WORKING PAPER | ISSUE 16/2025 | 25 AUG 2025

MEASURING GDP AT RISK IN THE LOW-CARBON TRANSITION

DIRK SCHOENMAKER AND WILLEM SCHRAMADE

As sustainability challenges push economies into low-carbon transitions, the question arises of what share of GDP is exposed to transition? We develop a two-stage model to examine the share of GDP facing transition risk. The first stage examines which sectors are directly exposed to transition(s) and the second stage assesses the transition preparedness of the exposed sectors. Applying this model to the energy transition in the European Union, we find that Sweden and France have low shares of GDP facing transition risk, while Poland and Bulgaria have high shares of GDP facing transition risk. The main driver is a country's carbon intensity, which we use as a proxy for transition preparedness.

Our GDP-facing-transition risk model can inform policymaking. Countries can stimulate directed change towards low-carbon activities with a combination of taxes for high-carbon technologies and subsidies for low-carbon technologies. Moreover, countries can accelerate reallocation of labour towards low-carbon technologies and sectors by investing in education and retraining.

Dirk Schoenmaker (dirk.schoenmaker@bruegel.org) is a Non-resident Fellow at Bruegel and Professor of Banking and Finance at the Rotterdam School of Management, Erasmus University Rotterdam
Willem Schramade is Professor of Finance at Nyenrode Business University

The authors thank Nica Vermeulen for excellent research assistance.

Recommended citation:
Schoenmaker, D. and W. Schramade (2025) 'Measuring GDP at risk in the low-carbon transition', *Working Paper* 16/2025, Bruegel

bruegel

1 Introduction

Sustainability challenges have pushed the economy into transition (Sachs, 2015). On the environmental side, climate change, biodiversity loss, freshwater shortages and depletion of nature resources demand new solutions. On the social front, political upheaval, social inequalities and poor labour practices in the supply chain put society under pressure. Governments play a major role in the transition to a sustainable economy. But sustainability transitions are uncertain and risk being driven by shocks (Loorbach *et al*, 2017; Bolton *et al*, 2020).

O'Neill *et al* (2018) found large differences in sustainability performance across countries, on both the environmental and social sides. Sachs *et al* (2024) also observed that progress towards the United Nations Sustainable Development Goals (SDGs) varies significantly across country groups. Moreover, they found that SDG progress has been stagnant since 2020. Countries may thus have some sectors that will be heavily affected by the transition to a sustainable economy, while other sectors are less affected. This raises the question: what part of GDP is exposed to transition? This is a question about economic structures. Governments can adopt policies to futureproof their economic structures (Eberhardt and Teal, 2013; Martins, 2019). To inform policymaking, governments need to know which part of their GDP is in transition.

In this paper, we develop a model to measure the shares of national GDP that are vulnerable to transition. Modelling GDP in transition is a two-stage process. First, a country's sectors that must transition to survive need to be identified. Second, an assessment needs to be made of how prepared these sectors are for the transition (Kurznack *et al*, 2021). The model provides a bird's eye view of a country's exposure to transition. This may help to evaluate sustainability exposures and progress from a more macro angle, in order to find new solutions. The model can be applied to any sustainability transition.

We illustrate our GDP-in-transition model with an example of the energy transition in the European Union. The main dynamics are in the second stage: a country's transition preparedness. We use carbon intensity as a proxy for transition preparedness. It appears that Sweden and France are well prepared for the energy transition because their economies have relatively low carbon intensities. By contrast, Poland and Bulgaria have the highest carbon intensities among EU countries. On the first stage of sectoral exposure, some smaller countries including Luxembourg, Cyprus and Malta are more services-oriented and thus less exposed to the energy transition. Among the larger countries, France and the Netherlands have relatively smaller industrial sectors, resulting in lower shares of GDP in transition.

Our paper contributes to the literature on GDP at risk. Lloyd *et al* (2024) examined the global drivers of GDP at risk, while Aikman *et al* (2019) investigated financial vulnerabilities affecting GDP. Our paper complements these papers by examining the transition drivers of GDP. Next, we contribute to the literature on structural change (Eberhardt and Teal, 2013). Martins (2019) found that labour reallocations (structural change) have played a critical role in enhancing economic performance since the early 2000s. Finally, our paper contributes to the literature on transition preparedness (Kurznack *et al*, 2021).

The goal of this paper is to inform policymaking. Policymakers want to discern the future earnings potential of their industrial sectors (Marijnissen *et al*, 2025). Broad value indicators, spanning financial, social and environmental value, are useful to guide the search for future earnings potential, as market-based valuations[1] are a poor proxy for the futureproofing of economies in a dynamic world that is subject to transitions. Germany, for example, for too long relied on the 'market' success of its traditional industry and has discovered belatedly that its main industries are not prepared for the future (Strategy&, 2023).

The policy recommendations for the energy transition are twofold. Countries can stimulate directed change towards lower carbon intensity with a combination of taxes on high-carbon activities and R&D subsidies for low-carbon technologies (Acemoglu *et al*, 2012). Countries can also accelerate reallocation of labour towards low-carbon technologies and sectors by investing in education and retraining programmes (Martins, 2019). It is important to stress that transitions should be well-managed to achieve a just transition for citizens and regions.

This paper is organised as follows. Section 2 introduces a model for GDP in transition. Section 3 provides an empirical illustration for the energy transition in the EU. We examine sectoral differences between EU countries. Section 4 discusses policy implications and section 5 concludes.

[1] Lo (2017) argued that equity analysts have been slow to pick up sustainability-related information. Stock markets may therefore not be fully pricing in transitions.

2 Modelling transition exposures

We first discuss the dynamics of sustainability transitions. Next, our model analyses which parts of GDP are exposed to transition. The share of GDP facing transition is a combination of the size of a country's high-carbon sectors and the transition preparedness of those sectors.

2.1 Transition

Transition is about transformational change rather than incremental change. The dynamics of societal transitions involve iterative processes of build-up and breakdown over a period of time (Loorbach *et al*, 2017). In a changing societal context, incumbent regimes develop path-dependently through optimisation, while change agents start to experiment with alternative ideas, technologies and practices. Over time, pressures build on regimes to transform, leading to destabilisation as alternatives start to emerge and accelerate. The actual transition is then chaotic and disruptive and new combinations of emerging alternatives and transformative regime elements grow into a new regime. In this process, elements of an old regime that do not transform are broken down and phased out.

To guide the transition towards a sustainable and inclusive economy, the United Nations has developed the 2030 Agenda for Sustainable Development (Sachs *et al*, 2024). The 17 UN Sustainable Development Goals (SDGs) are intended to stimulate action over the 2015-2030 period in areas of critical importance for humanity and the planet. Within the larger SDG framework, we identify four clusters of large-scale transitions that are important for countries:

1. **Climate – energy transition**: moving from the use of fossil fuels to renewable energy. This has not only an impact on the energy sector (eg oil and gas companies and electricity utilities), but also on other carbon-intensive sectors, such as manufacturing and transport.
2. **Raw materials – circular economy**: redesign and recycling of products leading to less use of raw materials. Sectors vary in their reliance on raw materials.
3. **Biodiversity – healthy food and regenerative agri- and aquaculture**: trend towards healthy food production with respect for land and water. This implies moving from intensive to regenerative farming to preserve the quality of the land without use of fertiliser and pesticides. Moreover, the transition from animal-based to plant-based proteins reduces land-use. Protecting biodiversity also implies no overfishing and preservation of ocean health.
4. **Labour practices – social transition**: trend towards decent labour practices across the value chain of production. Decent labour implies paying a living wage, ensuring safe working conditions and respecting human rights.

Transitions are not limited to the move to a sustainable economy. Other examples of major transitions in society are digitalisation and ageing. This paper deals with sustainability transitions.

2.2 Model

Transitions have a major impact on the viability of economic structures. Countries that can adapt to these transitions by changing their economic structures can maintain their GDP (Martins, 2019; Kurznack *et al*, 2021). Building on the model for transition losses (Schoenmaker and Schramade, 2022), we formalise the expected loss of GDP in transition $GIT_{i,j}$ of country i for transition j as follows:

$$GIT_{i,j} = EAT_{i,j} \cdot PT_{i,j} \cdot LGT_{i,j,k} \qquad (1)$$

where $EAT_{i,j}$ represents the exposure to transition. It measures which part b of country i's gross domestic product GDP_i is exposed to transition: $EAT_{i,j} = \sum_k b_{i,j,k} \cdot GDP_i$. The parameter $b_{i,j,k}$ is the weight of sector k in country i exposed to transition j. The extreme case is $b_{i,j,k} = 1 \;\; \forall\, k$, in which all sectors k in country i are exposed to transition j. Transition exposure ranges from no transition exposure to full transition exposure: $b_{i,j,k} \in \; [0, 1]$.

The second variable $PT_{i,j}$ presents the probability of transition j in country i. The size and timing of transition are uncertain. Scenarios analysis can be used to estimate the probability distribution for transition (De Ruiter, 2014). This analysis contains different scenarios for the degree of transition and the timing of transition. The probability of transition $PT_{i,j}$ is partly endogenous, as policymakers can accelerate or slow the speed of transition (see section 4). But history shows that transitions cannot be avoided; they happen shock-wise along a dynamic time-path (Loorbach *et al*, 2017)[2]. Our time horizon is medium to long term. Although exact timing cannot be predicted, transitions are expected to play out over this time frame.

The third variable $LGT_{i,k,j}$ is the loss arising from transition. In credit risk models, the recovery rate γ indicates how much can be recovered from a company in the case of default (Hull, 2018). The loss arising from default LGD is then: $LGD = (1 - \gamma)$. In a similar way, we introduce sector k's preparedness $a_{i,j,k}$ for transition j, whereby $LGT_{i,j,k} = (1 - a_{i,j,k})$. A sector can recover or retain its business by preparing for (ie adapting to) transition.

A sector (ie the companies making up a country's sector) can anticipate societal trends by building capabilities to learn about and serve these new societal needs, as part of its strategy (Schoenmaker and Schramade, 2022). $a_{i,j,k}$ is non-negative with the following range: $a_{i,j,k} \in [0, 1]$. $a_{i,j,k} = 1 \;\; \forall\, k$ denotes the case in which all sectors are fully prepared for the new world, allowing a country to reach its long-term business potential. As can be seen from equation 2, the expected GDP loss in transition is then zero: $GIT_{i,j} = \sum_k b_{i,j,k} \cdot GDP_i \cdot PT_{i,j} \cdot (1 - 1) = 0$.

[2] While the probability of default in the credit risk model (Hull, 2018) is dichotomous (zero or one at maturity), the probability of transition is more continuous: it can rise over a prolonged period (and the rise can even be delayed by policymakers), but it also reaches one if and when the transition happens.

We can now rewrite equation 1 as follows:

$$GIT_{i,j} = \sum_k b_{i,j,k} \cdot GDP_i \cdot PT_{i,j} \cdot (1 - a_{i,j,k}) \qquad (2)$$

Equation 2 provides the expanded formula for calculating GDP in transition. The next section applies our model to the energy transition.

3 Measuring GDP in transition (for energy transition)

We test our GDP in transition model with a case study on the energy transition in Europe. The research question is which part of GDP is exposed to transition when the energy transition ($j = energy$) happens ($PT_{i,energy} = 1$). As argued in the introduction, our GDP-in-transition model facilitates a bird's eye view. Claeys *et al* (2024) provided an excellent in-depth treatment of the macro-economics of the energy transition.

3.1 GDP in transition

The first step in the estimation is determining in which carbon-intensive sectors ($k = high\ carbon$) country i is active: $\sum_{k=high\ carbon} b_{i,k} = b_{i,high\ carbon}$. To assess which sectors are carbon-intensive, we examine sectoral data on carbon intensity. The carbon intensity (CI) of sector k in country i is computed as a sector's carbon emissions divided by its gross value added (GVA):

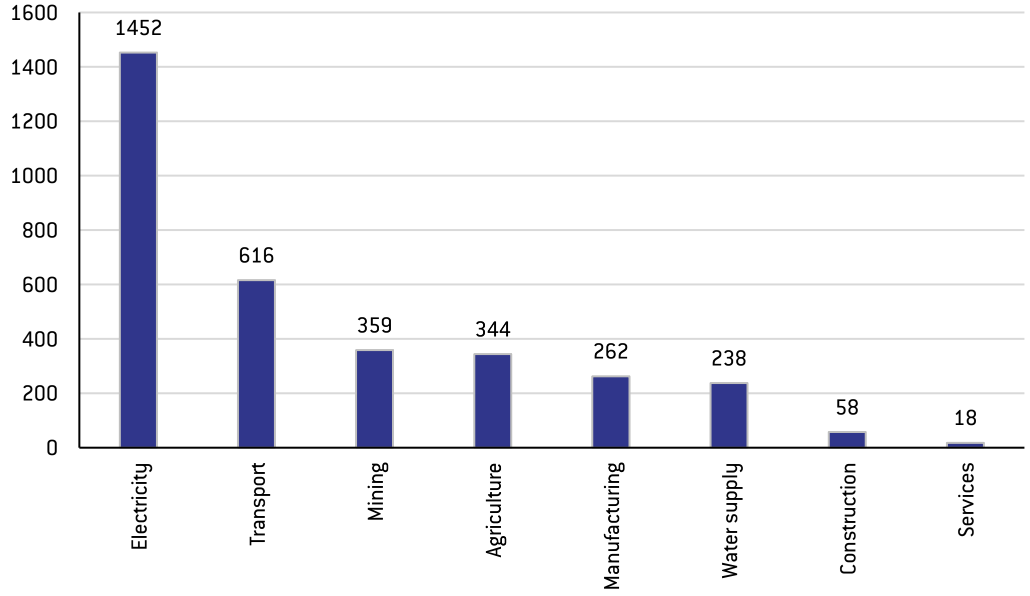
$$Carbon\ intensity_{i,k} = CI_{i,k} = \frac{Carbon\ emissions_{i,k}}{Gross\ value\ added_{i,k}} \qquad (3)$$

Throughout the paper we use carbon (CO_2) emissions as shorthand for greenhouse gas emissions. Annual data on greenhouse gas emissions and the data on the economic contribution (GVA) per NACE sector are retrieved from Eurostat for the EU countries[3]. Limiting our country selection to the EU facilitates comparisons across countries, as these countries are subject to the same EU regulatory and institutional framework.

Figure 1 presents the carbon intensity by sector at EU level for 2023 (Table 2 shows the calculations). It appears that agricultural and industrial sectors have high carbon intensities: $k = high\ carbon = agricultural\ and\ industrial$. The services sector has a very low carbon intensity of 18 tonnes CO_2 per €1 million GVA.

[3] Eurostat reports only direct emissions (scope 1) per sector. Indirect emissions (scopes 2 and 3) are also relevant, but are unfortunately not reported.

Figure 1: Carbon intensity by sector (EU, 2023)



Source: Eurostat. Note: This chart shows the carbon intensity of sectors in the EU, measured as emissions in metric tonnes of CO_2 divided by GVA in € millions.

The next step is to measure the transition preparedness of the high-carbon sectors: $a_{i,high\ carbon}$. We take the midpoint of the transition preparedness range from 0 to 1 as baseline: $a_{EU,high\ carbon} = 0.5$. Countries with lower carbon intensity than the EU average $CI_{i,high\ carbon} < CI_{EU,high\ carbon}$ have higher transition preparedness (ie their high-carbon sectors are better prepared for the energy transition), and vice versa. This is formalised as follows:

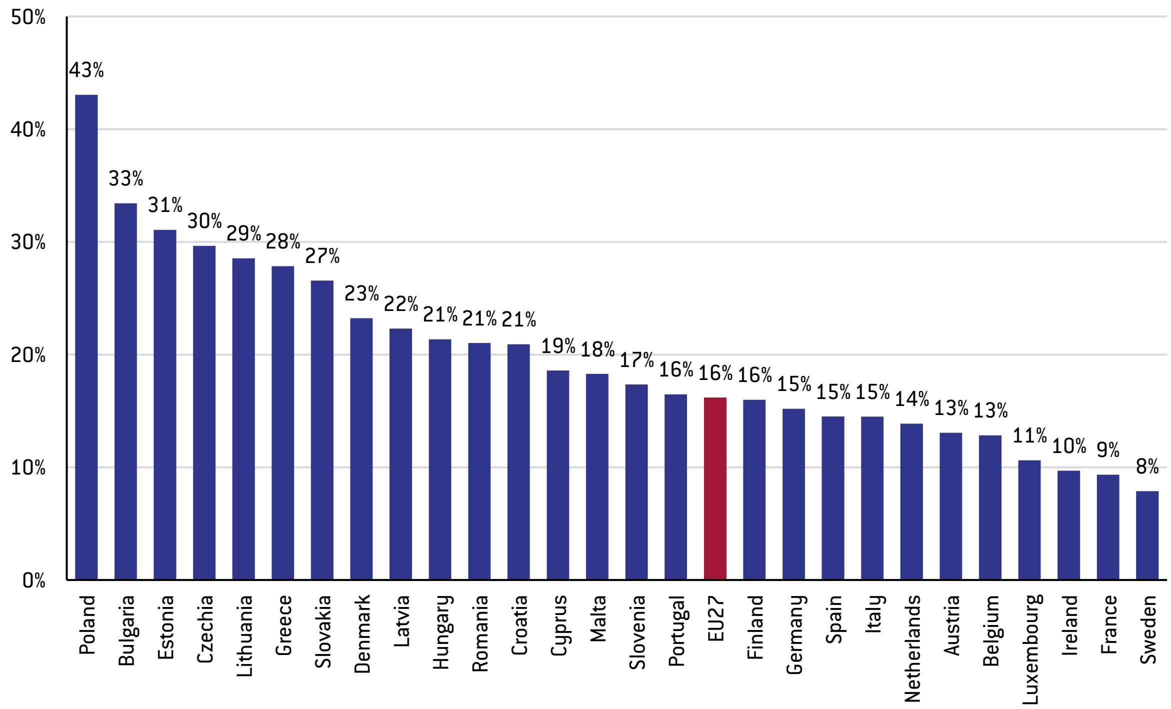
$$a_{i,high\ carbon} = \frac{(2 \cdot CI_{EU,high\ carbon} - CI_{i,high\ carbon})}{CI_{EU,high\ carbon}} * 0.5 \qquad (4)$$

Countries that are getting to zero emissions in their high carbon sectors $CI_{i,high\ carbon} \rightarrow 0$ are very well prepared for the energy transition: $a_{i,high\ carbon} \rightarrow 1$. By contrast, countries can have very high carbon intensities, indicating a lack of transition preparedness. Given that $a_{i,k} \in [0, 1]$, $a_{i,high\ carbon} = 0$ when $CI_{i,high\ carbon} \geq 2 \cdot CI_{EU,high\ carbon}$. Current carbon emissions provide a static picture of transition preparedness. Company transition plans could be used to develop a more dynamic, forward-looking picture of transition preparedness.

The above approach is top-down per sector. Further research could examine a breakdown at more granular level than NACE sectors. That would also allow the carbon intensity across the value chain to be analysed (eg car manufacturers and component producers in the car manufacturing value chain). Alternatively, we can assess transition preparedness bottom-up with carbon emissions data for companies in high-carbon sectors. As emissions are typically caused by a few large, capital-intensive companies in these sectors, such company analysis is feasible (in particular for the smaller central and eastern European countries that have only a few large companies). Marijnissen *et al* (2025) provided a framework for assessing the carbon performance of the largest companies in a country.

Using equation 2, we can calculate the share of GDP facing transition for the EU countries: $GIT_{i,energy} = b_{i,high\ carbon} \cdot (1 - a_{i,high\ carbon}) \cdot GDP_i$ provided that $PT_{i,energy} = 1$. Figure 2 presents our results. It shows the GDP facing transition as a percentage of GDP.

Figure 2: GDP vulnerable to transition, % of GDP (EU countries, 2023)



Source: Bruegel.

Figure 2 shows wide variation in the shares of GDP facing transition across the EU. At one end, we find Poland and Bulgaria, with exposures to the energy transition of 43 percent and 33 percent of GDP respectively. At the other end, Sweden and France have very low exposures of 8 percent and 9 percent of GDP respectively. The EU as a whole has an exposure of 16 percent of GDP.

Most results are as expected but there are also surprises. Scandinavian countries usually top any sustainability ranking. Finland, Sweden and Denmark are, for example, ranked first, second and third in the global SDG progress ranking (Sachs *et al*, 2024). While Sweden confirms this picture, Denmark has an exposure of 21 percent of GDP, exceeding the EU average exposure. In section 3.2, we disentangle the country differences in more detail.

3.2 Country and sectoral differences

EU countries vary in terms of how much they deviate from the EU average in terms of shares of GDP facing transition. Using equation 2, each country's deviation from the EU average is defined as follows:

$$Country\ difference_i = b_{EU} \cdot (1 - a_{EU}) - b_i \cdot (1 - a_i) \quad (5)$$

The country deviation is expressed as a percentage of GDP. For shorthand, we only keep the country subscript i and skip the transition subscript $j = energy$ and the sector subscript $k = high\ carbon$. Country differences can be decomposed into a sector-size component and a preparedness (ie adaptability) component. These are defined as follows:

$$Sector\ size\ component_i = (b_{EU} - b_i) \cdot (1 - a_{EU}) \quad (6)$$

$$Preparedness\ component_i = (a_i - a_{EU}) \cdot b_i \quad (7)$$

The sector-size component (based on b_i) and preparedness component (based on a_i) add up, of course, to the country deviation. We highlight that equations 5 to 7 present lower shares of GDP in transition as a positive deviation from the EU average. So, a smaller part of GDP ($b_i < b_{EU}$) or a higher preparedness ($a_i > a_{EU}$) result in lower shares of GDP in transition.

Table 1 reports the results. On the sectoral side, we observe only large positive deviations for three small countries, Luxembourg (+8 percent), Cyprus (+7 percent) and Malta (+7 percent). These countries are more services-oriented (financial, tourism) and thus have less exposure to industrial sectors. By contrast, several central and eastern European countries have relatively large industrial sectors: Slovakia (-6 percent), Poland (-5 percent) and Czechia, Lithuania, Romania and Slovenia (all -4 percent). Remember that a negative deviation means a larger industrial sector[4].

The real dynamics are on the transition preparedness side. The standard deviation of the preparedness component (7.5 percent) is twice that of the sector-size component (3.7 percent), as shown in the bottom row of Table 1. A large part of the country deviations can thus be explained by differences in preparedness (stage 2 of the model). Ireland (+9 percent compared to the EU average), Sweden (+8 percent), Austria (+4 percent) and France (+4 percent) have relatively high transition preparedness based on low carbon intensities. Looking at the combined sector and preparedness effects, Sweden and France top the country ranking in Figure 2 and Table 1. Apart from its natural advantage with hydro power, Sweden has a long history of high carbon taxes driving decarbonisation (Sterner, 2020; see also section 4.1). France gets about 70 percent of its electricity from nuclear plants, leading to a lower carbon intensity of electricity generation (see Table 3 in the annex).

[4] Please, note that the actual deviation from the EU average is twice the reported amounts, as equation 6 multiplies the sectoral difference $(b_{EU} - b_i)$ with the baseline adaptability of $(1 - a_{EU}) = 0.5$. So, the size of Slovakia's industrial sector is 12 percent larger than the EU average.

By contrast, Bulgaria (-17 percent compared to the EU average), Estonia (-15 percent), Greece (-14 percent) and Poland (-22 percent) have very high carbon intensities, translating into very low transition preparedness. The very high carbon intensity largely explains the high shares of GDP facing transition for Poland and Bulgaria, which still make heavy use of coal in power generation and high-heat industrial processes. It is interesting to note that Poland is moving remarkably fast (ie facing up to the transition risk), reducing its use of coal in power generation from 70 percent in 2022 to 54 percent in 2024[5].

It is also interesting to compare more or less 'similar' countries. Taking Germany, the Netherlands and Belgium, Germany has a larger industrial sector (2 percent larger, which is presented as a negative deviation[6] of -2 percent in Table 1) than the EU average and the Netherlands and Belgium smaller industrial sectors (both a positive deviation +3 percent). The preparedness differences are the other way round: Germany has a lower carbon intensity (+3 percent), while Belgium has only a slightly lower carbon intensity (+1 percent) and the Netherlands a higher carbon intensity (-0.3%) than the EU average. So, the country differences are smaller because of the opposite effects.

To investigate further the underlying causes of country differences, we can drill down to the sectoral level. While Table 1 measures the GDP exposed to the energy transition for the high-carbon sectors at the aggregate country level, we can examine the most important sectors in more detail. Table 2 indicates that manufacturing (32 percent of total carbon emissions), electricity (28 percent) and transport (22 percent) have the highest carbon emissions.

Another route would be to drill down to regional level. Economic dynamism has been increasingly dependent on agglomeration economies. This has led in turn to poor development prospects for lagging areas. Such regional analysis can inform place-sensitive territorial development policies (Rodríguez-Pose, 2018). This is left for future research.

[5] See Ember, 'Poland generated 54% of electricity from coal in 2024, down from 70% just 2 years ago', last updated 10 April 2025, https://ember-energy.org/countries-and-regions/poland/.
[6] Remember that a larger sector means a higher share of GDP in transition. Equations 5 to 7 and Table 1 present such sector differences as negative deviations.

Table 1: Country differences (EU, 2023)

Country	GDP at transition risk	Country difference	Sector size component	Preparedness component
Austria	13.1%	3.1%	-1.3%	4.4%
Belgium	12.8%	3.3%	2.7%	0.6%
Bulgaria	33.4%	-17.3%	-0.5%	-16.7%
Croatia	20.9%	-4.7%	-1.0%	-3.7%
Cyprus	18.6%	-2.4%	6.9%	-9.3%
Czechia	29.7%	-13.5%	-3.9%	-9.6%
Denmark	23.2%	-7.1%	-2.0%	-5.0%
Estonia	31.1%	-14.9%	0.0%	-14.9%
Finland	16.0%	0.2%	-0.7%	0.9%
France	9.3%	6.8%	2.8%	4.0%
Germany	15.2%	1.0%	-1.5%	2.5%
Greece	27.9%	-11.7%	2.2%	-13.9%
Hungary	21.4%	-5.2%	-2.9%	-2.3%
Ireland	9.7%	6.5%	-2.8%	9.2%
Italy	14.5%	1.7%	0.0%	1.7%
Latvia	22.3%	-6.1%	-1.9%	-4.3%
Lithuania	28.5%	-12.4%	-4.2%	-8.1%
Luxembourg	10.6%	5.5%	8.2%	-2.7%
Malta	18.3%	-2.1%	7.0%	-9.1%
Netherlands	13.9%	2.3%	2.6%	-0.3%
Poland	43.1%	-26.9%	-5.4%	-21.5%
Portugal	16.5%	-0.3%	2.7%	-3.0%
Romania	21.0%	-4.9%	-4.2%	-0.6%
Slovakia	26.6%	-10.4%	-5.8%	-4.6%
Slovenia	17.4%	-1.2%	-4.4%	3.2%
Spain	14.5%	1.7%	1.4%	0.2%
Sweden	7.9%	8.3%	0.2%	8.0%
EU27	16.2%			
EU27 mean		-3.7%	-0.2%	-3.5%
EU27 std. dev.		8.4%	3.7%	7.5%

Source: Bruegel based on Eurostat. Note: The country difference measures the deviation from the average share of EU GDP in transition and is expressed as a percentage of GDP. The sector-size component (b_i) and preparedness component (a_i) add up to the country difference. Positive values indicate a lower share of GDP in transition than the EU average; and negative values indicate a higher share of GDP in transition.

Table 2: Carbon intensity by sector (EU, 2023)

Sector	NACE	GVA (€ billions)	CO_2 emissions (in million tonnes)	Carbon intensity
High carbon		**5,024.2 (32.3%)**	**1,900.3 (91.0%)**	**378.2**
Agriculture	A	280.1 (1.8%)	96.5 (4.6%)	344.3
Mining	B	59.0 (0.4%)	21.2 (1.0%)	358.7
Manufacturing	C	2,526.7 (16.3%)	663.2 (31.8%)	262.5
Electricity	D	396.6 (2.6%)	575.9 (27.6%)	1,452.3
Water supply	E	144.9 (0.9%)	34.5 (1.7%)	237.9
Construction	F	872.6 (5.6%)	50.3 (2.4%)	57.7
Transport	H	744.3 (4.8%)	458.7 (22.0%)	616.3
Low carbon		**10,514.0 (67.7%)**	**188.4 (9.0%)**	**17.9**
Services sectors	G, I-V	10,514.0 (67.7%)	188.4 (9.0%)	17.9
Total		**15,538.2 (100%)**	**2,088.7 (100%)**	**134.4**

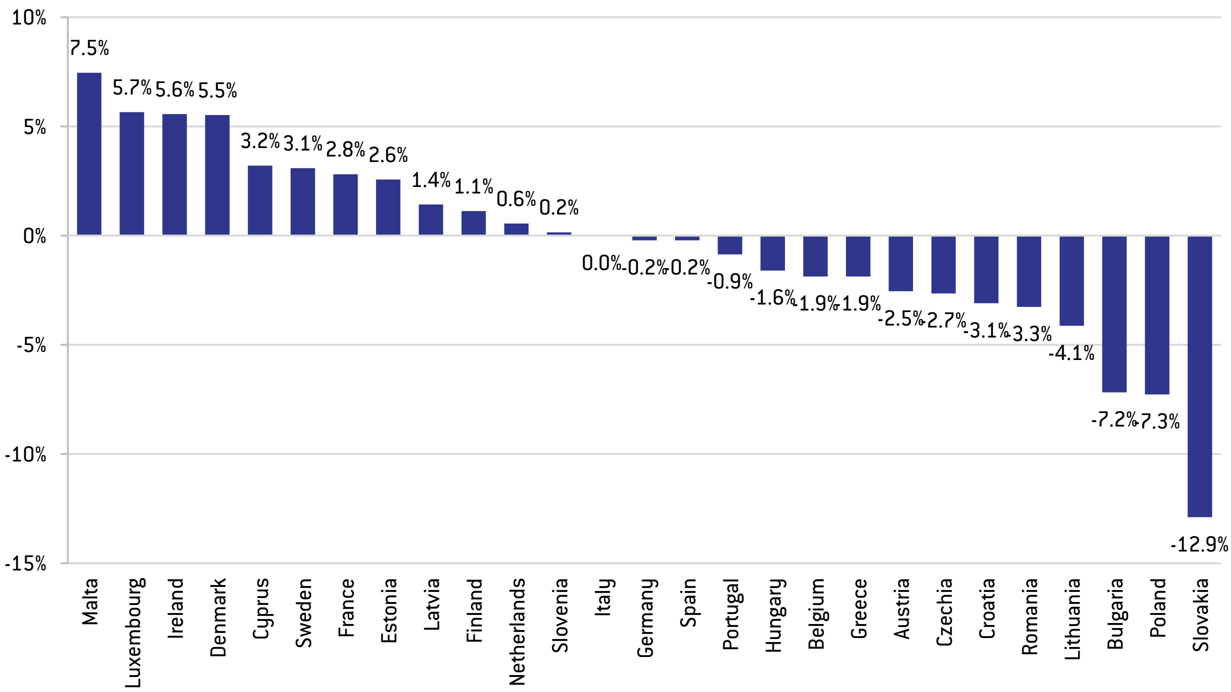
Source: Bruegel based on Eurostat. Note: NACE presents the statistical classification of sectors. Carbon intensity of sectors is measured as emissions in millions of metric tonnes of CO_2 divided by GVA in trillions of euros.

Figures 3 to 5 show the country deviations in share of GDP at transition risk at sector level. Starting with the largest sector, manufacturing, Figure 3 indicates that Luxembourg, Malta and Ireland have lower shares of GDP facing transition for manufacturing, as discussed earlier. At the other side, several central and eastern European countries (notably Slovakia, Poland and Bulgaria) have far larger shares of GDP facing transition in manufacturing, mainly due to the high carbon intensity of their manufacturing, at -9.7 percent, -6.1 percent and -7.7 percent respectively (see Table 3 for a sector size vs preparedness (ie carbon intensity) breakdown).

In the electricity sector, the country deviations are smaller (Figure 4). Again, several central and eastern European countries have higher shares of GDP facing transition in the electricity sector, because of the larger role for coal in power generation. Finally, the transport sector provides some interesting insights. Figure 5 shows that Denmark and Greece have very high shares of GDP facing transition in transport, because of their large international shipping sectors[7] – which adds to sector size and low preparedness (shipping has a very high carbon intensity).

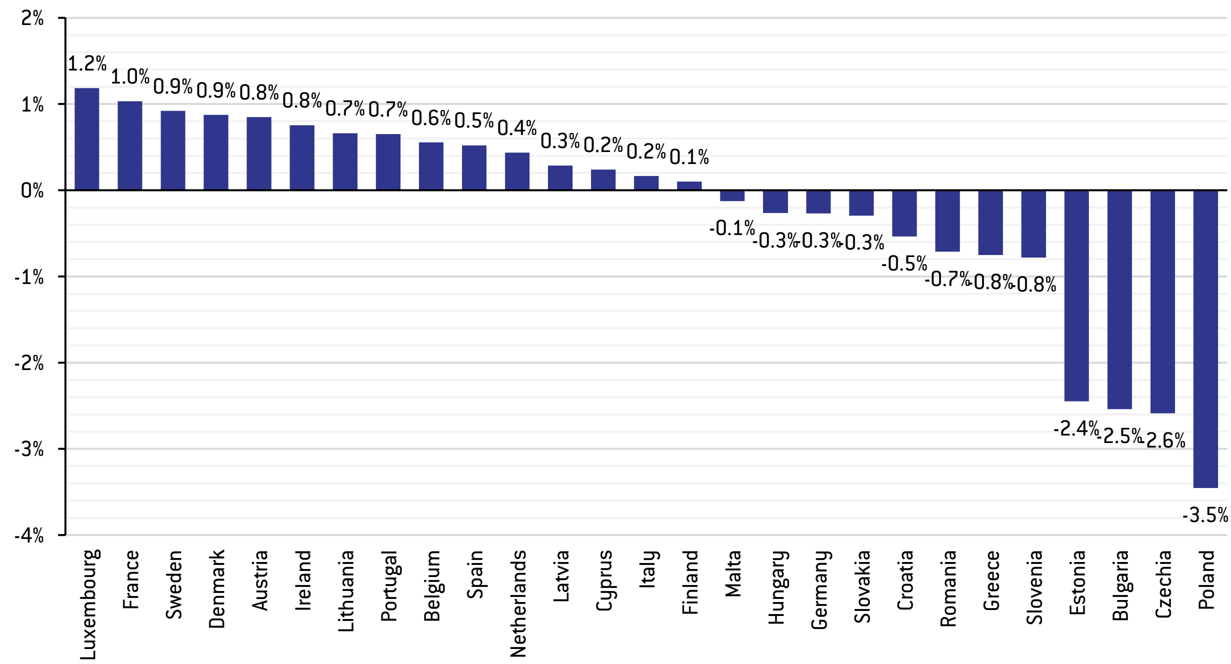
[7] Maersk is a leading shipping company headquartered in Denmark, while Greece is home to several shipping companies.

Figure 3: Country deviations for manufacturing (EU countries, 2023)



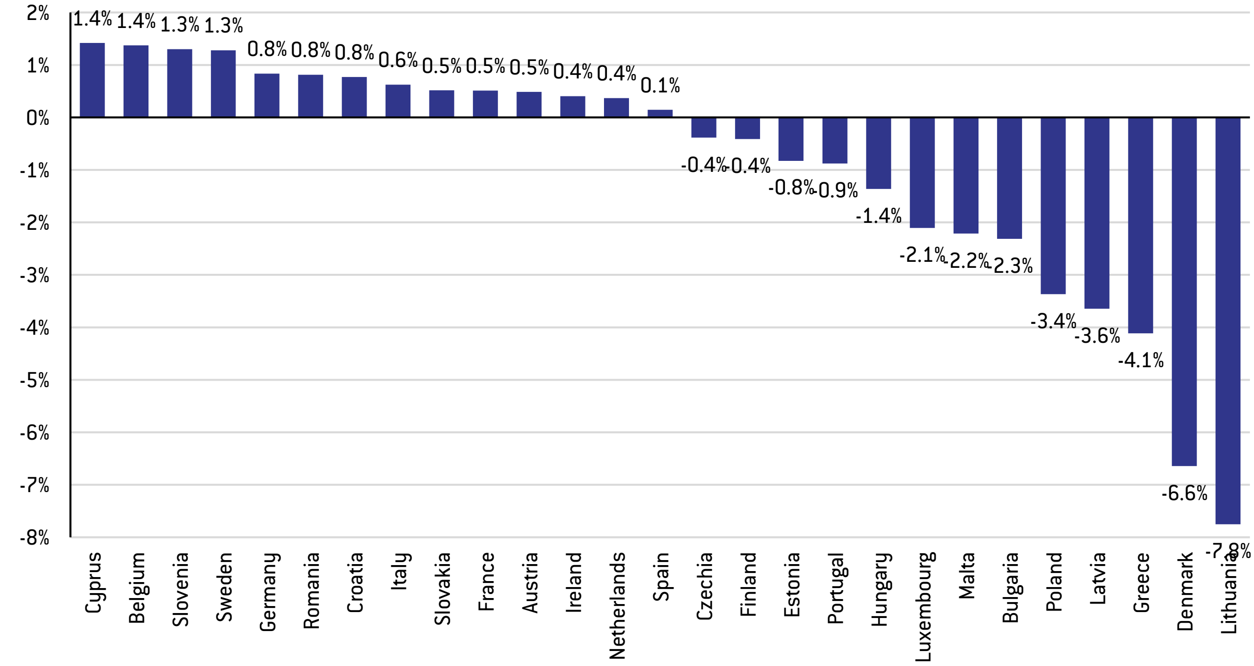
Source: Bruegel. Note: This graph expresses the share of GDP at transition risk as a percentage of GDP. Negative values indicate more GDP facing transition exposure.

Figure 4: Country deviations for electricity (EU countries, 2023)



Source: Bruegel. Note: This graph expresses the share of GDP at transition risk as a percentage of GDP. Negative values indicate more GDP facing transition exposure.

Figure 5: Country deviations for transport (EU countries, 2023)



Source: Bruegel. Note: This graph expresses the share of GDP at transition risk as a percentage of GDP. Negative values indicate more GDP facing transition exposure.

Table 3 in the Annex provides a further breakdown of country differences at sector level in a sector-size component ($b_{i,k}$) and a preparedness component ($a_{i,k}$). The bottom rows of Table 3 provide the mean and standard deviation of the differences. It appears that the differences are greatest in manufacturing (std. dev. of 4.4 percent), followed by transport (2.4 percent) and electricity (1.2 percent). That is unsurprising because transport and electricity are basic utilities that are largely land-based. Countries specialise (and thus differ) more in particular branches of manufacturing and some countries, such as Luxembourg, Cyprus and Malta, leave manufacturing largely to other countries and import manufactured products. Of the remaining countries, some have adapted with modern, low-carbon technologies. Examples are green steel in Sweden and modern spaceflight (ie satellites) in Slovenia (see +3 percent for preparedness of manufacturing for both countries in Table 3). Other countries still operate legacy factories with high carbon intensity. This latter group comprises several countries: Belgium (-4 percent for preparedness of manufacturing), Bulgaria (-8 percent), Croatia (-4 percent), Greece (-5 percent), Lithuania (-4 percent), Poland (-6 percent), Romania (-5 percent) and Slovakia (-10 percent).

4 Policy implications

The per-country results for the shares of GDP facing transition indicate the potential losses in GDP when the energy transition happens. Countries may adopt mixed strategies of speeding up transition in certain sectors and slowing it down in others. But countries cannot insulate sectors from transition pressure forever. At some point, high-carbon sectors will become obsolete, leading to lost GDP, as discussed in section 2.

The policy challenge is to reduce GDP exposures to the energy transition. Our empirical findings in section 3 suggest that the high carbon intensity of several industrial sectors is the main problem, highlighting the need to switch to low-carbon technologies. But there is also scope to adjust the economic structure. Agricultural economies transitioned to industrial economies in the late nineteenth and early twentieth centuries, and then from industrial economies to services economies[8]. However, in some countries and regions, services are still underdeveloped and legacy industries overrepresented.

The policy recommendations are two-fold. First, governments can adopt specific strategies to decarbonise their economies (Acemoglu *et al*, 2012; Claeys *et al*, 2024). Next, governments can use structural policies to futureproof their economies (Martins, 2019; Marijnissen *et al*, 2025).

4.1 Decarbonisation strategies

A main strategy to decarbonise is to impose a carbon tax. Sweden has the EU's highest carbon tax, introduced in 1991 at €24 per tonne of CO_2 and gradually increased to €134 per tonne in 2025 (Sterner, 2020) – compared to the EU emissions trading system carbon price of about €75 in 2025. As a result, carbon emissions have decreased faster in Sweden, by 33 percent from 1991 to 2021 than the EU average (27 percent over the same period; Crippa *et al*, 2022). The high carbon tax also stimulated the adoption of new technologies in Sweden, such as green steel.

Instead of reducing carbon emissions solely through carbon taxes, Acemoglu *et al* (2012) proposed to redirect technical change to low-carbon technology with a mix of carbon taxes (to make high-carbon technology more expensive) and R&D subsidies for low-carbon technology (to redirect research). Denmark and Greece could, for example, apply this policy-mix to their shipping sectors, which face international competition. Subsidies could be used to develop new low-carbon shipping motors and shipping biofuels, and taxes could be applied to existing high-carbon motors and fuels. In this way, Denmark and Greece can become leaders in clean shipping.

It is important to carefully watch and foster the health of industrial ecosystems and to help them make the transition. If applied in isolation, policy measures such as carbon taxes could leave industrial clusters without prospects and put them out of business. The result would not only be losses in GVA

[8] The sectoral breakdown in Table 2 shows that agriculture amounted to 2 percent of EU GDP, industry 30 percent and services 68 percent in 2023.

and employment in the cluster, but also in the indirectly exposed sectors that supply them, such as staffing companies, auditing firms and other services sector companies. Moreover, carbon-intensive production might be replaced by even more carbon-intensive production from outside the EU. Bollen *et al* (2025) warned that poor industrial policy has resulted in Dutch industrial activity coming under heavy pressure from lack of trained personnel, high energy costs and overregulation. Companies are reluctant to invest since they see no clear path and no de-risking by the government. A more proactive green industrial policy, as envisaged by the EU Clean Industrial Deal[9], is needed to build the low-carbon industries of the future.

4.2 Structural policies

Transition implies phasing out the existing technologies and business models that cannot adapt. If markets are efficient, Schumpeterian creative destruction can work on its own, as the highest return in the new sectors will enable the reallocation of workers. In reality, governments must help workers to retrain. In the destabilisation and disruption stages of transition, governments often have the kneejerk reaction of helping the business that is in trouble and/or to protect the jobs involved. History shows that attempts to delay transition are costly, with little lasting effects. Public support for the European textile industry and shipping industry in the 1970s led to high government expenditures, but this only delayed the move of bulk textile and shipping production to Asia.

It is better to focus on helping people to retrain and find new employment, and to change the system. The Danish labour market, for example, is known for its high level of flexibility when hiring, social welfare system and active employment policies. Together, these three components constitute what is known as the 'Flexicurity Model', which combines the market economy with the traditional Scandinavian welfare state (Jespersen *et al*, 2008).

Martins (2019) found evidence that labour reallocations (structural change) have played a critical role in enhancing economic performance since the early 2000s. The widespread reallocation of labour to the services sectors has been the key driver of structural change. Martins (2019) also found that the pace of structural change is significantly shaped by human and physical capital. The policy implication is that timely investment in education and economic infrastructure is crucial to accelerating structural change. In Germany, the traditional reputable technological universities changed belatedly from educating mechanical engineers to educating software engineers needed for the switch to low-carbon technologies. This belated change in education slowed down the transition from combustion engine cars to electric cars in the important German car industry (Kurznack *et al*, 2021).

Whereas national governments are the most powerful players with full access to taxation and regulation, subnational governments also have roles to play as transitions often occur at regional level (Brunckhorst, 2013). Moreover, as the latter are closer to the citizens, they can play key roles in

[9] See European Commission press release of 25 February 2025, 'A Clean Industrial Deal for competitiveness and decarbonisation in the EU', https://ec.europa.eu/commission/presscorner/detail/en/ip_25_550.

transition acceptance. Effective interplay between the national and regional level is crucial. A historical example is the transition from coal to gas in the Netherlands (Correljé and Verbong, 2004). When the coal mines in the south of the Netherlands were closed in the 1960s, the national government provided state aid to DSM (Dutch State Mines) to reform itself and offer alternative employment. The closure of the coal mines was prepared and executed jointly by the national government and the provincial government of Limburg. DSM has subsequently made several transitions and is now an innovative nutrition company[10].

Lack of political support can hamper regime change. The idea of a 'just transition' stresses the need to ensure that efforts to steer society towards a lower-carbon future are underpinned by a focus on issues of equity and justice: for those currently without access to reliable energy supplies and living in energy poverty, and for those whose livelihoods are affected by and dependent on a fossil-fuel economy (Newell and Mulvaney, 2013). It is especially in those places where regional transition failed that economic development stalled, social outcomes worsened and political populism gained traction (Rodríguez-Pose, 2018).

5 Conclusion

This paper develops a two-stage model to assess GDP in transition. The first stage identifies those parts of GDP that are exposed to transition, and the second stage assesses the extent to which sectors are prepared for transition. The model provides a bird's eye view of the degree to which economies are already futureproofed.

The model can be used to analyse sustainability transitions. Applying the model to the energy transition, we find large differences between EU countries. Some countries, such as Sweden and France, are well-prepared with only 8 percent to 9 percent of GDP facing transition, while other countries, such as Poland and Bulgaria, have 30 percent to 40 percent of their GDPs facing transition. The main dynamics are in the second stage of transition preparedness. Several countries still have very carbon-intensive industrial sectors, indicating low preparedness. Further research on transition plans could show a dynamic picture of transition preparedness.

The model is useful to inform policymaking. On the carbon side, countries can stimulate directed change towards low-carbon with a combination of taxes for high-carbon and subsidies for low-carbon technologies. On the structural side, countries can accelerate reallocation of labour towards low-carbon technologies and sectors by investing in education and retraining. Proactive and well-balanced industrial policy can help in guiding the transition from a high-carbon towards a low-carbon economy, without 'losing' citizens or regions.

[10] In 2023, DSM merged with the Swiss company Fermenich, forming DSM-Fermenich.

While the paper highlights sectoral differences, we leave regional differences in transition exposures for future research. It is important that all regions are developed, rather than only the central regions. Another issue for future research is to include indirect exposures to transition.

References

Acemoglu, D., P. Aghion, L. Bursztyn and D. Hemous (2012) 'The environment and directed technical change', *American Economic Review* 102(1): 131-166

Aikman, D., J. Bridges, S. Hoke, C. O'Neill and A. Raja (2019) 'Credit, capital and crises: a GDP-at-Risk approach', CEPR Discussion Papers DP15864, Centre for Economic Policy Research

Bollen, J., S. Kerssens, K. Kruijver, C. van Oosteren, D. Pisa, C. Schipper, A. Tukker and J. Vierhout (2025) *Het Nederlandse concurrentievermogen in het licht van het Draghi-rapport (Dutch Competitiveness in the context of the Draghi Report)*, TNO Vector

Bolton, P., M. Després, L. Pereira da Silva, F. Samama and R. Svartzman (2020) *The Green Swan*, Bank for International Settlements

Brunckhorst, D. (2013) *Bioregional Planning: Resource Management Beyond the New Millennium*, Routledge

Claeys G., M. Le Mouel, S. Tagliapietra, G. Wolff and G. Zachmann (2024) *The Macroeconomics of Decarbonisation: Implications and Policies*, Cambridge University Press

Correljé, A. and G. Verbong (2004) 'The transition from coal to gas: radical change of the Dutch gas system', in B. Elzen, F. Geels and K. Greens (eds) *System Innovation and the Transition to Sustainability,* Edward Elgar

Crippa M., D. Guizzardi, M. Banja, E. Solazzo, M. Muntean, E. Schaaf … E. Vignati (2022) *CO2 emissions of all world countries*, JRC Science for Policy Report JRC/IEA/PBL 2022, Joint Research Centre, European Commission

Eberhardt, M. and F. Teal (2013) 'Structural change and cross-country growth empirics', *World Bank Economic Review* 27(2): 229-271

Hull, J. (2018) *Risk Management and Financial Institutions*, 5th edition, John Wiley & Sons

Jespersen, S., J. Munch and L. Skipper (2008) 'Costs and benefits of Danish active labour market programmes', *Labour Economics* 15(5): 859-884

Kurznack, L., D. Schoenmaker and W. Schramade (2021) 'A Model of Long-Term Value Creation', *Journal of Sustainable Finance & Investment*, 1-19

Lloyd, S., E. Manuel and K. Panchev (2024) 'Foreign vulnerabilities, domestic risks: The global drivers of GDP-at-Risk', *IMF Economic Review*, 72(1): 335-392

Lo, A. (2017) *Adaptive Markets: Financial Evolution at the Speed of Thought*, Princeton University Press

Loorbach, D., N. Frantzeskaki and F. Avelino (2017) 'Sustainability Transitions Research: Transforming Science and Practice for Societal Change', *Annual Review of Environment and Resources* 42(1): 599-626

Marijnissen, W., D. Schoenmaker and W. Schramade (2025) 'Futureproofing companies & valuation ratios', CEPR Discussion Papers DP20243, Centre for Economic Policy Research

Newell, P. and D. Mulvaney (2013) 'The political economy of the just transition', *Geographical Journal* 179(2): 132-140

O'Neill, D., A. Fanning, W. Lamb and J. Steinberger (2018) 'A good life for all within planetary boundaries', *Nature sustainability* 1(2): 88-95

Ruijter, P. de (2014) *Scenario Based Strategy – Navigate the Future*, Gower Publishing

Rodríguez-Pose, A. (2018) 'The revenge of the places that don't matter (and what to do about it)', *Cambridge Journal of Regions, Economy and Society* 11(1): 189-209

Sachs, J. (2015) *The Age of Sustainable Development*, Columbia University Press

Sachs, J., G. Lafortune and G. Fuller (2024) *The SDGs and the UN Summit of the Future. Sustainable Development Report 2024*, Sustainable Development Solutions Network and Dublin University Press

Schoenmaker, D. and W. Schramade (2022) 'Valuing Companies in Transition', *Sustainability Letters* 1(1): 1-12

Sterner, T. (2020) 'The carbon tax in Sweden', in C. Henry, J. Rockström and N. Stern (eds) *Standing up for a Sustainable World*, Edward Elgar

Strategy& (2023) *In DEcline? The German industrial sector between perceptions and realities since 2020*, PwC

Annex

Table 3: Sectoral differences across countries (EU, 2023)

Country	Effects	Country difference	Sector size component	Preparedness component
Austria	Overall	3.1%	-1.3%	4.4%
	• Manufacturing	-2.5%	-0.7%	-1.8%
	• Electricity	0.8%	0.0%	0.9%
	• Transport	0.5%	-0.3%	0.7%
	• Other sectors	4.3%	-0.3%	4.6%
Belgium	Overall	3.3%	2.7%	0.6%
	• Manufacturing	-1.9%	1.9%	-3.8%
	• Electricity	0.6%	0.4%	0.2%
	• Transport	1.4%	-0.4%	1.7%
	• Other sectors	3.3%	0.8%	2.5%
Bulgaria	Overall	-17.3%	-0.5%	-16.7%
	• Manufacturing	-7.2%	0.5%	-7.7%
	• Electricity	-2.5%	-0.6%	-1.9%
	• Transport	-2.3%	0.0%	-2.4%
	• Other sectors	-5.2%	-0.4%	-4.8%
Croatia	Overall	-4.7%	-1.0%	-3.7%
	• Manufacturing	-3.1%	0.9%	-4.0%
	• Electricity	-0.5%	0.2%	-0.7%
	• Transport	0.8%	-0.2%	1.0%
	• Other sectors	-1.9%	-1.9%	0.0%
Cyprus	Overall	-2.4%	6.9%	-9.3%
	• Manufacturing	3.2%	5.7%	-2.5%
	• Electricity	0.2%	0.8%	-0.5%
	• Transport	1.4%	-0.3%	1.7%
	• Other sectors	-7.3%	0.7%	-8.0%
Czechia	Overall	-13.5%	-3.9%	-9.6%
	• Manufacturing	-2.7%	-2.8%	0.1%
	• Electricity	-2.6%	-1.0%	-1.6%
	• Transport	-0.4%	-0.1%	-0.3%
	• Other sectors	-7.9%	0.0%	-7.9%
Denmark	Overall	-7.1%	-2.0%	-5.0%
	• Manufacturing	5.5%	-0.9%	6.4%
	• Electricity	0.9%	0.5%	0.4%
	• Transport	-6.6%	-2.1%	-4.5%
	• Other sectors	-6.8%	0.5%	-7.3%
Estonia	Overall	-14.9%	0.0%	-14.9%
	• Manufacturing	2.6%	1.4%	1.2%
	• Electricity	-2.4%	-0.6%	-1.9%
	• Transport	-0.8%	-0.4%	-0.5%
	• Other sectors	-14.2%	-0.4%	-13.8%

Finland	Overall	0.2%	-0.7%	0.9%
	• Manufacturing	1.1%	-0.1%	1.3%
	• Electricity	0.1%	-0.1%	0.2%
	• Transport	-0.4%	0.3%	-0.7%
	• Other sectors	-0.6%	-0.7%	0.0%
France	Overall	6.8%	2.8%	4.0%
	• Manufacturing	2.8%	2.7%	0.1%
	• Electricity	1.0%	-0.4%	1.5%
	• Transport	0.5%	0.3%	0.2%
	• Other sectors	2.5%	0.2%	2.2%
Germany	Overall	1.0%	-1.5%	2.5%
	• Manufacturing	-0.2%	-1.9%	1.7%
	• Electricity	-0.3%	-0.3%	0.0%
	• Transport	0.8%	0.1%	0.7%
	• Other sectors	0.6%	0.6%	0.1%
Greece	Overall	-11.7%	2.2%	-13.9%
	• Manufacturing	-1.9%	3.1%	-5.0%
	• Electricity	-0.8%	-0.8%	0.0%
	• Transport	-4.1%	-0.9%	-3.3%
	• Other sectors	-4.9%	0.7%	-5.7%
Hungary	Overall	-5.2%	-2.9%	-2.3%
	• Manufacturing	-1.6%	-1.8%	0.2%
	• Electricity	-0.3%	0.0%	-0.3%
	• Transport	-1.4%	-0.2%	-1.1%
	• Other sectors	-2.0%	-0.8%	-1.1%
Ireland	Overall	6.5%	-2.8%	9.2%
	• Manufacturing	5.6%	-7.4%	12.9%
	• Electricity	0.8%	0.9%	-0.1%
	• Transport	0.4%	1.4%	-1.0%
	• Other sectors	-0.3%	2.3%	-2.6%
Italy	Overall	1.7%	0.0%	1.7%
	• Manufacturing	0.0%	-0.4%	0.4%
	• Electricity	0.2%	0.6%	-0.4%
	• Transport	0.6%	0.1%	0.6%
	• Other sectors	0.9%	-0.2%	1.1%
Latvia	Overall	-6.1%	-1.9%	-4.3%
	• Manufacturing	1.4%	1.7%	-0.3%
	• Electricity	0.3%	-0.7%	0.9%
	• Transport	-3.6%	-0.7%	-2.9%
	• Other sectors	-4.2%	-2.2%	-2.0%
Lithuania	Overall	-12.4%	-4.2%	-8.1%
	• Manufacturing	-4.1%	0.0%	-4.2%
	• Electricity	0.7%	0.2%	0.5%
	• Transport	-7.8%	-3.0%	-4.7%
	• Other sectors	-1.2%	-1.4%	0.2%

Luxembourg	Overall	5.5%	8.2%	-2.7%
	• Manufacturing	5.7%	6.0%	-0.4%
	• Electricity	1.2%	0.6%	0.6%
	• Transport	-2.1%	0.1%	-2.3%
	• Other sectors	0.8%	1.5%	-0.7%
Malta	Overall	-2.1%	7.0%	-9.1%
	• Manufacturing	7.5%	4.8%	2.6%
	• Electricity	-0.1%	0.3%	-0.4%
	• Transport	-2.2%	0.1%	-2.3%
	• Other sectors	-7.2%	1.8%	-9.1%
Netherlands	Overall	2.3%	2.6%	-0.3%
	• Manufacturing	0.6%	2.1%	-1.6%
	• Electricity	0.4%	0.3%	0.2%
	• Transport	0.4%	0.2%	0.2%
	• Other sectors	0.9%	0.0%	0.9%
Poland	Overall	-26.9%	-5.4%	-21.5%
	• Manufacturing	-7.3%	-1.1%	-6.1%
	• Electricity	-3.5%	-1.1%	-2.4%
	• Transport	-3.4%	-1.0%	-2.4%
	• Other sectors	-12.8%	-2.2%	-10.6%
Portugal	Overall	-0.3%	2.7%	-3.0%
	• Manufacturing	-0.9%	1.3%	-2.2%
	• Electricity	0.7%	0.9%	-0.2%
	• Transport	-0.9%	0.3%	-1.2%
	• Other sectors	0.8%	0.1%	0.6%
Romania	Overall	-4.9%	-4.2%	-0.6%
	• Manufacturing	-3.3%	1.2%	-4.5%
	• Electricity	-0.7%	-1.1%	0.4%
	• Transport	0.8%	-1.3%	2.1%
	• Other sectors	-1.7%	-3.1%	1.4%
Slovakia	Overall	-10.4%	-5.8%	-4.6%
	• Manufacturing	-12.9%	-3.2%	-9.7%
	• Electricity	-0.3%	-0.6%	0.3%
	• Transport	0.5%	-0.4%	1.0%
	• Other sectors	2.3%	-1.5%	3.7%
Slovenia	Overall	-1.2%	-4.4%	3.2%
	• Manufacturing	0.2%	-2.9%	3.0%
	• Electricity	-0.8%	-0.4%	-0.4%
	• Transport	1.3%	-0.6%	1.9%
	• Other sectors	-1.9%	-0.5%	-1.3%
Spain	Overall	1.7%	1.4%	0.2%
	• Manufacturing	-0.2%	2.2%	-2.4%
	• Electricity	0.5%	-0.1%	0.6%
	• Transport	0.1%	0.0%	0.1%
	• Other sectors	1.2%	-0.7%	1.9%

Sweden	Overall	8.3%	0.2%	8.0%
	• Manufacturing	3.1%	0.2%	2.9%
	• Electricity	0.9%	0.2%	0.7%
	• Transport	1.3%	0.0%	1.3%
	• Other sectors	3.0%	-0.2%	3.2%
EU27	**Country difference**	**Manufacturing**	**Electricity**	**Transport**
Mean	-3.7%	-0.4%	-0.2%	-0.9%
Std. dev.	8.4%	4.4%	1.2%	2.4%

Source: Bruegel based on Eurostat. Note: The overall effects measure the deviations from the EU average for the share of GDP facing transition, for sector size and for transition preparedness respectively. These overall effects are taken from Table 2. The size (GVA) of the main sectors is reported in Table 1. A breakdown for the largest sectors – manufacturing (31.8%), electricity (27.6%) and transport (22.0%) – is provided. The bottom rows present the mean and standard deviations for the country differences at sectoral level.

bruegel

Bruegel, Rue de la Charité 33, B-1210 Brussels
(+32) 2 227 4210
info@bruegel.org
www.bruegel.org