight cost from origin-to-origin port	Maritime transport cost	Road freight cost from destination port to destination	Total cost	Fraction of origin road freight costs, per cent
Krakow-Gdansk	Base case	42.97	17.34	2.51	62.82	68.41
	Low tax	51.56	17.34	2.51	71.41	72.21
	High tax	60.16	17.34	2.51	80.01	75.19
Krakow-Szczecin	Base case	46.65	17.34	2.51	66.50	70.15
	Low tax	55.98	17.34	2.51	75.83	73.83
	High tax	65.31	17.34	2.51	85.16	76.69

Figure 3.20. Transport routes from Krakow to Poland's main ports and from Krakow to main regions in the US

Annual transport volumes along cost-minimising routes

A. From Krakow to Poland's main ports



B. From Krakow to main regions in the US

Source: Equitable Maritime Consulting.

References

Agora Energiewende/AFRY Management Consulting (2021), *No Regret Hydrogen - Charting Early Steps for H_2 Infrastructure in Europe*, https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021_02_EU_H2Grid/A-EW_203_No-regret-hydrogen_WEB.pdf. [20]

Agora Verkehrswende/Agora Energiewende/Frontier Economics (2018), *Die zukünftigen Kosten strombasierter synthetischer Brennstoffe*, http://www.stiftung-mercator.de/media/downloads/3_Publikationen/2018/Maerz/Agora_SynCost-Studie_WEB.pdf. [18]

Benrath, D. (2021), *Rechtliche Rahmenbedingungen ener Kohlendioxidwirtschaft*, IN4climate.NRW GmbH, https://www.in4climate.nrw/fileadmin/Nachrichten/2021/Gutachten_KdW/in4climate.nrw-gutachten-ag-kdw-rechtliche-rahmenbedingungen-kohlendioxidwirtschaft.pdf. [5]

EC (2021), *European Emissions Trading System (ETS) – Calculations on the Regional Employment Impact of ETS Installations*, Publications Office of the European Union, European Commission, https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/reg_impact_ets_installations_en.pdf. [21]

EC (n.d.), "Using CO2 instead of storing it: carbon capture and use (CCU)", European Commission. [10]

ENTSO-E (2014), *D 2.1 Data Sets of Scenarios for 2050. June 2014. e-HIGHWAY 2050*, Modular Development Plan of the Pan-European Transmission System 2050, http://www.e-highway2050.eu/fileadmin/documents/Results/D2_1_Data_sets_of_scenarios_for_2050_20072015.pdf. [14]

ENTSO-E (2014), *D 2.2 European Cluster Model of the Pan-European Transmission Grid. e-HIGHWAY 2050*, Modular Development Plan of the Pan-European Transmission System 2050, https://docs.entsoe.eu/baltic-conf/bites/www.e-highway2050.eu/fileadmin/documents/Results/D2_2_European_cluster_model_of_the_Pan-European_transmission_grid_20072015.pdf. [13]

European Environment Agency (2000), *Wetland concentration in Europe*, https://www.eea.europa.eu/data-and-maps/figures/wetland-concentration-in-europe-2000. [11]

Forschungszentrum Jülich (2020), *Wege für die Energiewende - Kosteneffiziente und klimagerechte Transformationsstrategien für das deutsche Energiesystem bis zum Jahr 2050*. [17]

Fuentes Hutfilter, A. et al. (2023), "Regional industrial transitions to climate neutrality: Conditions for regional access to infrastructure". [3]

Gillessen, B. et al. (2020), "Umstellung von Erdgaspipelines auf Wasserstoff – eine wirtschaftliche Alternative für Deutschland?", *Energiewirtschaftliche Tagesfragen*, pp. 30 – 33. [31]

Global Gas & Oil Network (2020), *Global Fossil Infrastructure Tracker*, http://ggon.org/fossil-tracker/. [22]

Halim, R. et al. (2018), "Decarbonization pathways for international maritime transport: A model-based policy impact assessment", *Sustainability*, Vol. 10/7, p. 2243. [29]

Halim, R., T. Smith and D. Englert (2019), *Understanding the economic impacts of greenhouse gas mitigation policies on shipping. What Is the state of the art of current modeling approaches?*, World Bank Group. [24]

IEA (2019), *The Future of Hydrogen: Seizing Today's Opportunities*, International Energy Agency, https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf. [16]

IEAGHG (2013), *CO2 Pipeline Infrastructure*, International Energy Agency, https://www.ieaghg.org/docs/General_Docs/Reports/2013-18.pdf. [9]

Kjärstad, J. et al. (2016), "Ship transport - A low cost and low risk CO2 transport option in the Nordic countries", *International Journal of Greenhouse Gas Control*, Vol. 54/5, pp. 168-184. [8]

LBST (2017), *The Potential of Electricity-based Fuels for Low-emission Transport in the EU*, Ludwig Bölkow Systemtechnik GmbH, Deutsche Energie-Agentur GmbH. [15]

Material Economics (2019), *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry*, https://materialeconomics.com/publications/industrial-transformation-2050. [1]

Merten, F. et al. (2020), "Policy brief – Infrastructure needs of an EU industrial transformation towards deep decarbonisation, based on research project funded by EIT Climate-KIC. Task ID: TC_2.11.1_190229_P259-1B". [19]

Neele, F. et al. (2011), *Towards a Transport Infrastructure for Large-scale CCS in Europe*, TNO, http://www.co2europipe.eu/. [7]

Notteboom, T. and J. Rodrigue (2012), "The corporate geography of global container terminal operators", *Maritime Policy & Management*, Vol. 39/3, pp. 249-279, https://doi.org/10.1080/03088839.2012.671970. [26]

OECD (2021), *OECD Regional Outlook 2021: Addressing COVID-19 and Moving to Net Zero Greenhouse Gas Emissions*, OECD Publishing, Paris, https://doi.org/10.1787/17017efe-en. [27]

Persyn, D., J. Diaz Lanchas and J. Barbero Jimenez (2020), *Regional Transport Costs (dataset)*, JRC120532, European Commission. [28]

Samadi, S. et al. (2018), *Strategien für eine naturverträgliche Energiewende: Analyse von Strategien zur Umsetzung von ambitioniertem Klimaschutz unter Gewährleistung eines hohen Naturschutzniveaus*, NABU, Wuppertal. [12]

Science for Environment Policy (2017), "The Precautionary Principle: Decision making under uncertainty", *Future Brief 18*, Produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol, https://ec.europa.eu/environment/integration/research/newsalert/pdf/precautionary_principle_decision_making_under_uncertainty_FB18_en.pdf. [2]

Tavasszy, L. et al. (2011), "A strategic network choice model for global container flows: specification, estimation and application", *Journal of Transport Geography*, Vol. 19/6, pp. 1163-1172. [30]

Viebahn, P. et al. (2018), *Technologien für die Energiewende - Politikbericht*, Wuppertal Institut, https://www.energieforschung.de/lw_resource/datapool/systemfiles/elements/files/70013C70EE963F41E0539A695E8680ED/current/document/TFE_Politikbericht_komplett.pdf. [4]

Wang, A. et al. (2020), *European Hydrogen Backbone - How a Dedicated Hydrogen Infrastructure Can Be Created*, Guidehouse. [23]

Wilmsmeier, G., J. Hoffmann and R. Sanchez (2006), “The impact of port characteristics on international maritime transport costs”, *Research in Transportation Economics*, Vol. 16, pp. 117-140, https://doi.org/10.1016/s0739-8859(06)16006-0. [25]

Wuppertal Institute (2019), *Project INFRA-NEEDS - Infrastructure Needs of an EU Industrial Transformation towards Deep Decarbonisation*, https://wupperinst.org/en/p/wi/p/s/pd/818 (accessed on 15 December 2022). [6]

Note

[1] The characteristics of hydrogen lead to a higher fatigue of pipeline material. This can be countered with various measures such as adaptions in compressor stations, coatings or pipe-in-pipe solutions (Gillessen et al., 2020[31]).

Annex 3.A. Road freight carbon tax impacts on transport costs: Methods and further examples

For road transport, we use the cost specification as described by Persyn, Diaz Lanchas and Barbero Jimenez (2020[28]) to test the impact of carbon tax scenarios on road transport costs within EU regions. We assume shippers would opt to use the route with the lowest costs $R_{o,d}$, which is described by the following equation:

$$C_{o,d,road} = \min(DC_{o,d,road} + TC_{o,d,road}) + Tax_o + Vignette_{o,d,road} \quad (1)$$

In Equation (1):

- $C_{o,d,road}$ is the unit cost of the route from the location of origin o to destination d (USD/tonne).
- $DC_{o,d,road}$ are the distance-related costs for origin o, destination d, using road transport.
- $TC_{o,d,road}$ are the time-related costs for origin o, destination d.
- Tax_o are the taxes added to road freight from the location of origin o.
- $Vignette_{o,d,road}$ is the cost of vignettes between any pair of origin and destination locations.

Distance-related costs can be broken down into the following components:

$$DC_{o,d,road} = \sum_{a \in R,o,d} (fuel_a + toll_a)\, d_a + (tireCS + mainCS)\ (fuel_a\ d_a) \quad (2)$$

where $fuel_a$ are fuel costs for travelling via road connections a that make up the cheapest route $R_{o,d}$. $toll_a$ are toll costs associated with the use of toll roads in a specific country. d_a is the distance travelled on road connections. $tireCS$ is the cost of tire replacement, which is defined as a share of fuel costs. $mainCS$ are maintenance costs which represent a small fraction of total transport costs.

Time-related costs are composed of the following components:

$$TC_{o,d,road} = \sum_{a \in R,o,d} (1 + amortFinCS + insCS + indCS)\ (t_a\ lab_{od}) \quad (3)$$

The main components are the labour costs of the driver $t_a\ lab_{od}$. lab_{od} represents the hourly wage of the driver and t_a is the total travel time on a road connection. For more detailed descriptions of labour cost components, readers can refer to Persyn, Diaz Lanchas and Barbero Jimenez (2020[28]). The remaining components include amortisation and financing costs $amortFinCS$ of the vehicle, insurance $insCS$ and indirect costs $indCS$. For the sake of simplicity, they are assumed to be proportional to labour costs.

For transport between the location of origin and the destination using intermodal maritime transport, the analysis uses the costs specification described in Halim et al. (2018[29]) and builds on the road transport cost specification in Equation (1). Annex Figure 3.A.1 provides a schematisation of the components of intermodal transport costs.

$$C_{o,d,intermodal\_sea} = \min(C_{o,origin\_port,m} + C_{origin\_port,destination\_port,maritime} + C_{destination\_port,d,m}) \quad (4)$$

where:

- $C_{o,origin\_port,m}$ is the unit cost of the route from origin location o to the port of port (USD/tonne), using transport mode m.
- $C_{origin\_port,destination\_port,maritime}$ is the unit cost of the route from port of origin to the destination port (USD/tonne), using maritime transport.

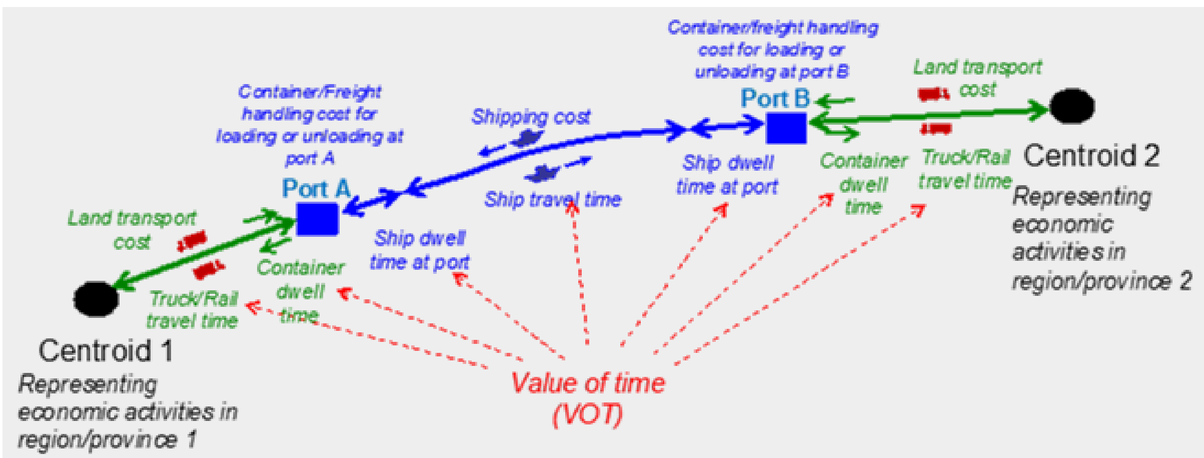
- $C_{destination\_port,d,m}$ is the unit cost of the route from the destination port to the destination location o (USD/tonne), using transport mode m.

Maritime transport costs are calculated by multiplying maritime transport costs (in USD/km) by the distance travelled (in km) between the port of origin and the port of destination:

$$C_{origin\_port,destination\_port,maritime} = \sum_{a \in R,o,d} maritime\_cost_a \, d_a \qquad (5)$$

Maritime transport costs include fuel, labour and maintenance costs, as well as the time value of goods shipped (Halim et al., 2018[29]).

Annex Figure 3.A.1. Schematisation of components of intermodal transport costs



Source: Equitable Marine Consulting.

Based on the analytical model above, the following subsequent computation steps are performed to estimate the total transport costs:

- Computation of travel time and travel distance between ports and hinterland destinations using a multimodal transport network model. The model will take into account available transport modes and predict shippers' choice of modes based on distance and time under the baseline scenario. For instance, if rail transport offers the shortest distance and time, the model will predict that a majority of goods will be shipped using rail instead of road.
- Computation of average unit transport costs per kilometre (USD/tonne-kilometre or USD/tkm) for road transport by dividing the average unit transport costs (USD/tonne) computed using Equation (1) with the average distance travelled by heavy duty vehicle (HDV) within a given country.
- Distance-related costs are computed by multiplying hinterland distance (km) with the unit cost of transport (USD/tkm) for each mode of transport that might be used to transport goods, such as rail or road (USD/km).
- Port handling costs are estimated by taking into account the observed port throughput and socio-economic variables of the port country.
- Transport costs are computed by summing up the hinterland and maritime transport costs in USD/tonne using Equation (4).
- The impact of carbon tax is calculated by computing the average increase in unit transport costs given a 50% increase in fuel price (low scenario) and a 100% increase in the high scenario.

This method has been used in various transport modelling literature such as in Tavasszy et al. (2011[30]) and Halim et al. (2018[29]).

Data used for transport costs calculation:

- Data for unit road transport costs (USD/tonne) between European regions at NUTS 2 level are obtained from the interregional transport costs dataset (Persyn, Diaz Lanchas and Barbero Jimenez, 2020[28]). The data used for computing costs are derived from empirical observations for HDVs compliant with Euro VI standards that transport goods across all commodity sectors in the EU. To date, data for road transport at the regional level for specific commodities are still scarce. A 50% and 100% increase in fuel price result in an 18% (low tax scenario) to 42% (high tax scenario) increase in total transport costs in different EU regions. The variation in the increase in transport costs is largely due to the different weights of fuel costs. Countries with higher labour costs such as Germany and the Netherlands tend to see a lower increase in total transport costs.
- Unit transport costs and the time value for goods for maritime transport have been obtained from the Equitable Maritime Consulting EMC) database. Transport cost data are estimated based on trade data obtained from the United Nations Comtrade database and United Nations Conference on Trade and Development (UNCTAD) global transport cost data.

Annex Table 3.A.1. Impact of carbon tax on fuel price and total road transport costs for selected countries in the EU

Region	Transport costs, baseline scenario (USD/tonne)	Increase in costs, low tax scenario (%)	Increase in costs, high tax scenario (%)	Average distance travelled (km)	Unit costs (USD/tkm), baseline scenario	Unit costs (USD/tkm) low tax scenario	Unit costs (USD/tkm) high tax scenario
Finland	28	21	42	298.00	0.0940	0.1137	0.1614
Germany	46	18	35	373.00	0.1233	0.1455	0.1965
Netherlands	21	18	35	181.00	0.1160	0.1369	0.1848
Poland	24	20	40	271.00	0.0886	0.1063	0.1488
Portugal	36	20	39	315.00	0.1143	0.1371	0.1906

Annex Table 3.A.2. Unit maritime transport costs for selected routes illustrated in the case study

Origin country	Destination country	Sector	Transport costs (USD/tonne)
Poland	United States	Petroleum chemical and non-metallic mineral products	17.34
Finland	United States	Wood and paper	13.79
Finland	Germany	Wood and paper	14.40
Portugal	Netherlands	Petroleum chemical and non-metallic mineral products	15.22
Portugal	Cameroon	Petroleum chemical and non-metallic mineral products	9.35

Furthermore, for the sake of simplicity and clarity, we adopt the following assumptions in carrying out our analysis:

- We apply a constant price for extra-EU components of transport costs and other modes of transport, notably maritime transport. We assume that transport costs for these other modes always follow the baseline costs assumption. Depending on the outcome of the International Maritime Organization (IMO) negotiation regarding market-based measures for emission reduction, non-EU costs of maritime transport might however increase due to the application of a carbon tax.

4 Regional industrial transitions to climate neutrality: Identifying potential socio-economic vulnerabilities

This chapter assesses the socio-economic characteristics of the regions most vulnerable to the transformations needed for the transition of key manufacturing sectors to climate neutrality. The chapter considers regional, worker and firm characteristics. These point to the specific vulnerabilities of each region and lay the basis for regional policy action for a just transition. The most vulnerable regions tend to underperform on key regional socio-economic indicators, including gross domestic product (GDP) per capita, wages and net migration. Workers employed in the key manufacturing sectors in the most vulnerable regions often have low educational attainment, work in low-skilled occupations and tend to have temporary contracts. Some firms in these regions underperform on productivity, reinforcing challenges to incorporate new technologies and finance needed investment.

Regions with high emissions per capita and high employment shares in at least one of the key manufacturing sectors are particularly vulnerable in the transition to climate neutrality in manufacturing by 2050. The key manufacturing sectors were identified in Chapter 1 and are the manufacturing sectors that will have to undergo particularly large transformations in the transition to climate neutrality. The sectors are oil refining, chemicals, steel and aluminium, cement, paper and pulp, and vehicles. The vulnerable regions were identified in Chapter 2. In the following analysis, these will be referred to as “most vulnerable regions”. The transformations key industries need to undertake will have implications for infrastructure to provide access to energy, raw materials and transport under climate-neutral conditions. These were analysed in Chapter 3.

Among the most vulnerable regions, some will in addition be particularly vulnerable to socio-economic impacts, notably with respect to job loss and job transformations. This chapter, therefore, assesses the socio-economic characteristics of the regions themselves as well as the characteristics of workers and firms in the key sectors.

The first section of this chapter discusses socio-economic characteristics of the most vulnerable regions. Using various indicators, vulnerabilities are identified. Regions underperforming on socio-economic characteristics, compared to the national and EU averages, potentially need policy attention to ensure a just transition. The section identifies whether the socio-economic characteristics of regions make them more vulnerable to the transformations to climate neutrality.

The second section takes a closer look at the characteristics of workers employed in the key manufacturing sectors in the most vulnerable regions. It identifies individual characteristics which may make workers particularly vulnerable to changes in skill needs, risks of job loss and other forms of employment restructuring the sectoral transformations may bring. This section identifies vulnerable workers who may need support to ensure a just transition.

The third section considers the productivity performance of firms in the most affected regions. As shown in the first chapter, integrating new zero-emission technologies is important for moving key manufacturing sectors to climate neutrality by 2050. The most productive firms are likely to be best able to integrate these new technologies. Regions with more productive firms in key manufacturing sectors may therefore face fewer challenges and may be better placed to grasp opportunities in the transition to climate neutrality.

Socio-economic characteristics of the most vulnerable regions

This section discusses the socio-economic indicators that point to further vulnerabilities to impacts of the transition to climate neutrality in regions already identified as vulnerable. It considers the following indicators to assess potential socio-economic impacts and vulnerabilities:

- Regions with lower **GDP per capita** will have fewer resources, in the public and private sectors, to provide services, infrastructure and other forms of support to firms and individuals involved in the transformations. They may also be less able to offer attractive alternatives for economic activity or employment.
- Similar to GDP per capita, the **regional wage** indicates workers’ resources available to absorb economic shocks and take advantage of opportunities during the transition.
- A higher relative **poverty risk** increases the vulnerability of regions, as a greater number of already vulnerable people will be affected by the transformations.
- Lower **unemployment** in each region indicates a larger number of alternative job opportunities. Increases in unemployment and poverty would most likely result in lower demand for services in a region.

- High **educational attainment** may reflect the skillsets of workers and their ability to adapt to transitional changes. Regions with lower levels of education may find it more difficult to smoothly transition their workers to the new employment opportunities that may arise from the transition.
- Regions with faster **Internet download speed** may have a better-developed capacity to take advantage of economic opportunities resulting from digitalisation. As discussed in the first chapter, circular economy practices require good data connectivity, for example to take advantage of asset-sharing business models. Moreover, Internet connectivity can offer opportunities for the diversification of economic activity. Hence, technical proficiency would likely help regions to mitigate negative effects during the transition to climate neutrality.
- **Net migration** reflects the attractiveness of a region and its ability to attract workers and retain its inhabitants. A positive net migration increases the flow of ideas and skills into a region, increasing the ability to capture the opportunities created by the transition. Net outmigration often leaves regions with an ageing population who may have more difficulty in facing challenges and seizing opportunities. Net outmigration may also increase per capita costs in providing infrastructure services, including the infrastructure needed for climate neutrality. Outmigration can however also help workers adapt by moving towards regions with transition opportunities.
- The difference between the average **wage in the key manufacturing sectors** and the average regional wage illustrates the contribution of key sector jobs to regional wealth. This is the only sector-specific regional indicator. Regions, where these wage differences are large, may be more vulnerable to any local job losses or restructuring of employment in key manufacturing sectors, especially if regional employment in these key manufacturing sectors is large. Regional employment shares in key manufacturing sectors were identified in the second chapter.

The most vulnerable regions underperform in most socio-economic indicators

In the majority of regions most vulnerable to the transformations of the key manufacturing sectors for climate neutrality, regional GDP per capita is below the national average (Table 4.1) and, in some, below the European Union (EU) average (Fuentes Hutfilter et al., 2023[1]). Capital city regions are typically among the exceptions, as they often host headquarter activities in which workers may be less vulnerable. Some of the most vulnerable regions with lower GDP per capita account for a large part of the national population, notably in Eastern Slovakia and Eastern and Northern Finland. While GDP per capita is above the EU average across more than half of vulnerable regions, just transition challenges remain. Many of these regions are in richer countries with stronger industrial activity and they often compare less favourably with other regions in the same country. The most vulnerable regions are particularly vulnerable in EU comparison and may require the most policy attention.

Moreover, the average wage in over two-thirds of the most vulnerable regions is below the national average (Table 4.1) and some are also below the EU average (Fuentes Hutfilter et al., 2023[1]). For example, the most vulnerable regions in the Czech Republic, Greece and Poland often have between 10% to 30% lower wages compared to the national average.

Many of the most vulnerable regions with lower GDP per capita and wages are also exposed to higher relative poverty risk. More than half of the most vulnerable regions face higher poverty risk than their national average.

Table 4.1. Socio-economic indicators in the most vulnerable regions

Relative difference between the regional and national indicator values, percentage of the national average,[1] large (NUTS 2) regions

Region		GDP per Capita	Wage	Poverty Risk	Unemployment Rate	Educational Attainment	Download Speed	Net Migration
AT22	Styria	-8.93	-5.84	0.57	-28.89	2.10	-20.42	0.35
AT31	Upper Austria	2.68	1.32	-33.71	-35.56	0.93	-14.96	0.47
BE21	Antwerp	19.08	5.25	..	-33.33	0.51	18.34	0.46
BE32	Hainaut	-37.20	-12.56	..	59.26	-8.26	-24.06	0.30
BE34	Luxembourg (BE)	-38.41	-19.17	..	0.00	1.78	-46.08	0.52
CZ02	Central Bohemian Region	-10.00	-10.02	-23.20	-35.00	1.60	-16.99	1.13
CZ05	Northeast	-18.57	-9.72	3.20	-15.00	0.00	-27.85	0.22
CZ08	Moravia-Silesia	-20.00	-8.50	19.20	85.00	-1.39	-12.40	-0.11
CZ04	Northwest	-30.48	-19.66	72.00	50.00	-7.57	3.89	0.08
DE11	Stuttgart	30.12	20.30	-23.56	-22.58	-1.04	9.12	0.38
DE91	Braunschweig	20.96	10.31	4.02	6.45	-0.58	-5.12	0.41
DEA1	Düsseldorf	2.41	5.01	17.82	22.58	-5.77	19.51	0.32
DEA3	Münster	-17.83	-8.80	5.75	9.68	-2.66	16.25	0.26
DE22	Niederbayern	-4.10	-8.41	11.76	-35.48	2.31	-17.52	0.88
DEB3	Rheinhessen-Pfalz	-9.16	-1.20	-5.17	6.45	-3.70	4.16	0.53
DEC0	Saarland	-11.33	-5.83	24.14	19.35	-2.89	-0.35	0.21
DEE0	Sachsen-Anhalt	-30.36	-16.91	6.90	48.39	5.77	-31.97	0.06
DK05	Northern Jutland	-16.36	-8.67	8.59	16.00	-4.41	-6.07	0.17
EL65	Peloponnese	-15.79	-20.75	21.33	-30.64	-8.20	-22.35	0.16
ES12	Asturias	-11.74	-3.48	-2.77	0.71	9.14	-15.32	0.20
FI1B	Helsinki-Uusimaa	29.59	13.18	-35.26	-4.48	-0.55	6.56	0.69
FI1C	Southern Finland	-10.78	-7.11	4.49	-5.97	-0.78	-5.40	0.02
FI19	Western Finland	-11.93	-5.85	..	-4.48	0.55	-12.73	0.16
FI1D	Eastern and Northern Finland	-16.97	-8.69	21.79	16.42	0.89	7.74	-0.19
HU22	Western Transdanubia	-2.68	-3.30	-13.76	-47.06	2.35	-16.19	0.80
HU21	Central Transdanubia	-7.38	0.42	-28.57	-41.18	-1.06	-6.90	0.71
HU31	Northern Hungary	-32.89	-2.28	26.46	32.35	-6.94	-7.45	-0.31
ITH4	Friuli-Venezia Giulia	7.74	6.86	-46.09	-39.00	12.70	-23.41	0.52
ITI2	Umbria	-11.11	-12.60	-48.05	-15.00	14.63	-11.87	0.19
NL33	South Holland	-1.93	5.26	17.58	20.59	-0.75	2.09	0.55
NL34	Zeeland	-19.49	-14.71	-13.33	-23.53	-4.40	-9.10	0.36
PL22	Silesia	2.16	12.49	-24.18	-27.27	2.70	8.26	-0.05
PL52	Opole region	-21.58	-12.19	-6.59	-3.03	1.08	-25.86	-0.07
PL72	Swietokrzyskie	-28.78	-27.62	13.74	27.27	-0.54	-24.75	-0.15
RO42	West	1.74	17.48	-29.81	-12.82	6.33	3.31	-0.06
SE33	Upper Norrland	-3.25	-5.04	-11.70	-10.29	5.46	-24.66	0.23
SE32	Central Norrland	-14.50	-9.14	25.53	-1.47	1.63	-23.11	0.07
SK01	Bratislava Region	130.81	48.53	-51.83	-58.62	5.03	53.63	0.99
SK04	East Slovakia	-29.07	-15.22	29.27	56.90	-3.94	-0.26	-0.12
UKD6	Cheshire	20.37	29.71	..	-13.16	2.96	-29.33	0.42
UKE1	East Yorkshire and Northern Lincolnshire	-21.45	-20.25	..	23.68	-9.12	-29.50	0.23

Note: The wage is the total remuneration paid including employer-paid social security contributions. Educational attainment is the share of the population with an upper secondary degree or more. Poverty risk is the share of the population at risk of poverty, severely materially deprived or that live in households with extremely low work intensity. Data for this indicator is not available for some regions of interest, this is represented by '..'. Download speed refers to how quickly data can be pulled from the server on the Internet to the device. Net migration is the population change not attributable to births and deaths.

1. All indicators are compared to the national average except for net migration. Net migration is the regional net immigration rate, as a percentage of the regional population. Red-coloured cells contain values below the national average, except for net migration. Red-coloured cells for net migration contain values below 0.2%. Most of these regions have net immigration rates below the respective national average and so appear little attractive.

Source: Own calculations using Eurostat and (Ookla, 2020[2]).

Unemployment rates are below the national rate in many of the most vulnerable regions. This may in part be because activity in the key manufacturing sectors provides job opportunities in these regions. For example, all vulnerable regions with high employment in vehicle manufacturing have lower unemployment rates than the national rate. Even so, unemployment rates are high in all the vulnerable regions of Finland, Greece, Italy, Spain and Sweden (Figure 4.1).

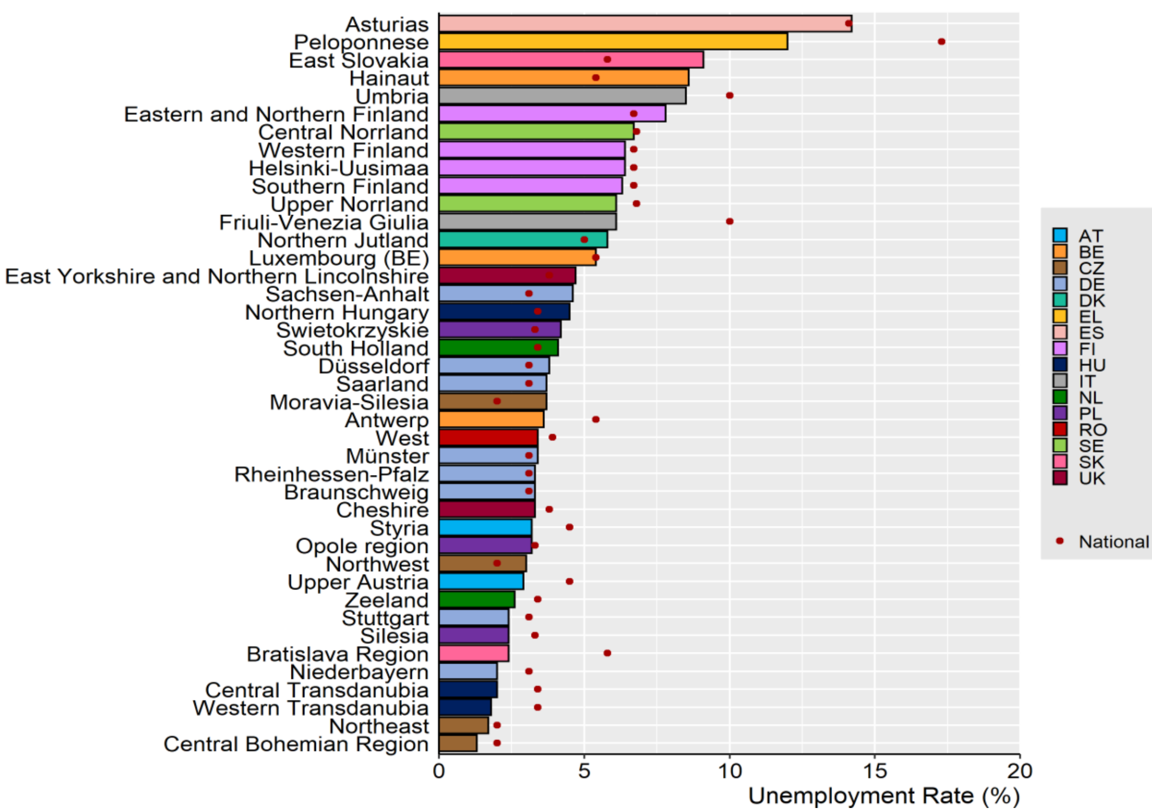
About half of the most vulnerable regions have a larger share of the population with at least an upper secondary degree (equivalent to a high school diploma or an upper secondary vocational qualification) than the national average and most have a bigger share than the EU (Fuentes Hutfilter et al., 2023[1]). However, in many of the most vulnerable regions where wages in key sector jobs are high, educational attainment in the region is relatively low. The low educational attainment level in these regions may weaken the capacity of regional economies and their workers to respond to any restructuring in the key manufacturing sectors.

Even though the most vulnerable regions tend to have high broadband access rates, the fixed Internet download speeds, measured in megabits per second (Mbps), are lower than the national averages. Only in a third of the most vulnerable regions is download speed above the national averages. Additionally, download speeds in all vulnerable regions in Austria, the Czech Republic, Italy and the United Kingdom (UK) are below 60 Mbps, i.e. particularly low (Figure 4.2).

Some of the most vulnerable regions appear to be little attractive overall. Indeed, several regions appear vulnerable on most of the indicators discussed (Box 4.1). Most of these also experience net outmigration or at least net immigration rates well below the national level, and so may be particularly unattractive to young workers (Figure 4.3).

Figure 4.1. Unemployment rate

Regional and national unemployment rate, large (NUTS 2) regions, 2019

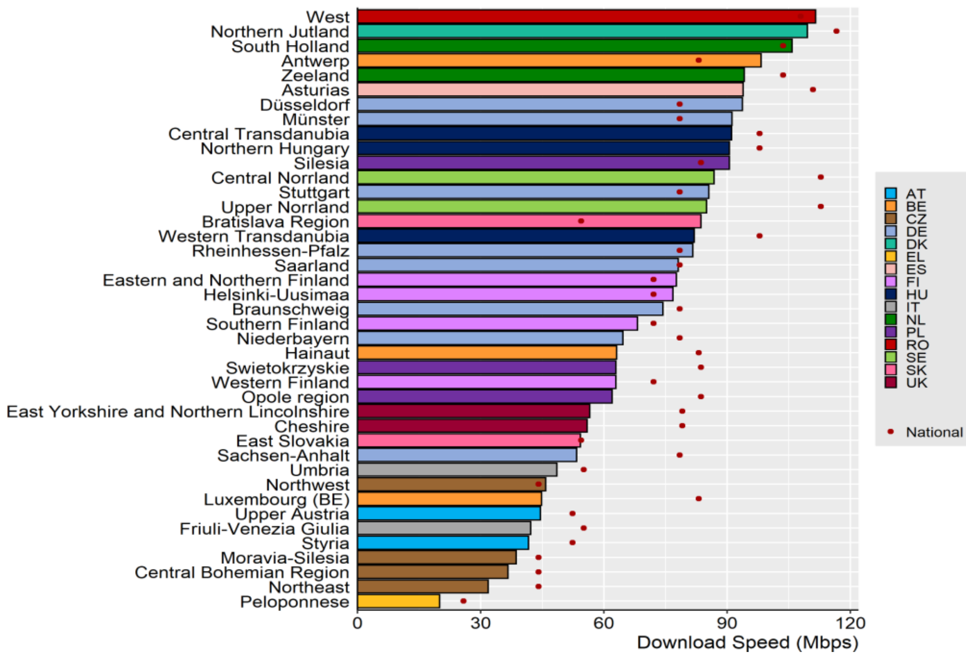


Source: Eurostat

StatLink https://stat.link/m56pvl

Figure 4.2. Fixed Internet download speed

Regional and national fixed broadband internet download speed, large (NUTS 2) regions, 2020

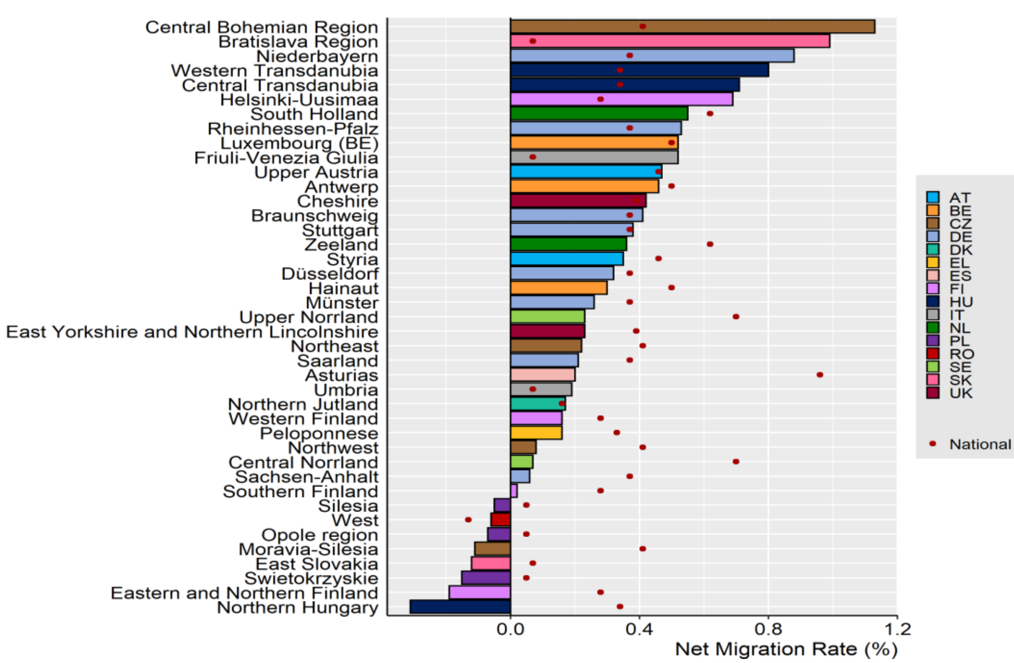


Note: Fixed internet download speed refers to how quickly data can be pulled from the server on the internet to the device using a non-cellular connection type (WiFi, ethernet).
Source: (Ookla, 2020[2])

StatLink https://stat.link/0f63kp

Figure 4.3. Net migration rate

Regional and national net migration rate, large (NUTS 2) regions, 2018



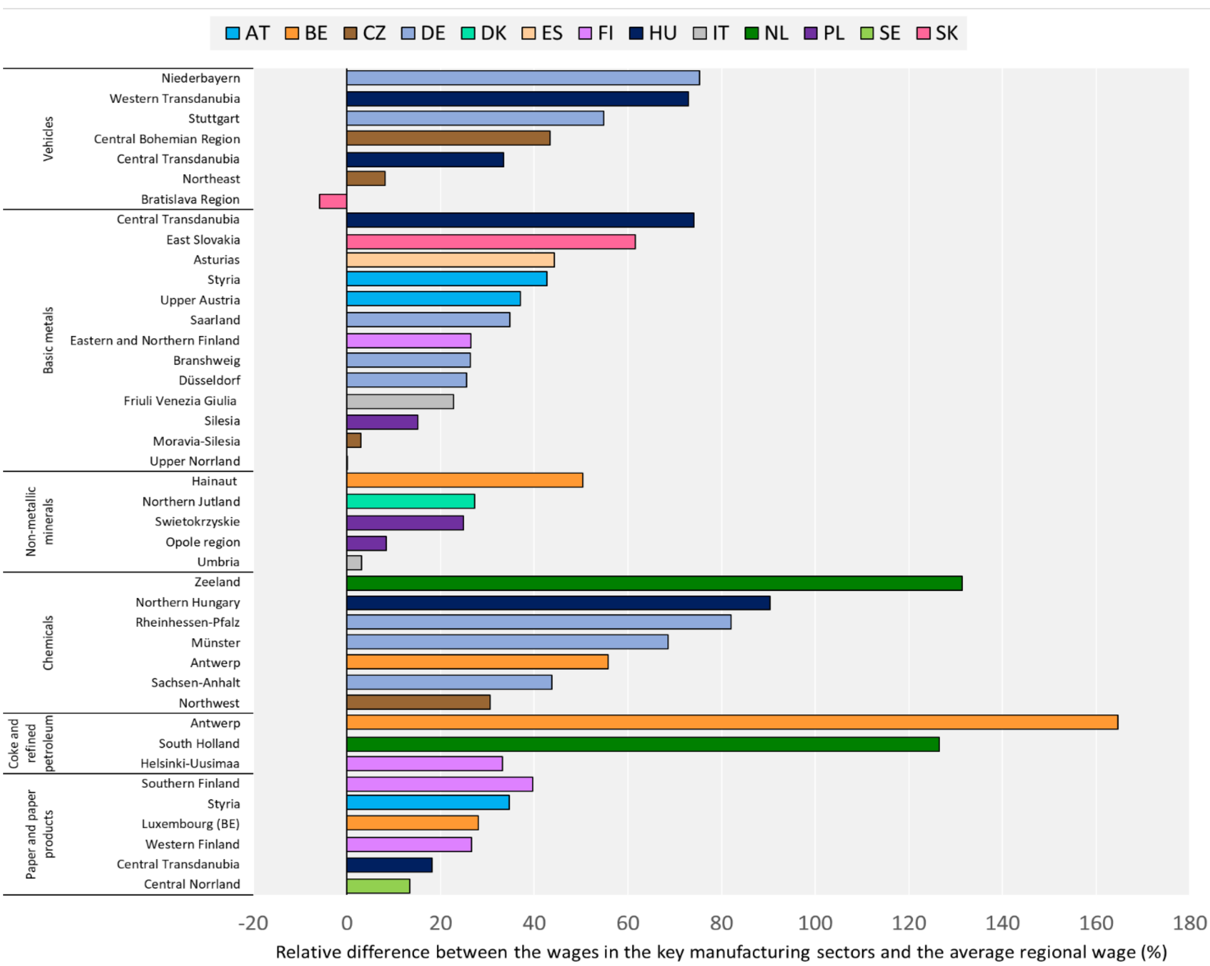
Source: Eurostat

StatLink https://stat.link/wl72rf

Wages in the key manufacturing sectors tend to be higher than the respective regional wage (Figure 4.4). In most vulnerable regions the average wage in key manufacturing sectors is more than 20% higher. In the manufacture of coke and refined petroleum products, the average sectoral wage is even more than double the regional average wage. For instance, in Hungary's most vulnerable regions, it can be 30% to 80% higher. Loss of such well-paid jobs would likely have regional development implications, especially if these regions are socio-economically weak. If workers lose these jobs, they may, in the absence of policy measures such as retraining, not be able to find alternative equally well-paid jobs. This could contribute to opposition to the transition to climate neutrality.

Figure 4.4. Sectoral wages tend to be much higher than regional wages

Relative difference between regional wages in each of the key manufacturing sectors and the average regional wage, in large (NUTS 2) regions, 2018



Note: The key manufacturing sectors identified in the first chapter are: paper and paper products (17), coke and refined petroleum products (19), chemicals and chemical products (20), other non-metallic mineral products (23), basic metals (24), and motor vehicles, trailers and semi-trailers (29). The regions of the Peloponnese in Greece, West in Romania and Cheshire and East Yorkshire and Northern Lincolnshire in the UK are not shown as there are no sectoral wage data in their respective sectors.
Source: Authors' calculations using Eurostat.

StatLink https://stat.link/m48kqn

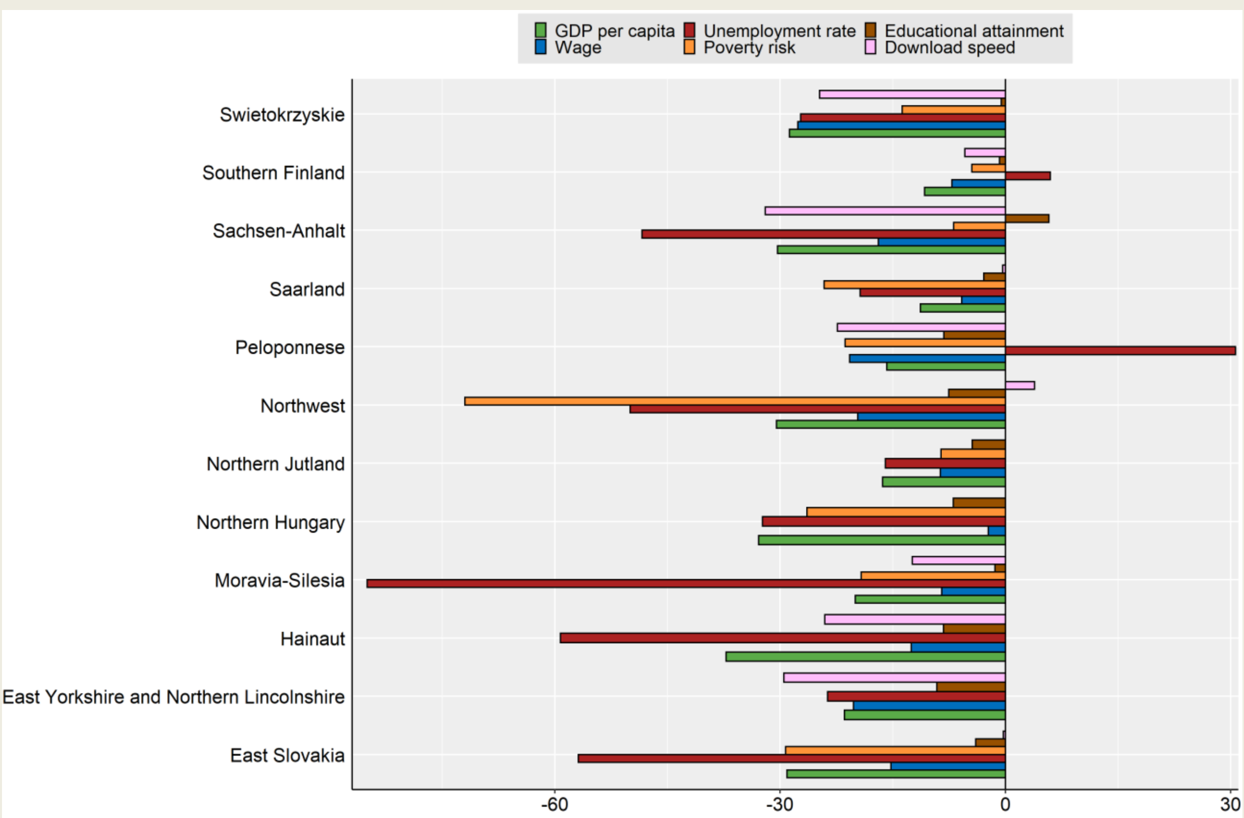
In the majority of the most vulnerable regions where GDP per capita is below the national average, wages in the key manufacturing sectors are above regional average wages, as described above. In these regions, the regional development implications of job losses would be particularly stark, as such job losses would further dampen GDP.

Box 4.1. Some regions are vulnerable on account of most socio-economic indicators

Ten of the most vulnerable regions stand out for underperforming in at least six of the seven indicators considered in Table 4.1. In these regions, lower GDP per capita overlaps with higher poverty risk, higher unemployment and lower average wage and significantly lower migration rates compared to national averages. Moravia-Silesia in the Czech Republic, Swietokryskie in Poland and Eastern Slovakia in the Slovak Republic underperform in every indicator for which data are available. Hainaut in Belgium, Southern Finland, Saarland and Sachsen-Anhalt in Germany, the Peloponnese in Greece and East Yorkshire and Northern Lincolnshire in the UK underperform in every indicator but have positive migration rates (Figure 4.5).

Figure 4.5. Magnitude of indicator performance in underperforming regions

Magnitude of performance of the socio-economic indicators in comparison to the national average, large (NUTS 2) regions



Note: Indicators in which regions perform worse than the national average are portrayed as negative. Indicators in which regions perform better than the national average are portrayed as positive.
Source: Own calculations using Eurostat and (Ookla, 2020[2]).

The magnitude of underperformance in these indicators is also particularly large in the regions which appear vulnerable on multiple indicators. With respect to unemployment and poverty risk, the regions are always in the top ten underperformers relative to national averages. The underperforming regions also have particularly low GDP per capita and wages.

These regions are mostly affected by transformations in basic metals and non-metallic minerals manufacturing, as shown in the second chapter of this series. In addition, Eastern Slovakia, Moravia-Silesia, Northwest and Saarland have significant employment in vehicle manufacturing, a sector that may experience significant employment loss. The big performance gaps between the key transition regions and their countries decrease the ability of the regions to mitigate the challenges and capture the opportunities of the transition.

Socio-economic characteristics of workers in the most vulnerable regions

This section assesses the socio-economic characteristics of workers who are employed in vulnerable regions and key manufacturing sectors. The following individual worker characteristics chosen for analyses reflect the needs of workers in key manufacturing sectors in coping with transformations:

- **Low earnings** limit the private resources of workers to deal with transformations, such as training or finding a new job, especially relocating is required.
- **Gender** differences exist in adapting to transformation. Women may face greater transformation challenges, as they receive on average 17% fewer hours of employer-sponsored training and earnings are often lower (Bassanini and Ok, 2004[3]).
- The **level of education** and **skill requirements of workers' occupations** reflect the ability of workers to acquire transferable skills in the transition. Workers with little education and in jobs with limited skill requirements will face greater challenges adapting to the transformations required.
- **Participation rates in job-related training** are low for individuals with low educational attainment and skills. More educated workers are more than three times as likely to participate in training compared to less educated workers (Cedefop, 2015[4]), while higher-skilled occupations are more than twice as likely to participate in training compared to lower-skilled occupations.
- Workers in **temporary employment contracts** face a larger risk of job loss without compensation and have limited access to employer-sponsored training programmes.
- **Young employees** are more likely to be in temporary employment, which tends to pay less, offer fewer unemployment benefits and reduce access to training compared to permanent jobs (OECD, 2002[5]). These young workers, however, will need to adapt to post-transformation societies and changing employment landscapes by acquiring new skills and education. **Older workers** are less flexible and more likely to become unemployed for prolonged periods and retire early as societies transform. This reinforces poverty risks for poorly paid older workers that do not enjoy adequate pension and unemployment benefits.
- **Collective wage bargaining and trade unions** benefit workers by aiming to improve employment conditions, provide job security and ensure access to long-life training (OECD, 2017[6]). Workers' access to collective representation may reduce workers' vulnerabilities during the transition.

The analyses are conducted using the EU Structure of Earnings Survey (Box 4.2). Due to data limitations, the analyses of worker characteristics are conducted at the NUTS 1 level. NUTS 1 regions are identified according to Table 4.1, where a NUTS 1 region is considered vulnerable if it contains at least one vulnerable NUTS 2 region.

Box 4.2. The Structure of Earnings Survey

The Structure of Earnings Survey (SES) is a large sample survey of enterprises on the characteristics of employees and their employers. It has been conducted in its current form every four years since 2002. The analysis uses the 2018 vintage, which includes data for 25 countries within the EU as well as EU candidate countries and European Free Trade Association (EFTA) countries. The SES provides regional breakdowns at the NUTS 1 level and industry breakdowns at the two-digit Nomenclature of Economic Activities (NACE) level.

The SES collects data for workers employed in enterprises with at least ten employees, in all areas of economic activity excluding public administration. The employees included in the sample are those who *actually received* remuneration during the reference month of October, thus excluding non-remunerated employees such as family or unpaid voluntary workers.

The sampling procedure for the SES usually contains two stages, where in the first stage a random sample of local units of enterprises (the primary sampling unit) is drawn using stratification criteria including the NACE industry and NUTS 1 region. The second stage consists of a simple random sample of employees within each selected local unit, where stratification may or may not be carried out.

The analyses that follow account for the two-stage sampling structure of the data as well as stratification. It is assumed that the first stage is stratified by NUTS 1 region and two-digit NACE industry. No stratification is assumed for the second stage. Thus, the estimated standard errors and confidence intervals may be overestimated and the statistical significance of results underestimated. The analysis produces point estimates for the population using grossing-up factors. These are sample weights, which correspond to how many employees in the population each sample observation represents.

Source: EC (2018[7]), Structure of Earnings Survey 2018: Eurostat’s arrangements for implementing the Council Regulation 530/1999, the Commission Regulations 1916/2000 and 1738/2005, (accessed on 29 November 2021).

Worker vulnerability in the most vulnerable regions in the manufacture of non-metallic mineral products is high

The NUTS 2 regions of Hainaut in Belgium, Northern Jutland in Denmark, Umbria in Italy and the Opole region and Swietokrzyskie in Poland are vulnerable in the manufacture of non-metallic minerals. Figure 4.6 depicts these NUTS 2 regions as well as the NUTS 1 regions that contain these NUTS 2 regions.

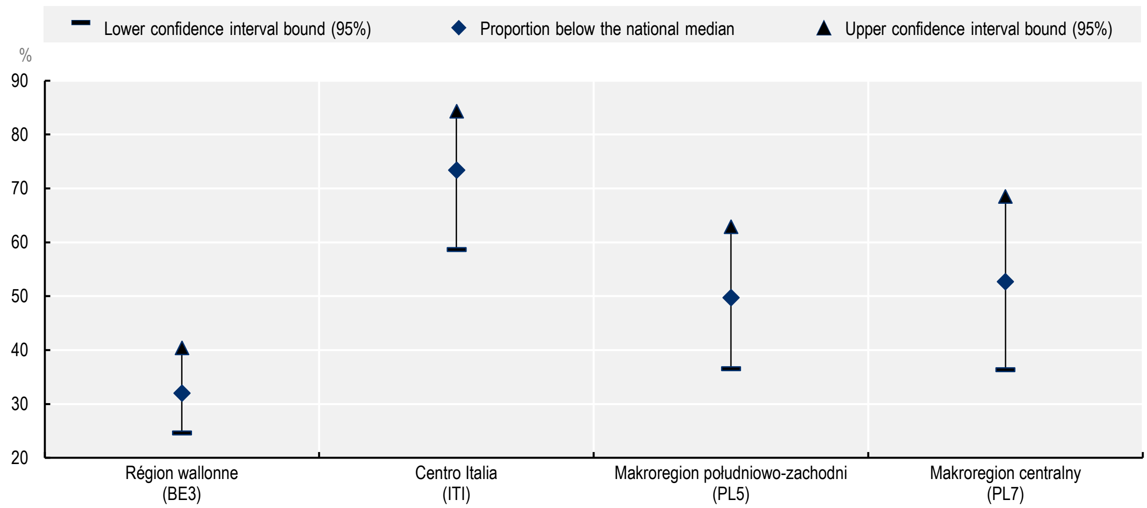
Figure 4.6. Regions with high employment and high emissions in non-metallic mineral production (NACE 23)

The share of low-earning workers differs substantially across regions (Figure 4.7). Workers in Wallonia are generally better paid than workers across all economic sectors in Belgium, with only 32% of workers employed in the sector in this region earning less than the median Belgian worker. The opposite is true for Central Italy, where 73% of workers earn below the national median. Wages are on par with the national level for the Polish regions of interest.

Low educational attainment and low skills increase low earnings vulnerability substantially (Fuentes Hutfilter et al., 2023[1]), except in Wallonia, where lower-skilled and lower-educated workers still earn more than the national median. In Central Italy, almost all workers with basic education or in low-skill occupations earn less than the national median. Similar patterns arise in the Polish regions.

Figure 4.7. Share of low-earning workers employed in non-metallic mineral production (NACE 23)

Share of workers employed in NACE 23 earning less than the national median of gross hourly earnings across all economic activities, 2018



Notes: National medians calculated using the SES sample data.
Source: Authors' calculations based on SES microdata.

Far more men work in the non-metallic mineral production sector than women (Figure 4.8, Panel A). While men working in this sector will generally be more affected by the transition, women are over-represented among low earners, who are less likely to receive retraining.

Workers employed in the sector tend to be less educated and lower-skilled (Panels B and C) than the median worker in the country, except in Wallonia. Fifty percent of workers in Central Italy possess only basic education and 70% are employed in low-skill occupations. The share of workers in low-skill occupations in the Polish regions is twice the share in the country. These workers also tend to earn less in the case of the Italian and Polish regions.

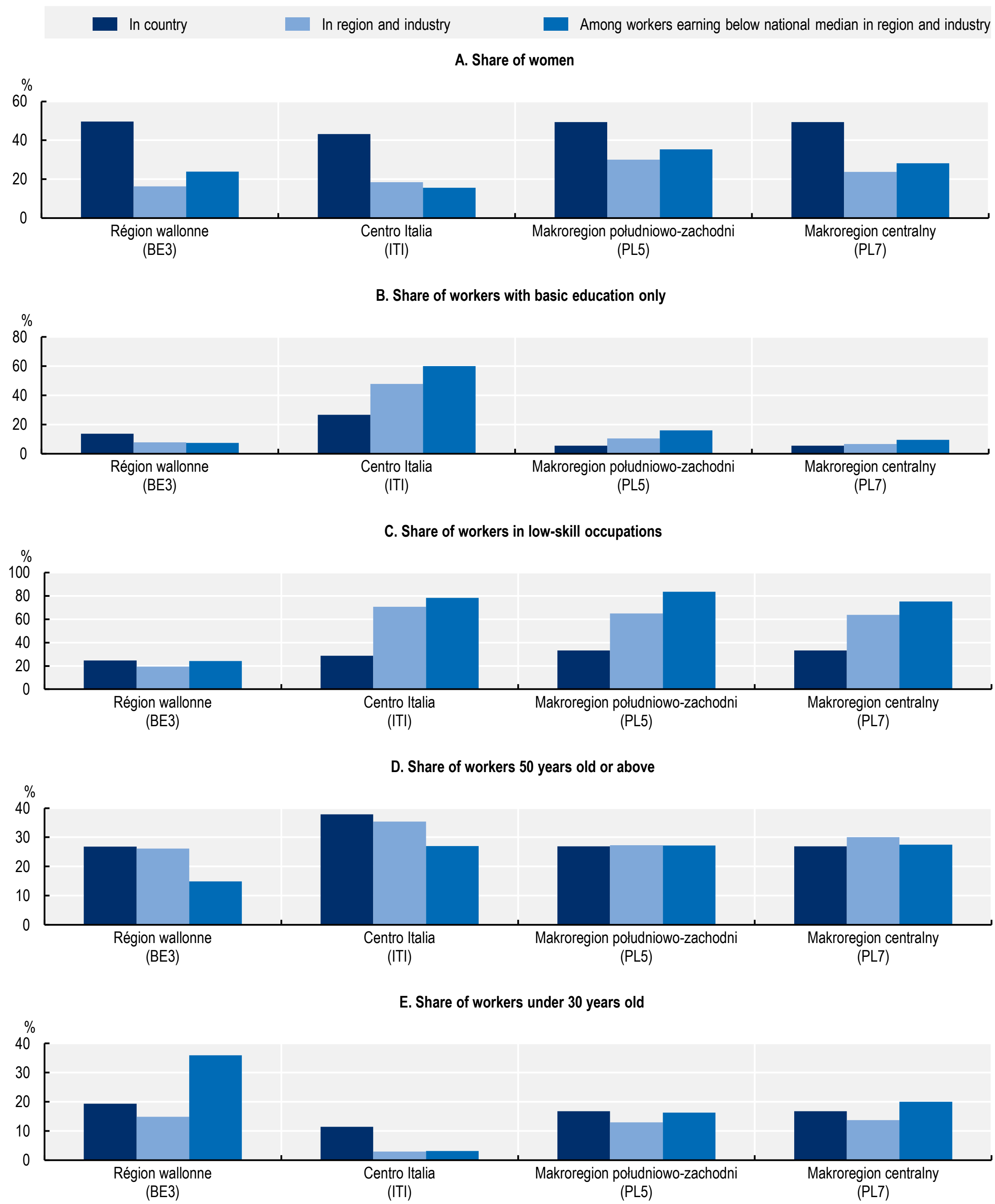
Many of these workers likely do not possess transferable skills and are less likely to acquire new skills in the changing employment environment. According to the OECD Survey of Adult Skills (PIAAC), less than one in four adults with low skills participate in professional training compared to 58% of adults with high skills. Low-educated workers are significantly less willing to develop their skills further through training than high-educated workers (Fouarge, Schils and de Grip, 2012[8]).

The share of young workers is relatively small, especially in Central Italy where only 3% of workers are under 30 (Panel E). Difficulty in attracting young workers may make it harder to achieve the profound transformations some activities in this sector require.

Older workers tend to earn more than the national median in Wallonia, while in the Polish regions, most older workers are on low earnings. Limited education and low-skill occupations reinforce poverty risks among older workers. Around two-thirds of workers in the industry with only basic education in Wallonia are more than 50 years old compared to 37% in Belgium as a whole. Similarly, older workers account for 56% of the workforce in low-skill occupations in this region, a proportion considerably higher than the national average of 31%.

Figure 4.8. Worker characteristics in non-metallic mineral production (NACE 23) in selected regions

Shares of workers with selected characteristics in the whole country, in the region and industry, and among workers earning lower than the national median in region and industry



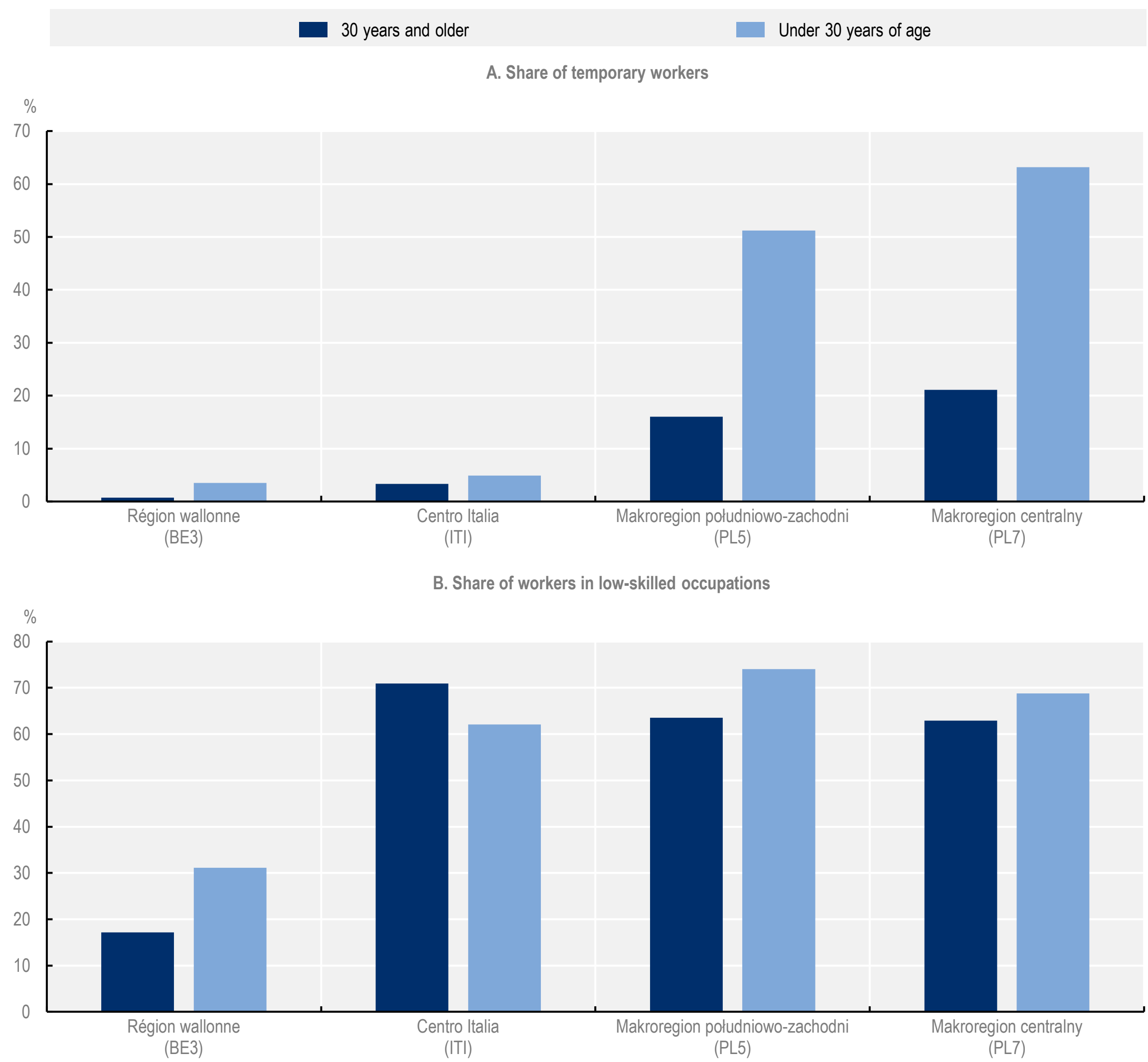
Note: Country values are calculated using the SES sample data. Basic education refers to the G1 level (below upper secondary educational attainment) according to the International Standard Classification of Education, 2011 version. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).

Source: Authors' calculations based on SES microdata.

Young workers are more likely to be in temporary work across all regions (Figure 4.9). They are also more likely to work in low-skilled occupations in all regions except Central Italy. In the Polish Southwestern Macro region, young workers are on average 3 times more likely to be in temporary employment than workers who are 30 years old and above. Furthermore, three-quarters of young workers are employed in low-skill occupations.

Figure 4.9. Vulnerability of young workers employed in non-metallic mineral production (NACE 23)

Share of temporary workers and low-skilled workers in NACE 23 across age groups, 2018



Note: Temporary refers to temporary or fixed duration contracts, except for apprenticeships, traineeships or students receiving remuneration. See notes for Figure 4.8 for the definition of low-skilled occupations.
Source: Authors' calculations based on SES microdata.

In Central Italia and Wallonia, all workers in the industry enjoy the benefits associated with collective bargaining. However, the majority of workers employed in the industry in the Polish regions are not covered by collective agreements. Moreover, hardly any collective agreements in Central and Eastern Europe provide provisions for training (OECD, 2019[9]).

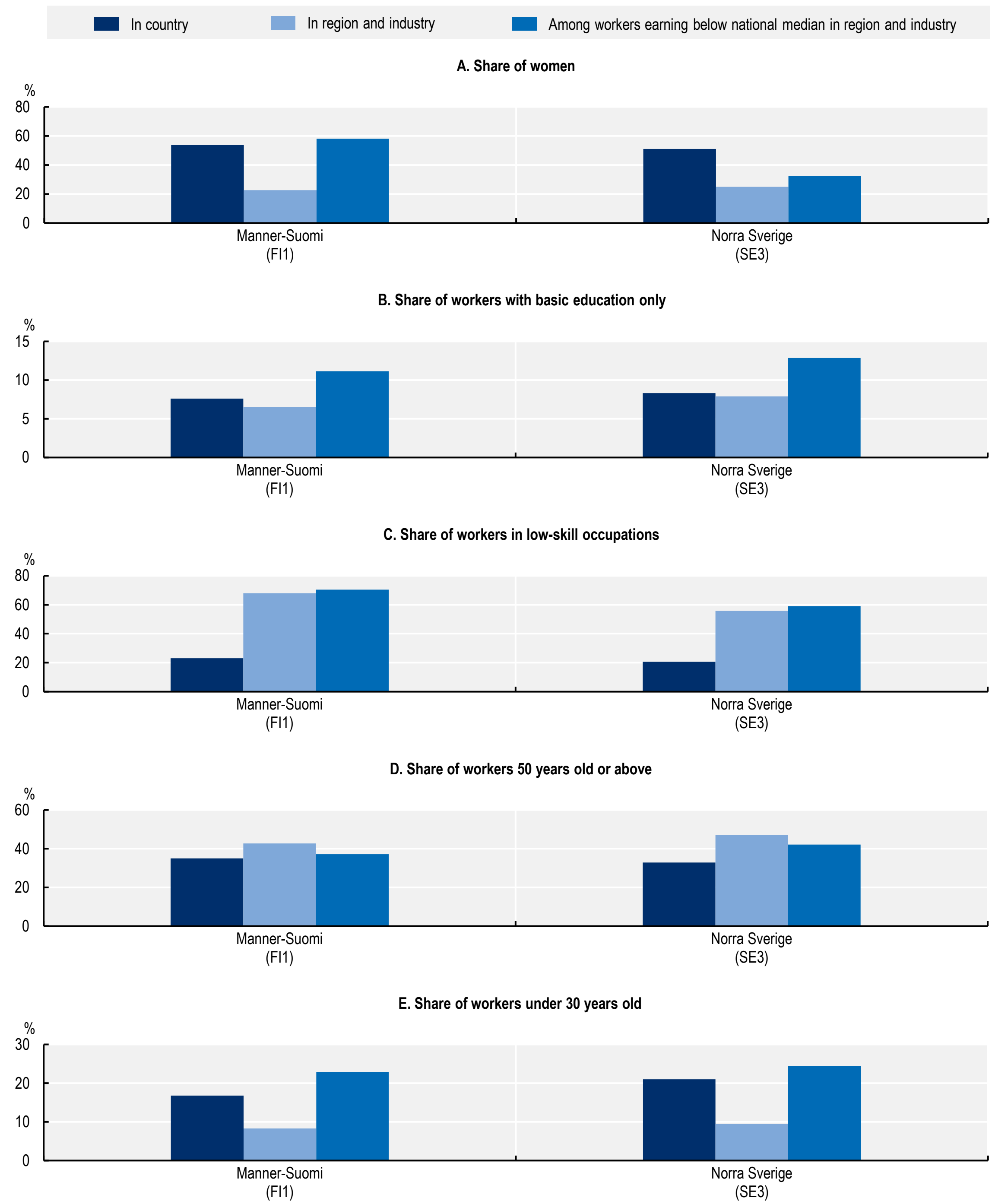
Worker vulnerability in regions vulnerable to transformations in the manufacture of paper and paper products (NACE 17)

Figure 4.10. NUTS 2 regions with high employment and high emissions in the manufacture of paper and paper products (NACE 17)

The vulnerable regions in paper and paper product manufacturing are located in Austria, Belgium, Finland and Sweden (Table 4.1). Nevertheless, due to data limitations related to insufficient observation units for Styria (Austria) and Luxembourg (BE) (Belgium), the analysis is limited to the Finnish and Swedish.

Figure 4.11. Worker characteristics in the manufacture of paper and paper products (NACE 17) in selected regions

Shares of workers with selected characteristics in the whole country, in the region and industry, and among workers earning lower than the national median in region and industry



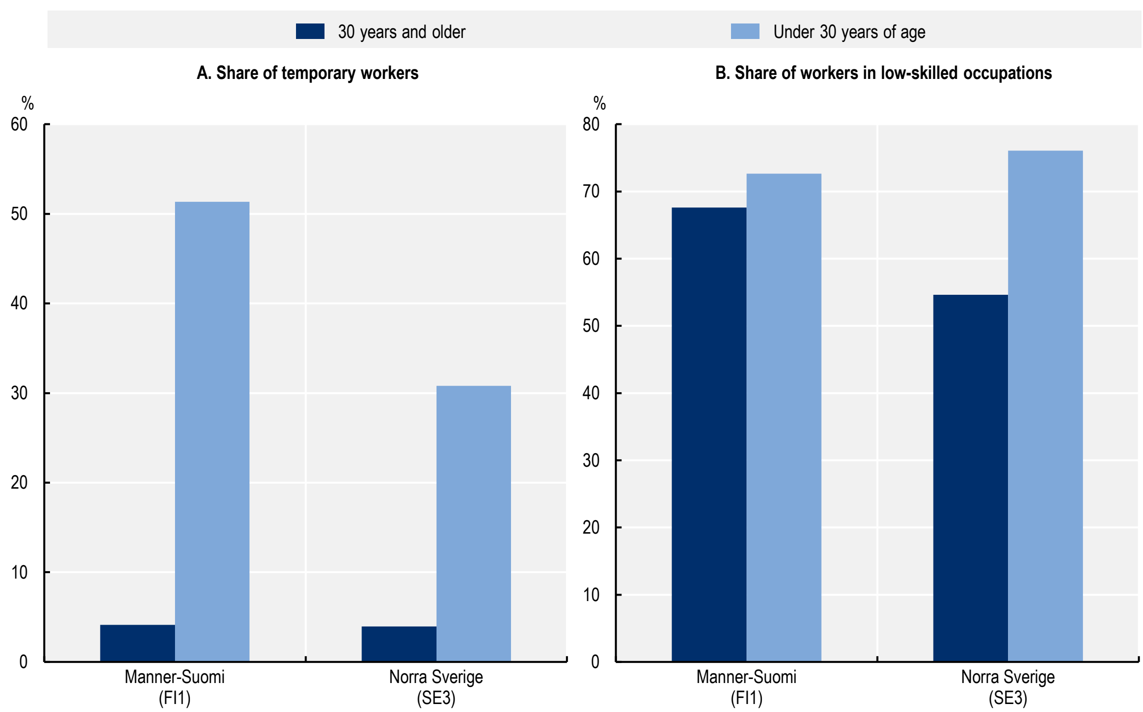
Note: Country values are calculated using the SES sample data. Basic education refers to the G1 level (below upper secondary educational attainment) according to the International Standard Classification of Education, 2011 version. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Workers employed in the industry in these regions tend to work more in low-skill occupations compared to workers across the respective country: 68% of the paper manufacturing workforce in Mainland Finland are in low-skill occupations, compared to 23% for all workers in Finland. A similar pattern, although less pronounced, emerges for North Sweden with respect to Sweden.

Young workers tend to be underrepresented in this industry, which may hamper industrywide transformation efforts. They account for less than 10% of the workforce in the most vulnerable regions, compared to 17% and 21% in Finland and Sweden as a whole respectively. Older workers may also be more vulnerable if production locations move. Such moves may occur as paper and pulp production continues to shift to recycled material inputs as biomass will become increasingly scarce, as argued in the first chapter of the series.

Figure 4.12. Vulnerability of young workers employed in the manufacture of paper and paper products (NACE 17)

Share of temporary workers and low-skilled workers in NACE 17 across age groups, 2018

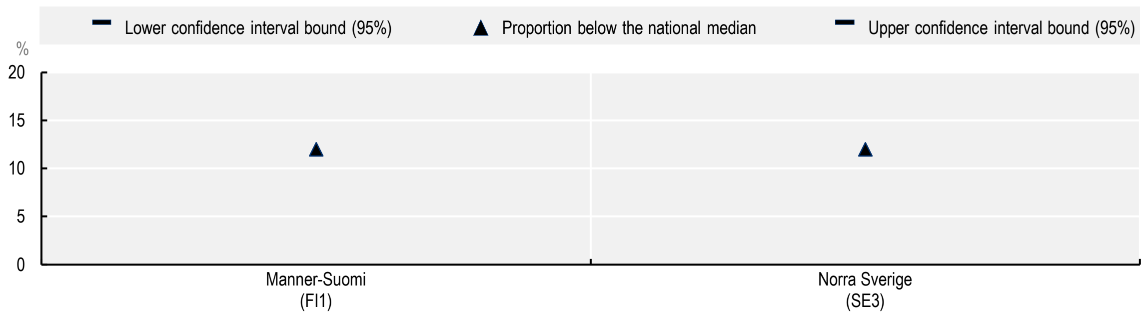


Note: Temporary refers to temporary or fixed duration contracts, except for apprenticeships, traineeships or students receiving remuneration. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Workers in the industry in the most vulnerable regions are well-paid (Figure 4.13), with 88% of workers in the industry in Mainland Finland and North Sweden earning more than the median country wage.

Figure 4.13. Share of low-earning workers employed in the manufacture of paper and paper products (NACE 17)

Share of workers employed in NACE 17 earning less than the national median of gross hourly earnings across all economic activities, 2018



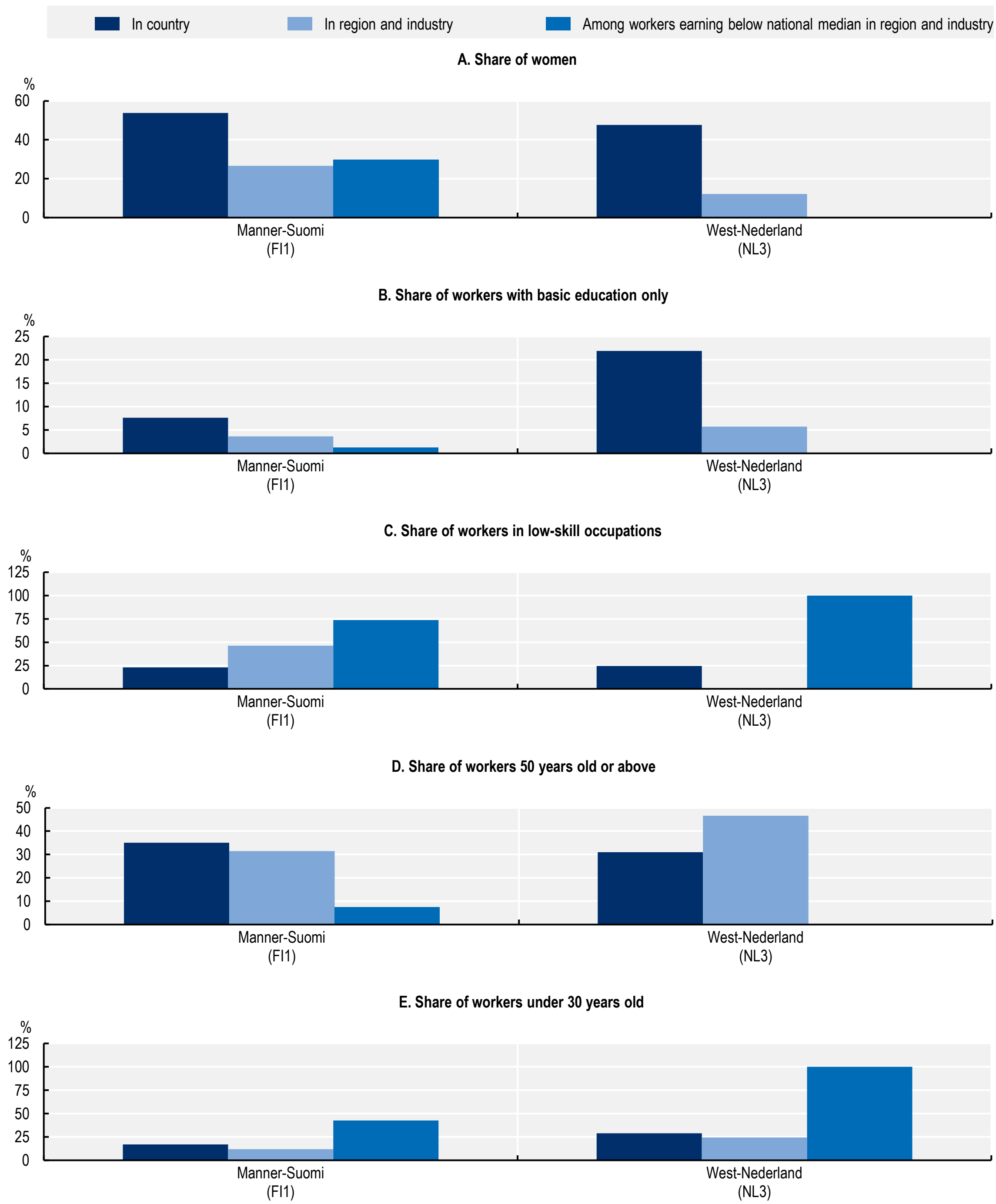
Note: National medians calculated using the SES sample data.
Source: Authors' calculations based on SES microdata.

Worker vulnerability in most vulnerable regions in the manufacture of coke and refined petroleum products (NACE 19)

Figure 4.14. NUTS 2 regions with high employment and high emissions in the manufacture of coke and refined petroleum products (NACE 19)

Figure 4.15. Worker characteristics in the manufacture of coke and refined petroleum products (NACE 19) in selected regions

Shares of workers with selected characteristics in the whole country, in the region and industry, and among workers earning lower than the national median in region and industry



Note: Country values are calculated using the SES sample data. Basic education refers to the G1 level (below upper secondary educational attainment) according to the International Standard Classification of Education, 2011 version. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

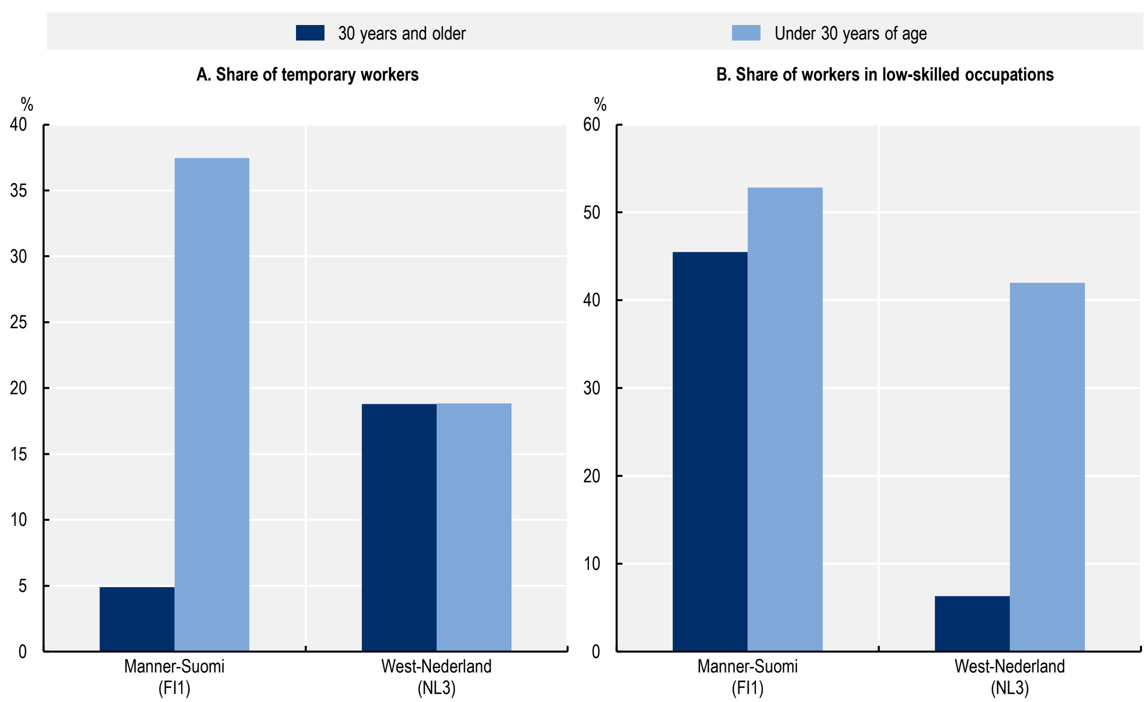
Among key sectors, the manufacture of coke and refined petroleum products stands out for facing substantial job losses. In the most vulnerable regions, workers' educational attainment is relatively high compared to the national averages, which could facilitate their employment transition to other sectors. The difference is largest for West Netherlands, where only 6% of workers have only basic education. Even so, these workers are likely to be employed in low-skill occupations.

As one of the most male-dominated manufacturing sectors, the industry employs between three to seven times more men than women in the most vulnerable regions (Figure 4.15, Panel A). When job displacement rates for men are high and men still provide the main source of household income, just transition impacts may be bigger.

Young workers in Mainland Finland are particularly vulnerable to reduced employment protection and income losses as they are approximately seven times more likely to hold temporary jobs than workers aged 30 and above (Figure 4.16, Panel A). In contrast, while young workers in West Netherlands are as likely as older workers to be in temporary employment, they have a greater tendency to be employed in low-skill occupations (Figure 4.16, Panel B).

Figure 4.16. Vulnerability of young workers employed in the manufacture of coke and refined petroleum products (NACE 19)

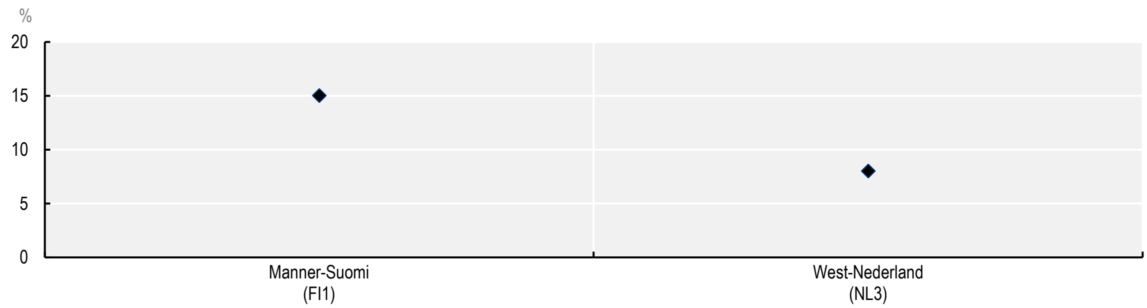
Share of temporary workers and low-skilled workers in NACE 19 across age groups, 2018



Note: Temporary refers to temporary or fixed duration contracts, except for apprenticeships, traineeships or students receiving remuneration. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Figure 4.17. Share of low-earning workers employed in the manufacture of coke and refined petroleum products (NACE 19)

Share of workers employed in NACE 19 earning less than the national median of gross hourly earnings across all economic activities, 2018



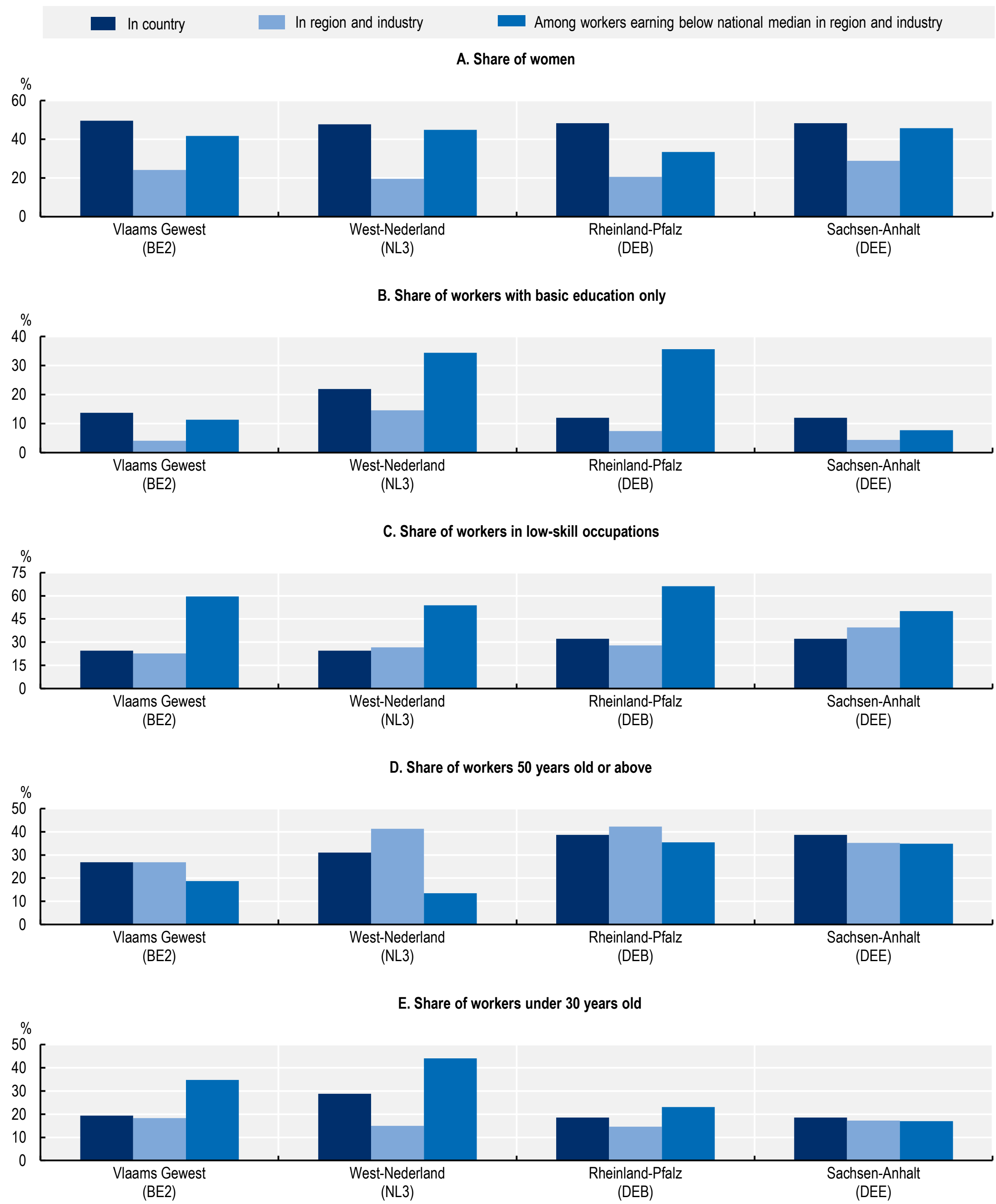
Note: National medians calculated using the SES sample data.
Source: Authors' calculations based on SES microdata.

Worker vulnerability in the most vulnerable regions in the manufacture of chemicals and chemical products (NACE 20)

Figure 4.18. NUTS 2 regions with high employment and high emissions in the manufacture of chemicals and chemical products (NACE 20)

Figure 4.19. Worker characteristics in the manufacture of chemicals and chemical products (NACE 20) in selected regions

Shares of workers with selected characteristics in the whole country, in the region and industry, and among workers earning lower than the national median in region and industry



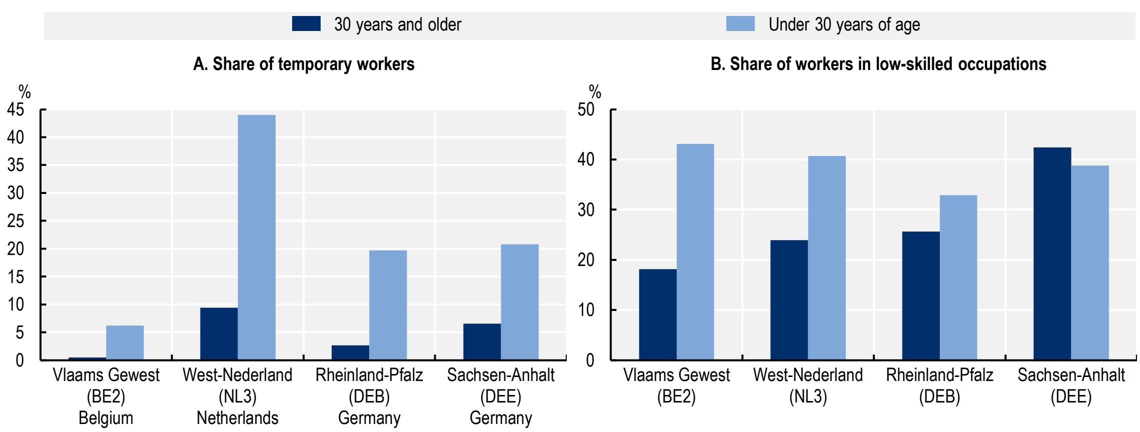
Note: Country values are calculated using the SES sample data. Basic education refers to the G1 level (below upper secondary educational attainment) according to the International Standard Classification of Education, 2011 version. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).

Source: Authors' calculations based on SES microdata.

Acquisition and adjustment of skills may be particularly important in the chemicals sector, given the breadth and complexity of required production processes and their transformations, often covering raw materials, and energy use with the high importance of reducing energy consumption. Circular economy challenges may also be particularly complex, as discussed in the first chapter. The transition is likely to be particularly challenging for older workers who display on average a 22 percentage points lower participation rate in adult learning than their prime-age colleagues (OECD, 2019[10]). Except for Flanders, workers aged 50 and above account for more than a third of workers in the manufacture of chemicals and chemical products industry and are over-represented in two of the most vulnerable regions (Figure 4.19). The vulnerability of young workers to the transition stems from their tendency to be in temporary employment and in low-skill occupations (Figure 4.20), which in turn limits workers' access to employer-sponsor training programmes.

Figure 4.20. Vulnerability of young workers employed in the manufacture of chemicals and chemical products (NACE 20)

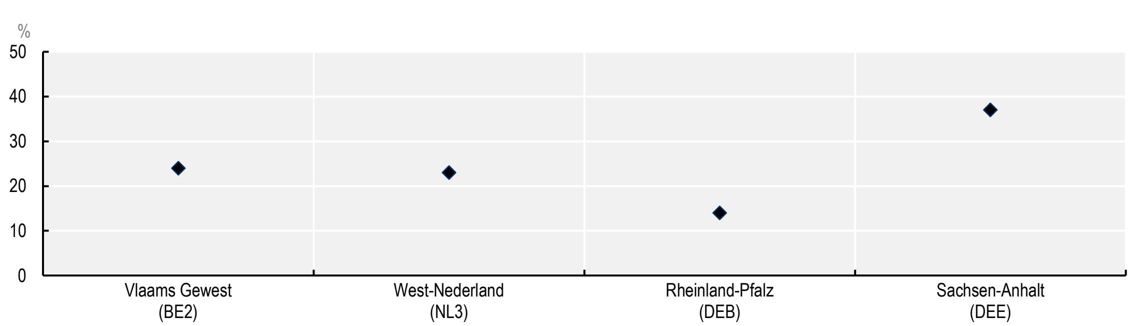
Share of temporary workers and low-skilled workers in NACE 20 across age groups, 2018



Note: Temporary refers to temporary or fixed duration contracts, except for apprenticeships, traineeships or students receiving remuneration. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Figure 4.21. Share of low-earning workers employed in the manufacture of chemicals and chemical products (NACE 20)

Share of workers employed in NACE 20 earning less than the national median of gross hourly earnings across all economic activities, 2018



Note: National medians calculated using the SES sample data.
Source: Authors' calculations based on SES microdata.

Wages in vulnerable regions in the manufacture of chemicals and chemical products industry tend to be relatively high. Nonetheless, differences across vulnerable regions are substantial. In Sachsen-Anhalt, Germany, 40% of workers in the industry earn less than the national median.

Worker vulnerability in the most vulnerable regions in the manufacture of basic metals (NACE 24)

Figure 4.22. NUTS 2 regions with high employment and high emissions in the manufacture of basic metals (NACE 24)

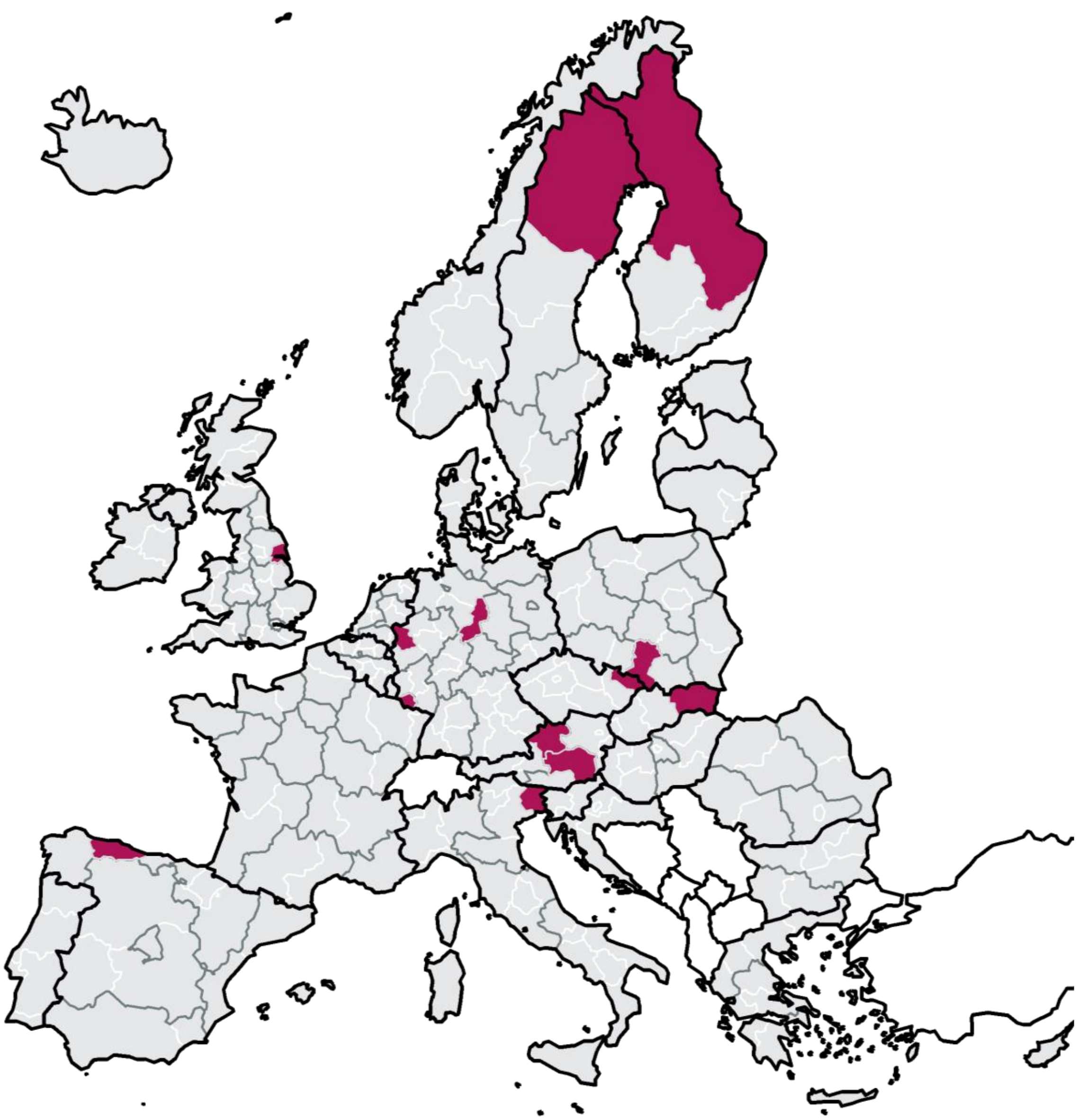
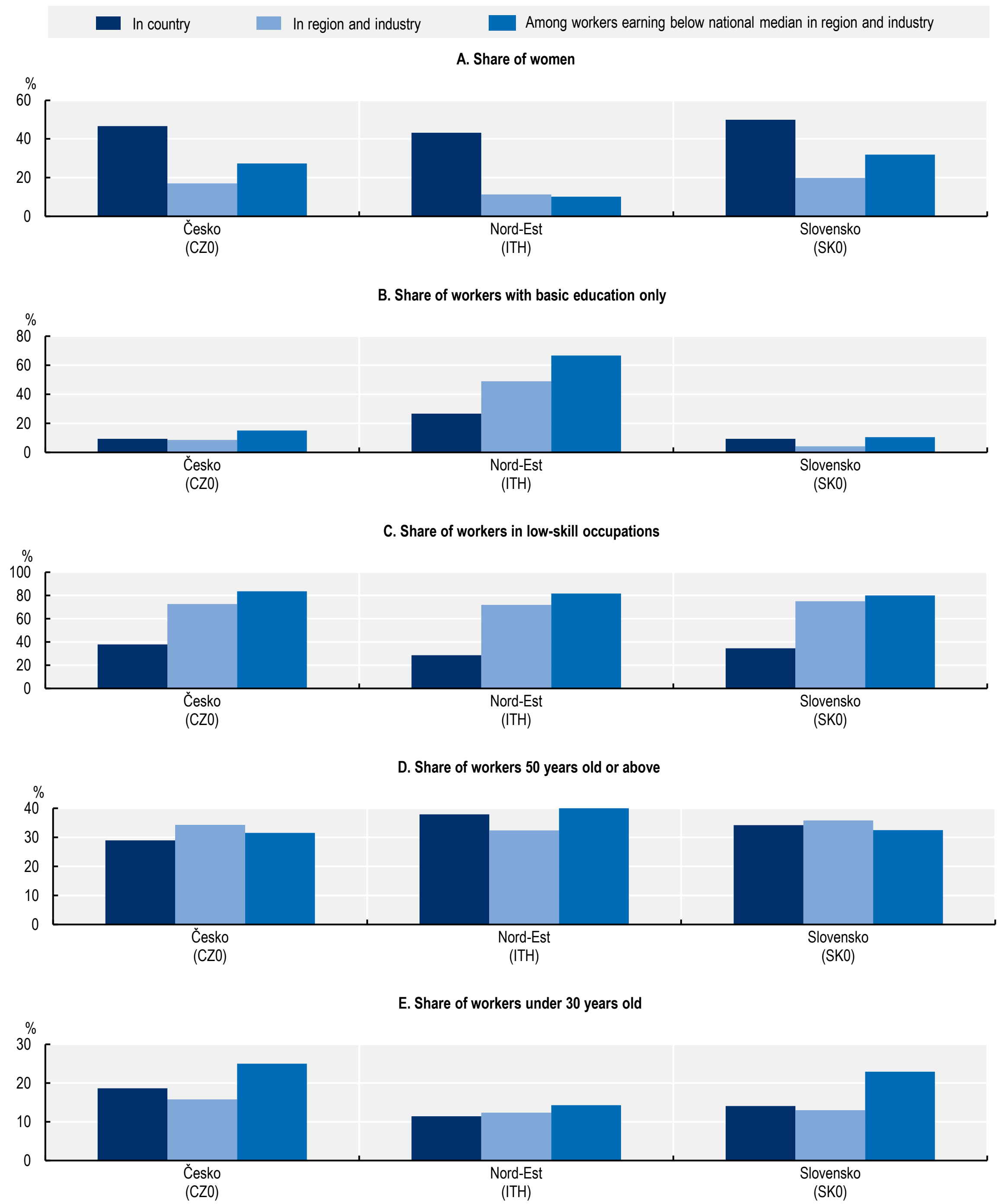


Figure 4.23. Worker characteristics in the manufacture of basic metals (NACE 24) in selected regions

Shares of workers with selected characteristics in the whole country, in the region and industry, and among workers earning lower than the national median in region and industry

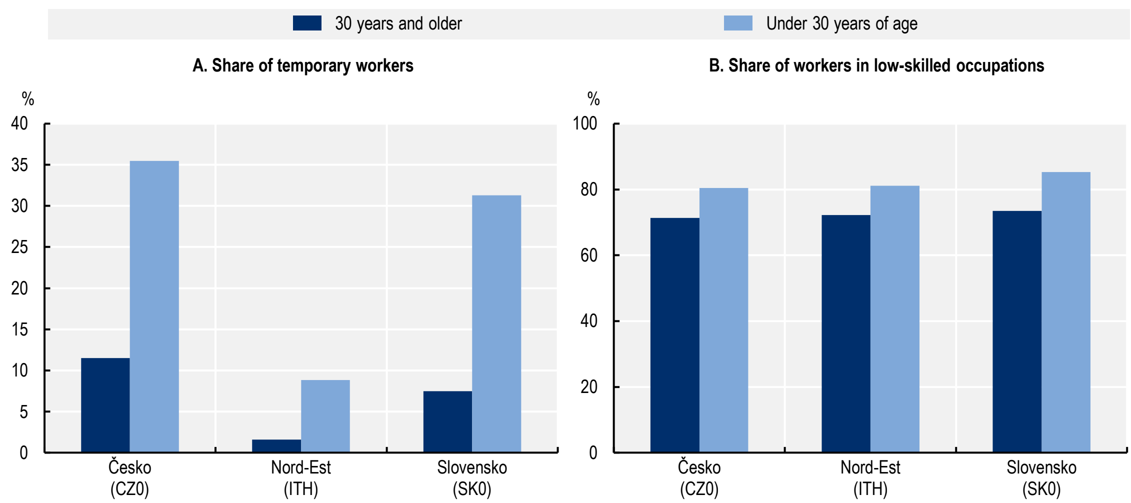


Note: Country values are calculated using the SES sample data. Basic education refers to the G1 level (below upper secondary educational attainment) according to the International Standard Classification of Education, 2011 version. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Regions with high employment shares and high emissions per capita in basic metals manufacturing are mainly in Northern and Central Europe. Workers in Northeast Italy will be particularly vulnerable in the transition as they tend to be low educated. Workers in low-skill occupations, such as manual workers and those in elementary occupations, account for three-quarters of the industry workforce in vulnerable regions. This exacerbates vulnerabilities since, as noted, lower-skilled and lower-educated workers tend to lack training opportunities.

Figure 4.24. Vulnerability of young workers employed in the manufacture of basic metals (NACE 24)

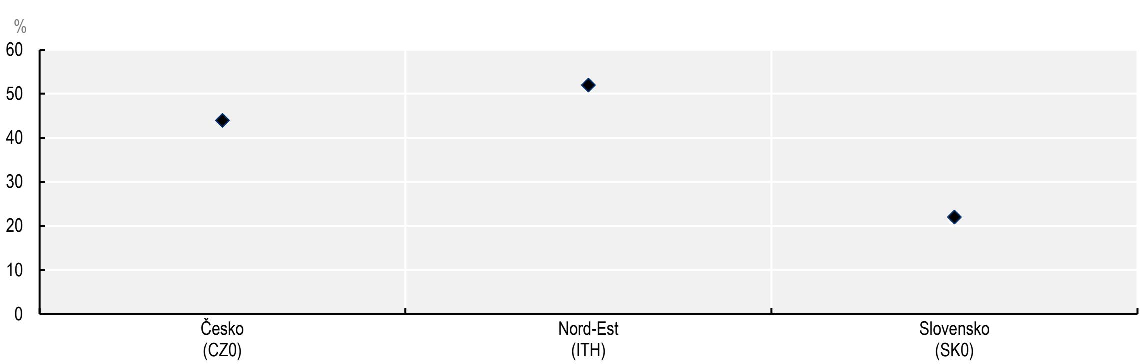
Share of temporary workers and low-skilled workers in NACE 24 across age groups, 2018



Note: Temporary refers to temporary or fixed duration contracts, except for apprenticeships, traineeships or students receiving remuneration. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Figure 4.25. Share of low-earning workers employed in basic metals production (NACE 24)

Share of workers employed in NACE 24 earning less than the national median of gross hourly earnings across all economic activities, 2018



Note: National medians calculated using the SES sample data.
Source: Authors' calculations based on SES microdata.

Despite the high incidence of low-skill occupations, wages in Northeast Italy for workers employed in the industry are on par with the national median wage. The proportion of workers earning above the national median is highest in Slovak Republic, at 78%.

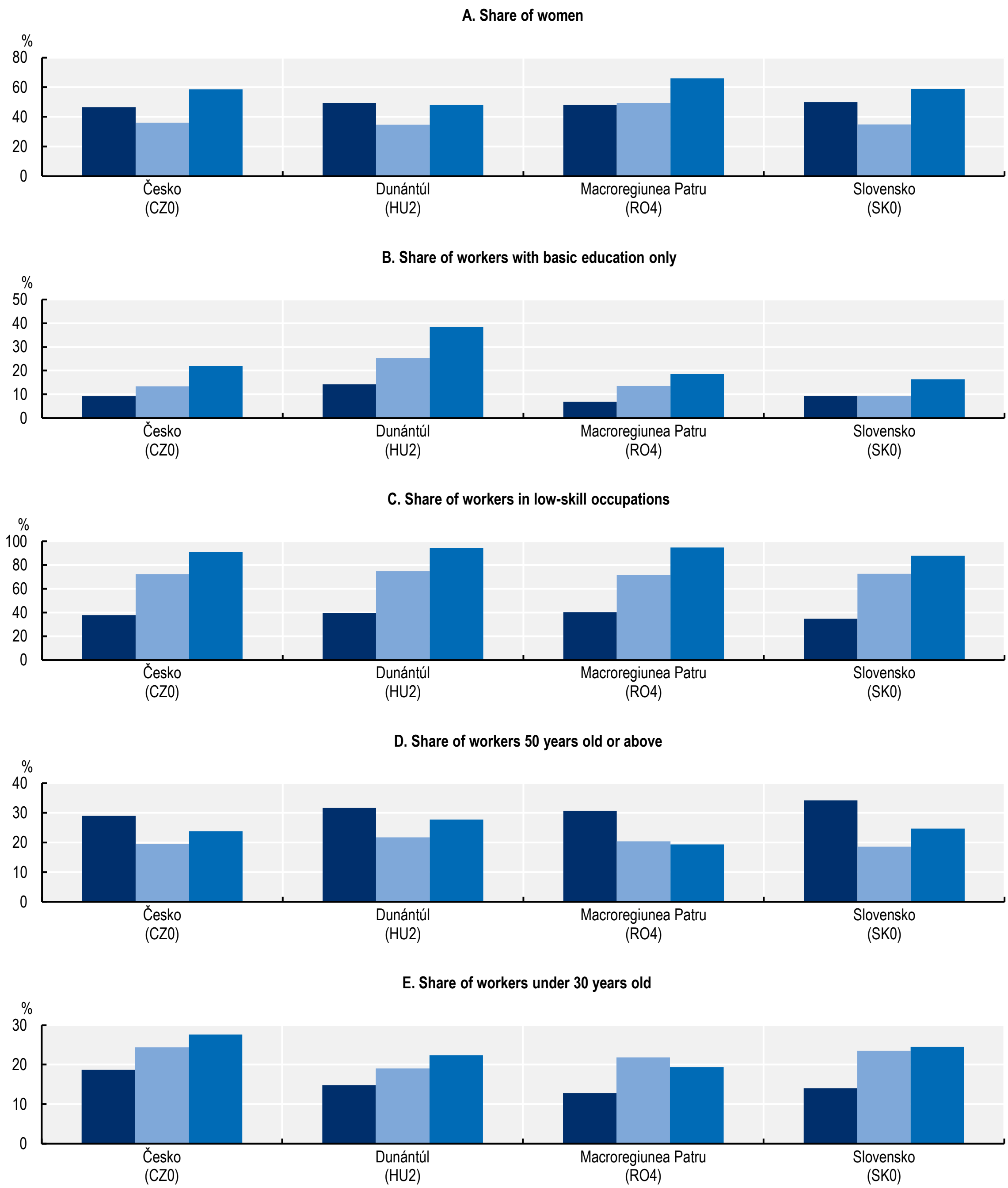
Worker vulnerability in the most vulnerable regions in the manufacture of motor vehicles, trailers, and semi-trailers (NACE 29)

Figure 4.26. NUTS 2 regions with high employment in the manufacture of motor vehicles, trailers and semi-trailers (NACE 29)

The vulnerable regions for the automotive manufacturing industry are spread across Europe, with a particular concentration in Central Europe. The incidence of low educational attainment is particularly high in Transdanubia in Hungary, where one in four workers have only basic education. Although most workers in the other vulnerable regions have at least upper secondary education, these workers tend to be employed in occupations with low skill requirements. Workers with lower educational attainment not only are less likely to participate in professional education and training but also experience difficulties in finding new jobs. This may be particularly relevant to the motor vehicles industry, which is likely subject to significant employment losses as well as increased outsourcing risks.

Figure 4.27. Worker characteristics in the manufacture of motor vehicles, trailers and semi-trailers (NACE 29) in selected regions

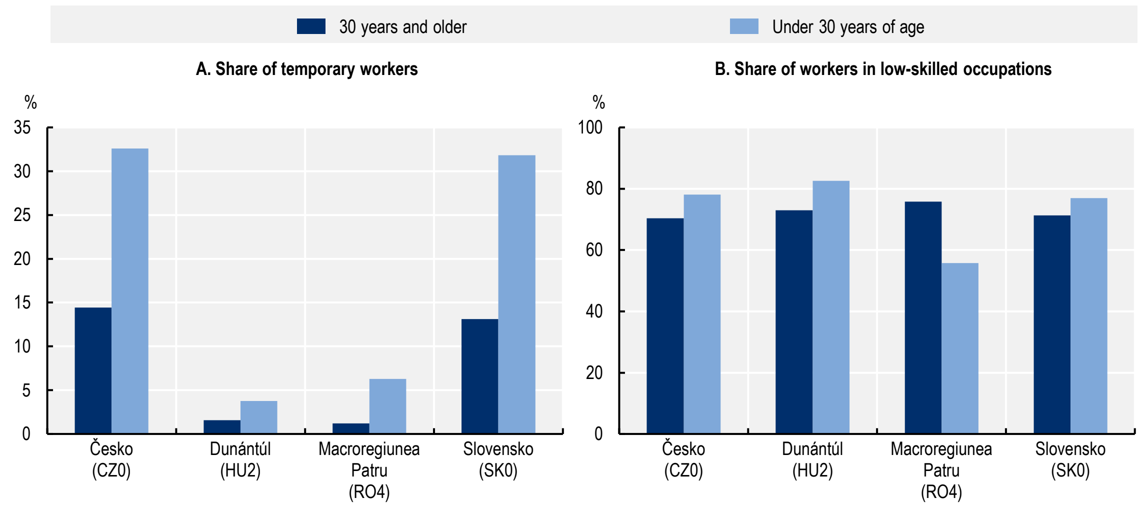
Shares of workers with selected characteristics in the whole country, in the region and industry, and among workers earning lower than the national median in region and industry



Note: Country values are calculated using the SES sample data. Basic education refers to the G1 level (below upper secondary educational attainment) according to the International Standard Classification of Education, 2011 version. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Figure 4.28. Vulnerability of young workers employed in the manufacture of motor vehicles, trailers and semi-trailers (NACE 29)

Share of temporary workers and low-skilled workers in NACE 29 across age groups, 2018



Note: Temporary refers to temporary or fixed duration contracts, except for apprenticeships, traineeships or students receiving remuneration. Low-skill occupations refer to craft and related trades workers, plant and machine operators and assemblers, and elementary occupations according to the International Standard Classification of Occupations (ISCO-08).
Source: Authors' calculations based on SES microdata.

Within-sector differences in firm productivity across the most vulnerable regions

Differences in firm productivity have implications for the just transition to climate neutrality. This section argues that regions with less productive firms in key manufacturing sectors may also be more vulnerable. It presents an analysis of the productivity performance of firms in the most vulnerable regions.

Manufacturing firms closer to the productivity frontier may find it easier to engage the needed transformations (Gal, 2013[11]). Moreover, high productivity sets the base for high profitability and profits are a key finance source. This is particularly relevant in the key manufacturing sectors, since the integration of new technologies, many of which are not yet deployed at scale, is essential for these transformations and will require substantial investment.

There is a risk that laggard firms exit the market, for example because of rising carbon prices. Hence, regions with more laggard firms are at a higher risk of losing firms and employment. Laggard firms within the key manufacturing sectors may need to follow different transition pathways with stronger policy support.

In what follows, firm-level labour productivity is calculated using a matched Emissions Trading System (ETS)-Orbis dataset, where data are available (Box 4.3). Indicators of firm productivity are analysed for companies in the key manufacturing sectors, for each relevant two-, three- or four-digit sector (NACE). The productivity frontier is defined as the top 5% of companies under EU ETS with the highest labour productivity. The figures below show companies' labour productivity performance and their relative distance to the labour productivity frontier. In addition, they show the percentile where the companies are positioned in the productivity ranking of all companies in the EU ETS, from least to most productive.

Box 4.3. Productivity data

Measuring firm productivity

Productivity data is from the ETS-ORBIS matched data provided by the European Commission (2021[12]) and the OECD-Orbis database (Gal, 2013[11]), the latter including several productivity measures (Andrews, Criscuolo and Gal, 2015[13]). This chapter draws on labour productivity defined as value-added relative to the number of workers in the company owning at least one installation in a region that is vulnerable to the transition of key manufacturing sectors to climate neutrality.

Source: European Commission (2021[12]) (Gal, 2013[11]). (Andrews, Criscuolo and Gal, 2015[13]).

Some of the most vulnerable regions host low-productivity firms, adding to the vulnerability

The productivity distribution of firms with available value-added-based labour productivity data and installations differs by sector. Some regions most affected by the transformations mainly have firms close to the productivity frontier in key manufacturing sectors, while other regions have mainly laggards.

The most vulnerable regions that are particularly affected by transformations in oil refining tend to have relatively productive companies (Figure 4.29). These regions tend to host a few companies with installations in the sector. Most firms are only 10% less productive than the frontier and they are in the top 25% of most productive firms. Oil refining is the key manufacturing sector where the most activity will disappear. The least productive installations are most likely to disappear or may be among the first to do so; still, some opportunities in biofuel refining could be captured, perhaps by the most innovative firms.

In the chemical sector, the most vulnerable regions have at least one installation from a company relatively close to the productivity frontier (Figure 4.29). In some regions, such as in Sachsen-Anhalt, Germany, the bulk of companies lag substantially, with labour productivity 10% to 20% lower than the frontier, and accounting for most of the employment.

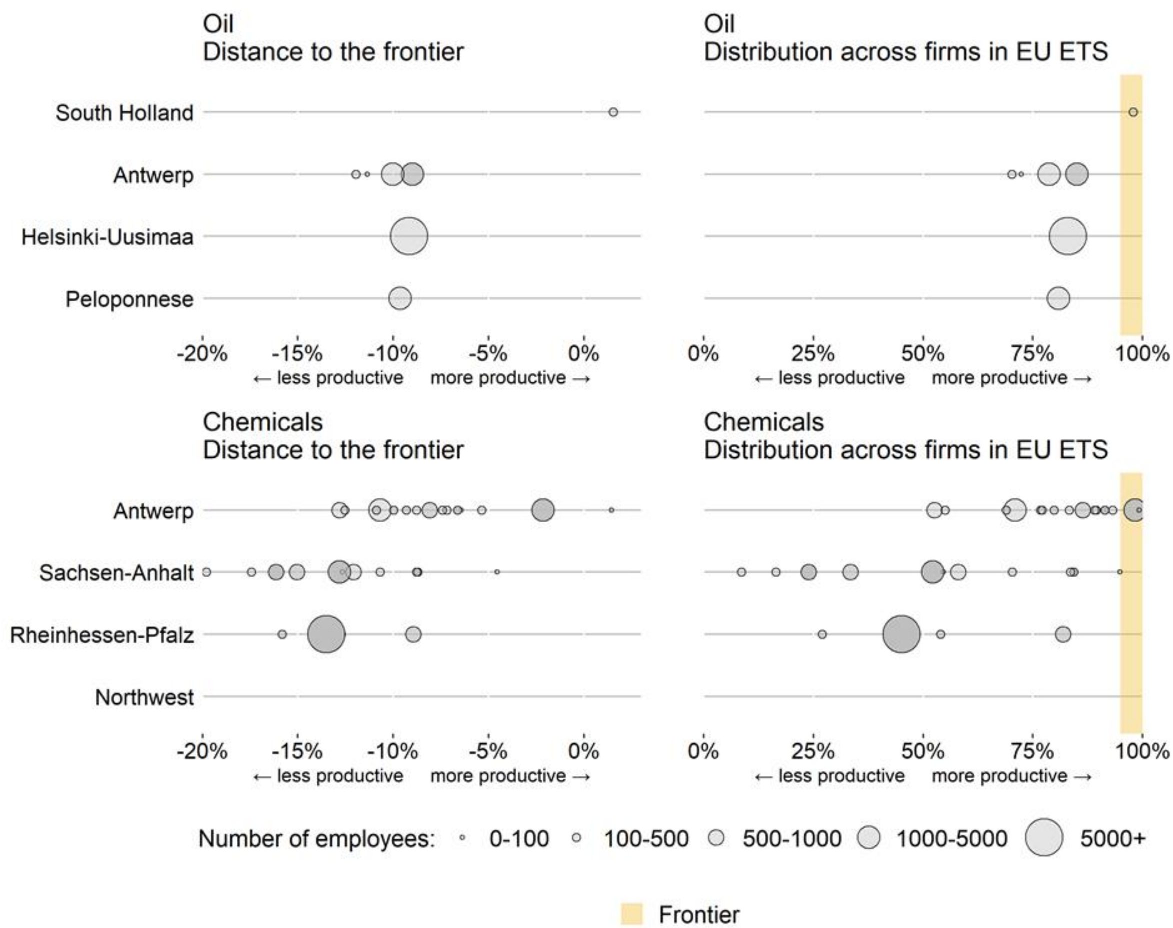
Companies in basic metals will also need to integrate new carbon-neutral technologies to produce steel and aluminium, especially so in steel production if carbon capture and storage is avoided. They will also need to invest substantially in these technologies. Only a few of the most vulnerable regions in steel have firms close to the productivity frontier, while the most vulnerable regions in aluminium have mainly laggard firms (Figure 4.30).

The most vulnerable regions in cement tend to have firms with average value-added-based labour productivity (Figure 4.31). In paper, the least productive firms tend to be smaller in terms of employment.

Among the key manufacturing sectors, only chemicals have a large enough number of companies with available data to establish correlations between firm productivity, the emissions intensity of value-added and capital intensity of employment (Fuentes Hutfilter et al., 2023[1]). Labour productivity is positively correlated with capital intensity and profitability, as expected. Less productive firms tend to be more emission-intensive after excluding outliers. This may suggest that some companies with high emissions, and therefore strong transformation needs in the most vulnerable regions, also face low productivity and therefore relatively large transition challenges. There is no correlation between the capital intensity of labour and emissions intensity of value-added, suggesting that stranded asset risks are not particularly strong in high-emission companies.

Figure 4.29. Firm productivity and size in the most vulnerable regions for oil and chemicals

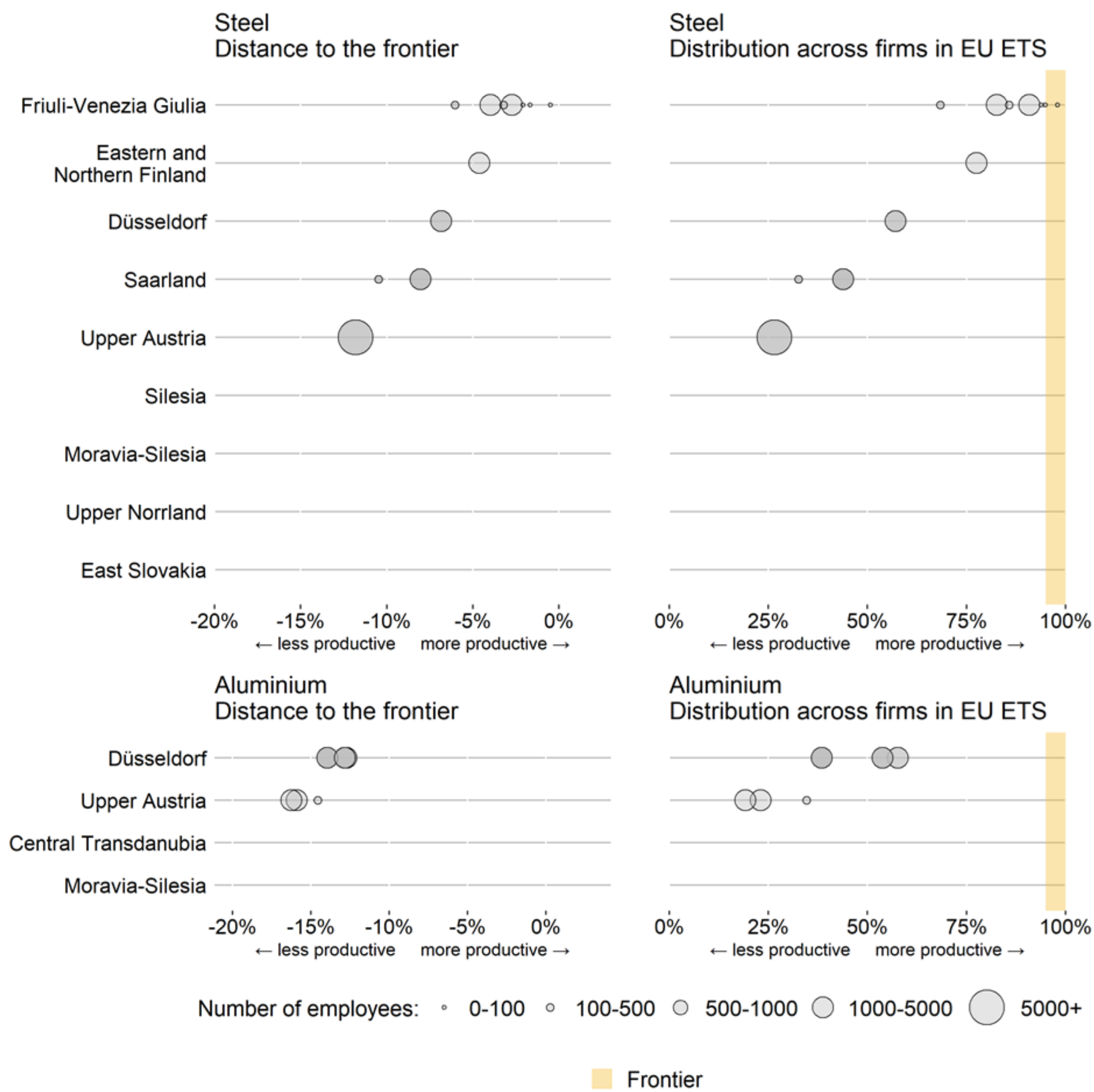
Value-added-based labour productivity and size of firms with installations in the most vulnerable regions for oil and chemical manufacturing, relative distance to the productivity frontier and percentiles of productivity distribution across firms under EU ETS



Note: The productivity frontier is defined as the average of the 5% most productive companies across all companies by sector under the EU ETS with available data. The most vulnerable regions are identified in Chapter 2. For some of the most vulnerable regions, no individual firm productivity data are available, sometimes because there are no value-added data. The sectors are NACE 19: manufacture of coke and refined petroleum products, and NACE 20: manufacture of chemicals and chemical products. Data for 2018.
Source: OECD-ETS-Orbis matched data.

Figure 4.30. Firm productivity and size in the most vulnerable regions for steel and aluminium

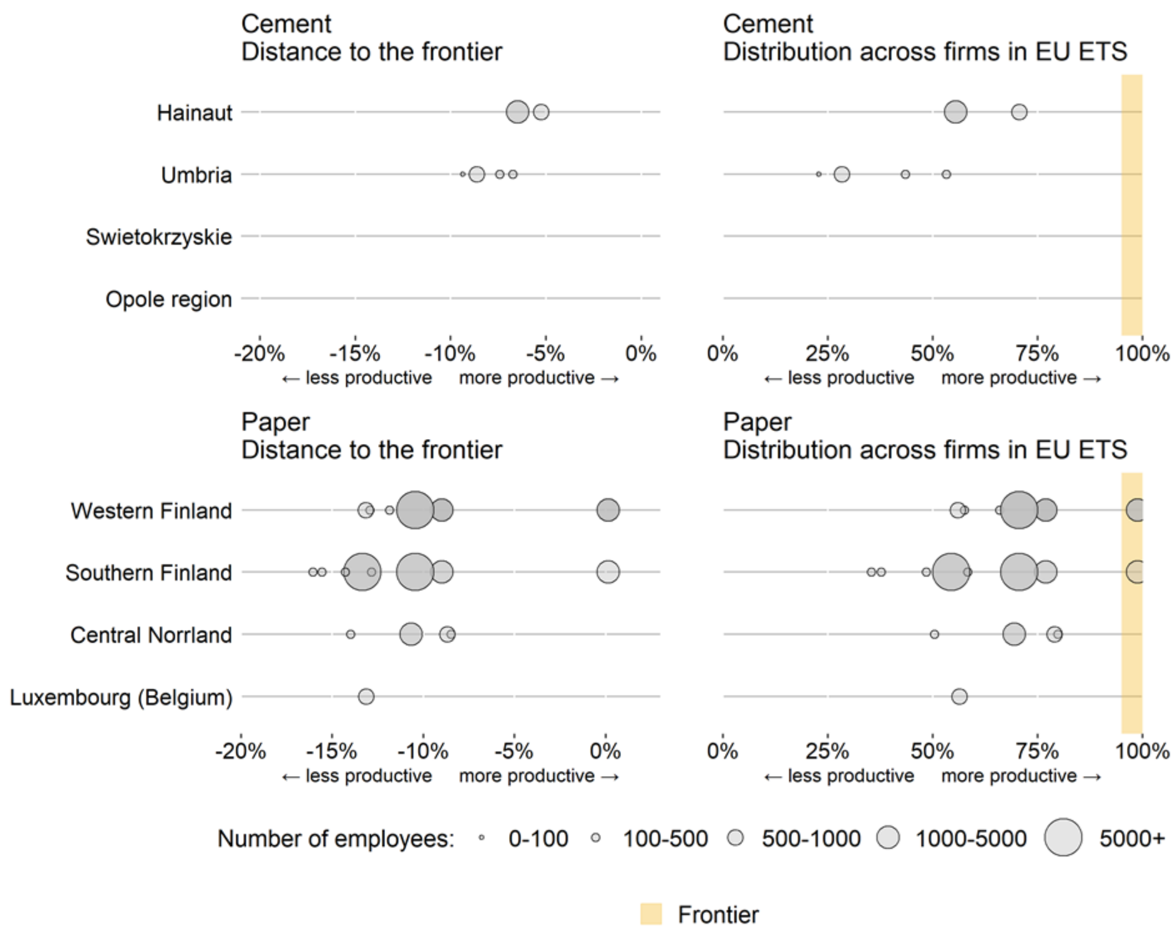
Value-added-based labour productivity and size of firms with installations in the most vulnerable regions for steel and aluminium production, relative distance to the productivity frontier and percentiles of productivity distribution across firms under EU ETS



Note: The productivity frontier is defined as the 5% most productive companies across all companies by sector under the EU ETS with available data. The most vulnerable regions are identified in Chapter 2. The sectors are NACE 241: manufacture of basic iron and steel and ferroalloys, and NACE 2442: aluminium production. Data for 2018.
Source: OECD-ETS-Orbis matched data.

Figure 4.31. Firm productivity and size in the most vulnerable regions for cement and paper

Value-added-based labour productivity and size of firms with installations in the most vulnerable regions for cement and paper production, relative distance to the productivity frontier and percentiles of productivity distribution across firms under EU ETS



Note: The productivity frontier is defined as the 5% most productive companies across all companies by sector under the EU ETS with available data. The most vulnerable regions are identified in working paper 2. The sectors are NACE 235: manufacture of cement, lime and plaster, and NACE 171: manufacture of pulp, paper and paperboard. Data for 2018.
Source: OECD-ETS-Orbis matched data.

References

Andrews, D., C. Criscuolo and P. Gal (2015), "Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries", *OECD Productivity Working Papers*, No. 2, OECD Publishing, Paris, https://doi.org/10.1787/5jrql2q2jj7b-en. [13]

Bassanini, A. and W. Ok (2004), "How do firms' and individuals incentive to invest in human capital vary across groups?", OECD, Paris, https://www.oecd.org/els/emp/34932892.pdf (accessed on 9 March 2022). [3]

Cedefop (2015), *Unequal access to job-related learning: Evidence from the adult education survey*, European Centre for the Development of Vocational Training, Luxembourg, https://doi.org/10.2801/219228. [4]

EC (2021), *European Emissions Trading System (ETS) – Calculations on the Regional Employment Impact of ETS Installations*, European Commission, https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/reg_impact_ets_installations_en.pdf. [12]

EC (2018), *Structure of Earnings Survey 2018: Eurostat's Arrangements for Implementing the Council Regulation 530/1999, the Commission Regulations 1916/2000 and 1738/2005*, European Commission, https://ec.europa.eu/eurostat/cache/metadata/Annexes/earn_ses_main_esms_an1.pdf (accessed on 29 November 2021). [7]

Fouarge, D., T. Schils and A. de Grip (2012), "Why do low-educated workers invest less in further training?", *Applied Economics*, Vol. 45/18, pp. 2587-2601, https://doi.org/10.1080/00036846.2012.671926. [8]

Fuentes Hutfilter, A. et al. (2023), "Regional Industrial Transitions to Climate Neutrality: Identifying potential socio-economic impacts", *OECD Regional Development Policy Papers*, OECD, Paris. [1]

Gal, P. (2013), "Measuring Total Factor Productivity at the Firm Level using OECD-ORBIS", *OECD Economics Department Working Papers*, No. 1049, OECD Publishing, Paris, https://doi.org/10.1787/5k46dsb25ls6-en. [11]

OECD (2019), *Getting Skills Right: Future-Ready Adult Learning Systems*, Getting Skills Right, OECD Publishing, Paris, https://doi.org/10.1787/9789264311756-en. [10]

OECD (2019), *Negotiating Our Way Up: Collective Bargaining in a Changing World of Work*, OECD Publishing, Paris, https://doi.org/10.1787/1fd2da34-en. [9]

OECD (2017), *OECD Employment Outlook 2017*, OECD Publishing, Paris, https://doi.org/10.1787/empl_outlook-2017-en. [6]

OECD (2002), *OECD Employment Outlook 2002*, OECD Publishing, Paris, https://doi.org/10.1787/empl_outlook-2002-en (accessed on 25 July 2022). [5]

Ookla (2020), *Speedtest by Ookla Global Fixed Network Performance Map Tiles*. [2]

OECD Regional Development Studies

Regional Industrial Transitions to Climate Neutrality

Some manufacturing activities are among the most difficult human activities to make climate neutral and they are typically regionally concentrated. Across Europe these regions are often socioeconomically relatively weak. Yet these sectors provide relatively well-paid jobs in many of these regions. Some of these regions may also have more difficult access to infrastructure to provide the hydrogen, carbon capture and storage and zero-emission freight, which can be important to some of these activities. Industrial transitions to climate neutrality therefore have regional development implications. Since regions differ in their socio-economic conditions, understanding these regional development implications will help policy makers prepare a just transition. This publication identifies manufacturing activities that are particularly difficult to decarbonise and the transformations they require. It shows how these activities are distributed across European regions, focusing on employment at emission-intensive production locations. It identifies conditions for getting access to needed infrastructure and how access conditions differ across regions. It investigates the socio-economic vulnerabilities of affected regions, their manufacturing businesses and workers. In some regions, workers and firms may be particularly vulnerable, for example, because of low-skill jobs, type of employment contract or low productivity.

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