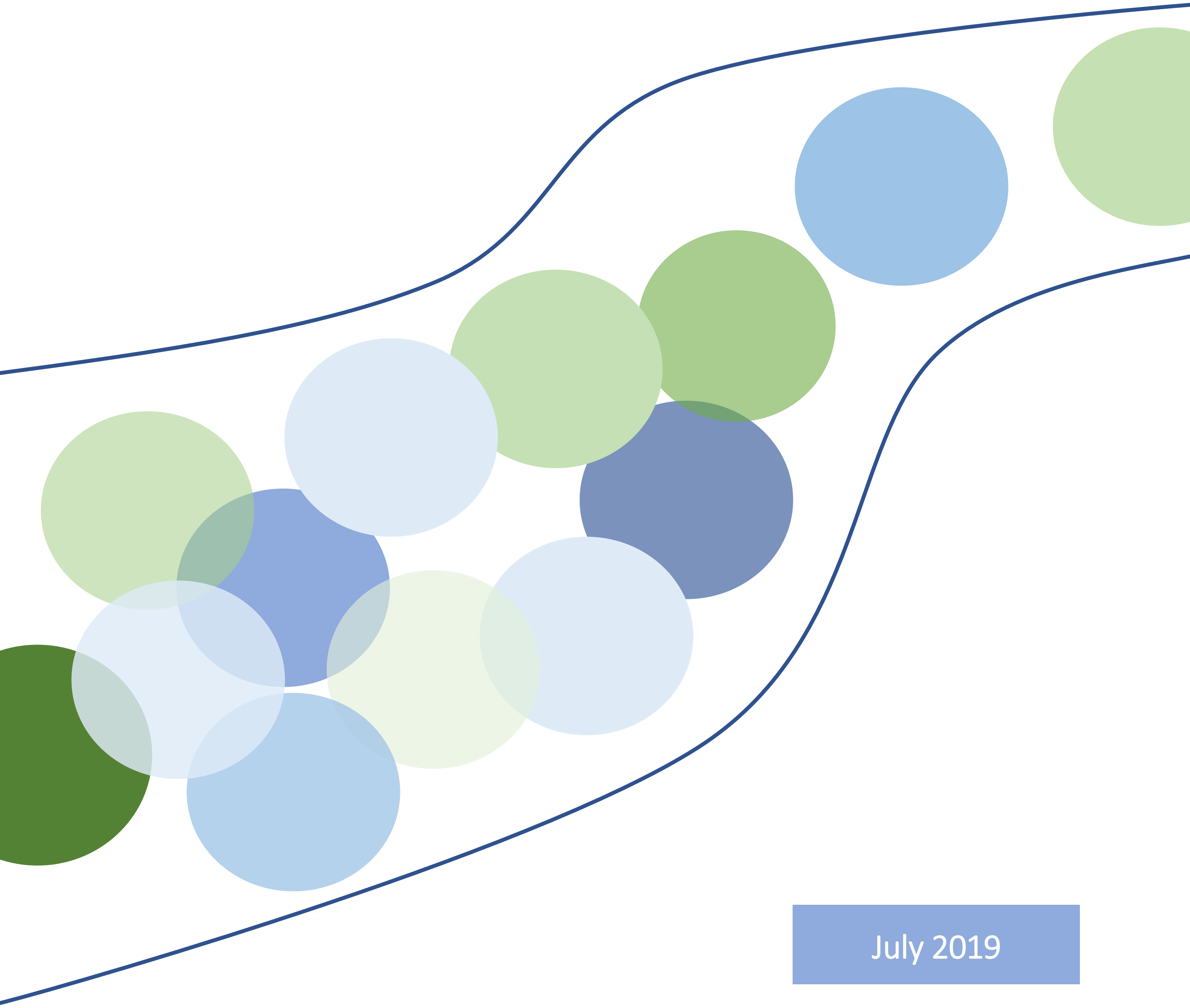
REEEM

Energy vulnerability and low carbon transitions in Europe



July 2019

About this report

This report has been undertaken under WP4 of the REEEM project ‘Role of technologies in an energy efficient economy – model based analysis policy measures and transformation pathways to a sustainable energy system’, and constitutes Deliverable 4.1b ‘Focus Report on distributional impacts’.

The authors would like to acknowledge the input to this report by the TIMES PanEU and NEWAGE teams at University of Stuttgart, particularly Pinar Korkmaz and Roland Montenegro, and to Russell McKenna who provided helpful review comments.

Authors

Steve Pye (UCL, London), Audrey Dobbins (IER, University of Stuttgart), Marko Matosović (EIHP, Zagreb), Vidas Lekavičius (LEI, Kaunas)

REEEM partners

About REEEM

REEEM aims to gain a clear and comprehensive understanding of the system-wide implications of energy strategies in support of transitions to a competitive low-carbon EU energy society. This project is developed to address four main objectives: (1) to develop an integrated assessment framework (2) to define pathways towards a low-carbon society and assess their potential implications (3) to bridge the science-policy gap through a clear communication using decision support tools and (4) to ensure transparency in the process.

The REEEM project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691739. This publication reflects only the views of its authors, and the European Commission cannot be held responsible for its content.

Contents

List of Figures

List of Tables

Member State abbreviations

AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR (or EL)	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherland
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

Summary

The low carbon transition envisioned for Europe is set to bring substantial benefits, from an increase in employment across specific sectors developing low carbon technology, to less reliance on fossil fuels and the associated price volatility, reduced levels of air pollution, and opportunities for lower energy costs through measures improving household insulation. However, it is inevitable that some households and industries more vulnerable to the changes that a rapid and large-scale transition brings could lose out, particularly if adequate mitigating measures are not put in place.

Recognising the sectoral and spatial distribution of impacts is important for two reasons; firstly, there is a need for broader stakeholder buy-in, which will be challenging to achieve if the low carbon transition is perceived as unfair. Secondly, the transition is a huge opportunity to address underlying structural problems across communities and industry, such as under-investment in inefficient buildings and the need for efficiency improvements to industrial processes.

This research is motivated by the absence of a recognition of distributional impacts in scenario analyses, particularly true of scenarios that use a techno-economic framing. It proposes a complimentary approach to highlighting the implications of different low carbon pathways for vulnerable regions, known as InVEST, or *Indicators of Vulnerability in Energy System Transitions*. This seeks to address the question of how we ensure that insights from modelled pathways used in strategy development take account of distributional impacts, and recognises vulnerable households and industries.

The InVEST approach first maps out different subnational regions across Europe that may be more vulnerable to impacts arising from the proposed low carbon energy transitions, based on a set of indicators. The indicator set captures energy vulnerable households, and industry sectors that are energy-intensive, both of which may struggle with increased costs, and sectors that are carbon-exposed, such as the coal sector. Based on the regional picture of vulnerability, the next step is then to consider how different pathways may impact such regions and communities in the future, if such vulnerabilities were to persist. We refer to regional vulnerability indicators as sensitivity metrics, and pathway impacts as exposure metrics, as per the vulnerability framing used in the climate impacts and adaptation field.

From the analysis the following findings emerge –

- Energy vulnerability in households is highest in regions of Eastern and Southern Europe, using both measures of affordability and lived experience. Factors giving rise to this include sufficiency of heating systems in colder periods of the year, while in Eastern Europe factors may relate to a range of issues from poor building fabric to inefficient energy systems.
- There are considerable differences in household energy vulnerability between countries as well as within regions in a country. This reflects differences in income between regions, and within regions, as shown by the analysis of deciles. For example, in Greece, the highest decile (10) has an average share of households unable to keep warm at 5%, while the lowest decile (1) has a share of 55%, a very large difference.

- The scenario metrics suggest that many of the energy vulnerable 'sensitive' regions in this research may also incur higher energy costs but also could see prospects of large investment, required to deliver the transition. This investment highlights the opportunity that the transition brings to resolving some of the underlying structural problems inherent in driving energy vulnerability (poor building stock, insufficient heating provision). Policy needs to manage the short-term risks of increasing cost, which could impact negatively on affordability, while incentivising and supporting the large-scale investment that is necessary.
- Specific regions have high concentrations of employment in vulnerable extractive sectors such as coal. Coal production and generation jobs are highly concentrated, based on regions with large extractive sites, notably Poland and Germany. The same is true for oil and gas extraction.
- All scenarios considered show rapid decline in both coal production and generation. Just Transition planning is therefore vital for the affected regions. This means planning focused on new opportunities for workers, which need to be put in place over the next decade.
- There are specific regions of Europe with higher shares of employees in energy-intensive industries, which could be subject to higher energy cost pressures, and in some case, global competitive pressures. Regions include those located in Eastern Europe, BENELUX, and parts of Scandinavia, where there is a focus on metals, non-metallic minerals, paper and pulp, and to a lesser extent, chemicals.
- The transition does see energy cost increases for these industries, but like in the residential sector, in large part the increase is driven by investments in low carbon technologies and cleaner fuels. If Europe is to compete in a low carbon world and retain its heavy industrial base, large investments will be required.
- Regions that have a higher dependency on energy-intensive industries do not necessarily experience higher costs under the scenarios. There is no obvious pattern between sensitivity and exposure for the scenarios used in this analysis. The main conclusion to draw from the analysis is that large investment will be needed across most regions to ensure a move to a low carbon system, allowing for the renewal and modernisation of different industry sectors.

This analysis highlights some of the regional vulnerabilities in both the household and industry sectors that should be considered by policymakers when thinking through the implications of low carbon transitions. Usefully there are key concepts in the policy discourse that will help embed such considerations, including Just Transitions and Energy Poverty. The former relates to industry, and concerns the protection of workers in industries that may be more vulnerable to sustainable development policies. The latter reflects a situation where households are unable to adequately meet their energy needs at an affordable cost, and arises due to a combination of inter-related factors including low income, high energy prices, and poorly insulated buildings.

Specific policy recommendations arising from this analysis include -

- Explore how the existing EU legislative process can further promote a recognition of distributional impacts. While energy poverty considerations are becoming increasingly integrated into EU policy, there is scope for further strengthening and integration into the policy process. The same is true of the preparedness for ensuring a just industrial transition that safeguards most industries and allows for a managed exit for others e.g. coal.

- Plan how new policies need to be designed to anticipate the needs of households and industrial sectors. The long-term climate policy goals and scenario exploration of these goals provide insights into some of the likely impacts. Therefore, policy makers know in advance of how such a transition may play out.
- Explore best practice in addressing energy vulnerability across different countries. Following on from the previous point, an interesting idea would be to develop a Just Transitions Observatory for Europe in the same way as there is now one established for energy poverty, to bring together metrics, examples of best practice, and to link up policy makers and researchers.
- Given that issues of vulnerability cut across different areas of policy, it is important that energy and climate policy are joined up with what is happening on social and economic (or industrial) policy, particularly as it relates to specific regions.
- Subnational analysis is critical for informing strategy and policy design. None of the above regional insights are possible without more spatially-disaggregated analysis. It would seem like a useful practice to build up the ESPON-funded Territorial Impact Assessment (TIA) approach, adopted strongly by the European Committee of the Regions – and think about how this can be mainstreamed into the Commission's impact assessment process.

This research was very much an exploration of how to enrich scenario analyses by providing additional information to enable a discussion of distributional impacts, reflecting that different regions and the sectors in those regions might be differentially impacted. Other emerging approaches mean that there is potential for developing the research in this area. A number of research recommendations emerge from this REEEM study -

- Ensure that vulnerability assessment for transitions take account of the broader impacts. The approach proposed in this research did not cover transport, and for those sectors that were considered, a relatively narrow set of metrics was used.
- Explore how regional resilience and policy intervention can be integrated for a more nuanced picture of how communities and sectors can mitigate negative impacts / enhance positive effects. This reflects that this study did not focus on exploring resilience or adaptive capacity of different regions, which are important for better understanding sensitivity of the impacts of a low carbon transition.
- Use both qualitative expert judgement on potential impacts, as used in the TIA methodology, alongside quantified scenario metrics, used here, to gain benefits from both types of approaches.
- Feed into data collection activities and agencies the needs of this type of assessment, and explore other data that could be used here, drawing on the expertise of the ESPON programme in particular.

1. Introduction

Highlighted in its recent long-term vision document, *A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy*, the (European Commission, 2018a) sets out how the energy system will need to be close to carbon neutral (net-zero CO_2 emissions) by the middle of the century. Such a transition to a low carbon energy system and economy will transform the production and delivery of energy services, require large-scale investment, and involve a wide range of actors to implement.

There will be benefits from this transition, from an increase in employment across specific sectors developing low carbon technology, to less reliance on fossil fuels and the associated price volatility, reduced levels of air pollution, and opportunities for lower energy costs through measures improving household insulation. However, it is inevitable that some households and industries more vulnerable to the changes that a rapid and large-scale transition brings could lose out, particularly if adequate mitigating measures are not put in place. For example, the period of price increase in Germany during the Energiewende has led to price increases, with concerns for lower income consumers (Frondel et al., 2015).

These challenges are highlighted to some extent in the Commission's long term climate strategy (European Commission, 2018a), for industry sectors that are facing decline or who will need to transform, and in specific regions more economically dependent on such sectors. The risk to households is also highlighted, for those that may be disproportionately impacted by increased costs, resulting in affordability concerns. The strategy notes the need for policy measures to mitigate these distributional effects because they '*have the potential to increase social and regional disparities in the EU as well as hamper the decarbonisation efforts.'* Compared to the earlier 2011 roadmap (European Commission, 2011a), which briefly covered some of these issues, this vision document puts a stronger emphasis on the socio-economic impacts of the transition, with a specific 'Social transition' document, and the objective to ensure fairness in the transition.

This stronger recognition of the distributional impacts of the transition reflects increasing visibility of and action on these energy vulnerability issues at the European level, specifically on consumer vulnerability and energy poverty[1], and on transitions for different exposed industry sectors.[2]

There remain some key challenges to European policy in developing options for implementation that account for energy vulnerability. Firstly, there is an absence of a suite of indicators on vulnerability across member states that provide a more comprehensive understanding of the location and scale. Secondly, there is no systematic appraisal of distributional impacts in this policy domain, through more disaggregated analysis of impacts across different socio-economic and industrial groups at subnational scales. While the technical analysis underpinning the recent long term vision has some assessment on impacts of regional industries ((European Commission,

---

[1] For example, the European Commission has set up an energy poverty observatory to 'improve the measuring, monitoring and sharing of knowledge and best practice on energy poverty'.

[2] Dedicated initiatives to support regions with higher coal and energy intensive industry dependence were launched as part of the Clean Energy for All Europeans package. https://ec.europa.eu/commission/sites/beta-political/files/support-action-coal-carbon-intensive-regions_en.pdf

2018b), chapter 5), previous impact assessments for earlier Roadmaps (European Commission, 2011b) avoided discussion of distributional impacts, with a clear focus on economic efficiency. This same deficit at the national level has recently been highlighted in the UK by (Zimmermann and Pye, 2018), who found a distinct lack of distributional analysis across energy and climate policy impact assessments. Thirdly, while this turns out not to be the case (as we discuss later), a motivation for this research was the lack of a clear framework for how vulnerability assessment could be taken forward.

Without both a broader, enhanced understanding of vulnerability across member states, there is a risk that specific regions are 'left behind' because of insufficient focus on and resulting resources into assisting communities with greatest need. This matters for two reasons; the first reason concerns the scale of the transition and the need for policies that implement the transition to gain societal buy-in. In reflecting on the recent Gillet Jaunes unrest over tax policy in France, the editorial in (Nature Energy, 2019) states that *'Energy policy should be mitigating … distributional disparity. In attempting to inform policy, scenario modelling could do more to examine the effects of rising disparities'*. Politicians can also be very sensitive to energy and climate policy if they sense that it is perceived as unfair and therefore unpopular, as the debate over the role of green levies in UK energy bills has proven.[3] Furthermore, this is set against the backdrop of increasing disillusionment with the economic systems (through globalisation) and the political classes, as manifested in Brexit, creating additional argument for transition policies that gain buy-in and are perceived as fair.

Therefore, holding issues of equity and fairness in mind is important. Policymaking without considerations of distributional impacts and notions of equity and fairness could foster resistance to change, and impact on progress in moving towards a lower carbon system. A report by the (OECD, 2017) set out the importance of a transition that is inclusive, with the benefits of new growth distributed more equally across society. Equitable distribution across society is considered key to reduce '*potential opposition to climate change policies and help to ensure existing inequalities are not compounded in the transition*' (OECD, 2017).

The second reason for recognising and dealing with vulnerability is that it provides an opportunity for addressing structural problems. For example, it could well be the catalyst for policies that retrofit poor building stock to improve energy efficiency, or increase diversification of local economies through low carbon industries and supply chains. Effective policy that mitigates unequal outcomes could address inequality more broadly; this is important as more equal societies do better across these domains (Wilkinson and Pickett, 2009). As (Chancel et al., 2017) notes, increasing *'inequalities is policy-driven: all the major drivers identified in the literature point to a certain extent to a policy failure. If policies, rather than exogenous forces drive rising inequality, then implementing more inclusive policies can reverse the trend.'*

In addition to the above two key reasons, there is a justice argument for recognising the distributional impacts of transitions, with unmanaged transitions often having a detrimental impact on communities. Work reflecting on coal transitions led by IDDRI (Caldecott et al., 2017) suggest that most coal transitions have left *'long-term*

---

[3] An example article that highlights this debate – 'MPs say green levies WON'T increase bills in longer term', https://www.energylivenews.com/2013/12/03/mps-say-green-levies-wont-increase-bills-in-longer-term/ (Accessed 12th March 2019).

effects on specific regions, often with high dependency ratios (non-working to working population), low educational attainment, below average wages and wage stagnation, environmental problems related to site remediation, etc. This often appears to be a legacy – at least in part – of a failure to anticipate and prepare for the transition.' It also notes that experience suggests that the cost of not supporting a transition can be much higher than the costs of the transition.

This research makes the case that long term scenario thinking should consider vulnerabilities across households and industries, to ensure that model results that characterise future pathways can be more effectively 'translated' for given regional contexts. This is particularly important if such results end up informing EU strategy and policy, or the debate around necessary action. In this report, we set out a complimentary approach to explore how pathway insights from techno-economic models, which typically focus on economic efficiency, can be translated through a vulnerability framing.

In summary –

1. Energy vulnerability implications of medium to longer-term transition pathways are useful to recognise and assess. Decision makers can then take stock of the possible risks for vulnerable groups and think about mitigation measures in the policy packages that follow.
2. Much of the pathways analysis is provided by techno-economic models that provide no insights on distributional implications. These models are likely to be used for some time to come.

   Given the policy need in 1) and the use of energy system models in 2), it makes sense to explore how these two issues can effectively interface.

Chapter 2 focuses on setting out what is meant by vulnerability, and how such issues are currently being considered in European policy. Chapter 3 sets out an approach for thinking about vulnerability in the context of long term pathway analysis, as is being undertaken in the REEEM project. Chapter 4 describes the vulnerability metrics used. Chapter 5 considers the implications of different scenario pathways on vulnerable regions. Chapter 6 highlights key research messages, proposing insights for EU policy, and setting out the future research agenda.

2. Energy vulnerability under low carbon transitions and policy and modelling responses

2.1. Framing vulnerability in energy transitions

There is a growing literature on how transitions may impact communities and industry sectors differentially, due to their vulnerability to such change, and what these distributional impacts imply for notions of equity and fairness. (Hall et al., 2013) consider issues of equity and justice in the energy sphere, linked to those on vulnerability. Equity can be thought of 'in terms both of access to affordable, safe and reliable energy and of the distribution of the risks and benefits of new technologies', varying over time and space and between and within groups in society. On justice, this concerns ideas of distribution, recognition and procedure, using the conceptual framework from (Jenkins et al., 2016). Distributional justice concerns where injustices arise and how they can be dealt with e.g. energy poverty in specific types of households. Recognitional justice focuses on which parts of society are ignored and misrepresented, and how this should be rectified. Finally, procedural justice focuses on issues of adequate engagement in the energy policy process. On issues of energy vulnerability, these have mainly been associated with the household sector, and associated with circumstances that underpin the risk of falling into fuel and energy poverty (Bouzarovski et al., 2017).

For the purposes of this research, we use the term 'energy vulnerability' to mean 'the propensity to be adversely affected by the collective negative impacts of [energy] policies' (Carley et al., 2018). Inherent in this is a recognition that impacts are distributed differentially across groups and across different localities, and therefore we most closely align to the idea of distributional justice.

A common thread running through much of the literature on energy justice is the notion that much of the energy policy debate, and analytical tools used to support it, fail to take into account social justice concerns. (Sovacool et al., 2016) argue that '*all too often, energy policy and technology discussions are limited to the domains of engineering and economics.*' Absent is the consideration of broader social justice concerns. Concepts of energy justice in energy systems, which focus on the fairness of how benefits and costs of energy services are distributed can help focus policy more on the societal implications of energy policy. (Sovacool et al., 2016) put forward a framework for decision-making to ensure justice issues are considered in energy policy and strategy, not just techno-economic issues. (Sovacool et al., 2017) also identifies that consideration of justice concerns can expose trade-offs and tensions in decision making, particularly as 'justice' defined across multiple critieria, and dimensions of time and space will differ between communities. For example, action on pollution reduction might have significant benefits for reducing harm for a specific community now but may have increased costs through loss of jobs or funding clean-up activities for other communities now or in the future.

(Miller et al., 2015) and (Miller and Richter, 2014) also highlight that '*energy policy remains a largely techno-economic problem*' with very limited consideration of human and social dimensions. Coming from the perspective of socio-technical transitions theory, they propose the term *socio-energy systems* defined as *'sets of interlinked arrangements and assemblages of people and machines involved in the production, distribution, and consumption of energy, in their supply chains, and in the lifecycles of their technologies and organizations.'* An argument for conceiving transitions in this way is that policy discussions can reflect on social change, its associated risk and how it meets societal goals e.g. reducing inequality. These papers highlight that part of this approach means methods for assessing outcomes of energy policy of different groups, such as how costs and benefits of energy production and consumption are distributed, often '*in highly heterogeneous ways across contemporary societies. Designing and developing just energy systems requires attending to how these factors are distributed across different physical, social, cultural, and economic geographies'* (Miller et al., 2015). (Miller and Richter, 2014) summarises new methods that (1) emphasize social dimensions e.g. wellbeing, equity, as outcomes of energy systems; (2) assess how costs and benefits are distributed; and (3) evaluate the implications of change for marginalized groups.

Most of the emerging thinking on energy justice and distributional implications comes from the social science field. A key questions is how this conceptual thinking can be more embedded in the field of quantitative techno-economic analysis that dominates the energy policy field.

2.2. Key concepts concerning vulnerability in the energy policy domain

There are two key ideas around energy justice, vulnerability and distributional impacts that have taken root in the climate and energy discourse in recent years – 'Just Transitions' and 'Energy Poverty'.

Just Transitions

Just Transitions relates to protection of workers in industries that may be more vulnerable to sustainable development policies. Although not only relevant to industry, the concept is most closely associated with the trade union movement. The UK Trade Union Congress stated that a '*Just Transition recognises that support for environmental policies are conditional on a fair distribution of the costs and benefits of those policies across the economy, and on the creation of opportunities for active engagement by those affected in determining the future wellbeing of themselves and their families*' (TUC, 2008). The agenda is very much one of both vulnerability but offset by the potential opportunities (Greenpeace / TUC, 2015).

There is a recognition that a low carbon transition needs to recognise the different opportunities and risks of the transition to different industries. This needs to be planned and well managed. Guidelines for facilitating just transitions have been put forward by the ILO (International Labour Organization, 2015), including –

- Policy coherence across economic, environmental, social, education, training and labour portfolios to generate an enabling environment for the transition.
- The anticipation of impacts on employment, social protection for job losses and displacement, skills development and social dialogue ‐ including the right to organise and bargain collectively.
- The need to take into account the specific conditions of countries, including their level of development, economic sectors and sizes of enterprises ‐ no "one size fits all" solutions.

A Just Transition Centre has also been established by the International Trade Union Confederation, which aims to bring relevant stakeholders together to 'develop plans, agreements, investments and policies for a fast and fair transition to zero carbon and zero poverty.'[4]

The Paris Agreement includes the concept at the start of the document, stating that Parties take *into account* the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities (United Nations, 2015). At the recent COP24 in Katowice, the Polish government put the issue at the heart of discussions about how the international community tackles climate change. They published the *Solidarity and Just Transition Silesia Declaration*,[5] which was committed to by multiple governments to take seriously the need for support of workers impacted by job losses and changing employment conditions. Clearly this agenda is very important to Poland, given its sizeable coal sector, and there have been concerns that the Just Transition agenda could be used as a brake on more ambitious action.[6] However, the support for the declaration also suggests tha this issue is gaining traction across other countries.

This agenda is also reflected in the EU's recent long term vision document for a low carbon transition *A Clean Planet for all*, where it states that the *'……ensuing deep modernisation process will have to be managed well, ensuring a fair and socially acceptable transition for all in the spirit of inclusiveness and solidarity.'* Other research institutes, such as the (OECD, 2017), have also made the case for a just transition, stating that '*Jobs will be lost, even if the shift to low emission, climate-resilient economies could result in net job creation*. *So a 'just transition' is needed (as recognised in the Paris Agreement) that creates jobs in low-emission sectors, anticipates changes in employment patterns and fosters business plans that help workers find new jobs and opportunities*.'

Different industry sectors across Europe are also highlighting the need for a just transition, for example, Eurelectric[7]. Institutional investors have also started to commit to and determine how they can effectively back a Just Transition[8], with research by (LSE Grantham Institute, 2018) providing an important basis for this. (Gambhir et al., 2018) provide a useful review of who might be adversely affected, and reflect on examples of previous or ongoing transitions to assess how adverse impacts may be mitigated. They note that features of successful transitions include –

- Policy-assisted managed decline, and promotion of new industries. This needs to be done as early as possible, to allow for the time to put measures in place, and address adverse impacts.
- Collaboration and dialogue to ensure procedural justice and buy-in to the transition
- Targeted social protections to mitigate short term losses. This is also highly relevant to the household energy vulnerability.

---

[4] Just Transitions Centre, https://www.ituc-csi.org/just-transition-centre

[5] Just Transition Declaration, https://cop24.gov.pl/presidency/initiatives/just-transition-declaration/

[6] IDDRI (2018). The Just Transition Silesia Declaration - Stepping up the transition and anticipating the redevelopment needs. https://www.iddri.org/en/publications-et-evenements/billet-de-blog/declaration-de-silesie-sur-la-transition-juste-la

[7] Eurelectric statement on a Just Energy Transition, https://www.eurelectric.org/media/2185/statement-energy-just-transition.pdf

[8] Business Green (2018), Investors worth $5tr in assets pledge to back 'just transition' guidelines, https://www.businessgreen.com/bg/news/3067827/investors-worth-usd5tr-in-assets-pledge-back-just-transition-guidelines (Accessed 12th March 2019)

- Investment in infrastructure, skills and training, and alternative industries. This requires an active and properly funded industrial policy.
- Government and business led investment in education and innovation

Some selected examples of measures aimed at ensuring a Just Transition are highlighted below in Box 1.

Box 1. Lesson from past transitions and examples of measures across different countries to help ensure a Just Transition

Past transitions

A range of studies have looked at previous transitions, often away from coal production or due to economic re-structuring, to reflect on what is required for future low carbon transitions. A study by (E3G, 2016) reflects on lessons from the transition away from coal in German's Ruhr area (starting in the 1960s) and large scale economic change in Eastern Germany in the 1990s. They highlight that successful structural policy requires three aspects, all of which are relevant for a move away from coal today. These include –

- Forums of Participation and Dialogue
- Support and compensation schemes for workers in affected sectors
- Regional support schemes to promote economic diversification and reorientation

A significant amount of work has been done under the recent EU-funded Coal Transitions project to reflect on different country experiences (Caldecott et al., 2017). This IDDRI report focused on coal transitions in 5 countries – USA, UK, Poland, Germany, Czech Republic and the Netherlands. The review notes that these are difficult processes, often due to the political economy factors such as geographical concentration, cultural identify, human capital issues (non-transferable skills) and lack of workforce mobility. It concludes that anticipation and acceptance of the transition is key, that financing of the transition needs to be thought through, there needs to be a long-term focus, and local circumstances will determine how to mitigate impacts. While the USA case study was considered in this report, the challenges in recent years faced by the US coal sector and the social impact on many of the areas are also well covered by (Popa et al., 2016), as are some of the solutions to manage such transitions.

Current practice

The (Just Transition Centre, 2017), set up by the International Trade Union Confederation (ITUC), has played an important role in raising the issue of just transitions, and in their report for the OECD, highlighted some interesting examples of the types of measures that could be envisioned.

- ENEL, Italian power company, shutting down many thermal generation plant, and entering into a just transition agreement with the unions. The agreement includes retention of workers, their redeployment and reskilling, and early retirement for elderly workers.
- The Canadian Government, in 2016, pledged to remove coal generation from the mix by 2030. As part of this they instigated a just transition process for workers affected, with a commitment to set up a task force to consider measures needed. In 2019, the task force published its recommendations.[9]
- Pacific Gas and Electric (PG&E), a Californian power utility, came to decision to close the Diablo Canyon nuclear power facility. A closure plan was put in place that, with a relatively long lead-time to closure (in 2025), offered workers

---

[9] Task Force: Just Transition for Canadian Coal Power Workers and Communities, https://www.canada.ca/en/environment-climate-change/services/climate-change/task-force-just-transition.html

retraining and redeployment provisions, and generous redundancy. A Just Transition Fund was also put in place to compensate the community for lost tax revenues and to create new jobs in renewable energy and energy efficiency.[10]

- The transition to wind power in Denmark started back in the 1970s, away from thermal power, and was based around a strong social dialogue that included the unions. This was a just transition towards a new industry, creating numerous job in the renewables sector, and increasing investment.
- Schweinfurt in Germany is heavily dependent on the automotive industry, and therefore faces a key challenge from decarbonisation policies. An NGO, Friends of the Earth Bavaria and the local union (metalworkers) collaborated to explore how to improve energy efficiency of plants and processes, skills development, improved mobility, and prospects for new job opportunities.

Other examples include –

- The Alberta Government, in 2017, establishing a $40 million Coal Workforce Transition Fund to provide income support to workers transitioning away from employment in coal mines and generation, to new jobs or retirement. This is in addition to an established Coal Community Transition Fund exploring regional economic diversification.[11]
- An Australian power company, AGL, announced that the closure of Liddell Power Station by 2022, with the site set to be repurposed to produce electricity from gas turbines, battery storage and pumped hydro storage. The company has given the union a commitment that there will be no forced redundancies across the 300 strong workforce.[12]
- The POWER (Partnerships for Opportunity and Workforce and Economic Revitalization) initiative is a federal support programme in the US to help communities and regions affected by job losses in the coal sector. Examples of the types of projects set up through this initiative by the Appalachian Regional Commission (ARC) include education opportunities, retraining and support for new businesses.[13] The Appalachian region is one of the largest coal producing and using areas in the USA.

Energy poverty

Energy poverty is a situation where households are unable to adequately meet their energy needs at an affordable cost. It is caused by a combination of inter-related factors including low income, high energy prices, poorly insulated buildings, inefficient technologies and sometimes limited access to clean and affordable energy sources (Dobbins et al., 2019). While it has traditionally been recognised primarily in West European countries (France, Ireland, UK), it is increasingly gaining traction as an important policy area at the European level.

Until recently, the main European legislation for addressing energy poverty was the Third Energy Package relating to common rules for the internal electricity and gas markets, under Directives 2009/72/EC and 2009/73/EC. This legislation focused on the protections and safeguards for vulnerable consumers, providing for subsidiarity in terms of how such groups were defined (Pye et al., 2017). A stronger focus on energy poverty has recently been

---

[10] Further information can be found here - https://www.slocounty.ca.gov/Departments/Administrative-Office/Countywide-Projects-Programs/Diablo-Canyon-Power-Plant-Closure-Planning.aspx

[11] Transition supports for worker in Alberta's coal industry, https://www.alberta.ca/support-for-coal-workers.aspx

[12] Jobs protected under planned closure of Liddell power station, https://me.cfmeu.org.au/news/agl-liddell-plan-ensures-job-security-over-300-workers

[13] ARC project examples via the POWER initiative, https://www.arc.gov/funding/POWER.asp https://www.arc.gov/images/grantsandfunding/POWER2019/ARCPOWERAwardSummariesbyStateApril2019.pdf. Further information on the initiative can be found here - http://www.powerplusplan.org/power-initiative/

introduced by the Clean Energy for All Package, which make provisions in different directives more explicit in tackling energy poverty (Dobbins et al., 2019; Thomson and Bouzarovski, 2018).

A challenge has been to understand the extent of energy poverty in the EU, primarily due to poor availability of the necessary data. Depending on how it is defined, some estimates suggest in the region of 45-50 million people are affected by energy poverty (Thomson and Bouzarovski, 2018).[14] A number of analyses have pointed to higher prevalence of energy poverty in Southern and Eastern European EU member states (Bouzarovski, 2014; Bouzarovski and Tirado Herrero, 2017). (Thomson and Snell, 2013) also noted this spatial pattern, using EU-SILC statistics. They concluded that Bulgaria, Cyprus and Romania consistently displayed the worst levels of composite fuel poverty across the scenarios undertaken. It is also evident that manifestation of energy poverty is distinctive across and dependent on a range of factors in different localities. (Bouzarovski et al., 2017) notes a range of factors in exploring the issue in Central and Eastern Europe, including institutional change e.g. the process of moving from centrally planned to liberalised market, policy design and implementation e.g. use of energy efficiency programmes, and embedded vulnerability due to legacy infrastructure and location of different socio-economic groups. (Bouzarovski and Simcock, 2017) conclude that '*spatial differences in energy poverty and vulnerability are not the responsibility of variations in individual 'choices', but instead predominantly result from structural geographical inequities that are engrained in various stages of energy systems, and, moreover, in the fundamental infrastructural, economic, and cultural make-up of societies.'*

Vulnerability issues in Europe and the policy response

In its recent long term climate strategy, the (European Commission, 2018a) has explicitly stated the objective 'to present a vision that can lead to achieving net-zero greenhouse gas emissions by 2050 through a socially-fair transition in a cost-efficient manner.' The 'socially-fair' criteria recognises the notion that different parts of society will be differentially impacted and should not be ignored, with mitigating measures needed to be put in place. In its sister document on the social transition (European Commission, 2018c), the Commission states that *'both the EU and the Member States must take into account social implications from the outset and not as an afterthought.'* Concerning distributional impacts and vulnerable sectors, the focus is on energy-intensive and high carbon producing industries, and households with vulnerable energy consumers and those at risk of or experiencing energy poverty.

The Energy Union, published in 2015, sets out the principles for achieving a secure, sustainable, competitive and affordable energy system (European Commission, 2015). Crucially, this strategy also recognised the social impacts of the transition, stating that *'an energy transition that is just and fair will ……..require retraining or up-skilling of employees in certain sectors and, where needed, social measures at the appropriate level.'* In a recent report on the state of the Energy Union (European Commission, 2017), the Commission stated that while the transition may not benefit everyone in the short term '*it will, if carefully managed, ultimately benefit the entire EU economy, by creating new job opportunities, bringing savings on energy costs or improving air quality. Many*

---

[14] For example, based on the EU-SILC survey in 2016, 8.7% of households in the EU reported an inability to keep warm, equivalent to almost 45 million people.

of the enabling actions under the 'Clean Energy for all Europeans' package are meant to address the difficulties some regions or population groups have in reaping the benefits of the energy transition.'

On **households**, the Commission's strategy states that '*unless adequate regulatory or mitigating measures are in place, the transition bears the risk to disproportionally affect people with low income, leading to the emergence of some form of energy poverty. This risk has to be addressed.'* The analysis for the strategy finds that while energy costs rise in absolute terms, as a proportion of income they start to decline in most cases after 2030. However, it notes that those households in energy poverty may be less able to access the necessary measures to offset increasing costs.

While energy poverty has been a recognised concept by the European Commission, albeit without clear definition, since the introduction of the third Energy Package in 2009, there has been limited focused policy proposal, with a more narrow focus on the protection of vulnerable consumers in energy markets (Pye et al., 2017). A key response has been to strengthen proposals to combat energy poverty under the 'Clean Energy for All Europeans' package (European Commission, 2016), and fund research into gaining an improved understanding of energy poverty across the European Union. On legislative proposals, the proposed Electricity Directive requires member states to assess the number of households in energy poverty and take into account the necessary energy services needed to guarantee basic standards of living. Member states that have a significant number of households in energy poverty are also required to develop national objectives to reduce the problem. The now adopted Directive on the Energy Performance in Buildings makes a specific requirement for energy efficiency actions in buildings to target energy poverty (Dobbins et al., 2019).

Research to enhance understanding is being focused around the Energy Poverty Observatory (EPOV), which is exploring approaches to measurement of the problem, collating experience of policy action across member states, and facilitating collaboration amongst researchers (Thomson and Bouzarovski, 2018). An earlier scoping project to the EPOV funded by the Commission also explored the potential use of different metrics to measure and monitor energy poverty across member states (Rademaekers et al., 2016). Much of the work on vulnerability indicators described later in this report builds on this work.

On **industry**, the recent 2018 strategy notes the challenge for specific regions whose economies are more dependent on specific sectors expected to decline such as coal mining, and *energy intensive sectors such as steel, cement and chemicals as well as car manufacturers will see a shift to new production processes with new skills required.* The strategy identifies regions more economically dependent on such sectors as in Central and Eastern Europe. Overall, the workforce in these sectors is low; 0.5% in mining and 2% in energy-intensive industries. However, these proportions are much higher in specific regions.

Initiatives by the European Commission include the Coal Regions in Transition Platform. Under this platform, four projects have been set up in the following regions to assist with transition strategies - Trencin (Slovakia), Silesia (Poland), Western Macedonia (Greece), and Jiu Valley (Romania).[15] Another initiative is the Pilot Action for regions in industrial transition, with funding from the European Regional Development Fund (ERDF). This

---

[15] Presentation by Anna Colucci, DG ENER. Coal Regions in Transition Platform. June 2018. https://ec.europa.eu/energy/sites/ener/files/documents/1_eu_coal_regions_in_transition.pdf

currently has 12 projects supporting regions facing industrial transition, exploring ways to maximise innovation and new opportunities.[16] Ongoing research by the (JRC, 2018) has identified the regions most exposed to the transition, given their reliance on coal; this is discussed in more detail later in this report. Finally, the European Economic and Social Committee (EESC, 2016), a consultative body of the EU, has put out an opinion document stating the need for a ‘Transition Support Plan for the Communities and Regions Dependent on Coal Production’. It recommends that this should be developed around Just Transition principles.

2.3. Vulnerability considerations in energy transitions modelling

While increased efforts have been made to explore issues of vulnerability in the recent strategy document (European Commission, 2018a), relative to previous documents (European Commission, 2011a, 2011c), there is still an absence of vulnerability impacts on different socioeconomic groups in different localities. One could argue that such assessments are more applicable at the policy implementation level, when policy action is put in place to deliver the overarching strategy. However, even at this level it is evident that the distributive impacts of climate and energy policy have typically not been given sufficient attention, both at the EU level (Haug et al., 2010) and in member states, such as the UK (Zimmermann and Pye, 2018). This may be reflective not only of the priority in the policy appraisal process given to economic efficiency but also to the limitations of analytical tools to provide insights on this.

The need for energy policy and modelling to better recognise issues beyond techno-economics is well articulated by a number of authors (Jenkins et al., 2016; Miller et al., 2015). (Miller et al., 2015) note that ‘*current approaches to energy policy have become too narrowly constrained around problems of electrons, fuel, and carbon, the technologies that provide them, and the cost of those technologies.*’ In calling for a socio-energy thinking (as described earlier), the authors note two key problems with current modelling approaches; i) they limit energy systems to their technological elements, neglecting to treat the social and political dimensions as robustly, and ii) they reflect energy policy and governance as systemically organised, rather than being conducted piecemeal, as per reality. This paper poses the problem, as opposed to providing solution, and challenges the energy policy and modelling community to respond.

There are a number of research endeavours to explore how modelling tools and the approach to their use can shift towards better representing socio-technical transitions (Geels et al., 2016; Holtz et al., 2015; Li et al., 2015). In this research, we consider the continuing use of techno-economic scenario analysis, and how we might build a complimentary approach to exploring vulnerability. Techno-economic scenarios have played an important role in shaping the ideas of how energy system change can be realised. This is true for the EU, who have long adopted modelling as an essential part of assessing the costs and benefits of different proposals (Capros et al., 2018). This has also been the case over the last 15 years in the UK (McDowall et al., 2014; Taylor et al., 2014). Recognising the merits of this type of modelling, this provides the central modelling platform in REEEM.

---

[16] Pilot Action for Regions in Industrial Transition. https://ec.europa.eu/regional_policy/sources/docgener/informat/industrial_transition/pilot_industrial_transition.pdf

However, it is equally important to recognise the limitations, and consider how these might be addressed. Often vulnerabilities are hidden, with a lack of explicit recognition of potential winners and losers. This is often a function of the type of techno-economic model framing used, modelling at aggregated scale, model tractability, lack of data to input etc.

A paper by (Fell et al., 2019) argues that scenario analyses undertaken by energy models need to start considering distributional impacts. The paper finds that analysis of longer-term scenario analysis typically avoids such consideration. It maps the possible distributional impacts arising from the transition (Figure 1), and considers how some of these impacts could be considered in techno-economic modelling. Finally, via stakeholder interviews, the paper finds that while key challenges exist for integration into models, this is a useful avenue of research.

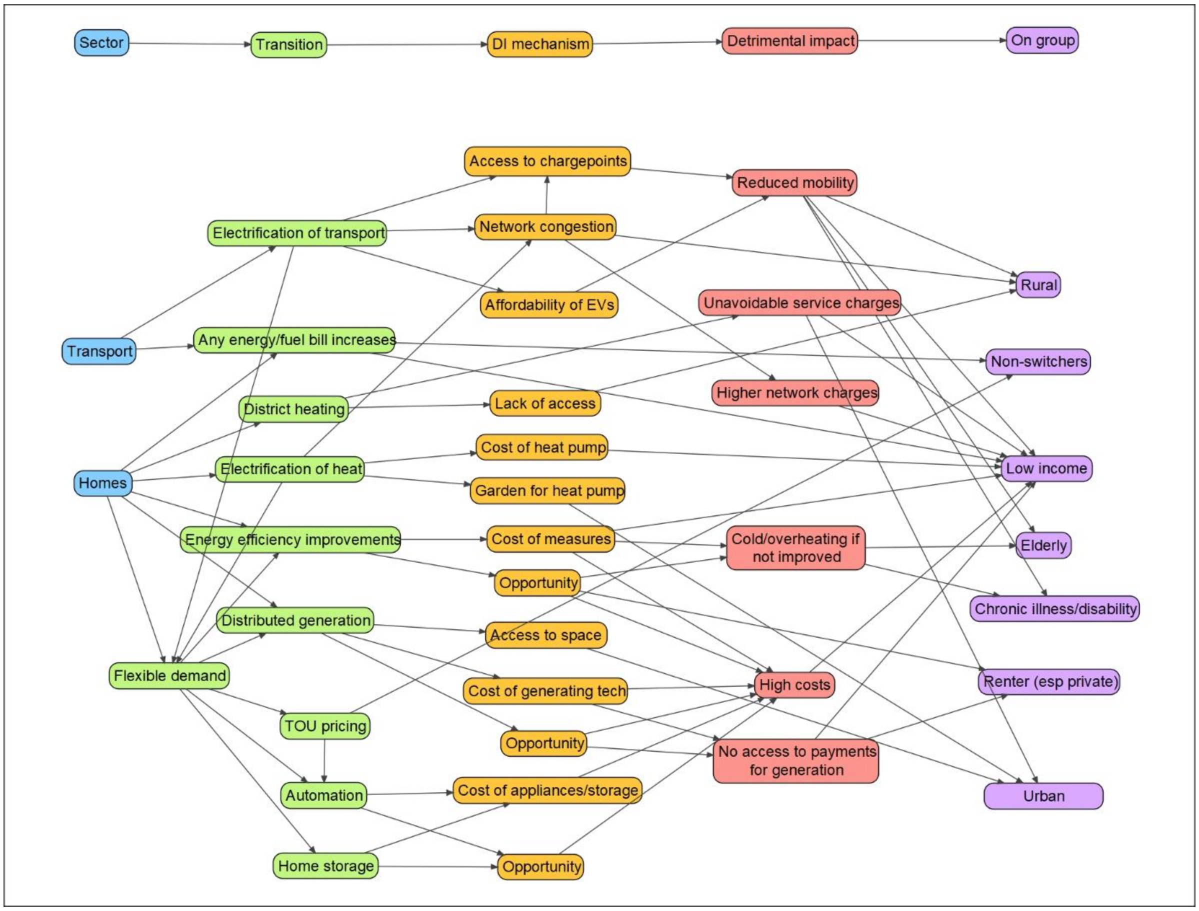


Figure 1. Mechanisms of distributional impacts, type of detriment and where and who these detriments might be expected to impact

Source: (Fell et al., 2019). Note that the above figure does not include industry, and the implications on households from reductions in employment, or the local economy impacts, arising due to declining industry sectors.

Implicit in the discussions of equity, justice and distributional impacts is that different industries and communities will see a disparity in exposure of the effects of a transition, sensitivity to the impacts, and means of response. Drawing from the climate adaptation literature, (Carley et al., 2018) propose a framework for thinking about energy transition vulnerability. They use a vulnerability scoping diagram (VSD) to think about vulnerability across three inter-related dimensions – exposure, sensitivity and adaptive capacity. Using this framework, they explore different ways of measurement across these dimensions to develop a vulnerability score for different regions in the US, based on the roll-out of renewable portfolio standards. Vulnerability in the energy context is defined as 'the propensity to be adversely affected by the collective negative impacts of policies.' A key strength of this framework is that it brings together issues of vulnerability across different sectors. In most research, the issues of household energy vulnerability and just transitions are discussed separately. The framework also allows for a more empirically based approach that could have utility for decision makers in determining vulnerability. We further consider how this framework can be applied in the next section of this report.

3. Approach

3.1. Concept

The research in REEEM fundamentally recognises the potential for energy system modelling to provide an integrated analysis of future systems, providing insights on technology mix, the investment requirements, and emission reductions potential. Crucially, it also recognises the limitations of a single techno-economic framework to provide full insight, and the need for ‘satellite’ linked models to help explore implications of different pathways. This concept is illustrated in Figure 2. This includes additional analysis, outside of the central TIMES PanEU model, on water, air pollution, macroeconomic impacts, life cycle emissions and materials, consumer behaviour and choice, and distributional impacts.

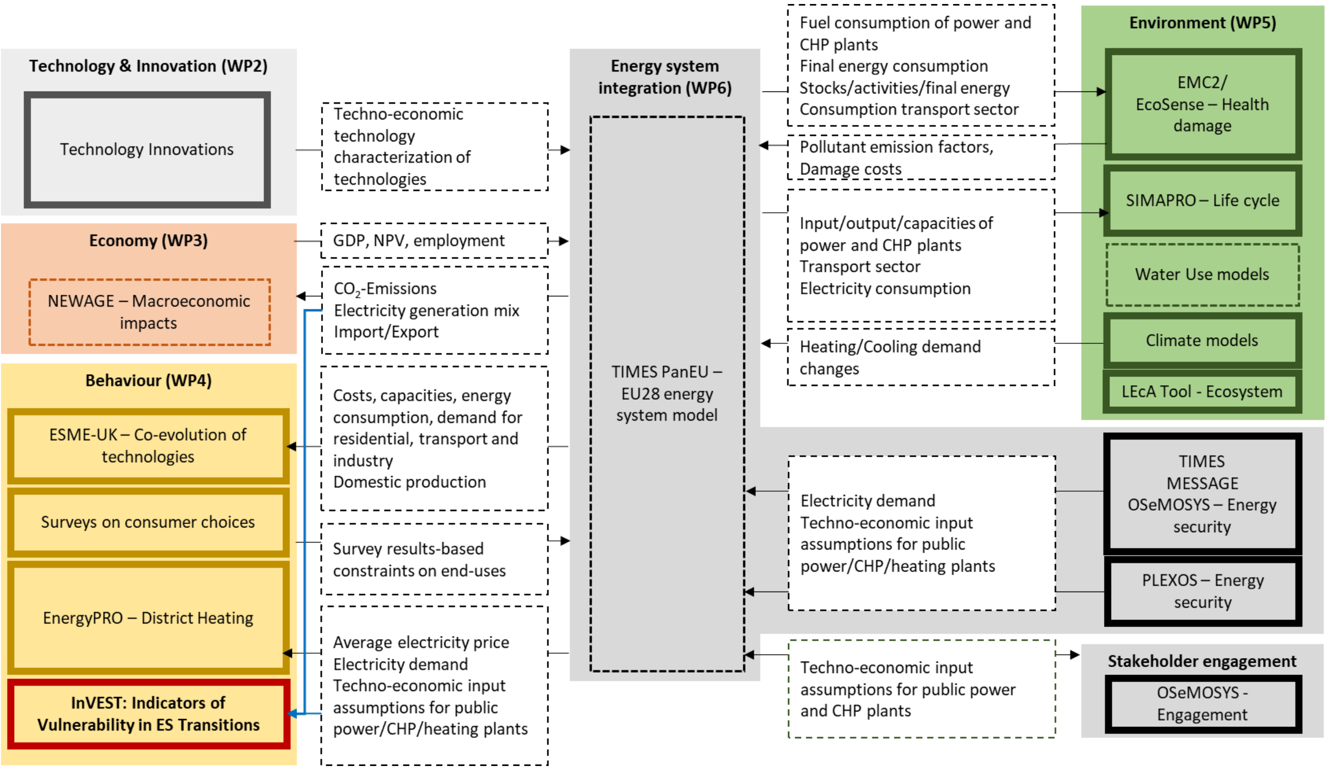


Figure 2. REEEM modelling framework. Blue lines represent inputs into the InVEST tool.

On distributional impacts, which are not typically considered in techno-economic analysis, the tool developed as part of this project is labelled InVEST, or *Indicators of Vulnerability in Energy System* Transitions. In the above framework, this tool is situated in the bottom left corner of the above figure. It aims to tackle the question of *how do we ensure that insights from modelled pathways used in strategy development take account of distributional impacts, and recognises vulnerable households and industries?*

The general approach is to map out different regions across Europe that may be more vulnerable to impacts arising from the proposed low carbon energy transitions, based on a set of indicators. Such indicators provide information on current vulnerability. They can be used to highlight the need for careful policy design, including differentiated action at the sub-national level. Given the observed regional vulnerability, a next step is then to consider how different pathways may impact such regions and communities in the future, if such vulnerabilities were to persist.

The concept is illustrated in Figure 3. EU wide indicators are first identified that highlight energy vulnerabilities across member state regions, for both the industry and household sectors. To gain a comprehensive picture, the approach requires the use of subnational datasets that are available across most member states. This feature of the approach constrains what vulnerability indicators can be considered.

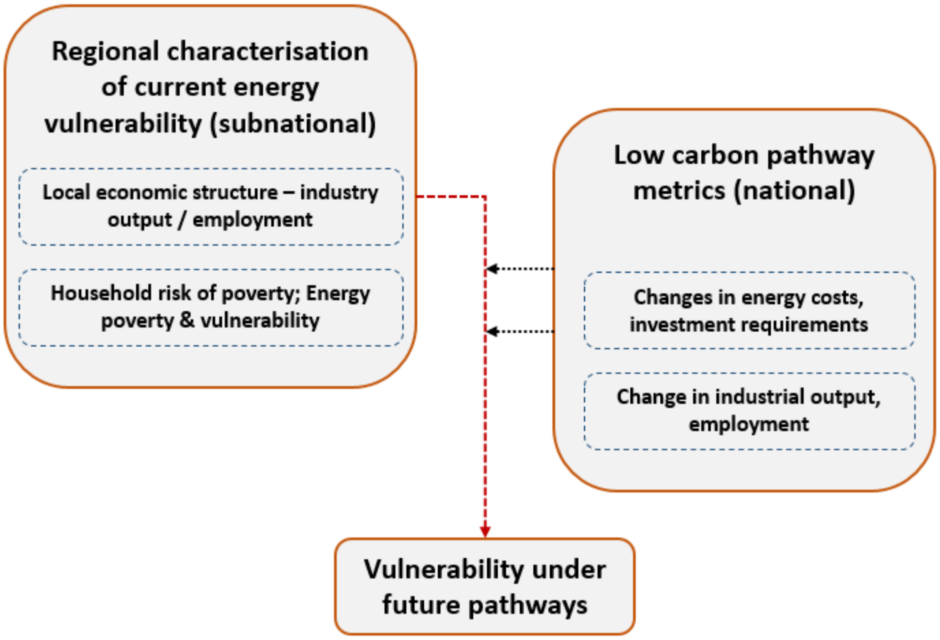


Figure 3. Concept of combining low carbon scenario metrics with proxy energy vulnerability datasets

A second aspect concerns how different future pathways may impact vulnerable regions, by combining pathway metrics with the subnational vulnerability indicators. For example, specific pathways may significantly drive energy costs upwards in the future, highlight poor prospects for specific industries, and / or result in large investment opportunities across specific technology groups.

The metrics from the modelling of different transition pathways are at the country-scale and provide an aggregate representation of sectors. They are therefore more spatially aggregated than the vulnerability indicators, at the subnational level. While this could be considered a limitation, it still allows for the recognition of the general characteristics of specific pathways and exploration of how these might impact vulnerable communities and industries. This can be justified in the sense that we are not attempting to undertake a quantified distributional impacts analysis for specific regions but rather highlight and recognise that i) there are existing vulnerabilities across member states and ii) different types of pathways could impact these stakeholders in different ways. To reiterate, this is not a standard distributional impact analysis focused on understanding specific policy impacts in detail in the near term[1]; rather, the approach envisaged here aims to ensure adequate recognition of distributional impacts across different scenarios in the medium to long term, in order that they feature in the policy debate.

A key benefit of this type of approach is that it avoids further disaggregation of large energy and economic models to identify vulnerabilities. Such models are more aggregated for good reason; they are already highly complex and rich in detail, and further disaggregation hits problems such as lack of data, complexity in interpretation of outputs, and increased computing resources etc. This approach was that described in (Fell et al., 2019), albeit not implemented, to avoid the re-structuring of existing models. Focusing on the different costs incurred by household groups based on socio-economic indicators e.g. income, it describes conceptually how model-derived metrics representing energy technology options can be allocated to different household quintiles, and the cost implications across such household types. Aspects of this thinking have been considered in our approach for this study, described in further detail in section 3.2.

Two research outputs have also helped to further inform the approach taken, which is described in the rest of this section. First, research was conducted within the framework of the ESPON 2013 Programme, focused on mapping vulnerabilities in relation to energy poverty. The ReRisk project (Velte et al., 2010) explored how different scenarios might impact different EU regions characterised by their vulnerability to rising energy prices across three dimensions – economic vulnerability, regions' dependence on motorized transport, and social vulnerability. The researchers used nine indicators representing five categories of effect – climate conditions, economic structure, transport dependency, social vulnerability, and production potential of renewables. This report differs in focusing exclusively on indicators of household and industry energy vulnerability, and considers quantitative scenarios of the future.

The second study, influencing the framing of this research, is a proposal for how to organise the different considerations of vulnerability, based on work by (Carley et al., 2018). In this framework, based on practice in the climate impacts and adaptation field, vulnerability is viewed as a function of exposure to impacts from the transition, sensitivity to those impacts, and adaptation measures put in place or local resilience to mitigate (enhance) them. Figure 4 illustrates these three dimensions, and how they contribute to vulnerability under transitions. 'Exposure' metrics are indicators that represent potential impacts from transitions on different sectors in society. This includes investment needs, changes in energy costs, and impacts on sector output and employment. It is also important to note that other drivers of change will also have profound impacts on different groups in society and industry, including local economic restructuring, automation, digitalisation, and changes to societal preference. It is therefore important that vulnerability under an energy system transition is considered within the broader context of societal and economic change.

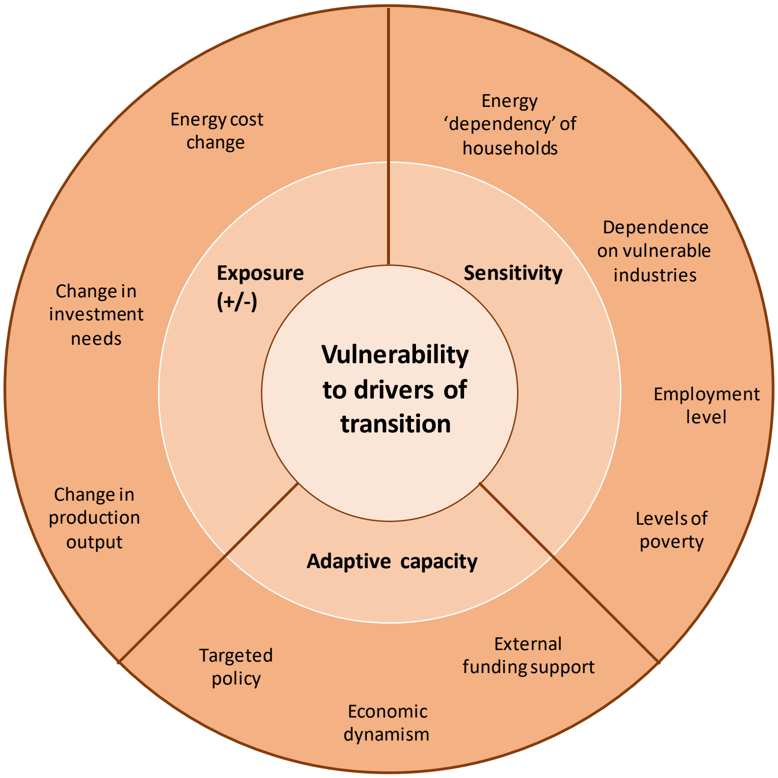


Figure 4. Vulnerability framework (based on (Carley et al., 2018))

'Sensitivity' metrics are reflective of the susceptibility of different sectors and groups in society to the impacts of transition. At the regional level, this is measured by employment dependency on industry sectors designated vulnerable, the levels of poverty, or the population at risk of poverty, and energy affordability concerns of households. Finally, there is a dimension labelled 'adaptive capacity', which includes interventions that support sectors facing impacts or reflect resilience of different regions in the face of change. A stronger adaptive capacity will help to mitigate the exposure of different groups in society, or sectors in the economy.

A similar methodology has been established by the ESPON (European Spatial Planning Observation Network) programme, largely funded by the EU and partner countries, although it does not appear to feature in formal EC impact assessments. Known as a Territorial Impact Assessment (TIA), this method assesses the territorial effects of policies. It recognises that impacts of policies will differ across regions, and understanding these beforehand will increase support for policy and reduce implementation delays. A range of TIA assessments can be found on the Committee of the Regions website.[17] A TIA tool has been developed, allowing '*users to make a "quick and dirty" ex-ante analysis of the potential impact of EU legislation, policies and directives on the development of regions, which might be unanticipated and undesirable*' (ESPON, 2013). Of interest is the recent application of

---

[17] Committee of the Regions TIAs, https://cor.europa.eu/en/our-work/Pages/Territorial-Impact-Assessment.aspx

the approach to explore the territorial impacts of the Clean Energy for All package on energy poverty (European Committee of the Regions, 2019).

The methodology is illustrated in Figure 5, and is based on the multiplication of three types of spatial layer to determine differentiated regional impacts of a given directive.

- Directive/Exposure matrix. This is based on expert opinion (determined in a workshop setting) and other evidence concerning the intensity of exposure associated with a given Directive. For household energy vulnerability, experts can score between -1.5 and 1.5 for the impact of a new energy efficiency directive on an exposure field such as ‘being in arrears on bills’ or ‘unable to adequately keep warm’. A score of -1.5 would denote high negative exposure while 1.5 would denote high positive exposure e.g. improving outcomes in relation to those two exposure fields mentioned.
- Regional exposure matrix. This provides information on policy reach across regions, identifying whether a region is or is not impacted (impacted / not impacted denoted by 1 / 0).
- Sensitivity matrix. This matrix holds information about regional sensitivity to the impacts of a given Directive. It uses normalised values, within a range of 0.75 to 1.25, for each metric, where 0.75 is lower sensitivity and 1.25 is higher sensitivity. For example, a region with a low share households unable to adequately keep warm would score less than 1.

The range of impact scores based on the above layer multiplication would range from -1.875 to 1.875.

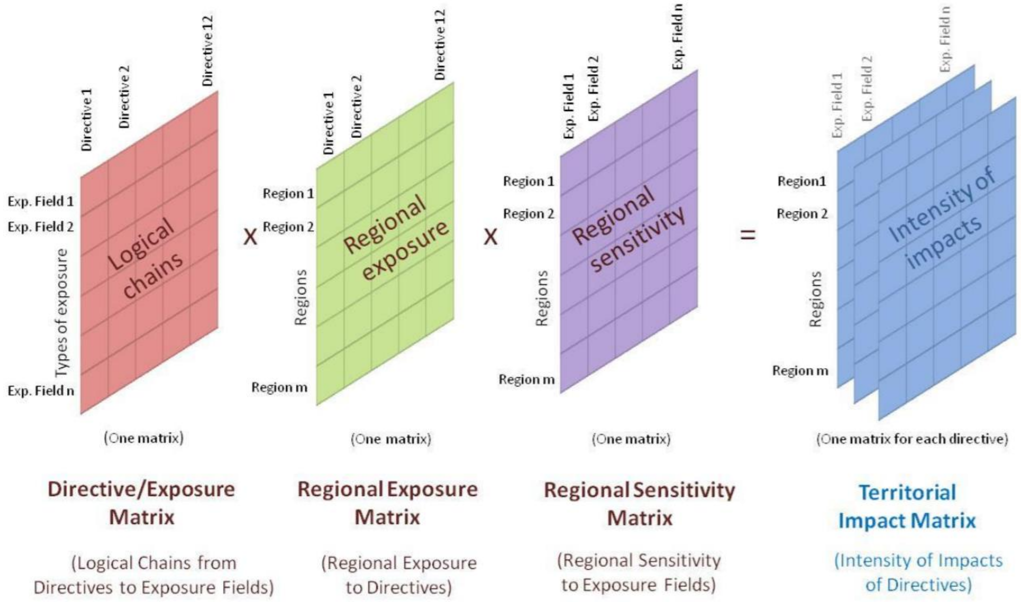


Figure 5. Assessment process of territorial impact of a EU Directive. Source: (ESPON, 2013)

These methods informed the approach in this study as further described in the next chapter.

3.2. InVEST approach

The InVEST tool takes elements of the different methods described above, to derive an approach based on the following steps.

a) Determine normalised energy vulnerability indicators for household and industry sectors at the regional level. These are akin to 'sensitivity' metrics as per the Carley framework, or used in the TIA's sensitivity matrix. The metrics were selected based on their relevance to the issues of energy vulnerability, based on literature review, and were not subject to expert workshop scrutiny as per the TIA process. They are described in detail in section 3.3.

b) Derive 'exposure' metrics from low carbon scenarios that could result in regional impact, described in section 3.4. These are akin to exposure metric in (Carley et al., 2018), which was the increase in the price of electricity due to the introduction of renewable portfolio standards. In the TIA approach, these are represented via the Directive/Exposure matrix, but quantified through expert elicitation.

   The approach used here diverges from other approaches, through the use of scenarios, which i) represent the broader economy wide transition, not a single policy, and ii) focus on longer term impacts in the future. This brings challenges; a broader transition will implicitly represent a package of policies needed for implementation, making it harder to identify specific impacts. Thinking long term is also challenging, because the sensitivity metrics focus on vulnerability today.

   In trying to quantify exposure metrics, this approach differs from the TIA, where expert judgements are made concerning likely impacts. As we discuss later in section 6.3, both have strengths and weaknesses.

c) For each sensitivity metric (determining vulnerability), plot these against the exposure metric (determining impact), to identify those regions that have both high sensitivity and high exposure. The initial idea was to combine both metrics into an aggregate score, as shown in Appendix 5 (Figure 39), to see how region exposure to scenario metrics changes over time. However, this was not taken forward, mainly because the understanding of which of the metrics drives the resulting score would be lost.

   This approach differs from both the TIA approach and that set-out in (Carley et al., 2018). Under the TIA approach, the following calculation is used to derive spatial maps using the following approach -

$$SInd_r \times R_{aff} \times PExp_i$$

   Where $SInd_r$ is an indicator of sensitivity to impacts in a given region (*r*), R_{aff} concerns whether a region is affected by a given policy, and $PExp_i$ is the expert determined impact of a policy on a specific sensitivity indicator *(i)*. Crucially, the different indicators (*SInd*) are not combined to create a composite to reflect an overall impact score for any given region. Composite indicators are challenging to compile for several reasons. They can be difficult to interpret as they typically benchmark one territory against another in a single time period, whereas the changes within each region and their impact on other regions over time is more significant. The selection of weighting for the individual indicators will influence the overall outcome. Additionally, some individual indicators change only slowly over time and therefore exhibit no bearing on the overall indicator (ESPON, 2018).

(Carley et al., 2018) take a similar approach with a couple of notable differences. Firstly, sensitivity metrics are combined to help develop an overall vulnerability score. Second, the adaptive capacity is taken into account, which has the effect of reducing vulnerability scores in those regions where it is applicable. The example used is financial support to reduce the impact of the specific policy measure under consideration.

The sensitivity metrics considered in this approach do not, in isolation, give a full picture of regional vulnerability. For this we also need to consider 'adaptive capacity'. For the purposes of this research, and relating to the framework by (Carley et al., 2018), this includes measures that support sectors facing impacts or reflect resilience of different regions in the face of change. A stronger adaptive capacity will help to mitigate the exposure of different groups in society, or sectors in the economy. The two indicators of unemployment (for industry) and disposable income (for households) could be regarded as giving some indication of resilience to job losses and to increasing energy prices. However, in the main it is our view that issues of adaptive capacity should be considered when more detailed regional level assessments are undertaken, as they are arguably challenging to determine based on dataset providing EU coverage. Key adaptive measures that could be considered, mainly in view of industry sector adaptive capacity include –

- Local and EU policy expenditure to support regions, both for a specific policy e.g. low carbon transitions, and more broadly for regional development and infrastructure
- Level of education, as a proxy for retraining and labour mobility
- Local economic dynamism, using business demographics data
- Regional proximity to other regions with sectoral employment opportunities
- Level of exposure to international markets across different vulnerable industries

From an industry perspective, (Velte et al., 2010) consider regional competitiveness, and identify the different drivers that matter, which may also feature in this adaptive capacity domain. These include –

- Innovative capacity, which is about the capacity to generate new ideas. This can reduce vulnerability because it diversifies the local economy through the the creation of new industries and products.
- Attractiveness of the region (linked to the above issue), based on good living conditions and highly developed business environments that attract both workers and economic investment.
- Economic robustness to withstand shocks, determined by the presence of different types of capital (economic, social and resource), as well as diversity in the region's economic structure.
- Governance, provided by political stability via well-functioning authorities who ensure good policy frameworks for innovation and entrepreneurship.

The main point is that a region's adaptive capacity will be a function of many different factors, most of which are interrelated, making it a complex issue.

3.3. Regional characterisation of current energy vulnerability

The chosen indicators of energy vulnerability focus on two sectors, households and industry. For industry, the focus is on those regions with high levels of employment in industries that are energy-intensive, with exposure to high prices, and whose goods may reduce in demand due to climate policy. For households, the focus is on regions most vulnerable to increased energy prices, with already high levels of vulnerable consumers and energy poor. Neither indicator set are necessarily comprehensive, representing every aspect of vulnerability. However, those selected align with the policy areas set out in section 2.2, and provide a basis for further development and additions in future research (see section 6.3).

For households, the focus is on regions most vulnerable to increased energy prices as a result of shifting energy policies, with already high levels of vulnerable consumers and energy poor. This is essential as lower income households will not be in the financial position to afford the higher upfront costs of renewable and energy efficient technologies required to ensure the successful implementation of the energy transition. However, with targeted policy, they could also benefit hugely from higher levels of investment.

Household indicators

As a multifaceted issue, energy vulnerability in households is difficult to encompass within a single metric (Rademaekers et al., 2016; Thomson and Bouzarovski, 2018). Based on the framework described previously, six different indicators have been selected to describe household energy vulnerability (Table 1). These indicators have been chosen because they reflect different aspects of household energy vulnerability, and because they are the type of metrics that are widely considered as indicators of energy poverty at the European level (Rademaekers et al., 2016; Thomson et al., 2017; Thomson and Bouzarovski, 2018). They very much focus on the drivers of household energy vulnerability (income, energy costs, energy requirement) for which proactive policy can tackle and will reflect the necessary attention to key areas around changes in energy prices, investment requirements and other related socio-economic trends. Most of the indicators are provided by decile in each of the regions, to better understand differences within regions for different income groups, and were calculated using to Eurostat microdata covering Household Budget Survey (HBS) (Eurostat, 2017a) and Survey on Income and Living Conditions (SILC) (Eurostat, 2017b). A seventh indicator on incomes provides an additional proxy indicator for vulnerability. The datasets as well as the calculations performed with these datasets are further detailed in Appendix 1.

Table 1. Chosen vulnerability indicators for households

Metric type	Household metric	Description	Data source
Expenditure	ExpShare	Share of expenditure on energy: Average energy expenditure level as a share of total expenditure	HBS microdata, Eurostat (see https://ec.europa.eu/eurostat/web/microdata/household-budget-survey)
	M/2	Half the Median expenditure on energy: % households where energy expend. less than half the national median level	
	2M	Twice the Median expenditure on energy: % households where energy expend. twice the national median level	
Consensual	TotArrears	Share of households with arrears: % households in arrears on utility bills at least once in the past 12 months	EU SILC microdata, Eurostat (see https://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions)
	SevArrears	Share of households with severe arrears: % households in arrears on utility bills more than once in the past 12 months	
	AdWarmth	Share of households unable to keep adequately warm: % households who state that they are unable to keep their home adequately warm	
Contextual	DispInc	Disposable income per inhabitant, on a purchasing power standard (PPS) basis	Eurostat Regional economic accounts (reg_eco10), data code [nama_10r_2hhinc]. Metadata https://ec.europa.eu/eurostat/cache/metadata/en/reg_eco10_esms.htm

Indicators typically fall into two categories: expenditure-based and consensual-based metrics. Expenditure-based metrics aim to measure the affordability of meeting energy needs, while consensual-based metrics are a self-assessment of the household's perceived difficulty in meeting basic energy needs. Each has advantages and disadvantages to describing the extent of energy poverty experienced. While expenditure-based indicators will underpin the actual expenditure of households with widely available data, they do not capture the reasons households consume energy the way they do (i.e. limiting energy use due to affordability issues or motivated by saving energy). There are also potential issues with some methodology differences from HBS surveys undertaken in different member states, as highlighted by (Deller, 2018). Consensual-based metrics typically better capture the experience associated with energy poverty and data to support these are collected across the EU. However, as they are based on self-assessment they are subjective. These also do not determine the causes of the experience, nor can they be easily compared across the EU (Rademaekers et al., 2016; Thomson and Snell, 2013). Nonetheless, assessing indicators from each of these categories allows the analysis to be flexible and cover a broader span of issues as well as allowing the evaluation of the implications of the various indicators in different contexts.

Three indicators are expenditure-based, relying on the Household Budget Survey (HBS) microdata, collated by Eurostat from across the member states for the year 2010.[18] These indicators are provided for income deciles and the population as a whole, and as far as possible, at the NUTS1 level.

- 'ExpShare' reflects the proportion of household expenditure spent on energy
- 'M/2' estimates the share of households whose energy expenditure is less than half the national median level. The purpose of such an indicator is to identify households who are under-spending to avoid energy costs, indicative of affordability issues.
- '2M' estimates the share of households where energy expenditure is greater than twice the national median in the current year. This indicator concerns households who have high costs of energy, and which may be squeezing household budgets.

While we use the HBS dataset, a key limitation is that the approach only estimates actual expenditure rather than required expenditure. This means it might not capture households struggling to pay for energy and thereby self-disconnecting or otherwise under consuming. The inclusion of the M/2 indicator looks to help address this, by estimating the share of households spending less than the expected average consumption of the equivalised household. However, this indicator has limitations, as it is difficult to determine whether estimates reflect underspend by households on affordability grounds or due to highly efficient building stock.

The equivalisation of households in both M/2 and 2M brings with it a drawback in that the national values do not accurately capture the regional and socio-economic differences relating to household composition, economy and temporal shifts. This would be improved with regularly updated, region-specific equivalisation factors (Tirado Herrero, 2017). Single indicators are insufficient to convey the multidimensional complexity of energy poverty and could illustrate a vastly different picture of energy poverty experienced. It is key to note that particular indicators will delineate which types of households require support with the challenge being that these households are grouped according to criteria or definitions that will include households not needing support while at the same time exclude households that do need support.

Nonetheless, assessing indicators from each of these categories allows the analysis to be flexible and cover a broader span of issues as well as allowing the evaluation of the implications of the various indicators in different contexts and the monitoring of qualitative and quantitative data over time. For comparison of the situation between member states, not only does the underlying framework differ between member states the various components that make up the expenditure on energy varies greatly and as such do not carry the same significance in each member states. For example, standard of living, quality of the housing stock, energy prices, incomes, etc. will influence how households use energy and will vary by member state. The chosen indicators can readily be applied to monitor the situation within these countries.

Three indicators are defined as consensual indicators, and are derived from the EU Statistics on Income and Living Conditions (EU-SILC) survey microdata.[19] Such indicators have been used for some time as a measure of

---

[18] HBS microdata, https://ec.europa.eu/eurostat/web/microdata/household-budget-survey

[19] EU-SILC microdata, https://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions

energy vulnerability across the EU (Thomson and Snell, 2013). These indicators are provided for income deciles and the population as a whole, and as far as possible, at the NUTS2 level.

- ‘AdWarmth’ measures the % of households stating that they are unable to keep adequately warmth
- ‘TotArrears’ measures the % of households stating that they have been in arrears on bills in the last 12 months.
- ‘SevArrears’ measures the % of households stating that they have been in arrears on bills more than once in the last 12 months.

Consensual indicators remain proxy indicators of energy poverty, meaning they do not directly measure energy poverty but instead provide information around the perception of households to be experiencing certain aspects of energy poverty, e.g., ability to keep warm or pay bills. Furthermore, while the ability to pay bills is captured with the arrears indicators, alone they do not indicate whether a household is experiencing energy poverty in particular since this indicator also captures arrears in other utility payments, such as water (Rademaekers et al., 2016).

A final indicator, which does not provide a direct representation of energy vulnerability but does provide important contextual information regarding affordability, is disposable income. It highlights in which regions of Europe households have lower disposable income, and therefore potentially less able to respond to increased costs of higher investment requirements. This metric is provided on a purchasing power standard basis to allow for comparison between member states.

The application of these indicators to portray the differences in spatial distribution across member states is shown in section 3.

Industry indicators

Five industry indicators have been developed, in three categories (Table 2). They focus on vulnerability based on exposure to a shift away from carbon-intensive goods, and exposure of energy intensive industries to increasing costs of low carbon energy and technology. The first category represents a sector that will be subject to falling production, namely coal production and its use for generating electricity. There are two indicators, one for employees in mining (including employees in supporting sectors, known as ‘indirect’) and one for those working in the power generation sector. The data are sourced from recent analysis by the (JRC, 2018).

Table 2. Vulnerability indicators for industry

Metric type	Industry metric	Description	Data source
Coal	CoalMemp	Level of employment from coal mining + indirect jobs (normalised against highest region)	(JRC, 2018)
	CoalPemp	Level of employment from coal plant generation (normalised against highest region)	(JRC, 2018)
En. int.	EmplElc	% of manufacturing employment in sectors who have high unit expenditure levels on energy (Group 1)	Employee numbers from – Eurostat. Structural Business Statistics (SBS). Regional Labour Market Statistics (reg_lmk), dataset [lfst_r_lfe2emp]. https://ec.europa.eu/eurostat/cache/metadata/en/reg_lmk_esms.htm Employee groupings based on Odyssee industry energy intensity indicators.
	EmplElc1&2	% of manufacturing employment in sectors who have high unit expenditure levels on energy (Group 1&2)	
Other	LTunempl	Long-term unemployment (12 months and more) by NUTS 2 regions, as a percentage of active population	Eurostat. Structural Business Statistics (SBS).Regional Labour Market Statistics (reg_lmk), dataset [lfst_r_lfu2ltu]. https://ec.europa.eu/eurostat/cache/metadata/en/reg_lmk_esms.htm

The second category of indicator represents employees in sectors that are defined as energy-intensive, whose costs per unit of economic output are highest, and therefore would be most affected by increasing costs of the transition. Many such sectors who trade global commodities are also subject to competitive pressures from overseas.

The industry sectors are first grouped according to their energy intensity across member states, that is the ratio between the final energy consumption and the value added measured. Using data from the ODYSSEE database[20], sectors in different member states are allocated to broader groups, with group 1 representing the most energy-intensive sectors, and group 3 the least energy-intensive. Group 1 represents the sector in different countries that are most energy intensive. This means that a sector in group 1 in one country may be in group 2 in another country if its energy intensity is below the threshold for group 1 membership. Constructing the metric in this way allows for differences for a sector across member states to be taken into account.

There are two choices of energy intensity indicator, one based on GDP expressed in purchasing power parities (PPP) or on an exchange rate basis. The PPP metric has been used, as preferred for comparison between countries as it removes the impact of price differences (that inflate GDP levels), providing a better measure in respect of volume produced. Using PPP tends to decrease the intensity of lower income countries, and increases those of higher incomes, and reduces the range of intensity values (ODYSSEE-MURE project, 2018). These energy

---

[20] Odyssee database (24.10.2018), https://odyssee.enerdata.net/database/ (Accessed 21.11.18)

intensity groupings are further described in Appendix 1. A key limitation is that differences in energy-intensity between regions is not reflected as the data are only available at the national level.

Once allocated to different groups, the employees associated with those different industries in member states, at a NUTS2 region level, are identified using the Eurostat Structural Business Survey (SBS). These employee numbers for the three groups are then divided through by total employees and manufacturing employees to estimate the share of group 1-3 employees at the regional level. The metric *EmplEIc* represent energy intensity group employees as a share of regional manufacturing sector employees.

An indicator of industry exposure to increasing costs was also developed as part of the ReRisk project (Velte et al., 2010). Rather than using energy intensity metrics, industries were identified based on their actual energy expenditure, using statistics from the SBS. A metric was developed that estimated the share of energy purchases against all purchases, with regional employee numbers in these high energy purchase sectors identified. A key issue with using this approach is that the last data year for energy purchases available from Eurostat is for 2007.

As with the household sector, a contextual indicator is provided for industry, on regions with long-term unemployment. The rationale is that regions with higher unemployment may be less able to deal with increase job losses under a low carbon transition, or conversely could benefit from employment increases from new low carbon industries. All of these metrics are presented and described in section 4, in terms of their spatial distribution across member states.

3.4. Low carbon pathway metrics

There are two core EU-scale models used within the REEEM project: TIMES-PanEU, an integrated energy systems model for Europe (Fais et al., 2015), and NEWAGE, a global CGE macroeconomic model (Montenegro and Fahl, 2017). Both models provide insights into how the energy system and economy will evolve over time, based on the distinctive narratives modelled. From the many hundreds of metrics produced by these models, we determine those relevant for exploring how these pathways may impact on vulnerable households and industries.

As indicated earlier in the report, the scenario metrics are at a national-scale (TIMES PanEU) or aggregate country groups (NEWAGE), so only provide a spatially aggregated view of transitions for subnational regions. We argue that this difference in scale is reasonable, given that we are interested in developing indicative insights, not a detailed vulnerability assessment. We also want to retain the aggregate scale of the models to avoid increased complexity, remain with computation limits, and minimise large resource efforts in re-structuring models. This approach allows for insights on vulnerability now – and the challenges of future system evolution given those current vulnerabilities.

The mapping of scenario metrics with the vulnerability metrics (described in the last section 3.3) are shown in Table 3 below. From TIMES PanEU, the pathway metrics provide insight into how the costs of energy change over time, and the production of fossil fuels. We also consider the investment requirements, as upfront capital costs (in addition to many other factors) can be a barrier to households switching to lower carbon energy sources but also a significant opportunity (Table 3). While the NEWAGE model provides insights into how low carbon transitions impact sectoral GVA and employment in the future, metrics have not been used due to the aggregation level, based on combining member states.

Table 3. Scenario metrics from TIMES PanEU used the in assessment of future vulnerability
(A) Households; B) Industry). Other sensitivity metrics are not included such as LTunempl / DispInc as these are contextual for other sensitivity metrics, and not intended to be linked to pathway metrics.

A.	**Vulnerability metric**	**Pathway metric**
Expenditure	**ExpShare**	Household energy cost index; investment requirements
	HEP	
	2M	
Consensual	**TotArrears**	
	SevArrears	
	AdWarmth	

B.	**Vulnerability metric**	**Pathway metric**
Coal	**CoalMemp**	Domestic coal production
	CoalPemp	Domestic coal generation
En. int.	**EmplElc**	Energy cost index, and investment requirements
	EmplElc1&2	

For the residential sector, the investment requirements are directly output from the modelled scenarios. The household energy cost uses the aggregate of annualised investment, O&M costs, and electricity and fuel costs divided by dwelling, to construct an index to show cost change over time at the household level. Fuel costs are based on input fuel prices that are used in TIMES PanEU, multiplied by fuel use, while electricity costs are similarly derived, except that electricity marginal values are used, not exogenously defined prices.

For industry, the domestic coal production and generation are direct metrics that come out of the model, as are the investment requirements across the G1 and G1&2 sector groupings. The energy cost index development requires a degree of post-processing using metrics from the modelling, and is derived based on the following steps –

- Cost values per unit produced are first derived for each individual subsector.
- The change in cost values over time are then indexed, based on 2015, where 2015=1.
- The indexes for country-sector combinations that are allocated to groups G1 or G1&2 are aggregated, using a weighting that reflect the relative costs across the different subsectors.

This give an indication of the relative cost change experienced by these groupings in each of the different countries over time.

The above metrics come from three modelled pathways used in this research (Table 4). The idea is that these pathways are quite distinctive, and result in differing implications across sectors. For example, the Local Solutions has stronger efforts across the household sector in terms of mitigation than the Base case. A full description of these scenarios can be found in REEEM's Final Integrated Impact Report.

Table 4. Description of REEEM scenario narratives

Scenario name	Scenario description
Base*	Energy carrier suppliers (supply-side sectors) take on the highest burden in the decarbonisation of the EU energy system, with consumers observing this transition in mostly a passive way and being reactive to policies as they emerge. An 80% reduction in CO2 emissions by 2050 is the overarching climate policy target.
Local Solutions	Consumers (especially households) engage more proactively in the transition, through choices on end use appliances, energy efficiency measures and transportation technologies. This demand-side orientated scenario also achieves an 80% reduction in CO_2 emissions by 2050.
Paris Agreement	The EU undertakes an ambitious decarbonisation effort, with a target of 95% reduction of CO2 emissions by 2050. This overshoots the Paris Agreement pledges. Both energy carrier suppliers and consumers engage in the challenge.

* Known as *Coalitions for a low carbon path* in other REEEM deliverables.

4. Metrics of current vulnerability

This section of the report presents and describes the metrics of current vulnerability, or ‘sensitivity’ metrics as per the proposed vulnerability framework. The objective of this section is to provide an understanding of the spatial distribution of these different metrics across member states.

4.1. Household metrics

There are a range of household metrics that can be used to better understand the regional pattern of energy vulnerability facing different households. As described earlier, each have their own limitations in terms of the insights that can be gained but nonetheless can be useful.

Expenditure-based indicators

Expenditure-based indicators focus on using expenditure data from household budget surveys, to determine levels of expenditure on energy relative to overall expenditure. From these, we can get a sense of the ‘burden’ of energy expenditure as a proportion of overall household expenditure. As described in section 3.3, three indicators have been considered, from a metric that estimates share of energy as a proportion of overall expenditure (EnExp), to two threshold-based indicators that estimate the percentage of households who spend twice the median level (2M) and half the median level (M/2) of total expenditure on energy.

For the indicator EnExp, of those countries with the highest median share of expenditure, 9 of the top 10 are in Eastern Europe (Figure 6). Countries in Southern Europe have relatively low expenditures on energy (ES, CY, MT, EL). The spatial pattern is shown in Figure 7, with national averages shown on the right hand side. It is challenging to understand what is driving this at the country level due to a range of factors including average energy consumption per household, level of energy tariffs, average income level, and whether energy expenditure is an explicit item or incorporated into broader housing expenditure. On energy consumption, this is higher in the northern and eastern European countries, while southern European countries have much lower demand (due to climatic factors)[21].

The variation between subnational regions is relatively low, probably reflective of the fact that the spatial unit is NUTS1, which reflect large regions that cover a diverse array of communities and geographies. What is apparent is that for those member states with NUTS1 data available, the lower shares are found in regions that include the large metropolitan capitals. The resulting lower shares probably reflect income effects and perhaps lower per household demand, due to higher density building stock.

---

[21] http://www.odyssee-mure.eu/publications/efficiency-by-sector/households/average-energy-consumption-dwelling.html

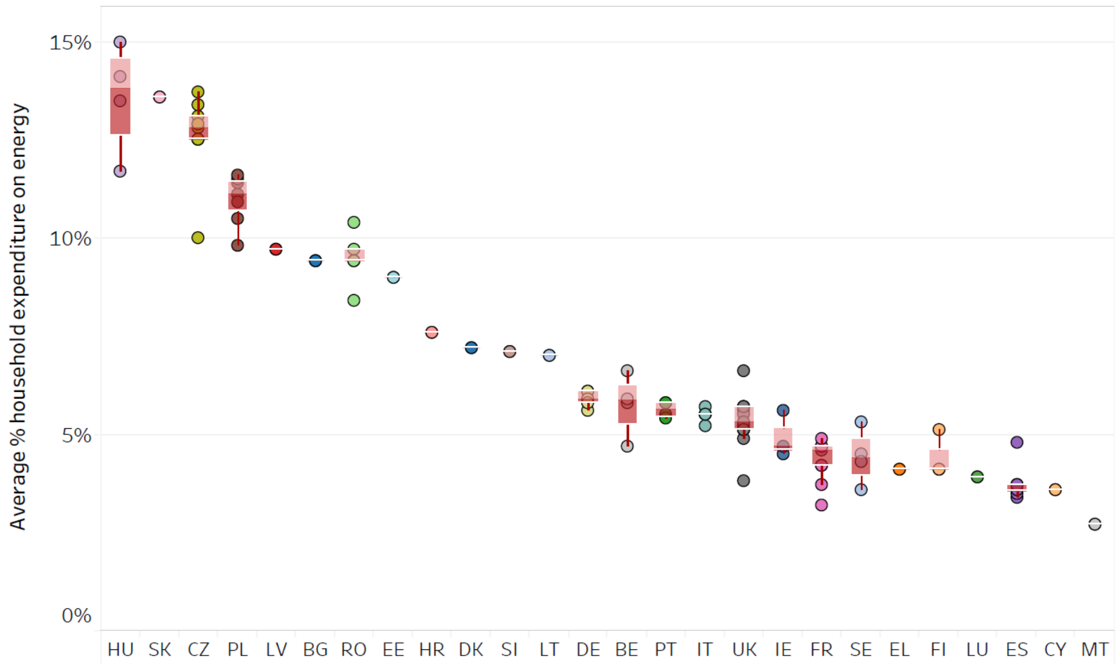


Figure 6. Average share of expenditure on energy by households across NUTS1 regions in member states
Countries without a box plot do not have subnational data available. Data are for the year 2010. HBS data for Austria and the Netherlands were not available.

Differences in the share of energy expenditure by decile are also highlighted in Figure 7. The energy vulnerability as measured by this metric for lower income households (in decile 1) is much higher, as would be expected, again most notably in Eastern Europe but also in other parts of the EU. This is particularly the case when compared to the decile 10. France, Scandinavian countries and Spain appear to have lower expenditure shares for this low income decile compared to other parts of Europe (as shown by the lighter colour shades).

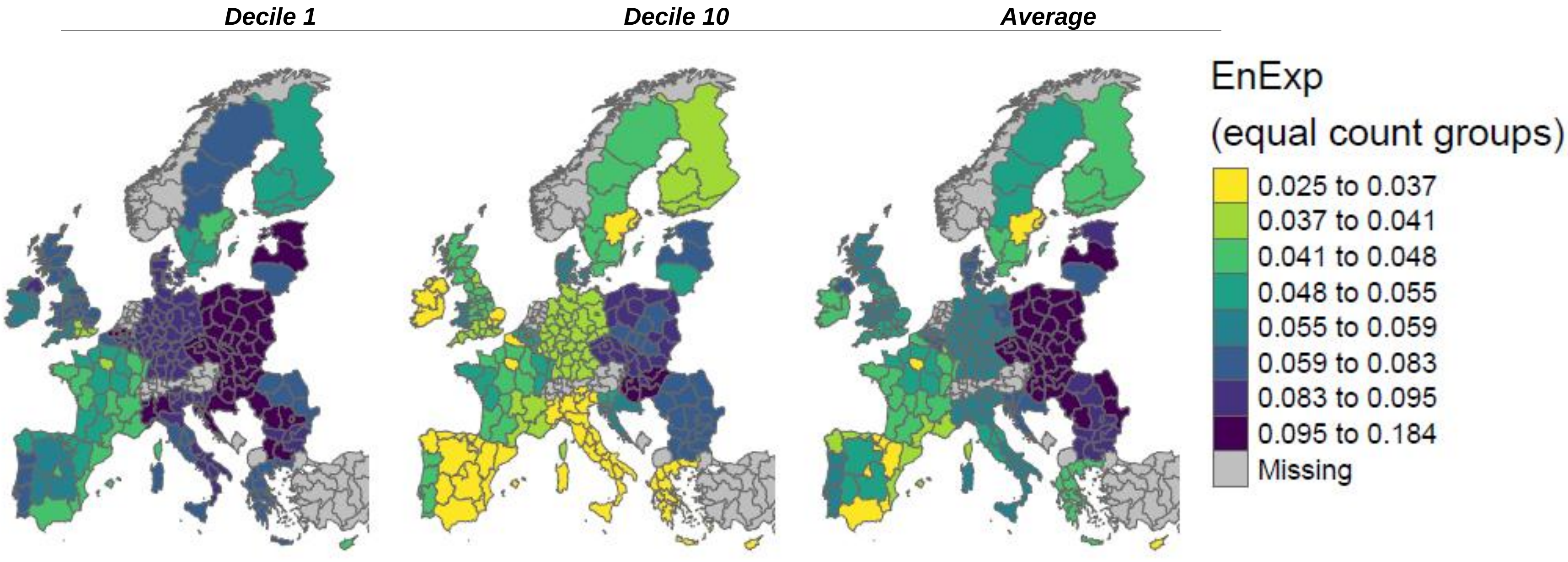


Figure 7. Share of decile 1, decile 10 and average household expenditure on energy by NUTS1 region across member states
The legend reflects value binning on the basis of equal counts of NUTS regions. Countries with no subnational data (as shown in Figure 6) have national data allocated to the corresponding NUTS1 areas. Data are for the year 2010. HBS data for Austria and the Netherlands were not available.

Two additional metrics focus on the percentage of households that have relatively higher or lower expenditure than the national median level. Discussed widely as a basis for energy poverty indicators, they are used to provide insight on over-expenditure (2M) or under-expenditure (M/2) on energy. The challenge with these indicators in isolation is that they do not necessarily explain the underlying reasons. For example, a high share for the M/2 indicator could be indicative of opposing explanations: highly efficient housing stock or chronic under-expenditure.

The share of households paying a much higher level of expenditure on energy (2M) is plotted in Figure 8a. Countries with the highest expenditure shares (HU, SK, CZ - Figure 6) have a lower share of households spending twice the median, as the median is high in those countries. This does not hold for Poland (PL), which ranks high for both metrics. Conversely, countries that have relatively lower expenditure shares e.g. FR, SE, UK have higher number of households whose expenditure is twice the median. It is also apparent that regional climate factors may be playing a role, with higher values typically in Northern and Eastern parts of Europe (with the exception of Portugal). This is also shown by differences between regions in SE, IT and FR (with most northerly regions have higher shares).

The share of households paying a much lower level of expenditure on energy is plotted in Figure 8b. Countries that have the highest proportion of households spending very low levels on energy include Finland and Sweden. This likely reflects that a large proportion of the building stock is highly energy efficient. Beyond this, it is difficult to assess this metric in isolation from without the addition of other supporting indicators, such as status of housing stock, heating system types, disposable income, energy prices, and other socio-economic characteristics like household composition.

An important aspect of this analysis is that we can also explore how these metrics differ across income deciles. As shown in Figure 32 / Figure 33 (Appendix 3), the lowest income deciles (1) score much more highly on these metrics in general (compared to the average and decile 10). However, the highest values for 2M and M/2 differ for decile 1 as one might expect. For example, high values for decile 1 for the 2M metric are found in southern France, UK, Spain, Greece, Croatia and the Baltic States. For M/2, it is Poland, France, Southern Italy, Scandinavia and Bulgaria. For Scandinavia, this ‘underspend’ might be due to efficient buildings, or incorporation of energy expenditure into other expenditure categories e.g. housing costs. As discussed earlier, it is a difficult metric to interpret in isolation.

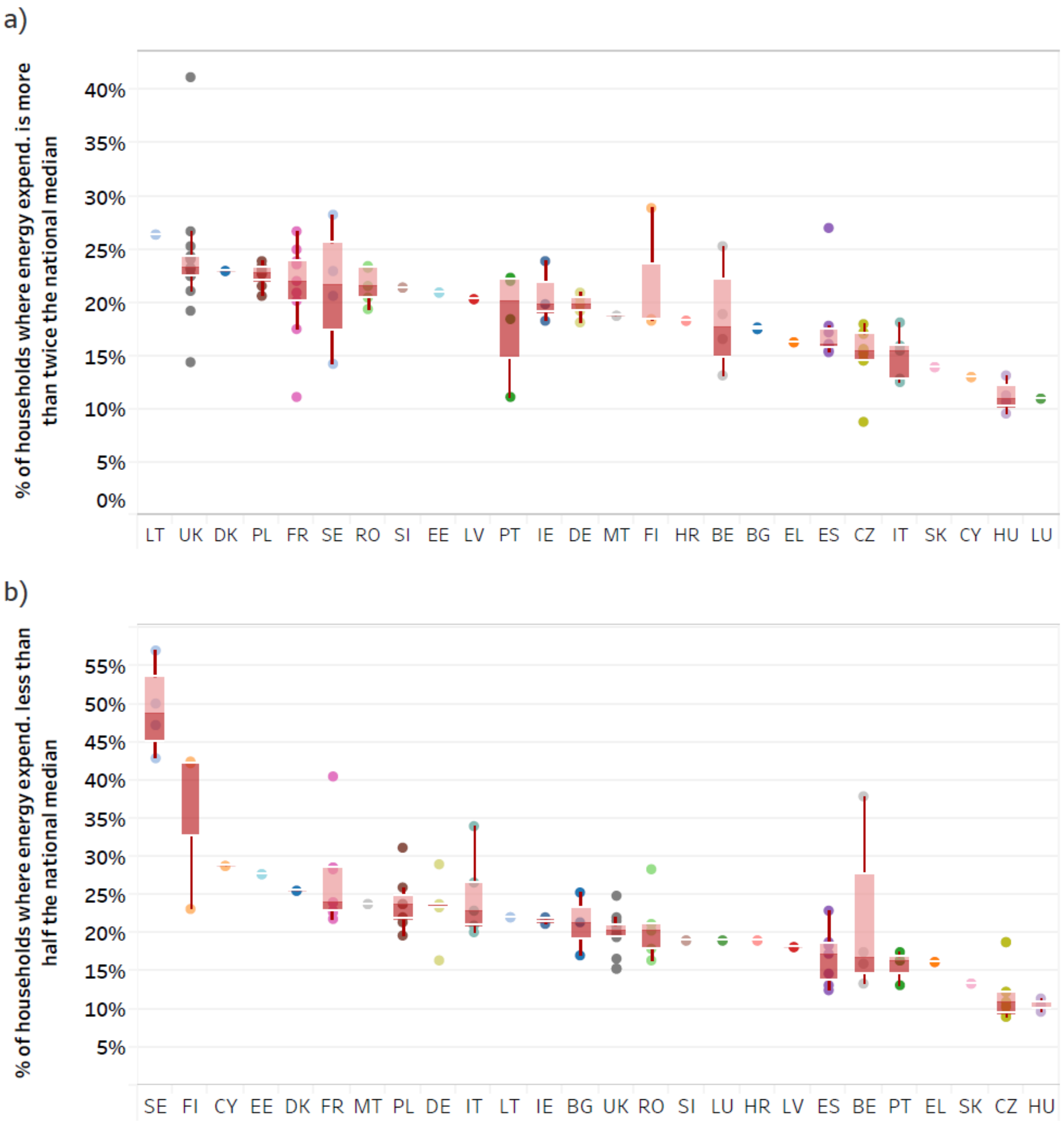


Figure 8. Average % of households across NUTS1 regions in member states where expenditure is a) twice (2M) or b) half (M/2) the national median

Countries without a box plot do not have subnational data available. Data are for the year 2010. HBS data for Austria and the Netherlands were not available.

The spatial distribution of these indicators can be found in Figure 32 and Figure 33.

Consensual-based indicators

The consensual measures of energy vulnerability clearly show that at a national level, it is the countries in the south and east of Europe that have the highest share of households reporting problems around bills arrears and the ability to keep their homes adequately warm. The consensual indicators provides quite a different country ranking to that observed for the expenditure indicators such as share of expenditure on energy (compared to Figure 6). The countries in Figure 9 are ordered based on the average of the two indicators. The 12 countries from the left in descending order (from BG to PL)[22] are all located in the south or east of Europe. Most Northern or Western European member states have shares below 5%.

These indicators provide different information, and are therefore not necessarily aligned; for example, Portugal (PT) has only 5% of households in severe arrears – despite having electricity prices higher than the EU average - whilst nearly 25% for inadequate warmth. These differences point towards (but of course do not prove) inadequacy of household heating and building fabric as the key issue rather than affordability (for the average household). Similar large differences between values are observed for Lithuania, Cyprus and Bulgaria. At the same time, Slovenia (SI) exhibits the opposite pattern with a lower share of households inadequately warm and a higher share of households in severe arrears, likely as a result of the colder weather and the need to heat regardless of whether households are able to afford the costs of energy. These trends have also been observed by (Bouzarovski and Tirado Herrero, 2017), who identified the inheritance of deficient thermal characteristics of the housing stock as brought on by the centrally planned economy in Central Eastern European (CEE) countries coupled with increasing energy prices to reflect real prices with the liberalisation of the energy market.

---

[22] The descriptions of the country abbreviations used in this section can be found in the abbreviations section at the start of this report.

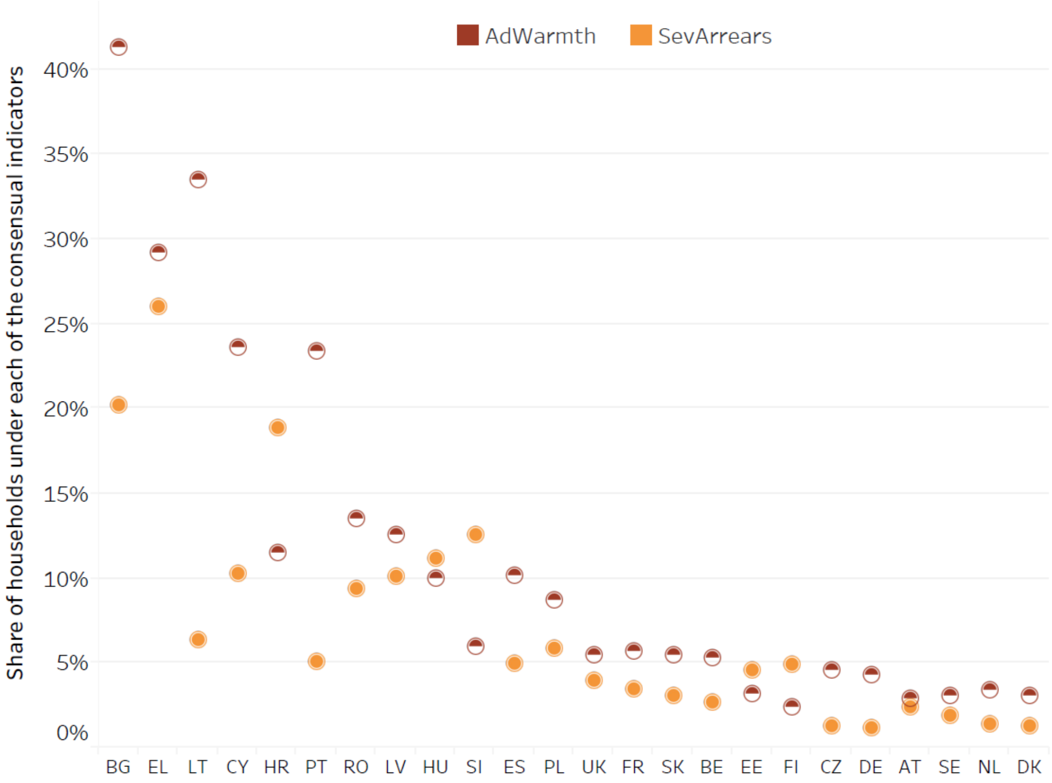


Figure 9. Average share of households under each of the consensual indicators by member state (Source: EU-SILC microdata 2015, Eurostat). The consensual indicators plotted include i) share of households in arrears more than once in the past 12 months (SevArrears) and ii) share of households unable to keep adequately warm (AdWarmth). Total arrears has not been plotted, as it shows a similar trend to severe arrears, although the % values are of course higher.

Figure 10 shows the distribution of average household shares under each of the consensual indicators across different regions. The biggest regional range can be seen for Spain (ES), with one of the reasons being the higher spatial resolution of the data (NUTS2). For the adequate warmth metric, the highest values are for regions in the south and east of the country (Figure 12), indicating again that this is more about adequacy of heating provision and building insulation than it is about climate.

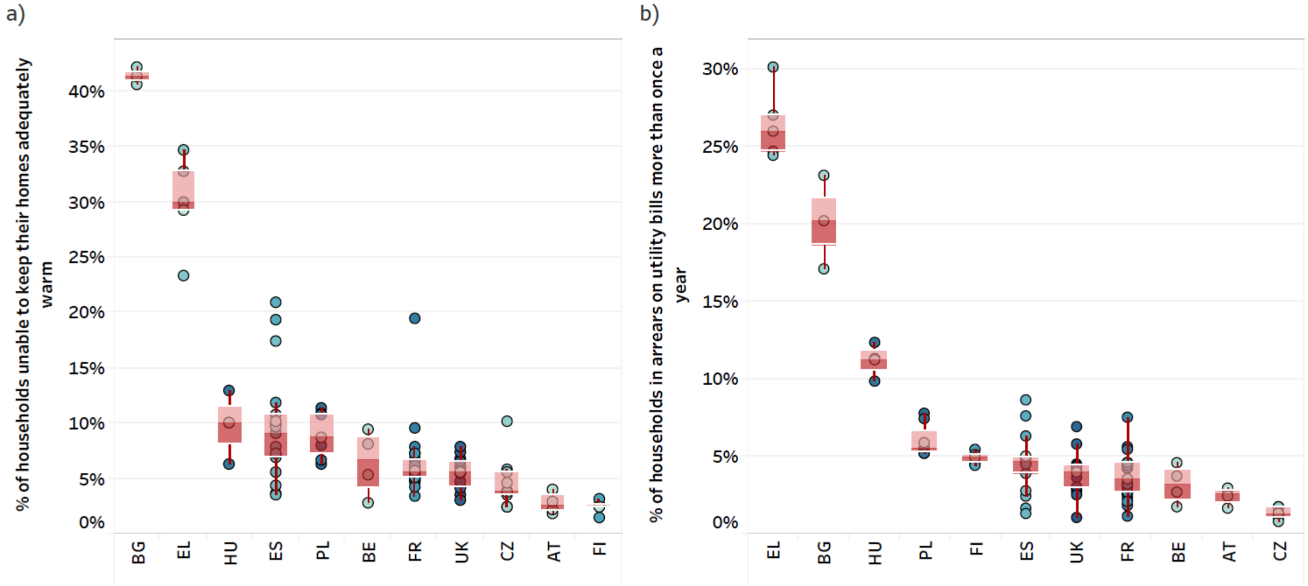


Figure 10. Average share of households by NUTS region under each of the consensual indicators by member state (Source: EU-SILC microdata 2015, Eurostat). The consensual indicator plotted include a) share of households unable to keep adequately warm (AdWarmth) and b) share of households in arrears more than once in the past 12 months (SevArrears). Total arrears has not been plotted, as it shows a similar trend to severe arrears, although the values are of course higher. member states not included did not have NUTS level data provided. All regions are NUTS2, except for France and Spain, where NUTS2 level is used.

Figure 11 plots the same national level indicators as shown in Figure 9, but for selected income deciles. This highlights that not only are there differences between member states but also between income groups within countries around adequate warmth and being in arrears on bills.

On adequate warmth (Figure 11a), a number of interesting observations can be made. Firstly, for Scandinavian countries (SE, FI, DK) the variation between deciles is small, suggesting that building standards and heating adequacy are high irrespective of income. Secondly, from the countries to the right of Spain (ES), with the exception of the Scandinavian countries, the variation between deciles is low except for the lowest income decile D1. This points to the need for targeted action on that specific income decile. For the countries to the left of RO, the difference between deciles widens, with higher shares of households unable to adequately heat their homes. The disparity between decile 1 (lowest income) and 10 (highest income) is over 40% for these countries (BG, LT, EL, PT, CY). This is likely to be for a number of factors, including income disparity, but also the types of housing that specific income groups live in. On arrears (Figure 11b), a similar pattern can be observed.

The large differences between deciles for the adequate warmth indicator are well illustrated in Figure 12, and in Figure 31 (Appendix 3) for severe arrears.

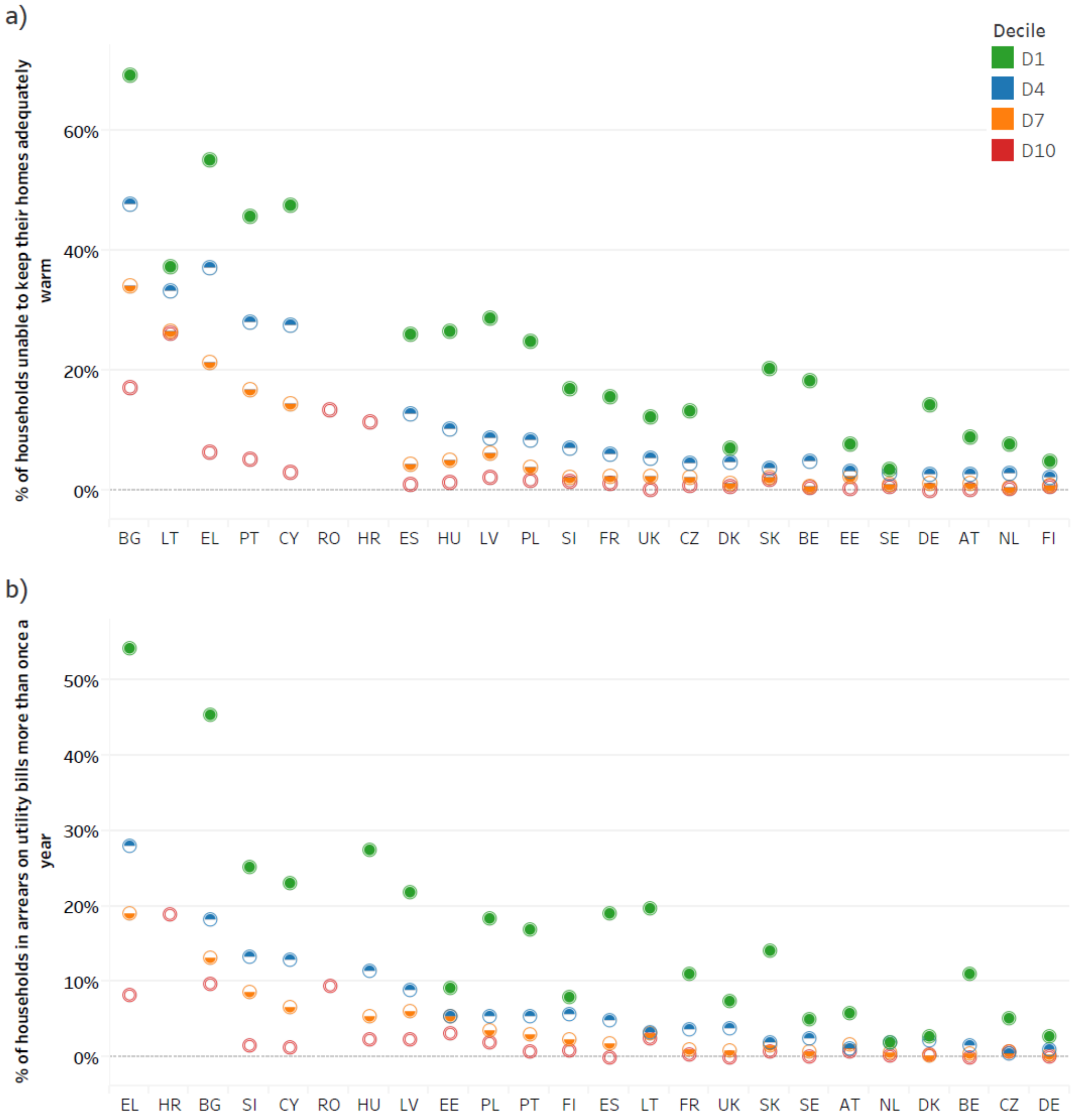


Figure 11. Average share of households by decile under each of the consensual indicators by member state (Source: EU-SILC microdata, Eurostat). The consensual indicator plotted include a) share of households unable to keep adequately warm (AdWarmth) and b) share of households in arrears more than once in the past 12 months (SevArrears). The values for HR and RO are averages (not decile 10), in the absence of decile data. Total arrears has not been plotted, as it shows a similar trend to severe arrears, although the % values are of course higher.

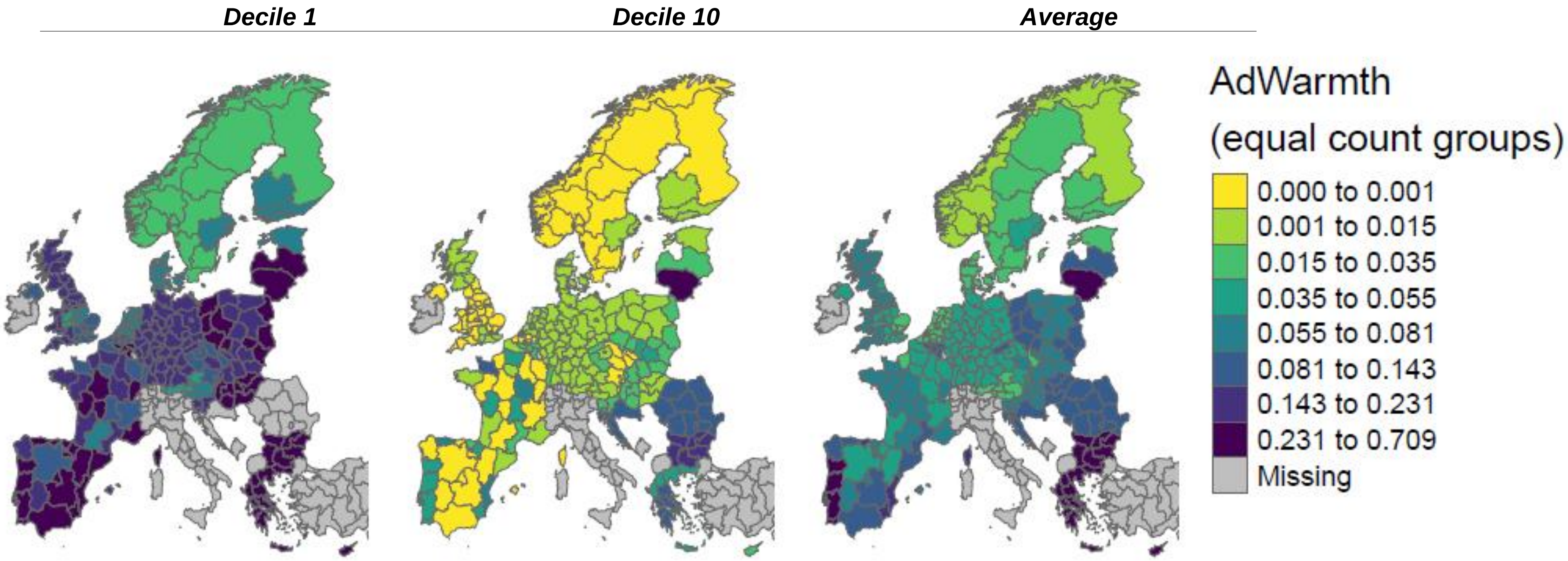


Figure 12. Share of decile 1, decile 10 and average households by NUTS1 regions for the ‘adequate warmth‘ consensual indicator
The legend reflects value binning on the basis of equal counts of NUTS regions.

Contextual indicator: disposable income

A final indicator shows disposable income per capita, on a PPS (purchase power standard) basis to allow comparison between member states (Figure 13). It clearly shows lower disposable incomes in Eastern and Southern European countries (from the left hand side of the graph). It also shows wide regional variation in some countries, notably the UK, Spain (ES) and Italy (IT). This is an important indicator as it helps provide context to the earlier indicators more closely associated with energy vulnerability, given that income is an important driver. It also provides insight into the ability of different regions to respond to the necessary investments and expenditures required under the transition, as discussed in section 5.2, and shown in Figure 27.

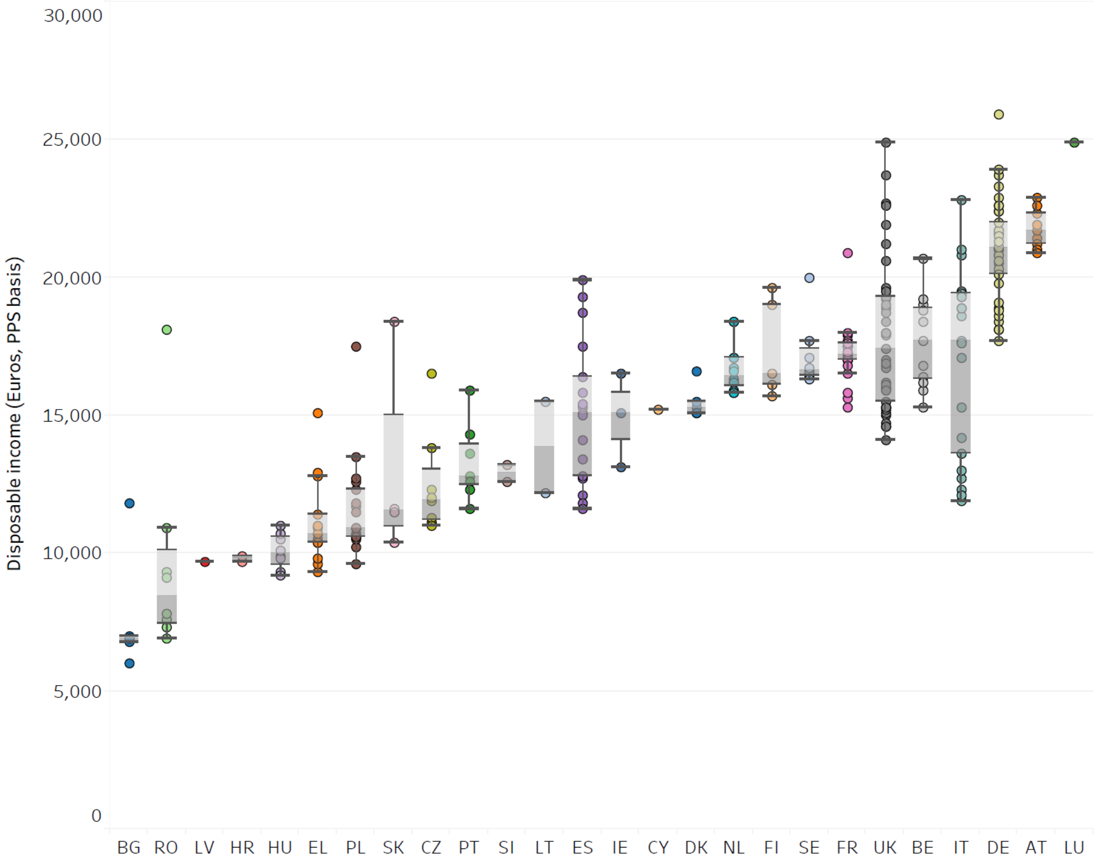


Figure 13. Disposable income per capita on a Purchasing Power Standard (PPS) basis by NUTS2 region across member states

(Source: Eurostat). Data ranked based on median disposable income. Inner London (UKI3) is not plotted on the above figure, but has an average disposable income of 45,000, significantly higher than any other region.

4.2. Industry metrics

Employees in the coal sector

Coal sector employees total 400,000 in the mining sector (including indirect jobs) and around 50,000 employees directly employed in the coal generation sector. The distribution across countries, and further split by NUTS2 region, shows a concentration of these industries in specific countries, notably in Eastern Europe (Poland, Czech Republic, Romania and Bulgaria) and Germany (Figure 14). Specific regions in these countries also dominate coal production, notably in Eastern European member states. In particular, Śląskie in Poland (situated in the Silesian basin) is the region most dependent on coal mining, accounting for over 100,000 employees. Other regions with over 15,000 employees include Miasto Łódź (Poland), Yugoiztochen (Bulgaria), Severozápad (Czech Republic), and Sud-Vest Oltenia (Romania).

Large producing countries such as Poland and Czech Republic have already gone through transitions in the 1990s, following the collapse of the Soviet Union, when employment levels were more than halved due to production levels dropping significantly (Caldecott et al., 2017). These experiences and those other countries in Europe can provide useful lessons for the future transition to a low carbon energy system.

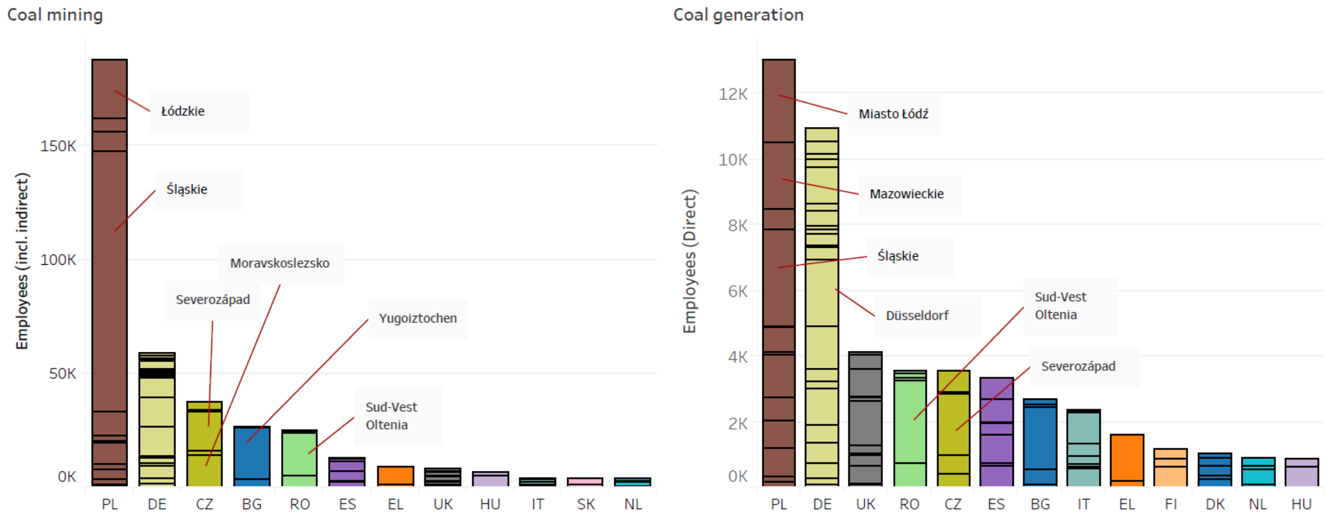


Figure 14. Coal sector employees by member state (JRC, 2018)
Coal mining employees shown only for countries with more 4000, and for generation, only above 800.

By comparison, regional dependency on employment from coal power generation is much lower, with it being a much lower employment sector. The primary coal users for generation are Germany and Poland but in either, no one region has more than 3000 employees. The trend in declining coal power generation is set to continue, with generation reducing from a 30% share in 2000 to 20% in 2017[23].

The spatial distribution of coal employees is shown in Figure 15. The spatial pattern between coal mining and generation is relatively similar, given that coal generation tends to be located near to areas of production. As described earlier, the focus of employment (denoted by dark blue / purple colours) is in the Eastern part of Europe, notably in Poland, Germany, the Czech Republic, Bulgaria and Romania.

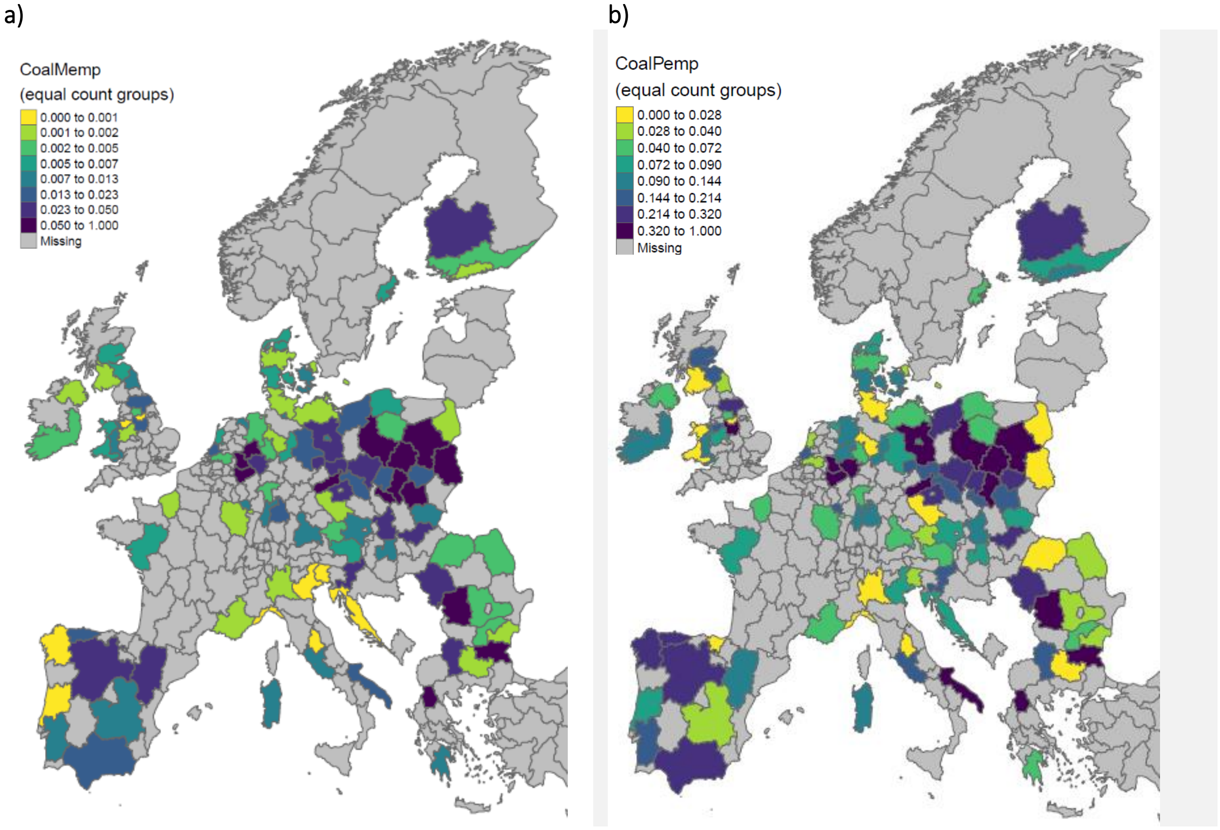


Figure 15. Distribution of coal sector employees across EU
Source: (JRC, 2018). a) Employees in coal mining (direct & indirect), normalised to 1 by highest region (1 = 114,000 in Śląskie, Poland); b) Direct employees in coal generation, normalised to 1 by highest region (1 = 2910 in Śląskie, Poland). The legend reflects value binning on the basis of equal counts of NUTS2 regions.

The other resource sector set for decline is the oil and gas extraction sector, although this is not considered in detail in this report. The prominent countries where extractive-based activities are located include the UK and

---

[23] In 2017, coal generation was at 66% of the 2000 level (660 versus 920 TWh). Data is sourced from the Eurostat database, and taken from the data series *Energy balances (nrg_bal)* (Accessed 22.05.19).

the Netherland for gas, and the UK for oil (Norway is the largest European producer but positioned outside of the EU).

Employees in energy-intensive industries

A second category of industrial indicator is employees in industries that may be exposed due to both the costs of energy rising but also the level of investment required to move to low carbon production. On the question of investment, this is also an opportunity for industries, to reduce their energy costs, modernise production, and harness future competitive advantage from production that is low carbon.

Figure 16 shows the number of employees by country, split into the most energy-intensive sectors across countries (group 1), and then combined with the next lower energy intensity group (2). Plots a) and b) show the disaggregation by region to highlight those regions that have higher employee shares. It is of interest to note that using the PPP indicator metric that the UK does not have any industry in group 1 (based on the thresholds used). In plots c) and d), the employment level by industry is shown, with group 1 dominated by primary metals, non-metallic minerals, paper and chemicals. Adding group 2, in d), sees an increase in food and tobacco, and manufacturing employees.

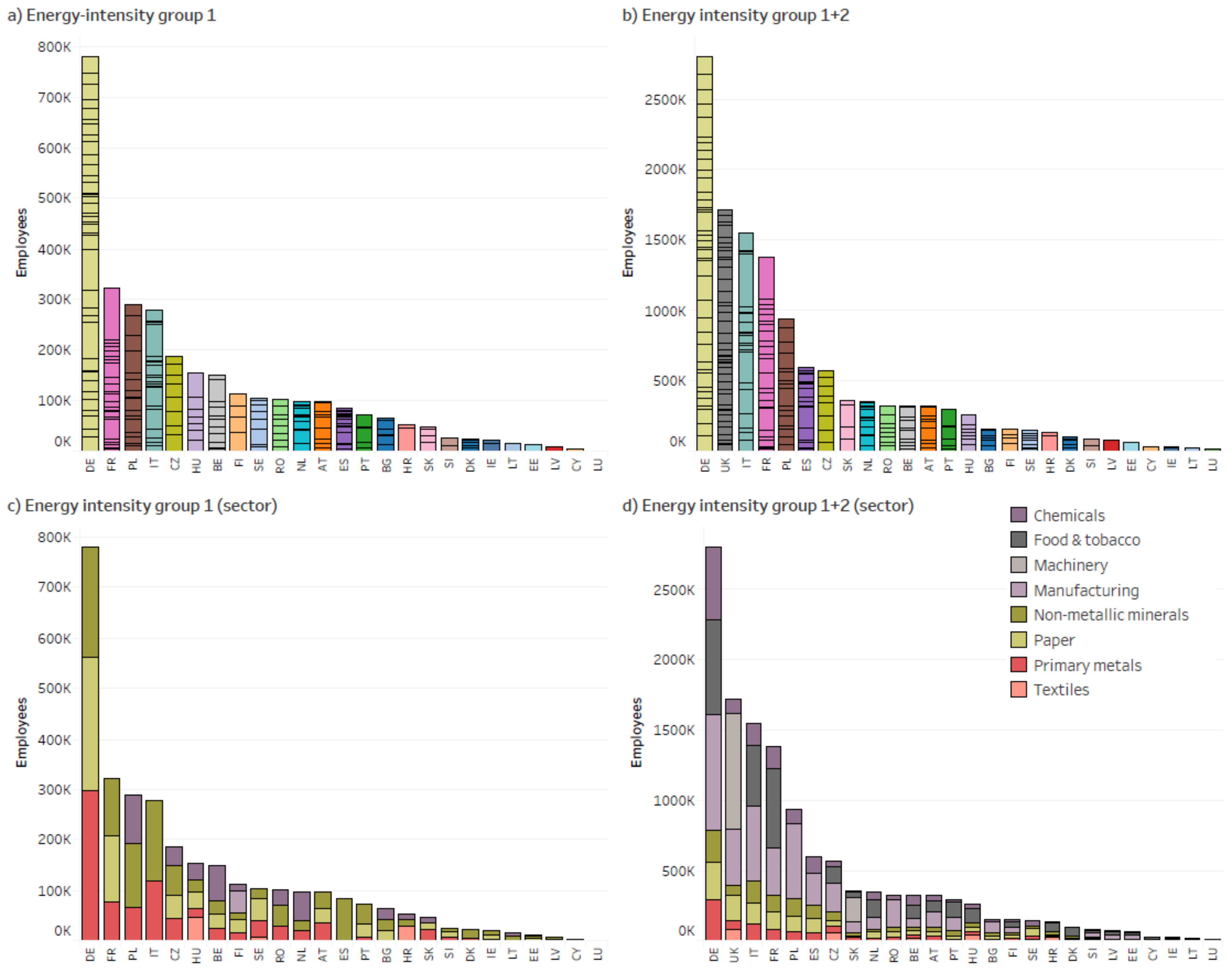


Figure 16. Employees in different energy-intensity sector groups by member state
(Source: SBS, Eurostat). a) Employees in group 1 by country (highest energy intensive sectors, >0.3 koe/€2010); b) groups 1 and 2 with energy intensity >0.1 koe/€2010. For a) and b) black dividing lines show the regional (NUTS2) levels. c) provides the employee sector splits for a), while d) does the same for b).

The above data is useful for showing the absolute level of employees, and the types of sectors in which they are employed. However, to get a sense of vulnerability of employees, it is more interesting to understand the percentage contribution of a specific sector to a region's manufacturing employment level. Figure 17 maps the shares of employees associated with group 1 and group 1&2 industries. The darker blues and purples highlight specific parts of Europe with higher dependence for both groups, notably eastern Europe, Benelux, Baltic countries and parts of Scandinavia. In Appendix 3, the distribution of shares levels across the NUTS 2 regions are shown, in addition to the NUTS regions with the highest shares (Figure 34 and Figure 35, Appendix 3). For group 1, the majority of regions have manufacturing employee shares of between 0-5%.

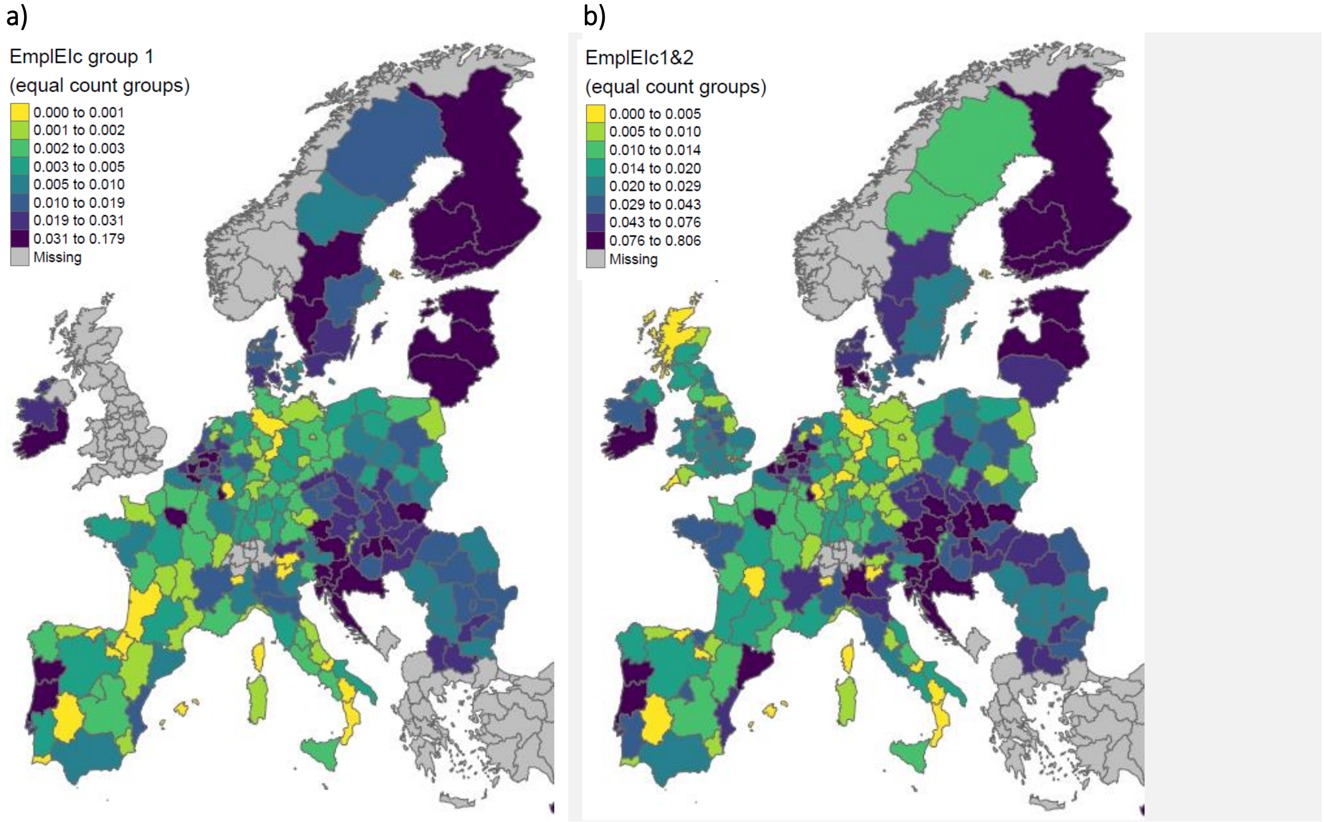


Figure 17. Share of manufacturing employees in a) energy intensive employee group 1 and b) both employee group 1& 2
Regions have been binned into 8 categories (differentiated by colour) based on equal counts of regions ordered by share level – and therefore bins represent different ranges.

Contextual indicator: Long term unemployment

A third vulnerability indicator reflects the long-term unemployment across the different regions. This is an important indicator because it underlines the importance of jobs to a specific region. Higher unemployment regions may be less able to deal with job losses; conversely, they can also benefit from job opportunities that might arise from a low carbon transition.

Figure 18 highlights the high levels of long-term unemployment in specific member states, predominantly in southern Europe, compounded by the financial crisis in the 2000s. Particularly high levels are observed across regions of Greece, Spain and Italy, at over 8%. Greece has been particularly hit hard, with a median long-term unemployment level at 17%, double the median level in Spain. It is also worth noting the disparity between regions, particularly in the countries mentioned above, plus Belgium. Regions with higher unemployment include the south of Italy, and in Spain, the regions of Andalucía, Extramadura, and Castilla-La Mancha. In Greece, the problem is less regionally focused, with a number of regions suffering higher levels. A compounding factor is that this long-term unemployment is characteristic of general unemployment. For the Southern European countries mentioned, on average at least 50% of those unemployed have been so for at least 12 months.

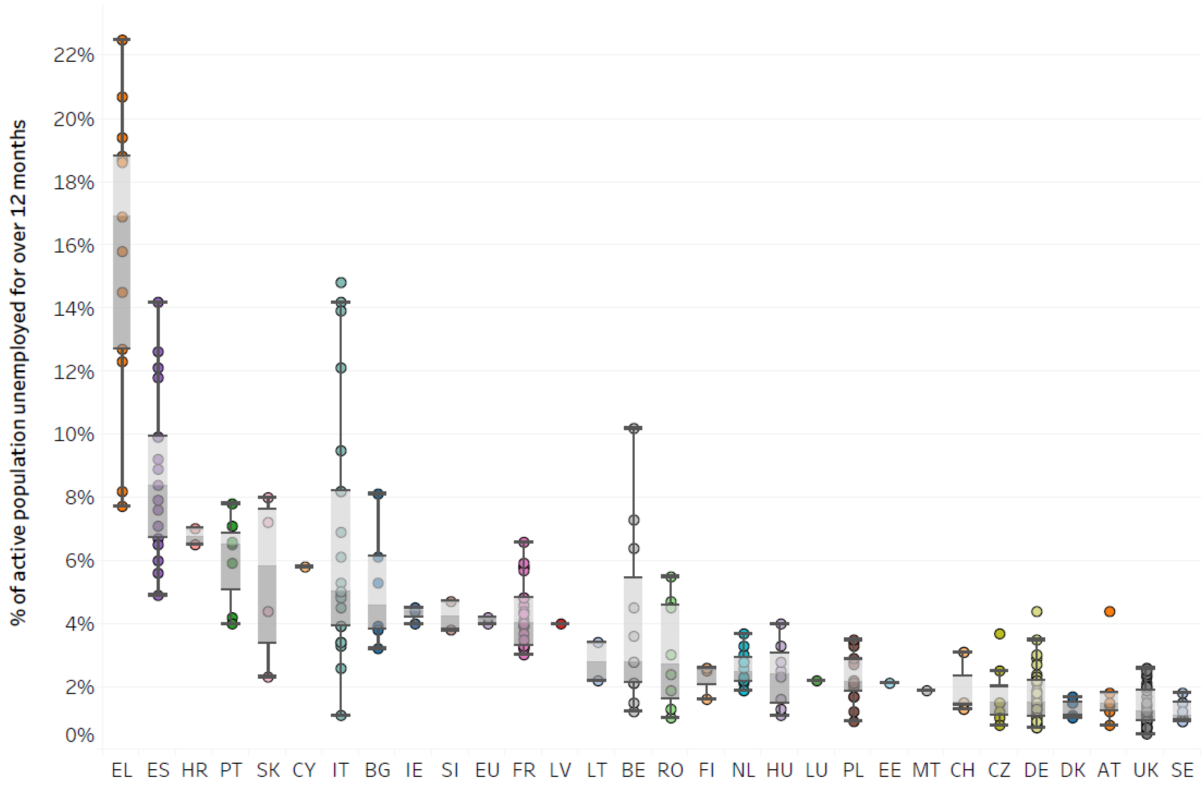


Figure 18. Percentage of the active population in NUTS2 regions who have been unemployed for more than 12 months, 2016 (Source: SBS, Eurostat)

4.3. Regional assessment of sensitivity to impacts

Based on all of the above metrics, we can identify which regions have more than one metric where they have a normalised score greater than 1 (Table 5). This is useful for identifying regions which are sensitive to transition impacts across a range of metrics. The most vulnerable regions, based on the selected metrics, are in Bulgaria and Greece, based on many of the household vulnerability metrics, lower disposable income, and in the case of Greece, problems with unemployment. In these two countries, the only overlap with an industry metric is in Yugoiztochen, Bulgaria, which has relatively high coal sector employment. It is also the region with most metrics highlighted. Regions in Poland, Romania, Slovakia, Czech Republic and Hungary all feature due to having low disposable income and higher levels of energy expenditure.

There is limited overlap between residential and industry metrics, although some examples include coal regions where household energy vulnerability issues are observed, including Yugoiztochen (BG), Severozápad (CZ), Śląskie (PL), Sud-Vest Oltenia (RO). In terms of regions which have high employment in energy intensive industry sectors and household energy vulnerability, this includes regions in Slovenia, Hungary, Lithuania and Estonia.

From a policy perspective, this is interesting to gain a more holistic understanding of sensitivity across multiple sectors to transitional impacts.

Regions in Spain and Italy feature mainly because of lower disposable incomes and higher levels of unemployment rather than based on their specific energy vulnerability metric scores. However, recognising specific issues around capacity to respond to the low carbon transition (as indicated by these indicators) is important for designing policy and targeting resources. It is also notable that both countries rank highly in respect of the cost of energy today, with Spain and Italy ranking 5th and 4th in terms of highest electricity prices and 4th and 5th in terms of highest gas prices based on Eurostat prices for 2015.

Table 5. Regions with higher levels of energy vulnerability

Includes regions with more than two normalised metrics greater than 1, where the normalised range is 0.5-1.5, with 1.5 being most vulnerable. The colour shade across region names denotes number of metrics greater than 1, with a dark shade meaning a higher number. There are fewer regions highlighted across industry metrics as the distribution of the normalised range has a more strongly positive skew.

Member State	NUTS2 Region	Region Name	Lack of adequate warmth	Severe bill arrears	High energy expenditure	Low disposable income	High sector coal employment	Higher EI sector employment	Medium EI sector employment	High LT unemployment
BG	BG31	Severozapaden	■	■	■	■				
BG	BG32	Severen tsentralen	■	■	■	■				
BG	BG33	Severoiztochen	■	■	■	■				
BG	BG34	Yugoiztochen	■	■	■	■	■			
BG	BG41	Yugozapaden	■			■				
BG	BG42	Yuzhen tsentralen	■			■				
CY	CY00	Cyprus	■			■		■		
CZ	CZ02	Střední Cechy			■	■				
CZ	CZ03	Jihozápad			■	■				
CZ	CZ04	Severozápad			■	■	■			
CZ	CZ05	Severovýchod			■	■				
CZ	CZ06	Jihovýchod			■	■				
CZ	CZ07	Střední Morava			■	■				
CZ	CZ08	Moravskoslezsko			■	■				
EE	EE00	Estonia			■			■	■	
ES	ES42	Castilla-La Mancha				■				■
ES	ES43	Extremadura				■				■
ES	ES61	Andalucía				■				■
GR	EL30	Attica	■	■		■				■
GR	EL41	North Aegean	■	■		■				■
GR	EL42	South Aegean	■	■		■				
GR	EL43	Crete	■	■		■				■
GR	EL51	Eastern Macedonia and Thrace	■	■		■				■
GR	EL52	Central Macedonia	■	■		■				■
GR	EL53	Western Macedonia	■	■		■				■
GR	EL54	Epirus	■	■		■				■
GR	EL61	Thessaly	■	■		■				■
GR	EL63	Western Greece	■	■		■				■
GR	EL64	Central Greece	■	■		■				■
GR	EL65	Peloponnese	■	■		■				■
HR	HR03	Jadranska Hrvatska		■		■				
HR	HR04	Kontinentalna Hrvatska		■		■			■	
HU	HU10	Közép-Magyarország			■			■		
HU	HU11	Budapest			■	■				
HU	HU12	Pest			■	■				
HU	HU21	Közép-Dunántúl			■	■				
HU	HU22	Nyugat-Dunántúl			■	■				
HU	HU23	Dél-Dunántúl			■	■				
HU	HU31	Eszak-Magyarország			■	■				
HU	HU32	Eszak-Alföld			■	■				
HU	HU33	Dél-Alföld			■	■				
IT	ITF3	Campania				■				■
IT	ITF4	Puglia				■				■
IT	ITF6	Calabria				■				■
IT	ITG1	Sicilia				■				■
LT	LT01	Capital region	■			■		■		
LT	LT02	Central and Western Lithuania	■			■		■		
LV	LV00	Latvia			■	■				
PL	PL11	Łódzkie			■		■			
PL	PL21	Małopolskie			■	■				
PL	PL22	Slązkie			■	■	■			
PL	PL41	Wielkopolskie			■	■				
PL	PL42	Zachodniopomorskie			■	■				
PL	PL43	Lubuskie			■	■				
PL	PL51	Dolnośląskie			■	■				
PL	PL52	Opolskie			■	■				
PL	PL61	Kujawsko-pomorskie			■	■				
PL	PL62	Warmińsko-mazurskie			■	■				
PL	PL63	Pomorskie			■	■				
PT	PT11	Norte	■			■				
PT	PT15	Algarve	■			■				
PT	PT16	Centro (PT)	■			■				
PT	PT17	Area Metropolitana de Lisboa	■			■				
PT	PT18	Alentejo	■			■				
RO	RO11	Nord-Vest			■	■				
RO	RO12	Centru			■	■				
RO	RO21	Nord-Est			■	■				
RO	RO22	Sud-Est			■	■				
RO	RO31	Sud-Muntenia			■	■				
RO	RO41	Sud-Vest Oltenia			■	■	■			
RO	RO42	Vest			■	■				
SI	SI03	Vzhodna Slovenija				■		■		
SI	SI04	Zahodna Slovenija				■		■		
SK	SK02	Západné Slovensko			■	■			■	
SK	SK03	Stredné Slovensko			■	■				
SK	SK04	Východné Slovensko			■	■				

5. Scenario metrics, and implications for vulnerable sectors

As described in section 3.4, we consider the potential implications of future scenarios on regions with higher levels of vulnerability, or sensitive to impacts of a low carbon transition. This section first describes the scenario metrics that have been selected (section 5.1), which provide a proxy for some of the impacts that could arise from a low carbon transition (see Table 3). The three scenarios considered are described in Table 4. They have been developed as part of the REEEM project to show quite different pathways to a low carbon transition, by reflecting different types of solutions (Local Solutions versus Base) and levels of ambition (Paris Agreement versus Base).

In section 5.2, we then explore what these scenario metrics mean for the different energy vulnerable regions.

5.1. Scenario metrics

Residential energy costs

The residential costs are estimated based on fuels, electricity and the investments and maintenance costs associated with the provision of building-based energy services. There are two key findings that emerge from these pathways – i) energy costs are increasing over time, and ii) the energy costs are becoming more capital-intensive (Figure 19). Both matter for energy-vulnerable households; current households facing challenges in paying for energy bills may face additional pressures of meeting payment. On capital-intensity, this could make payment more challenging, if more upfront investment needs to be found.

However, there is an important opportunity underlying this metric. The increased capital investment in appliances, infrastructure and building fabric offer prospects for large improvements in sector energy efficiency. This is a means of ensuring that energy vulnerable households have adequate heating at affordable cost. It is also important to highlight that if incomes increase in real terms, this might reduce the proportion of expenditure on energy.

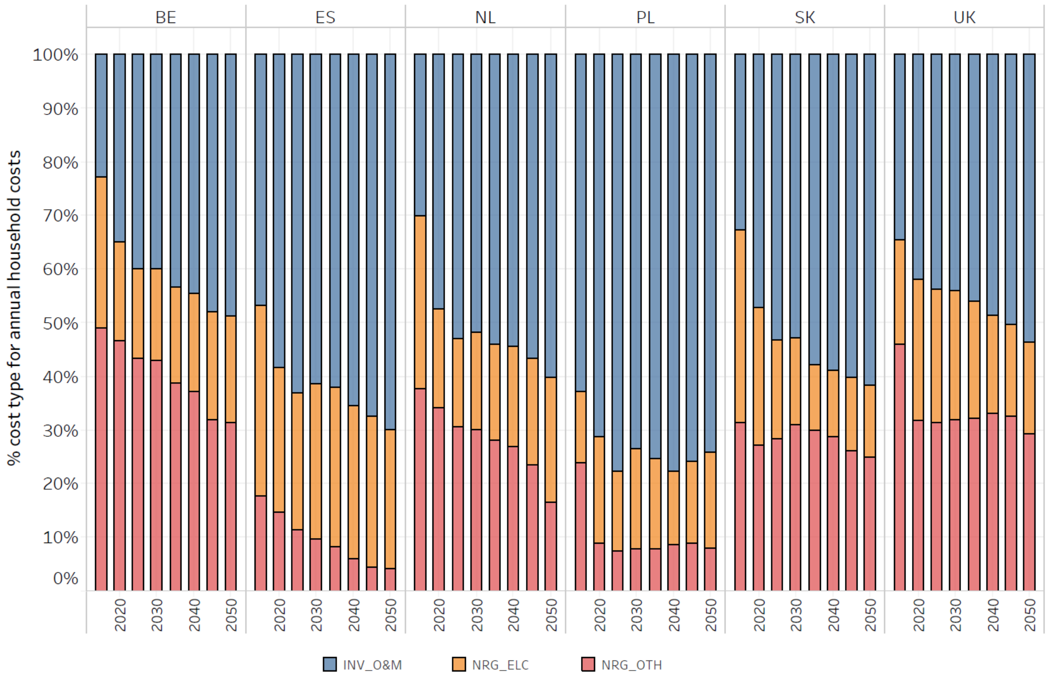


Figure 19. Share of cost type in average annual household energy costs across selected member states under the REEEM Base scenario (Source: TIMES PanEU, REEEM analysis)

The evolution of costs of household energy service provision in each of the scenarios is shown in Figure 21. The values are indexed household cost values to meet in-house energy service requirements (heat, electrical appliances, lighting etc.). Overall, most countries see an increase in costs, particularly in the near term, with costs then flattening out post-2030. This is driven by increasing electricity costs (based on shadow prices) and increased investments. Offsetting these increases to a certain extent are the ‘other fuel costs’, consisting mainly of fossil-based energy, which in the main reduce as the sector becomes increasingly electrified. It is important to note that investments and electricity prices (which embodies investments in power generation) increase more rapidly in the earlier periods because models such as TIMES PanEU often do not track annualised investment from existing stock. This means that a sudden increase in the index between 2015 and 2020 is partly down to hidden (ongoing) investment of existing stock in the 2015 period, and that an index value of two is therefore likely to be less than a doubling of cost.

Driving the changing cost is the transition to low carbon fuels in the household sector, as shown by the percentage change in fuel use between 2015 and 2050 (Figure 20). This shows a reduction in the use of gas and petroleum products, and an increase in the use of electricity and derived heat. This shift has important implications for vulnerable and low income households, because the per unit price of electricity and district heating (derived heat) is higher than the retail price of gas. This will be particularly significant for countries such as BE, CZ, DK, IT.

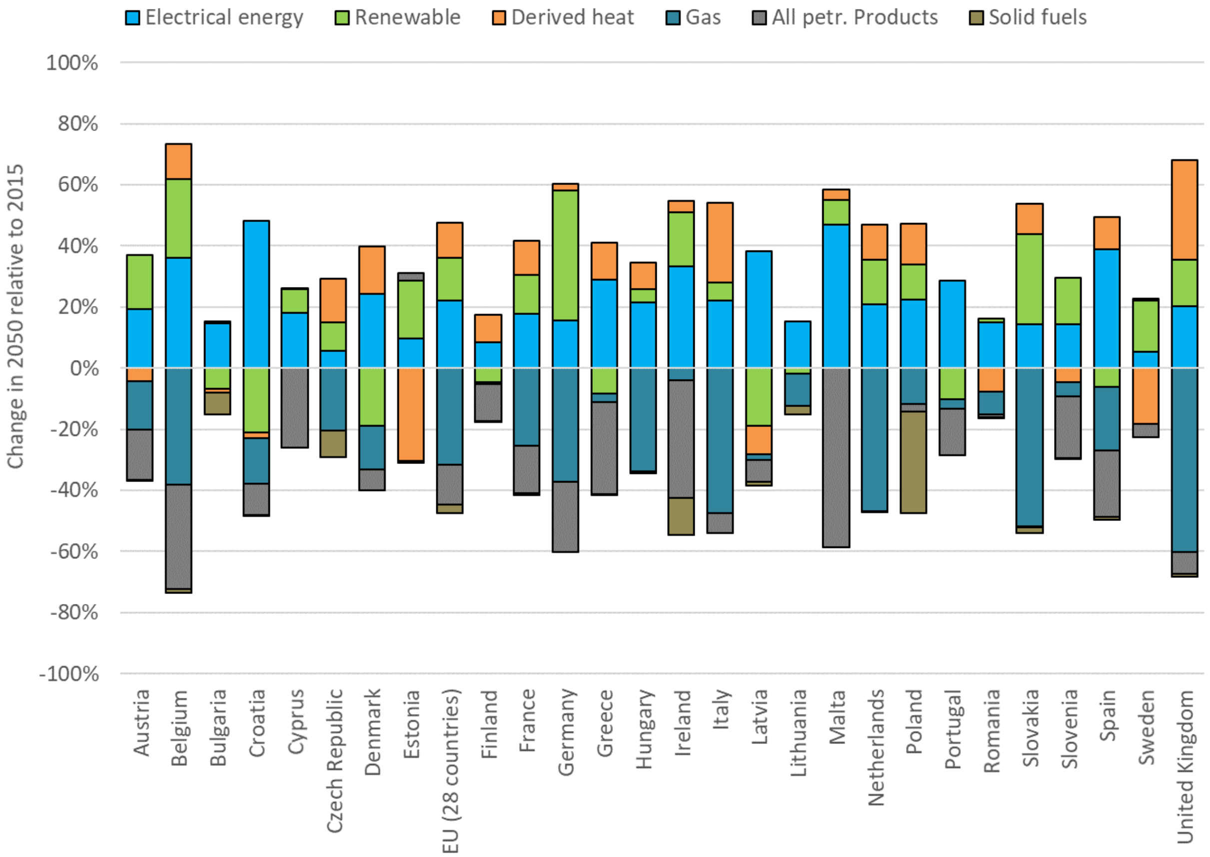


Figure 20: Percentage change in fuel types in households between 2015 and 2050 by member state, with 2050 represented by Paris Agreement scenario.

On costs, while there is a spread of results across different member states, most stay below an index value of 2. The exception is a group of countries who have higher levels of investment (ES, PL, CZ) or higher electricity costs (GR, CZ). A number of countries have very flat costs (HR, NL, AT, BE, DE). Further investigation would be needed to understand why specifically these patterns are observed – and whether they are specific country-based insights or a function of the modelling, with limits on representation of sector-level specifics in a large Pan-European model. Another factor is the relative level of mitigation in the residential sector versus other sectors in any given country. In a specific country, costs may be higher as more action is being undertaken in the residential sector, whereas in other countries there is a stronger focus on other sectors.

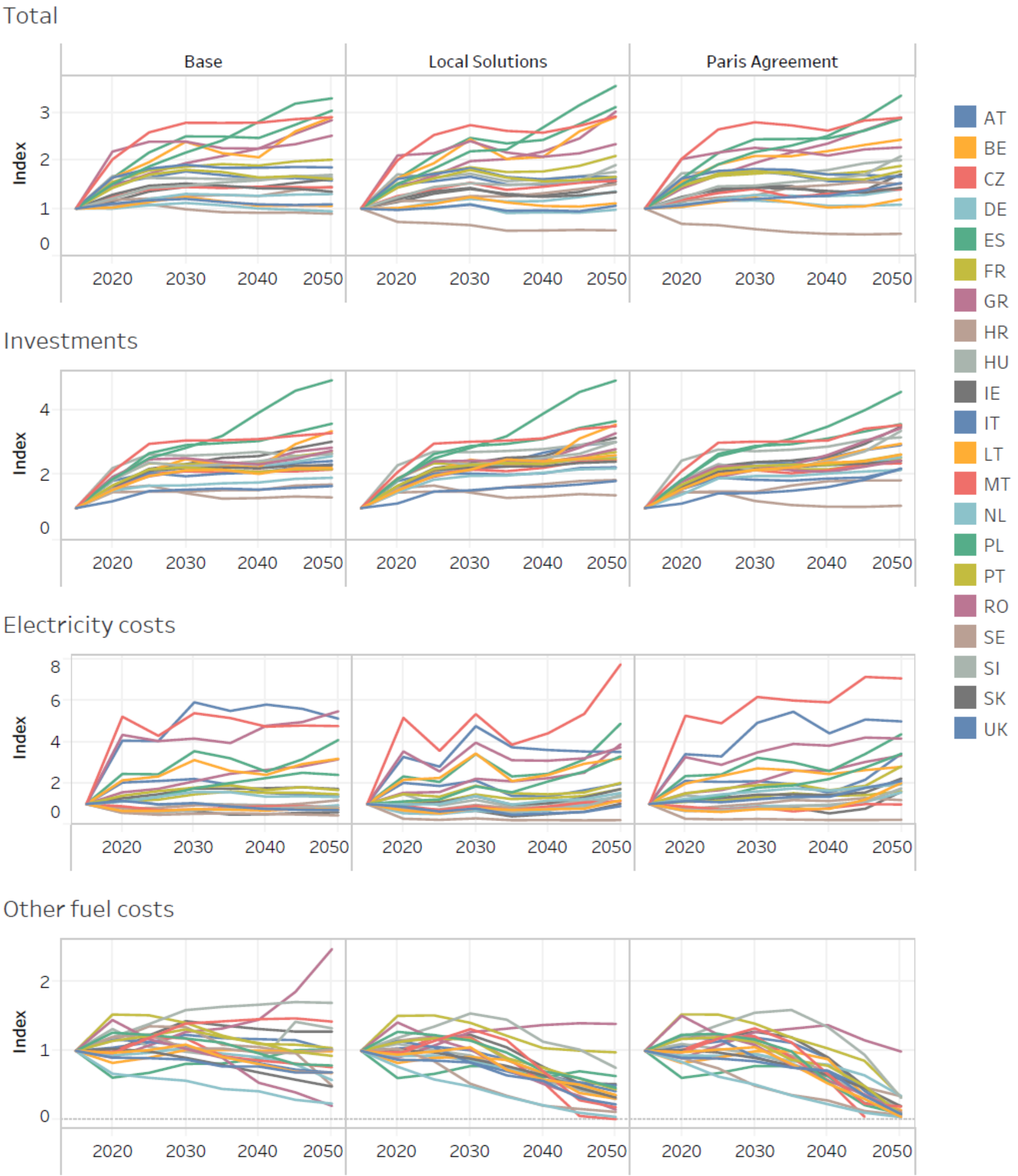


Figure 21. Change in household annual costs (disaggregated into investment, electricity and other fuel costs) over time by member state under core REEEM scenarios, 2020-2050

(Source: TIMES PanEU, REEEM analysis). Sharp increases between 2015 and 2020 for electricity costs and investments are likely to arise from incomplete accounting of annualised capital costs in earlier years.

We can also observe that there is limited variation between the three scenarios. This is also observed for the industry metrics below, and probably reflects that most of the scenario levers used in the modelling are focused on the supply side of the system, rather than the demand side. This has important implication for the approach taken, which are subsequently discussed in section 6.3.

In summary, key insights from these scenarios include –

- Under a more capital-intensive, fixed cost system, vulnerable households are going to require support to ensure there are flexible options for payment, and opportunities for access to capital.
- Countries that have a stronger dependency on higher carbon intensive fuels and related heat networks will see a more disruptive transition, and may require more support. While gas-based systems will need to be fully phased out, they may need to be turned over at a slower rate, compared to oil and fossil-based systems. Vulnerable households in these countries will require targeted support.
- While difficult to draw firm conclusions, countries in Eastern and Southern Europe appear to experience higher costs on average than other member states. Further work would be needed to assess how robust such an insight was, and the extent to which this is due to structural features of the model.
- While the cost picture is mixed due to different drivers around investment and other costs, it is evident that energy use drops over time due to energy efficiency measures. The EU sees a 30% drop in energy use for heat on a household basis in the Base scenario, and a 35% drop under the Paris Agreement case. The respective numbers for overall energy use (not just heat) are 22% and 28%. This highlights the opportunity to reduce consumption through improved efficiency, a key part of reducing energy vulnerability.
- In terms of overall per household costs, for a range of countries the cost increase is mainly to 2030, after which a decline or plateau is observed. This highlights a possible limitation of using these metrics, which do not include the annualised investments associated with existing stock.

Coal production and use outlook

The outlooks for coal production and generation are shown below in Figure 22, for each of the REEEM scenarios. All show a bleak outlook for both. On generation, this goes to zero by 2050 under the Local Solutions case, and to less than 15% of 2015 levels in the Base scenario. The Paris Agreement case shows a slight increase (following a sharp decline in the preceding decade) in generation from 2040 onwards, due to the uptake of CCS application for coal generation. (There is, however, a question as to whether coal CCS would be invested in, if indeed system emissions need to get to zero, given the associated emissions due to less than 100% capture rates).

For production, a strong phase out is observed, with coal production at zero in Germany by 2040, and Poland by 2050. Out to 2035, production in Poland holds firm at relatively high levels (~70% of 2015 levels) before falling rapidly in the last 15 years of the time horizon. In the Paris Agreement case, the drop to near zero in production means that coal generation is from imports.

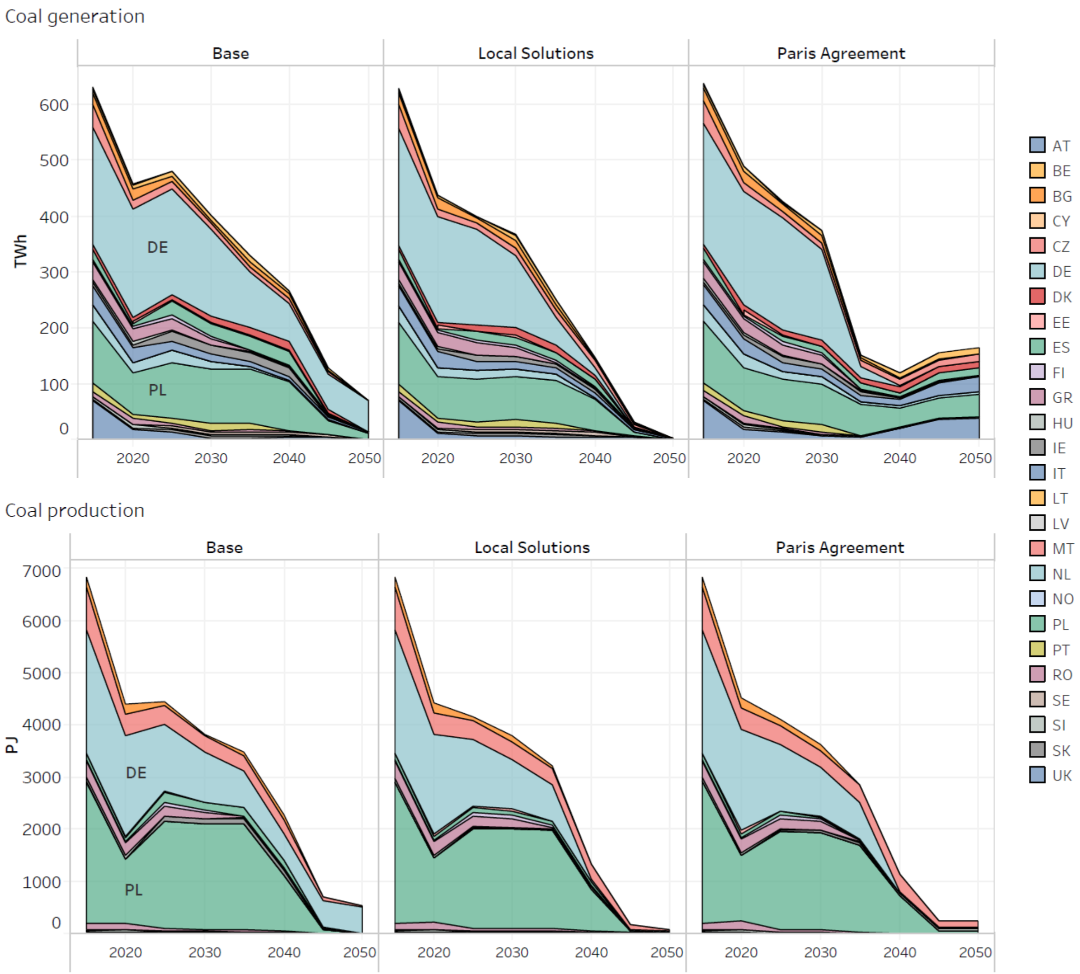


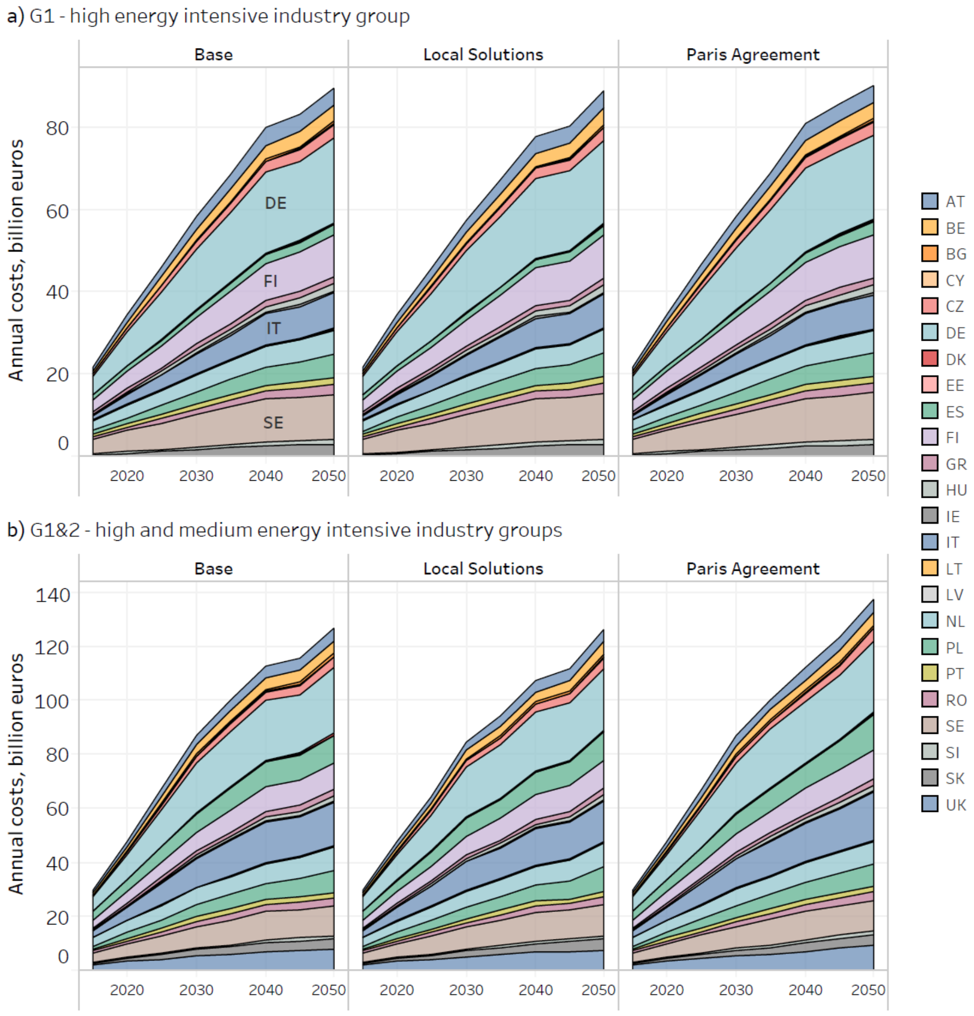
Figure 22. Coal production and generation by member states under core REEEM scenarios, 2020-2050 (Source: TIMES PanEU, REEEM analysis)

These outlooks clearly show that the employment prospects in these industries are limited, and that strong consideration will need to be given to how to effect managed exits from these sectors for those regions that are more job dependent on these sectors.

The other relevant sector, which is not a focus of this analysis, is oil and gas extraction, with the main European players being Norway and the UK (for oil and gas) and the Netherlands (for gas). The scenarios appear to show some room for continued production but which rapidly falls off during the 2030s. These production sectors also appear to have fully declined by 2040, in part due to reductions in commodity use (and reduced markets) but also because of declines in European reserves.

Industry sector costs and investments

The scenarios also provide information about the costs of energy, and required investments across industry sectors. Figure 23 shows the level of investment and O&M costs in the energy-intensive sectors in each of the modelled scenarios. A large increase in investment requirements across these sectors over the time period is clearly evident. This four-fold increase is slightly misleading as the flows of investment prior to 2015 are not accounted for and are considered sunk (as observed for the residential sector). Two-thirds of the investment and other costs is for the most energy-intensive group of sectors, with Germany (DE), Finland (FI), Italy (IT) and Sweden (SE) dominating. The main sectors where these arise are other non-metallic minerals, and pulp and paper in the Scandinavian countries, iron and steel, cement, and pulp and paper in Germany, and Iron and steel, and aluminium in Italy.



a) G1 - high energy intensive industry group

b) G1&2 - high and medium energy intensive industry groups

Figure 23. Annual investment levels for energy intensive industries across REEEM scenarios, 2015-2050.

A cost index has also been constructed for the different energy-intensive industry groupings, using investments, O&M costs, electricity and other fuel costs. It is constructed for each country-sector, before being weighted (based on the levels of costs) to provide the aggregate index for each country (see section 3.4 and Appendix 1 for a full description). As shown in Figure 24, the majority of countries see some increase up to an index level of between 1.5-3.0 by 2050. Notably, Italy (pink trend) increases more quickly and remain at a higher trajectory than observed for other countries.

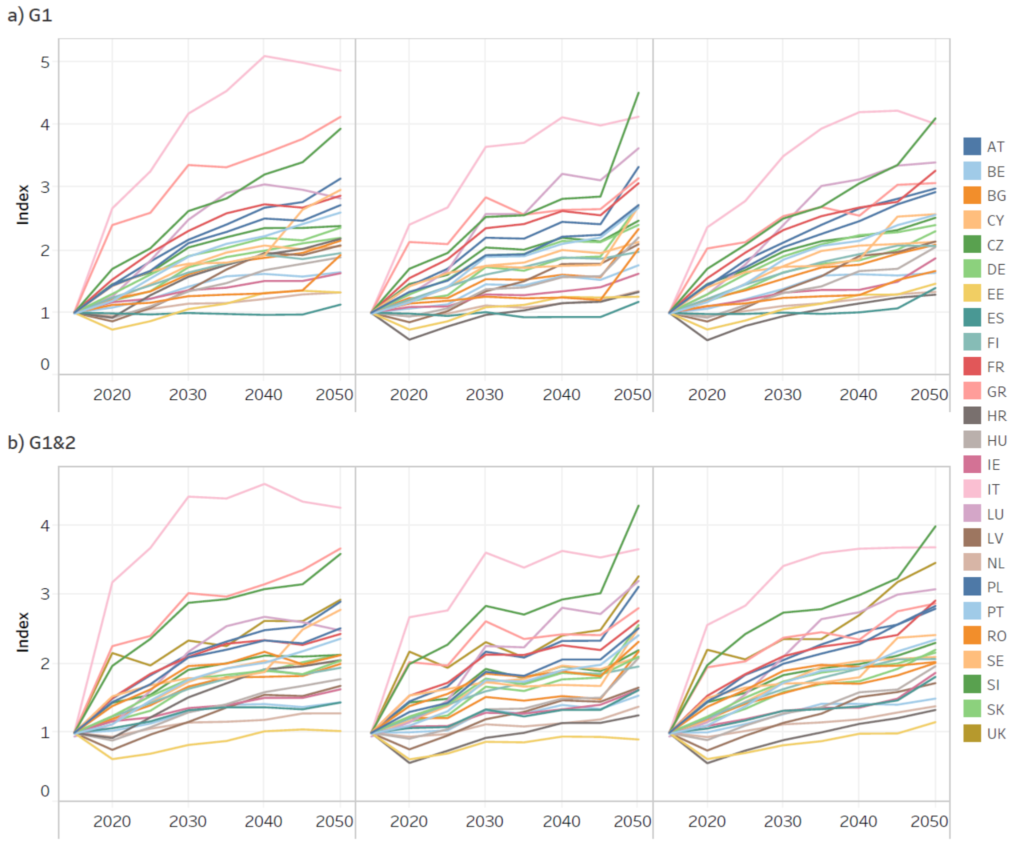


Figure 24. Change in unit costs for energy intensive industries across REEEM scenarios, 2015-2050
Costs information is first indexed to 2015 by sector (in G1 and G2), with a weighted index produced based on the costs attributed to the different sectors.

In summary, the industry metrics highlight the increasing investment requirements across the industry sectors, with variation in absolute investment level (Figure 23) a function of sector size. As with the residential sector, these increased levels offer new investment in helping drive a competitive industrial base in a low carbon world. However, increasing cost pressures will need to be managed to ensure that these industries have the opportunity to re-invest whilst remaining competitive, often in the global market place. Further understanding of differences in the costs across different countries again requires additional scrutiny of model inputs and assumptions that are specific to member states, as well as the mitigation effort each country is undertaking in this specific sector.

5.2. Combining scenario and vulnerability metrics

As described in the approach taken (section 3.2), we compare sensitivity metrics (indicating vulnerability) and exposure metrics (indicating impact of a low carbon transition). The rationale for such an approach is to identify both regions which are sensitive to impacts from the transition, and where impacts are relatively higher. In doing so, we can start to provide insights to decision makers concerning what regions may be more exposed, in both positive and negative terms, with a view to designing policies that recognise this.

In this section, all of the sensitivity metrics, described in section 4, have been compared to exposure metrics from the Base scenario. Comparison with other scenarios are not provided here because of the limited difference between pathways. Despite different pathways having distinctive narratives, the variation has not fed through into the costs and investment metrics across end use sectors. This issue of limited variation, and its implications for this approach, are discussed further in section 4.

Residential sector

Two types of energy vulnerability metric have been considered – consensual and expenditure-based. The consensual indicators (households who lack adequate warmth, and who are in bills arrears more than twice a year) are considered first, and plotted against two model metrics; i) energy cost increases (Figure 25) and ii) increases in investment levels (Figure 37, Appendix 4). Note that all regions in a given country will see the same energy cost or investment level value, as the scenario metrics are produced at the country scale.

In the figures, those country regions that are in the upper right quadrant of the figures, highlighted by a red boxed area, have higher sensitivity to impacts and are projected to experience higher than average cost increases, or investment levels. The regions situated in this quadrant (in both figures) are composed almost entirely of those in Southern European (GR, ES, PT, CY[24]) and Eastern European member states (BG, HU, SI). The pattern from both energy costs and investments is similar as investment are an important component of energy costs; hence Figure 37 has been appended.

These results highlight both a risk and opportunity, and indicate an important role for policy. On energy cost increases (risk), the higher sensitivity regions will need more targeted assistance with managing cost increases, through energy efficiency interventions, especially to address the shift in fuel types and the accompanying required investment in infrastructure and new household appliances. For most countries, with Spain (ES) the notable exception, costs do not increase significantly beyond 2030, highlighting that policy in the near term will be important for a transition to higher costs but that in the longer term, such cost increases may not continue. While not highlighted in this graph, targeted policy will be needed not only for specific regions but specific households within regions, as shown by the earlier decile analysis (e.g. for decile 1 households, Figure 12).

The opportunity is that targeted regional and within-region interventions can help address the underlying structural challenges around poor building energy efficiency, and adequacy of heating systems. This investment can ensure that regions where higher prevalence of household struggling with bill payments or heating their

---

[24] The FR region of Corsica is included in the red box under the AdWarmth metric.

homes can be helped to improve heating services that are affordable. Critical will again be acknowledging where the investment is needed and recognising that regions and households will be in relatively different positions on being able to access and raise investment. In summary, short term risks of energy costs increases could be offset by large-scale investment to address structural issues. This approach starts to help identify where available resource could be targeted, based on sensitivity and exposure to impacts.

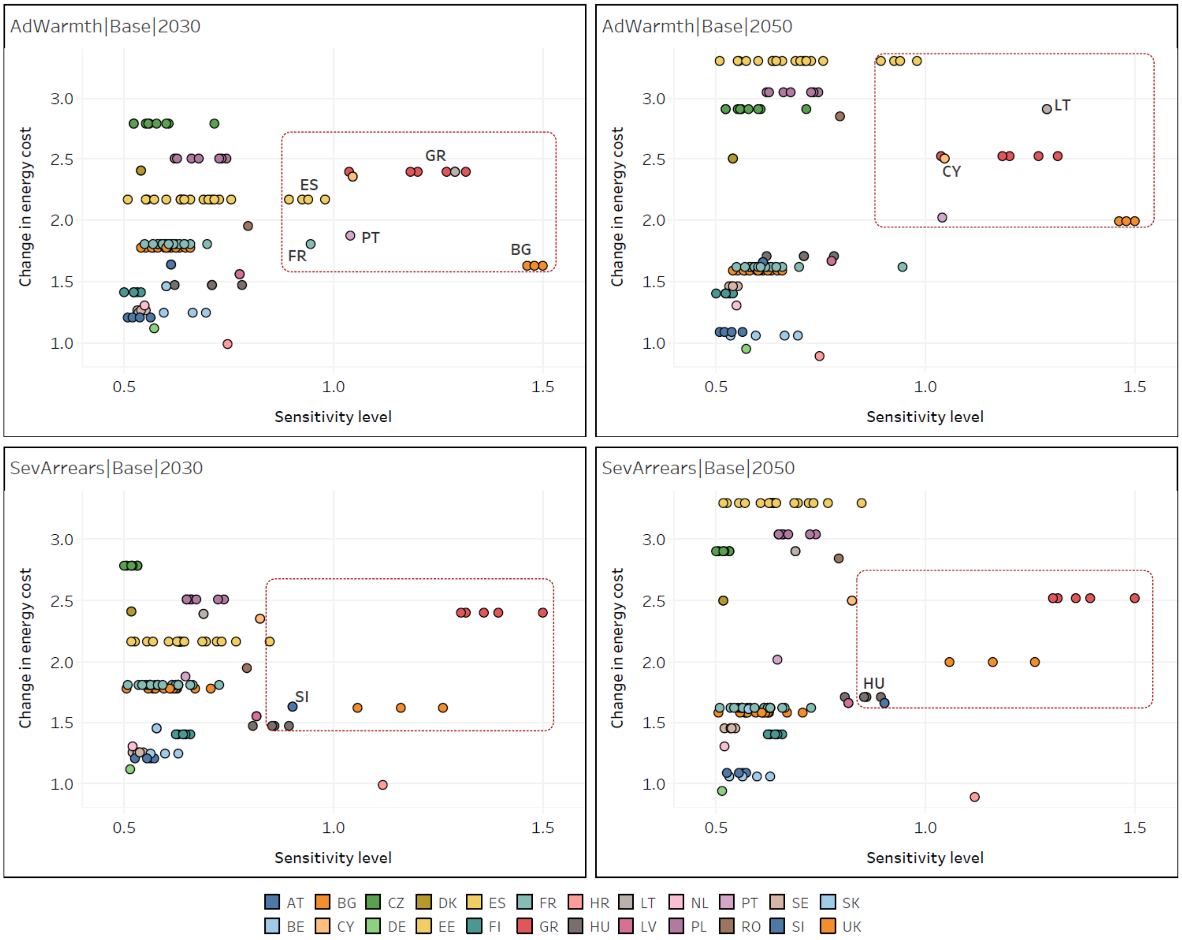


Figure 25. Change in energy cost level in 2030/50 (relative to 2015) under Base pathway versus current household sensitivity as measured by consensual indicators, AdWarmth and SevArrears.

The sensitivity indicators are for the average household in a region i.e. not for a given decile group. Red boxes highlight those regions who are both sensitive and see high levels of cost. MS not represented include IE, MT, LU and IT.

Using expenditure metrics, we identify a different group of regions in the upper right quadrant, due to the different type of information that they are underpinned by e.g. expenditure as opposed to lived experience. Like for the consensual indicators, we only plot the comparison against one exposure metric, this time investment level (Figure 26); the comparison with energy cost can be found in Figure 38 (Appendix 4).

Most regions are in Eastern European countries, where a higher proportion of household budget is spent on energy. Countries with regions in the red box under the EnExp metric (upper panel of Figure 26) include RO, PL, CZ, SK and HU. Southern European countries, which were identified under the consensual metrics, are not highlighted here, probably because those regions spend less on bills due to lower energy demand given the warmer climate for much of the year, and because a lower share of households have central heating systems in these countries.

The 2M metric comparison, in the lower panel of Figure 26, again shows a different set of regions in the red boxed area to those under the EnExp metric. This metric identifies the share of households in a region who pay significantly more than the median level of expenditure, and therefore who may have affordability issues. This is more interesting for exploring variability within a country, because it is based on the median expenditure of a given country. For those countries with a higher median expenditure, indicated by EnExp to some extent, their regions are less likely to feature due to higher median threshold – and hence the different regions emerging. Regions in PL, LT, UK, ES and FI feature in the red box.

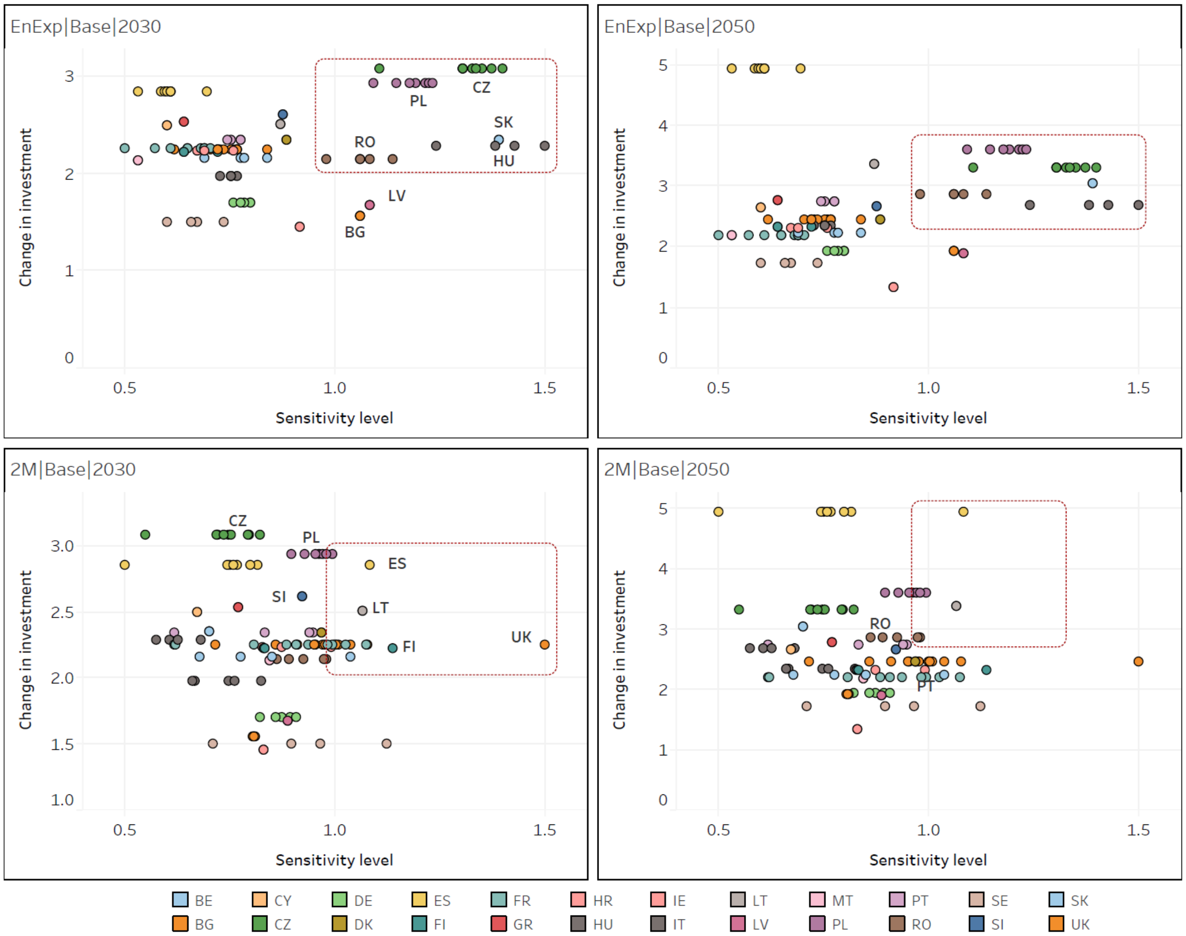


Figure 26. Change in investment level in 2030/50 (relative to 2015) under Base pathway versus current household sensitivity as measured by expenditure indicators, EnExp and 2M.
The sensitivity indicators are for the average household in a region i.e. not for a given decile group. Red boxes highlight those regions who are both sensitive and see high levels of cost. MS not represented include AT, NL, EE, and LU.

As we have noted, country regions most vulnerable to the impacts of the transition need policy to target resources to help make the investments necessary to address structural problems. This support is needed because many of the regions identified are least able to afford the necessary investment. Using a proxy indicator for affordability of level of disposable income (PPS basis), we plot this against the sensitivity metrics in Figure 27 below. It shows that the country regions that have a high vulnerability (<1 on horizontal axis) typically have lower disposable incomes (<1 on vertical axis). This type of comparison is useful to provide insights on the adaptive capacity of regions and countries to respond to different policy interventions.

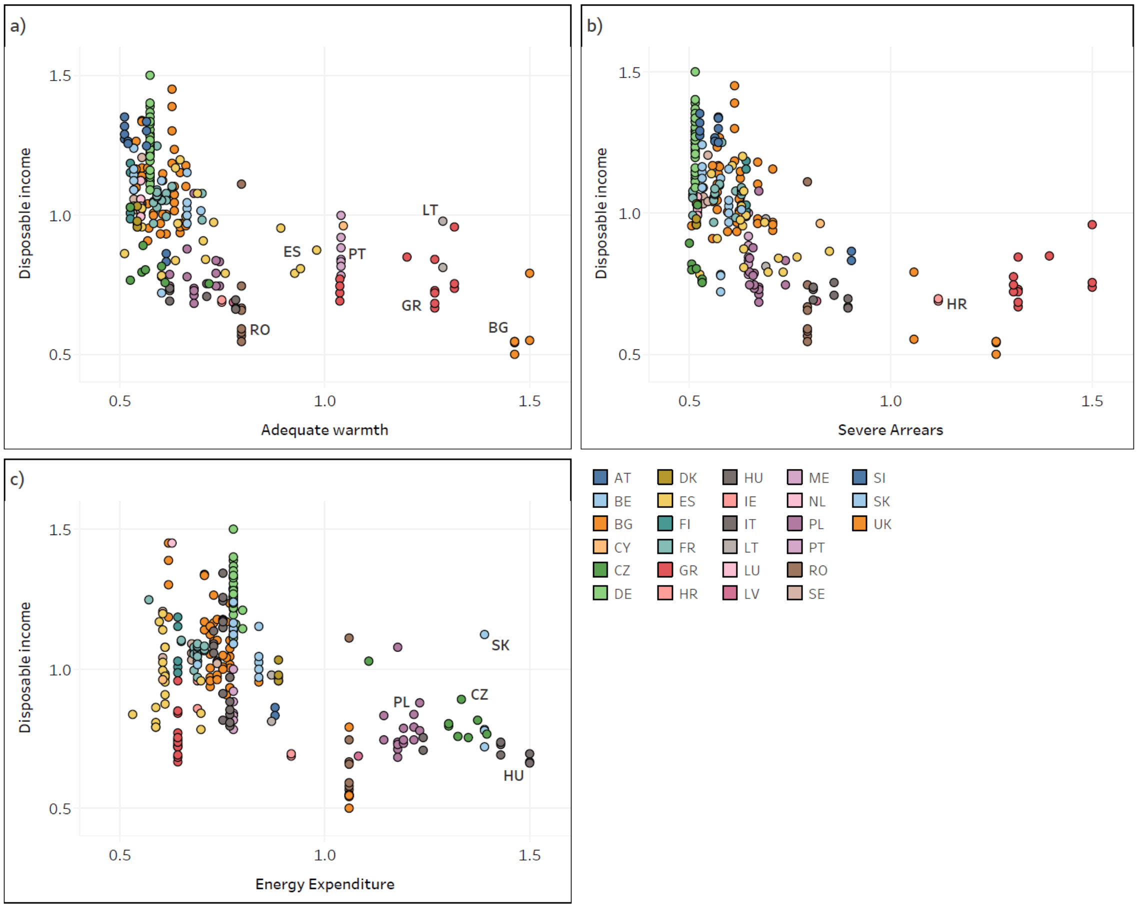


Figure 27. Disposable income versus household sensitivity metrics

The panel includes the following metrics compared to disposable income (PPS basis); a) Adeqaute warmth; b) severe arrears; and c) energy expenditure. A high sensitivity value for these three metrics means increased vulnerability. The sensitivity indicators are for the average household in a region i.e. not for a given decile group.

Industry sectors

The sensitivity metrics for the coal sector (share of employees indexed against the region with most coal sector employees) is compared to the exposure metrics of coal production and generation levels in Figure 28. For both production (upper panel) and generation (lower panel), the reduction in both is stark. In 2030 (left-hand panel), all of the most sensitive country regions have levels below what they had in 2015 (1 on vertical axis). By 2050, both production and generation are near zero, with only DE sustaining very low levels (although not in the other scenarios). This has important implications for those regions with high levels of employment in this sector, focused in PL, DE, CZ, RO and BG. Scenario analysis can provide some insight into how this transition may unfold, and the planning timescales that might be needed to assist the sector. After 2030, both sectors decline relatively steeply, as shown in Figure 22.

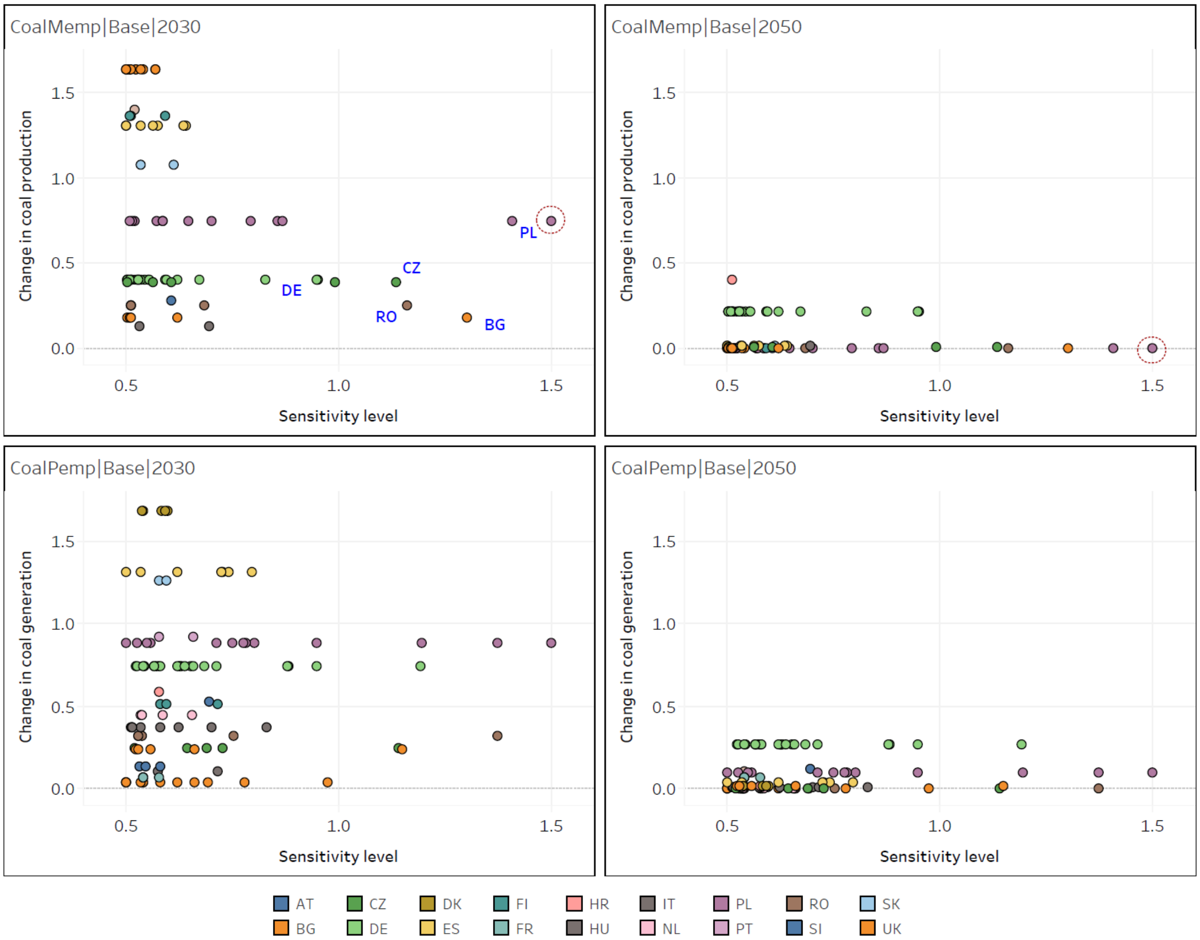


Figure 28. Change in coal production (upper) and generation (lower) in 2030/50 (relative to 2015) under Base pathway versus current coal sector sensitivity as measured by sector employees

The sensitivity indicators are for number of employees in these coal sectors, indexed against the region with largest number of employees. Note that the Poland region (circled) has an employee level four times that of the next largest region; to enahnce presentation, this difference has been reduced. Note unlike other graphs, exposure increases with lower values on the vertical axis e.g. reducing coal production and generation, relative to 2015.

Finally, the sensitivity metric (EmplEIc), which represents the percentage of manufacturing employees in sectors that might be exposed due to higher energy costs, is compared against the cost and investment estimates under the Base scenario (Figure 29). As with the residential metrics, there is limited difference between scenarios (see Figure 24), and therefore the Base scenario has been used again. As with the residential sector, the exposure metrics selected represent both a risk and opportunity – and again highlights the key role for policy.

It is very difficult to draw any firm conclusions based on this comparison, particularly due to the very large spread of costs across different member states, and limited insight into what is driving those differences in the modelling. In relation to those regions most sensitive, they do not appear to have relatively higher costs on average than other regions (upper panel) although high exposure values (vertical axis) for IT and LT make this difficult to determine, as it compresses the range that the rest of the countries sit in. The member states SI and LT both sit in the high sensitivity / high cost range. In the lower panel, investment levels are shown, and have a similar pattern.

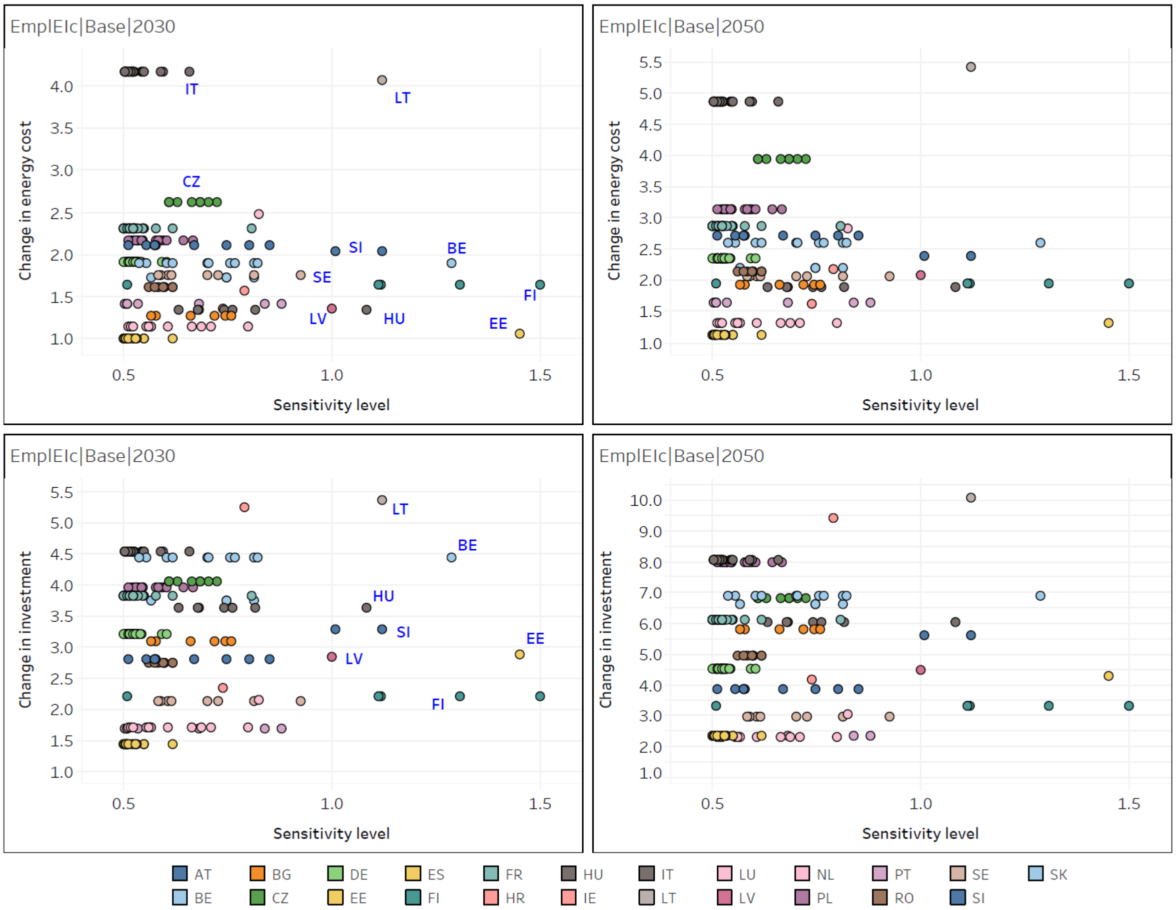


Figure 29. Change in energy cost (upper) and investment level (lower) in 2030/50 (relative to 2015) under Base pathway versus current industry sensitivity as measured by share of employees in energy intensive industries.

MS not represented include DK and CY (due to having extremely high change in cost metrics. Sensitivity data are not available for GR and MT. UK is not represented as none of its sectors fall into this energy intensity grouping (for further explanation see section ***Industry indicators*** in section 3.3).

In the same way that we considered disposable income as a proxy metric for regional ability to deal with cost increases, we have used long-term unemployment as a proxy indicator of resilience to job losses under the transition. Figure 30 shows that those regions more sensitive in terms of industry vulnerability are not those that currently have a long-term unemployment problem. Regions with more acute problems of long-term unemployment are predominantly focused in Southern Europe. Some of the identified employment issues could be alleviated with the required investment shown for the residential sector earlier in this section.

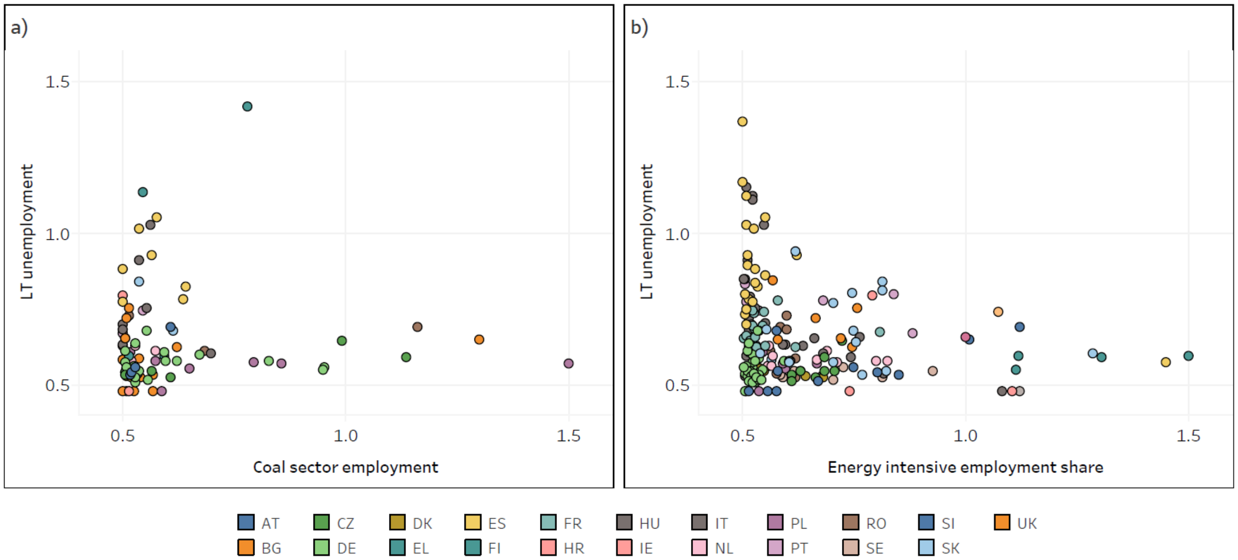


Figure 30. Long term unemployment (unemployed for at least 12 months) versus industry sensitivity metrics
a) long term unemployment versus coal sector employment, and b) long term unemployment versus energy intensive industry sector employment

6. Discussion and conclusions

In recognising that that there has been limited consideration in modelled low carbon transitions of energy vulnerability at a subnational scale, a range of metrics have been compiled that highlight sensitivity to, and exposure resulting from different low carbon transitions. We explore across both industrial and residential sectors at the regional level, to gain more comprehensive insights into the potential distributional implications of the package of measures required to deliver the EU's low carbon policy objectives.

What is evident are the large regional differences across the European Union in potential vulnerability, both between and within member states – and that they will be impacted by low carbon transitions in different ways. This has important implications for energy and climate policy. And without this analysis, such differences are missed in the discussion of strategy and policy design. Whilst knownto some extent, their lack of visibility is an issue. This is problematic, given that there is a widely held view that the transition will need to be equitable to garner support.

In this discussion, it is crucial to recognise that there are many other drivers of change, with a changing economy, evolution of consumer preferences and practice driven by technology, and the influence of automation, to name a few. This means that policy in the domain of climate and energy also needs to recognise these other drivers, and work in a joined-up way with other policy functions. It may be that the climate and energy agenda can be used to align with ongoing transitional issues to help put support in place for communities and sectors.

We first summarise the key insights from the analysis, before exploring the implications for policy at the European and member state level. We then take a critical look at the approach used in this report, and make suggestions for future research.

6.1. Key insights from analysis

In respect of the household sector -

Energy vulnerability in households is highest in regions of Eastern and Southern Europe, using both measures of affordability and lived experience. Factors giving rise to this include sufficiency of heating systems in colder periods of the year (notably in Southern Europe), while in Eastern Europe factors may relate to a range of issues from poor building fabric to inefficient energy systems. Affordability is also a key factor in these regions, where incomes are typically lower than in other EU countries (as highlighted in Figure 27).

There are considerable differences in household energy vulnerability between regions in country, and within those regions, not just between countries. This reflects differences in income between regions, and within regions, as shown by the analysis of deciles. For example, in Greece, the highest decile (10) has an average share of households unable to keep warm at 5%, while the lowest decile (1) has a share of 55%, a very large difference. This type of pattern is replicated across other member states (Figure 11) – and across the range of household sensitivity metrics. In terms of regional variation, this again arises from differences in local economies, incomes, and other factors (local energy systems, building stock, access to services etc.).

The scenario metrics suggest that many of the energy vulnerable 'sensitive' regions in this research may also incur higher energy costs but also the prospects of large investment, required to deliver the transition. This investment highlights the opportunity that the transition brings to resolving some of the underlying structural problems inherent in driving energy vulnerability (poor building stock, insufficient heating provision). It is likely that some of these regions see higher investment due to the need for improved efficiency and associated infrastructure. Policy therefore needs to manage the short-term risks of increasing cost, which could impact negatively on affordability, while incentivising and supporting the large-scale investment that is necessary.

In respect of the industry sector -

Specific regions have high concentrations of employment in vulnerable extractive sectors such as coal. Coal production and generation jobs are highly concentrated, based on regions with large extractive sites, notably Poland and Germany. Śląskie in Poland (situated in the Silesian basin) is by far the region most dependent on coal mining, accounting for over a quarter of the total sector employees across Europe.

While not considered in this research due to data issues, oil and gas extraction is also concentrated in specific regions, such as North East Scotland. While such sectors may not experience as rapid a decline, reserves are reducing fast so the industry will need to manage the decline anyway, perhaps moving into other offshore activities such as renewables or carbon storage.

All scenarios considered show rapid decline in both coal production and generation. Just Transition planning is therefore vital for the affected regions. As shown in Figure 22, the decline after 2030 is rapid, with very low or zero output by 2050, meaning that effective planning focused on new opportunity for workers needs to be put in place over the next decade. Unlike other industries, there are no prospects for keeping these extractive industries in business. Learning from past transitions should help inform just transition strategies.

There are specific regions of Europe with higher shares of employees in energy intensive industries, which could be subject to higher energy cost pressures, and in some case, global competitive pressures. Regions include those located in Eastern Europe, BENELUX, and parts of Scandinavia, where there is a focus on metals, non-metallic minerals, paper and pulp, and to a lesser extent, chemicals. These sectors, labelled group 1, account for some 3 million employees (Figure 16).

The transition does see energy cost increases for these industries, but like in the residential sector, in large part this increase is driven by investments in low carbon technologies and cleaner fuels. If Europe is to compete in a low carbon world and retain its heavy industrial base, large investments will be required. Unlike the coal sector, the vulnerability of employment in these sectors can be reduced through investment, much of which will need to be incentivised through policies, including measures that recognise and reward the low carbon provenance of goods.

Regions that have a higher dependency on energy-intensive industries do not necessarily experience higher costs under the scenarios. There is no obvious pattern between sensitivity and exposure for the scenarios used in this analysis. The main conclusion to draw from the analysis is the large investment that will be needed across most regions to ensure a move to a low carbon system, allowing for the renewal and modernisation of different industry sectors. In general, we also did not find that sectors with higher energy-intensive sector employment were experiencing challenges of long-term unemployment, meaning that many of these regions have some resilience in terms of employment levels (Figure 30).

6.2. Implications for policy

Whilst this analysis highlights some interesting insights into the spatial distribution of sensitivity to impacts, a key question is how should policymakers, both at the European and member state level, respond. In this section, we state what should be priority areas for policy making, and how we think the process of policy deliberation and design needs to change.

On policy priorities -

Explore how the existing EU legislative process can further promote a recognition of distributional impacts. For household energy vulnerability, represented by energy poverty, the concept and measures to address the challenge have been much more strongly integrated in recent years, notably in the Clean Energy for All package of measures (Thomson and Bouzarovski, 2018). However, recent commentary has suggested that this could be strengthened and go further by integrating this into the policy process (Dobbins et al., 2019). Current approaches are described towards the end of section 2.2.

Further consideration of how industrial policy can help sectors under the transition is needed. Important research initiatives such as the Sustainable Industry Low Carbon (SILC) programme are supporting the development, demonstration and dissemination of low-carbon technologies through financing projects.[25] Such initiatives are important for helping industry move towards low carbon production – but they need to be significantly scaled up. There are also specific support initiatives for vulnerable industries, via the Platform on coal regions in transition, and industrial transition regions.[26] It will be key that such initiatives are well-joined up with energy and climate policy, particularly if industrial policy evolves towards other mechanisms in addition to the EU ETS. This is of course an important area of policy consideration at the member state level.

Plan how new policies need to be designed to anticipate the needs of households and industrial sectors. The long-term climate policy goals and scenario exploration of these goals provide insights into some of the likely impacts. Therefore, policy makers know in advance of how such a transition may play out. Research on coal transitions highlights that a key success factor for these transitions is in anticipating them, and making necessary recommendations upfront e.g. guidance for young workers to steer them towards sustainable employment, managed retirement of older workers, and retraining programmes where necessary.[27]

Explore best practice in addressing energy vulnerability across different countries. Following on from the previous point, an interesting idea would be to develop a Just Transitions Observatory for Europe in the same way as there is now one established for energy poverty, to bring together metrics, examples of best practice,

---

[25] Sustainable Industry Low Carbon (SILC) web page, https://ec.europa.eu/growth/industry/sustainability/climate-neutral-economy/silc-programmes_en

[26] Structural Support Action for Coal and Carbon Intensive Regions, https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/coal-regions-in-transition

[27] IDDRI (2018). Blog post: The Just Transition Silesia Declaration - Stepping up the transition and anticipating the redevelopment needs. https://www.iddri.org/en/publications-et-evenements/billet-de-blog/declaration-de-silesie-sur-la-transition-juste-la

and to link up policy makers and researchers. This could be done in partnership with industry associations, trade union groups, and member state representatives. Some examples of Just Transition measures can be found in Box 1 in section 2.2. Any observatory should also focus on exploring whether existing datasets are sufficient to develop the necessary indicators to help explore vulnerability.

On the policy process -

Climate and energy policy needs to be joined up with other policy domains such as social and industrial policy. Given that issues of vulnerability cut across different areas of policy, it is important that energy and climate policy are joined up with what is happening on economic and social policy, particularly as it relates to specific regions. This means joined up thinking between different European Commission DGs, but also at the member state and sub-national regional level. This is an important recommendation made by energy poverty researchers due to the cross-cutting and dynamic nature of the issue e.g. (Pye et al., 2017).

Subnational analysis is critical for informing strategy and policy design. None of the above regional insights are possible without subnational analysis. It would seem like a useful practice to build up the ESPON-funded Territorial Impact Assessment (TIA) approach, adopted strongly by the European Committee of the Regions – and think about how this can be mainstreamed into the Commission's impact assessment process. A starting point might be to consider how this approach can be considered in the context of the Commission's modelling framework.[28]

The approach set out in this report and the TIA do not produce cost-benefit analysis numbers. However, such approaches do ensure that the regional dimension is discussed, and that the distribution of impacts, which differs by region, is recognised. This is a relatively simple approach to raise recognition and make a first assessment of possible regional-based impacts; therefore, further assessment of regional impacts is likely to be needed to fully explore options for impact mitigation and support.

6.3. Implications for the research agenda

This research was very much an exploration of how to enrich scenario analyses by providing additional information to enable a discussion of distributional impacts, reflecting that different regions and the sectors in those regions might be differentially impacted. Prior to starting, we were not aware of approaches to assess regional vulnerability and policy impact beyond that published by (Velte et al., 2010) under the ESPON ReRisk project. It was therefore unexpected (but very welcome) to find emerging work on this, such as the approaches proposed by (Carley et al., 2018) and the TIA being used by the European Committee on the Regions, helping to take this agenda forward.

On reflecting on the approach described in this report, we believe there are a number of elements that require additional scrutiny, and from which a set of research recommendations emerge.

---

[28] The framework and its description can be found here - https://ec.europa.eu/clima/policies/strategies/analysis/models_en#Models

1. The approach described in this report attempts to provide a more holistic approach to vulnerability assessment, focusing on both the industry and residential sectors. However, vulnerability was represented by a small range of metrics, which could look to be expanded. One element missing was vulnerability in terms of changes to transport systems, and access.
   Recommendation: *Explore how this assessment can be broadened to reflect the multiple impacts from low carbon transitions. This could be done through a workshop format (as used in the TIA process), or thought targeted interviews e.g. as in (Fell et al., 2019).*

2. The framework proposed by (Carley et al., 2018) also considers adaptive capacity, as a way of reducing impacts through policy or due to resilience in specific sectors or communities. This was very much considered in earlier thinking, and is reflected in the two contextual indicators to some extent, on disposable income and long-term unemployment. However, more thinking on what other metrics could be considered to assess adaptive capacity could be interesting e.g. flexibility of workforce, recent investment in industry, business demographics (business churn, local economic dynamism) [29], level of EU funding in specific sectors, policy interventions (from different domains) to safeguard vulnerable communities etc.
   Recommendation: *Identify metrics of adaptive capacity that could be used to assess how negative impacts of low carbon transitions on regions could be reduced, and positive impacts increased, and consider how such metrics could be integrated into the analysis.*

3. The InVEST approach proposed in this research used scenario metrics to determine regional impacts. This was primarily driven by the overall project approach of exploring the implications of large-scale European scenarios to capture those aspects of low carbon transitions that do not easily fit into models. However, it was evident that there were limitations with the use of scenario metrics for this type of assessment. Firstly, a secondary user of scenario metrics does not necessarily have the insights of the modelling team to explain country differences. Therefore, it is not always clear whether differences are due to model structure, simulation or reflect real differences. Secondly, and related to the first point, the scale of the model and the number of countries represented means that some of that country-level detail has to be sacrificed. Therefore, care is needed when drilling down into the detail at sector level and using specific cost metrics. Thirdly, there are also specific issues with insights under these specific scenarios; they differed little despite divergent narratives, and critical aspects were not explicitly modelled, such as the prospects for building energy efficiency.

   In defence of scenarios, these provide a quantitative assessment of the whole system that is internally consistent and meets given climate policy objectives, a sense of how the transition may unfold over time, and useful metrics such as investment needs. The TIA approach, which is very much tied to the assessment of specific Directives, uses an approach based on expert judgement to determine impacts. This is useful as it allows for a diverse set of views, and different disciplines to contribute.

---

[29] Business demographics. Eurostat. Structural Business Statistics (SBS). Business demography (bd), dataset [bd_hgnace2_r3]. https://ec.europa.eu/eurostat/cache/metadata/en/bd_esms.htm

Recommendation: *Explore how this approach can integrate both qualitative expert judgement alongside scenario metrics to inform potential impacts across regions. It would seem like a promising avenue to follow the TIA approach of convening expert workshops alongside scenario analysis, as the latter provides some quantitative and consistent assessment of how a given policy may play out.*

4. One of the attractions of the approach by (Carley et al., 2018) was that a composite indicator was devoped that provided an overall vulneraiblity score. This was avoided in this analysis for a number of reasons – i) the much wider scope of the scenario assessment, which focuses on strategy rather than a specific policy; ii) because the exposure metrics are time dependent, and provided out to 2050. There was therefore concern about combining current sensitivity metrics with future metrics of exposure (based on the scenarios).
   Recommendation: *Further consideration could be given to the use of composite indicators, using (OECD, 2008) best practice.*

References

Bouzarovski, S., 2014. Energy poverty in the European Union: Landscapes of vulnerability. Wiley Interdiscip. Rev. Energy Environ. doi:10.1002/wene.89

Bouzarovski, S., Herrero, S.T., Petrova, S., Frankowski, J., Matoušek, R., Maltby, T., 2017. Multiple transformations: Theorizing energy vulnerability as a socio-spatial phenomenon. Geogr. Ann. Ser. B Hum. Geogr. 99, 20–41. doi:10.1080/04353684.2016.1276733

Bouzarovski, S., Simcock, N., 2017. Spatializing energy justice. Energy Policy 107, 640–648. doi:10.1016/j.enpol.2017.03.064

Bouzarovski, S., Tirado Herrero, S., 2017. The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the European Union. Eur. Urban Reg. Stud. 24, 69–86. doi:10.1177/0969776415596449

Caldecott, B., Sartor, O., Spencer, T., 2017. Lessons from previous 'Coal Transitions' High-level Summary for Decision-makers. Paris.

Capros, P., Kannavou, M., Evangelopoulou, S., Petropoulos, A., Siskos, P., Tasios, N., Zazias, G., DeVita, A., 2018. Outlook of the EU energy system up to 2050: The case of scenarios prepared for European Commission's "clean energy for all Europeans" package using the PRIMES model. Energy Strateg. Rev. doi:10.1016/j.esr.2018.06.009

Carley, S., Evans, T.P., Graff, M., Konisky, D.M., 2018. A framework for evaluating geographic disparities in energy transition vulnerability. Nat. Energy 1.

Chancel, L., Hough, A., Voituriez, T., 2017. Reducing inequalities within countries: converting the global debate into action.

Deller, D., 2018. Energy affordability in the EU: The risks of metric driven policies. Energy Policy 119, 168–182.

Dobbins, A., Fuso Nerini, F., Deane, P., Pye, S., 2019. Strengthening the EU response to energy poverty. Nat. Energy 4, 2–5. doi:10.1038/s41560-018-0316-8

E3G, 2016. Instruments for a managed coal phase out – Experiences with structural change.

EESC, 2016. Indigenous coal in the EU energy transition.

ESPON, 2018. Indicators for integrated territorial and urban development.

ESPON, 2013. ESPON TIA Quick Check Moderator's Guide and Methodological Background. Luxembourg.

European Commission, 2018a. A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.

European Commission, 2018b. IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773: A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. Brussels.

European Commission, 2018c. Our Vision for A Clean Planet for All: Social Transition.

European Commission, 2017. Third Report on the State of the Energy Union.

European Commission, 2016. Clean Energy For All Europeans (No. COM(2016) 860 final). Brussels.

European Commission, 2015. Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM(2015) 80 final.

European Commission, 2011a. A Roadmap for moving to a competitive low carbon economy in 2050, COM(2011) 112 final. doi:10.1002/jsc.572

European Commission, 2011b. Energy Roadmap 2050 Impact Assessment Part 1 including Part I of Annex 1 “Scenarios - assumptions and results” [SEC(2011)1565/1], Commission Staff Working Paper. doi:SWD(2013) 527

European Commission, 2011c. A Roadmap for moving to a competitive low carbon economy in 2050: Impact Assessment (No. SEC(2011) 288 final).

European Committee of the Regions, 2019. Territorial Impact Asessment: Energy Poverty.

Eurostat, 2017a. HBS Household Budget Survey microdata. Survey 2010.

Eurostat, 2017b. EU-SILC European Union Statistics on Income and Living Conditions microdata.

Fais, B., Blesl, M., Fahl, U., Voß, A., 2015. Analysing the interaction between emission trading and renewable electricity support in TIMES. Clim. Policy. doi:10.1080/14693062.2014.927749

Fell, M., Pye, S., Hamilton, I., 2019. Capturing the distributional impacts of long-term low-carbon transitions. Environ. Innov. Soc. Transitions.

Frondel, M., Sommer, S., Vance, C., 2015. The burden of Germany’s energy transition: An empirical analysis of distributional effects. Econ. Anal. Policy 45, 89–99. doi:10.1016/j.eap.2015.01.004

Gambhir, A., Green, F., Pearson, P., 2018. Towards a just and equitable low-carbon energy transition.

Geels, F.W., Berkhout, F., van Vuuren, D.P., 2016. Bridging analytical approaches for low-carbon transitions. Nat. Clim. Chang. 6, 576–583. doi:10.1038/nclimate2980

Greenpeace / TUC, 2015. Green Collar Nation: a Just Transition to a low-carbon economy.

Hall, S.M., Hards, S., Bulkeley, H., 2013. New approaches to energy: equity, justice and vulnerability. Introduction to the special issue.

Haug, C., Rayner, T., Jordan, A., Hildingsson, R., Stripple, J., Monni, S., Huitema, D., Massey, E., van Asselt, H., Berkhout, F., 2010. Navigating the dilemmas of climate policy in Europe: evidence from policy evaluation studies. Clim. Change 101, 427–445. doi:10.1007/s10584-009-9682-3

Holtz, G., Alkemade, F., de Haan, F., Köhler, J., Trutnevyte, E., Luthe, T., Halbe, J., Papachristos, G., Chappin, E., Kwakkel, J., Ruutu, S., 2015. Prospects of modelling societal transitions: Position paper of an emerging community. Environ. Innov. Soc. Transitions 17, 41–58. doi:10.1016/j.eist.2015.05.006

International Labour Organization, 2015. Guidelines for a just transition towards environmentally sustainable economies and societies for all.

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., Rehner, R., 2016. Energy justice: A conceptual review. Energy Res. Soc. Sci. 11, 174–182. doi:10.1016/j.erss.2015.10.004

JRC, 2018. EU coal regions: opportunities and challenges ahead.

Just Transition Centre, 2017. Just Transition - A Report for the OECD.

Li, F.G.N., Trutnevyte, E., Strachan, N., 2015. A review of socio-technical energy transition (STET) models. Technol. Forecast. Soc. Change 100, 290–305. doi:10.1016/j.techfore.2015.07.017

LSE Grantham Institute, 2018. Climate change and the just transition: A guide for investor action. London, UK.

McDowall, W., Trutnevyte, E., Tomei, J., Keppo, I., 2014. Reflecting on Scenarios. UK Energy Research Centre (UKERC), London, UK.

Miller, C.A., Richter, J., 2014. Social Planning for Energy Transitions. Curr. Sustain. Energy Reports 1, 77–84. doi:10.1007/s40518-014-0010-9

Miller, C.A., Richter, J., O'Leary, J., 2015. Socio-energy systems design: A policy framework for energy transitions. Energy Res. Soc. Sci. 6, 29–40. doi:10.1016/j.erss.2014.11.004

Montenegro, R.C., Fahl, U., 2017. Carbon leakage and competitiveness: Socio-economic impacts of greenhouse gas emissions decrease on the European area until 2050, in: 2017 14th International Conference on the European Energy Market (EEM). IEEE, pp. 1–5.

Nature Energy, 2019. Fuelling dissent. Nat. Energy 4, 85. doi:10.1038/s41560-019-0344-z

ODYSSEE-MURE project, 2018. Definition of data and energy efficiency indicators in ODYSSEE data base.

OECD, 2017. Investing in Climate, Investing in Growth. Paris.

OECD, 2008. Handbook on Constructing Composite Indicators: Methodology and User Guide. Paris. doi:10.1787/9789264043466-en

Popa, A., Menon, A. Das, Walentyński, B., Young, J.R., Ching, H.Y., Cairone, L., Brito, M.B., Yung, W.Y.K., 2016. The challenges of the US coal industry and lessons for Europe.

Pye, S., Dobbins, A., Baffert, C., Brajković, J., Deane, P., De Miglio, R., 2017. Energy poverty across the EU: Analysis of policies and measures. Analysis of policies and measures, Europe's Energy Transition: Insights for Policy Making. doi:10.1016/B978-0-12-809806-6.00030-4

Rademaekers, K., Yearwood, J., Ferreira, A., Pye, S., Hamilton, I., Agnolucci, P., Grover, D., Karásek, J., Anisimova, N., 2016. Selecting Indicators to Measure Energy Poverty.

Sovacool, B.K., Burke, M., Baker, L., Kotikalapudi, C.K., Wlokas, H., 2017. New frontiers and conceptual frameworks for energy justice. Energy Policy 105, 677–691. doi:10.1016/j.enpol.2017.03.005

Sovacool, B.K., Heffron, R.J., McCauley, D., Goldthau, A., 2016. Energy decisions reframed as justice and ethical concerns. Nat. Energy 1, 16024. doi:10.1038/nenergy.2016.24

Taylor, P.G., Upham, P., McDowall, W., Christopherson, D., 2014. Energy model, boundary object and societal lens: 35 years of the MARKAL model in the UK. Energy Res. Soc. Sci. 4, 32–41.

Thomson, H., Bouzarovski, S., 2018. Addressing Energy Poverty in the European Union: State of Play and Action.

Thomson, H., Bouzarovski, S., Snell, C., 2017. Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data. Indoor Built Environ. doi:10.1177/1420326X17699260

Thomson, H., Snell, C., 2013. Quantifying the prevalence of fuel poverty across the European Union. Energy Policy. doi:10.1016/j.enpol.2012.10.009

Tirado Herrero, S., 2017. Energy poverty indicators: A critical review of methods. Indoor Built Environ. doi:10.1177/1420326X17718054

TUC, 2008. A Green and Fair Future.

United Nations, 2015. Adoption of the Paris Agreement. Conf. Parties its twenty-first Sess. 21932, 32. doi:FCCC/CP/2015/L.9

Velte, D., Magro, E., Jiménez, I., 2010. ReRisk Regions at Risk of Energy Poverty.

Wilkinson, R.G., Pickett, K., 2009. The spirit level: Why more equal societies almost always do better. JSTOR.

Zimmermann, M., Pye, S., 2018. Inequality in energy and climate policies: Assessing distributional impact consideration in UK policy appraisal. Energy Policy 123, 594–601. doi:https://doi.org/10.1016/j.enpol.2018.08.062

Report appendices

Appendix 1. Additional information on household energy indicator development

The objective of the household indicator set is to identify households across member state regions that are energy vulnerable, limited in being able to affordably provide household energy services at an adequate level. This is often captured under the concept of energy poverty. Consensual indicators have been developed based on microdata from the EU-SILC survey, and expenditure-based metrics, using Household Budget Survey microdata. Both datasets were sourced from Eurostat.

Indicators

There are six indicators provided at different spatial scales, as listed in Table 6.

Table 6. Household sector indicators

	Metric	Description	Source dataset	Data Year
Expenditure	ExpShare	Average energy expenditure level as a share of total expenditure	HBS microdata, Eurostat (NUTS1)	2010
	M/2	% households where energy expend. less than half the national median level. This measure is really to identify those households whose expenditure appears lower than necessary to meet basic energy needs.		
	2M	% households where energy expend. Is twice the national median level. This measure is to identify those spending a proportion of their budget that is much higher than others.		
Consensual	TotArrears	% households in arrears on utility bills at least once in the past 12 months	EU-SILC microdata, Eurostat (NUTS1 & 2)	2015
	SevArrears	% households in arrears on utility bills more than once in the past 12 months		
	AdWarmth	% households who state that they are unable to keep their home adequately warm		

Data processing

The Access to Eurostat microdata covering Household Budget Survey (HBS) (Eurostat, 2017a) and Survey on Income and Living Conditions (SILC) (Eurostat, 2017b) was been granted to the Lithuanian Energy Institute by Eurostat to be used in the REEEM Project. All the results of calculations using the datasets and conclusions are provided by the authors of this report and not those of Eurostat, the European Commission or any of the national statistical authorities whose data have been used.

To ensure confidentiality of respondents and to make our calculations comparable to other datasets, all indicators are calculated at decile level. To group individuals covered by the dataset to deciles, equivalized disposable income[30] has been calculated by dividing net income of a household by the equivalised household size (the number of adult equivalents in the household). Equivalised household size has been calculated using modified OECD scale in which the first adult is equal to 1, the second and each subsequent person aged 14 and over is equal to 0.5, and each child aged under 14 is equal to 0.3. Finally, decile groups have been formed taking into account equivalised income, household size, and sample weight.

The same methodology has been applied for both SILC and HBS datasets. In the case of HBS dataset, Monetary net income (total monetary income from all sources minus income taxes, EUR_H\H095) variable represented household's disposable income, while Total disposable Household Income (HY020) has been used for SILC dataset.

Energy poverty indicators have been calculated using the same principles as those applied for the calculation of the deciles. To calculate M/2 metric, the national median of household expenditure on energy (045 Electricity, gas and other fuels according to the COICOP) has been calculated taking into account the sample weight of each household. Then the shares of households whose total expenditure on energy is less than half the national median level have been calculated in each by the NATIONAL decile group in each NUTS1 region. The so-called 2M indicator or the share of households whose share of expenditure on energy is twice the national median has been calculated similarly, but national median expenditure on energy share has been used as the calculation basis and the share of households whose expenditure shares are higher have been calculated.

The present approach fits very well with the calculations of poverty indicators presented in Eurostat[31]. Some of these indicators directly use quantiles (e.g., S80/S20 is based on top and bottom quintiles; at-risk-of-poverty threshold is calculated as 60 per cent of median income (top cut-off level of 5th decile). The structures of consumption expenditure at country level appear to be very much in line with the official statistics - there are some deviations, but they can partially be explained by some corrections in the dataset (e.g., dropping "sin consumption" (narcotics, games of chance) that changes overall consumption structure).

---

[30] Eurostat (2018). Definition of equivalised disposable income. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Equivalised_disposable_income

[31] Eurostat (2015). Household Budget Survey: 2010 Wave EU Quality report https://ec.europa.eu/eurostat/cache/metadata/Annexes/hbs_esms_an6.pdf

Appendix 2. Additional information on industry indicator development

The objective of the industry indicator set is to identify the regions that are vulnerable to change given their industrial characteristics. Vulnerability is based on exposure to a shift away from carbon-intensive goods and / or energy-intensity, and impacts relating to the cost of low carbon energy.

Indicators

There are four indicators provided at the NUTS2 spatial scale, as listed in Table 7.

Table 7. Industry sector indicators

	Metric	Description	Source dataset	Data year
Coal	CoalMemp	Level of employment from coal mining + indirect jobs (normalised against highest region)	Sector employee numbers (JRC coal sector analysis)	2015
	CoalPemp	Level of employment from coal plant generation (normalised against highest region)		
En. int.	EmplElc	% of manufacturing employment in sectors who have high unit expenditure levels on energy (Group 1 of three industry groups, based on differing energy intensity)	Sector employee numbers (Structural Business Statistics (SBS), Eurostat), NUTS2 level	2015
	EmplElc1&2	% of manufacturing employment in sectors who have high unit expenditure levels on energy (Group 1&2 of three industry groups, based on differing energy intensity)	Energy intensity of sector (ODYSSEE energy indicator database), Country level	2015

The coal indicators are quite straightforward, using data taken directly from (JRC, 2018). These data were much more complete than those in the SBS dataset, which we originally intended to use. The oil and gas sector employee data in the SBS dataset was not used due to many apparent data gaps.

The energy intensive industry indicators were compiled using two sources – ODYSSEE information on the energy intensity per unit output to identify grouping of sectors according to energy intensity. This took account of differing energy intensities of sectors in different countries. For example, primary metal production in the majority of countries would be in group 1 (highest energy intensity) but in some countries this sector was allocated to group 2 (as shown in Table 8). Group 1 is dominated by primary metals, non-metallic minerals, paper and chemicals. Group 2 has a broader set of sectors included. Three groups have been defined, although only groups 1 and 2 that were used in the analysis are shown in Table 8.

Table 8. Allocation of industry group to energy intensity categories 1&2

This is based on sector-country combinations within specific energy intensity threshold values, where group 1 >0.3, and 2= 0.1-0.3 koe/€2010 (PPP basis) in 2015. The highest value for a specific industry sector is provided in the table, and is for the country at the start of the list. The country list is in descending order, with the first listed country that with the highest intensity. In the absence of data, IE, HR, SE, & HU industries are allocated to groupings based on the allocation of most other country-sector combinations.

Sector	Country	Highest value of countries	Group
Paper	FI, PT, AT, SI, FR, BG, BE, CZ, EE, DE, SK	2.09	1
Primary metals	NL, CZ, SI, FI, RO, PL, FR, LU, DE, AT, LV, GR, IT, SK, PT, BE, DK	1.72	1
Non-metallic minerals	CY, GR, SI, RO, PT, DK, ES, IT, BE, FR, LV, LT, DE, CZ, EE, NL, FI, AT, BG, PL	1.49	1
Chemicals	RO, BG, SK, NL, LU, CZ, FI, EE, LT, PL, BE	1.13	1
Manufacturing	FI	0.45	1
Other industry	FI, SE, BE, LU, GR, NL, SK, SI, LV, BG, PT, AT	0.30	2
Chemicals	UK, FR, PT, DE, AT, IT, ES, LV, GR, SI	0.29	2
Manufacturing	LU, BE, CY, GR, LV, SK, NL, BG, PT, FR, AT, SI, CZ, UK, RO, EE, PL, IT, ES, DE	0.29	2
Paper	ES, PL, IT, NL, GR, UK, DK, RO	0.27	2
Primary metals	ES, UK, BG, EE	0.26	2
Non-metallic minerals	LU, UK, SK	0.25	2
Food and tobacco	FI, DK, BE, NL, EE, FR, AT, DE, SK, CZ, LU, CY, GR, SI, LV, IT, PT	0.22	2
Machinery	CY, UK, SK	0.20	2
Textiles and leathers	LU, BE, UK, CZ	0.16	2
Transport equipment	GR	0.10	2

The energy intensity indicator is based on GDP expressed in purchasing power parities (PPP). The PPP metric has been used for comparison between countries as it removes the impact of price differences (that inflate GDP levels), providing a better measure in respect of volume produced. Using PPP tends to decrease the intensity of lower income countries, and increases those of higher incomes, and reduces the range of intensity values (ODYSSEE-MURE project, 2018). The employees in member states at a NUTS2 region level, associated with those different industries allocated to energy intensity groups, are sourced from the Eurostat Structural Business Survey (SBS). These employee numbers for the three groups are then divided through by total employees and manufacturing employees to estimate the share of group 1-3 employees at the regional level.

Appendix 3. Additional information on metrics of current vulnerability

Household energy vulnerability: Arrears on bills

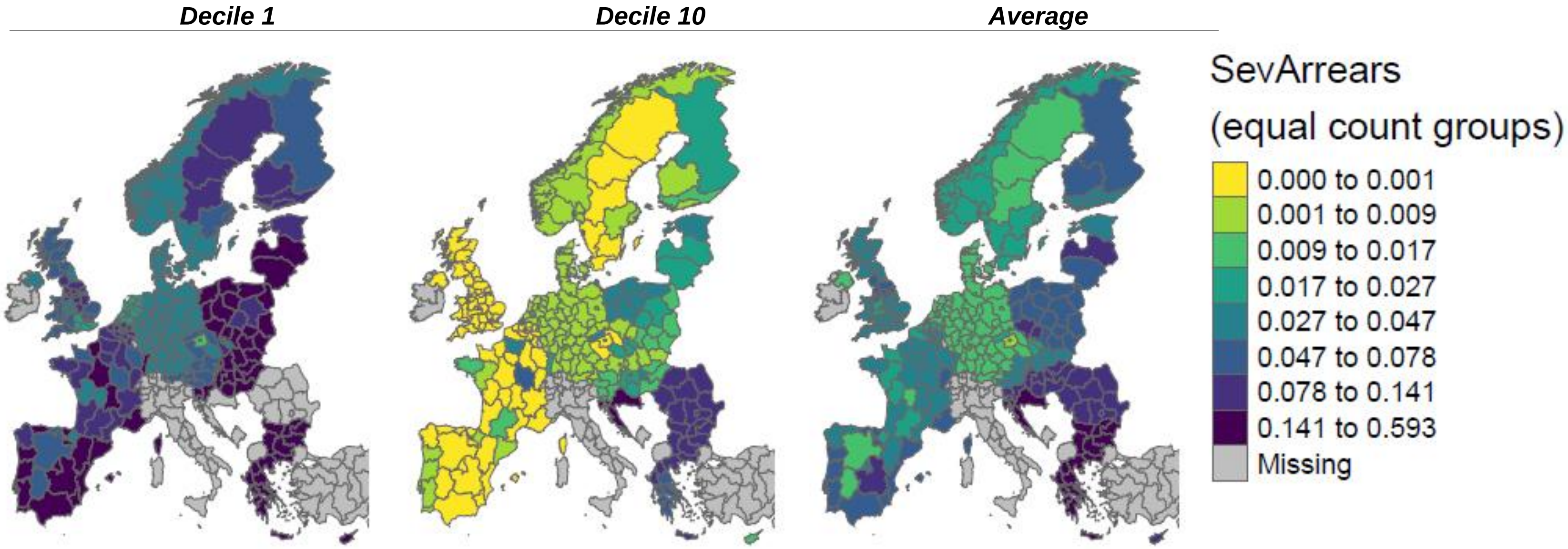


Figure 31. Share of decile 1, decile 10 and average households by NUTS1 region for the 'severe arrears' consensual indicator.

Household energy vulnerability: Energy expenditure at twice the national median level

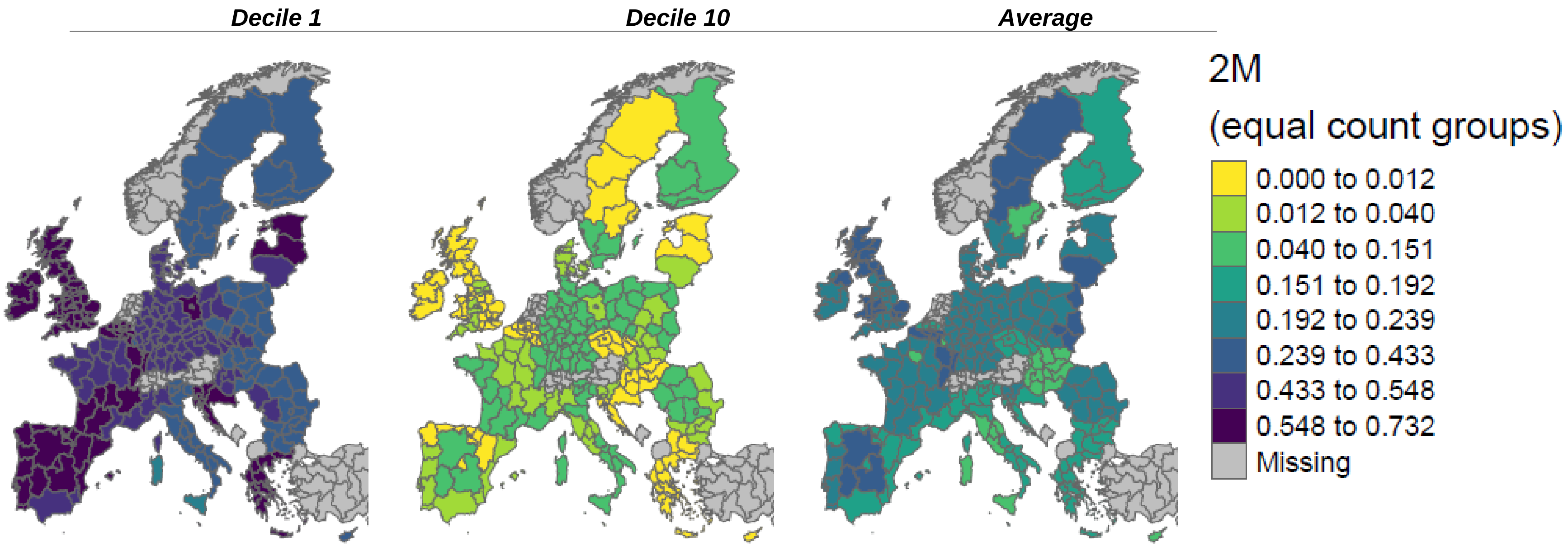


Figure 32. Share of decile 1, decile 10 and average households in NUTS1 regions whose expenditure on energy is twice the national median level
The legend reflects value binning on the basis of equal counts of NUTS regions. Countries with no subnational data have national data allocated to the corresponding NUTS1 areas. Data are for the year 2010. HBS data for Austria and the Netherlands were not available.

Household energy vulnerability: Energy expenditure at half the national median level

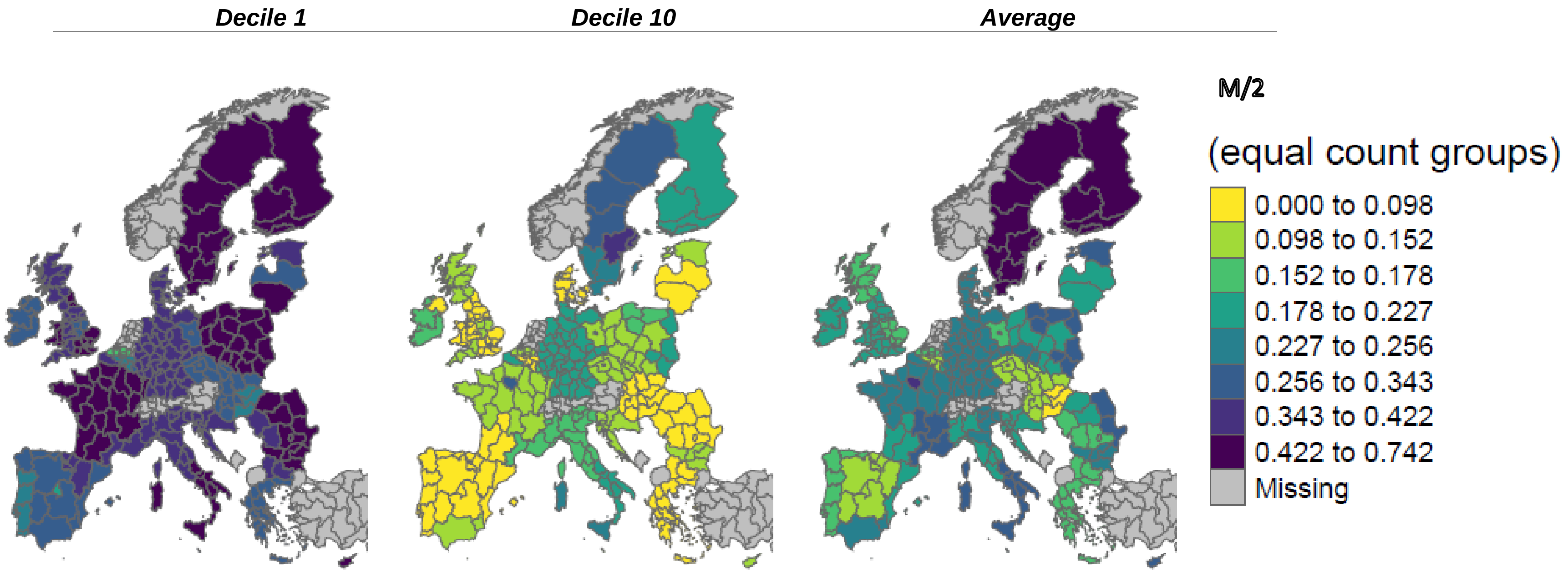


Figure 33. Share of decile 1, decile 10 and average households in NUTS1 regions whose expenditure on energy is half the national median level
The legend reflects value binning on the basis of equal counts of NUTS regions. Countries with no subnational data have national data allocated to the corresponding NUTS1 areas. Data are for the year 2010. HBS data for Austria and the Netherlands were not available.

Employment in energy-intensive industries

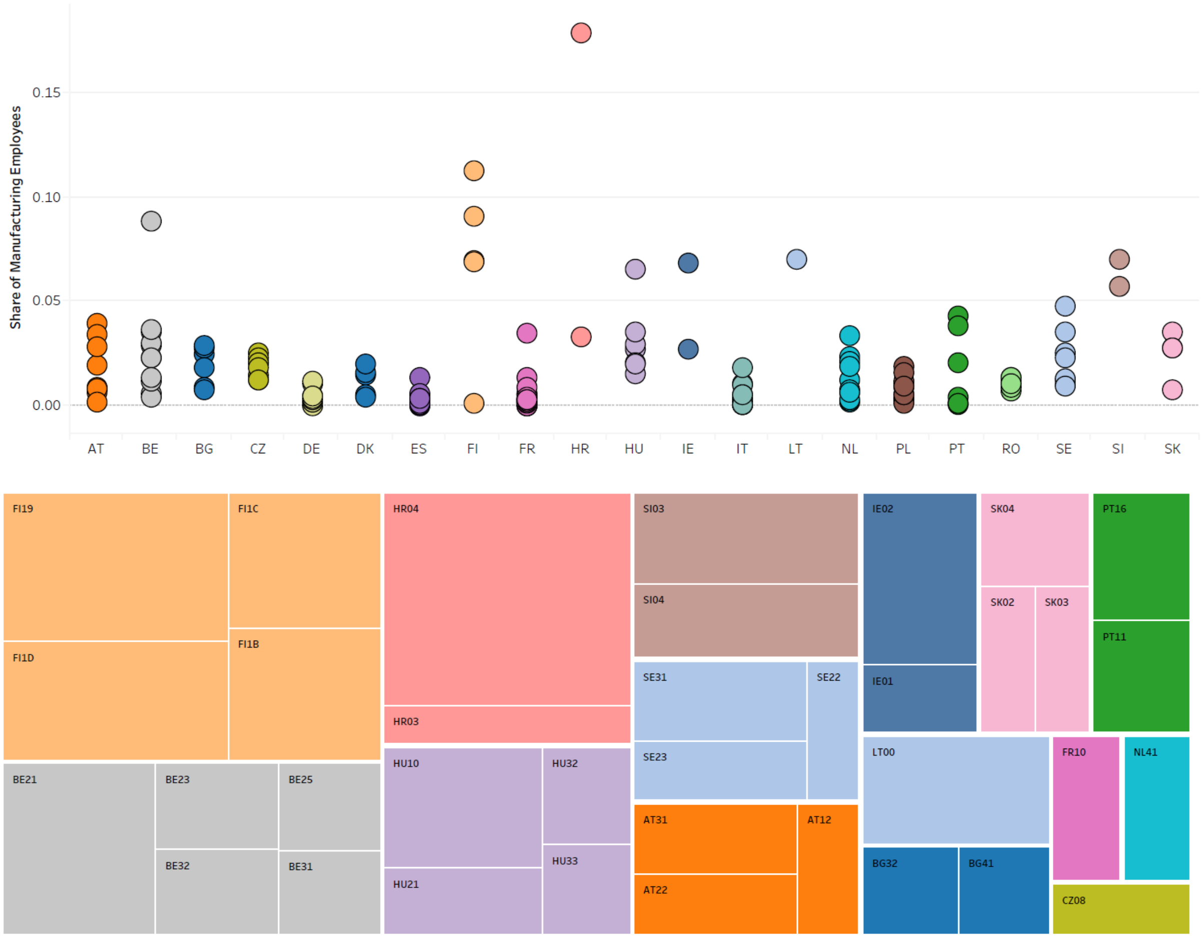


Figure 34. Shares of manufacturing employees in energy intensive sector group 1
(Source: SBS, Eurostat). The top plot shows the distribution of employee shares in NUTS2 regions by member state, and the bottom plot identifies NUTS2 regions with shares above 2.5%.

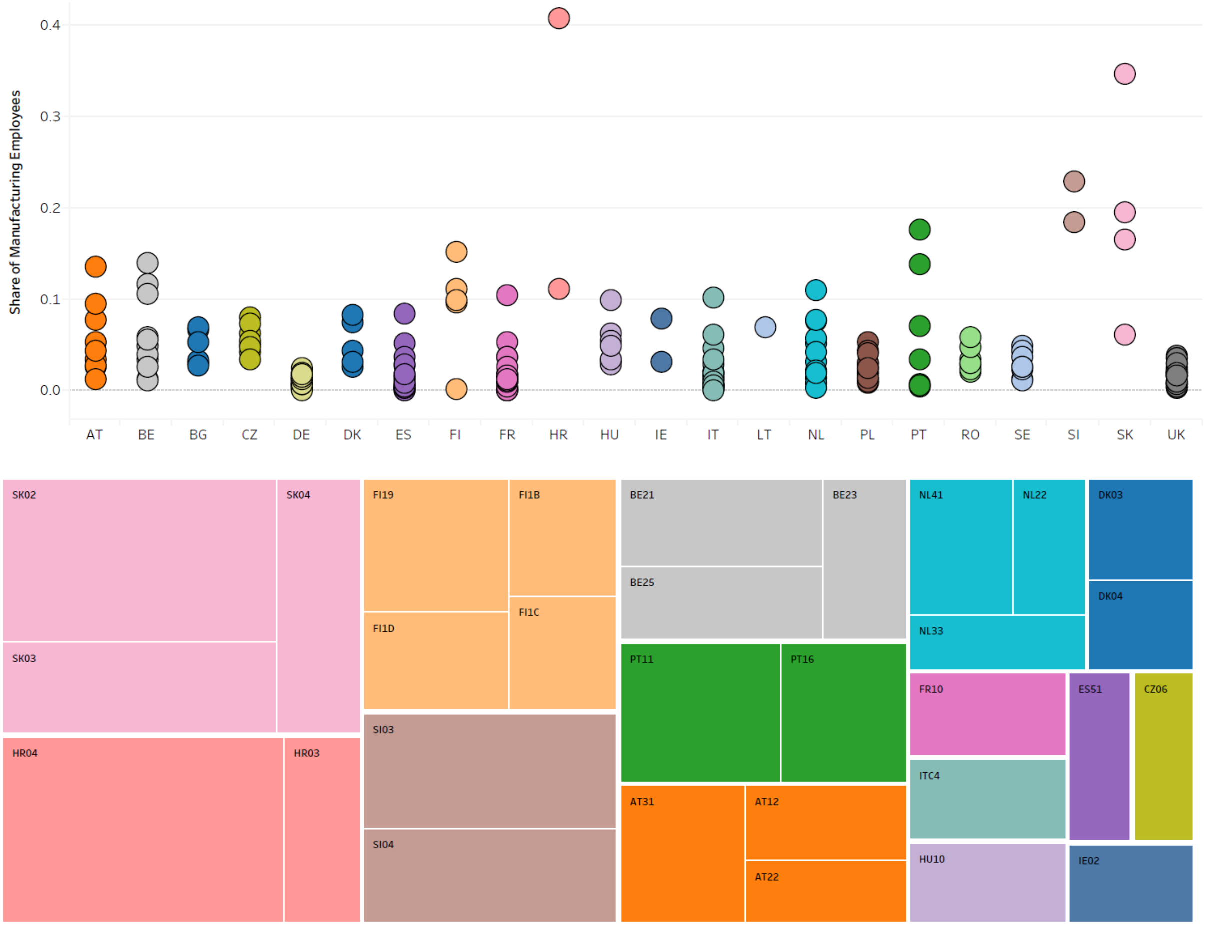


Figure 35. Shares of manufacturing employees in energy intensive sector group 1 & 2
(Source: SBS, Eurostat). The top plot shows the distribution of employee shares in NUTS2 regions by member state, and the bottom plot identifies NUTS2 regions with shares above 7.5%.

Long-term unemployment

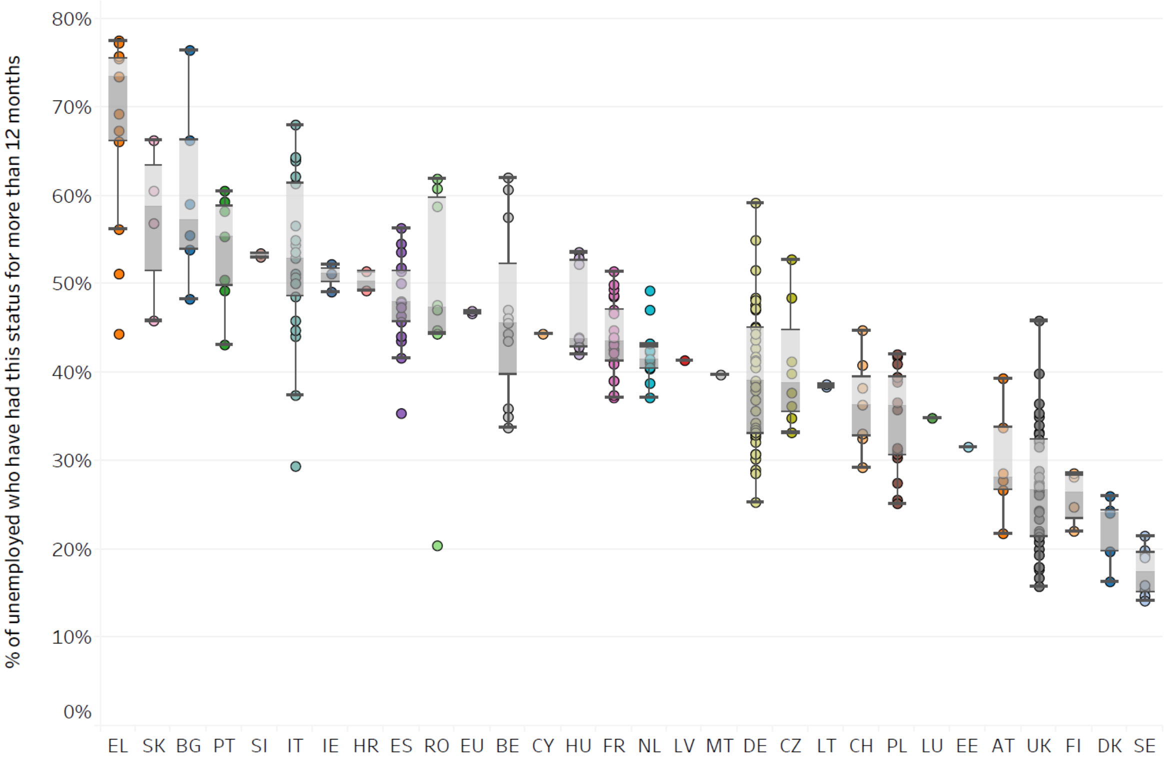


Figure 36. Long term unemployed, as a % of unemployed persons who have had that status for over 12 months (Source: SBS, Eurostat).

Appendix 4. Additional information on comparison of exposure and sensitivity metrics

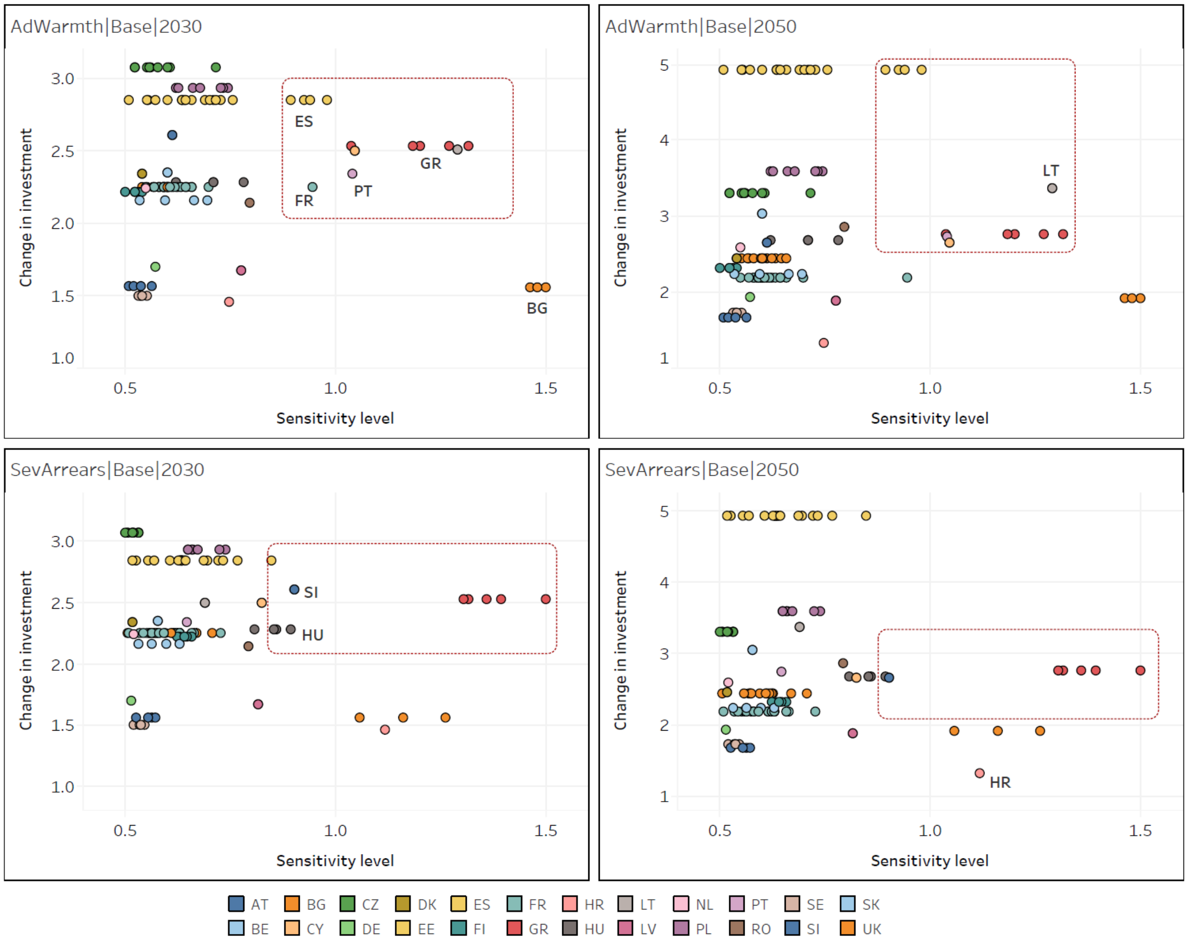


Figure 37. Change in investment level in 2030/50 (relative to 2015) under Base pathway versus current household sensitivity as measured by consensual indicators, AdWarmth and SevArrears.

The sensitivity indicators are for the average household in a region i.e. not for a given decille. Red boxes highlight those regions who are both sensitive and see high levels of investment.

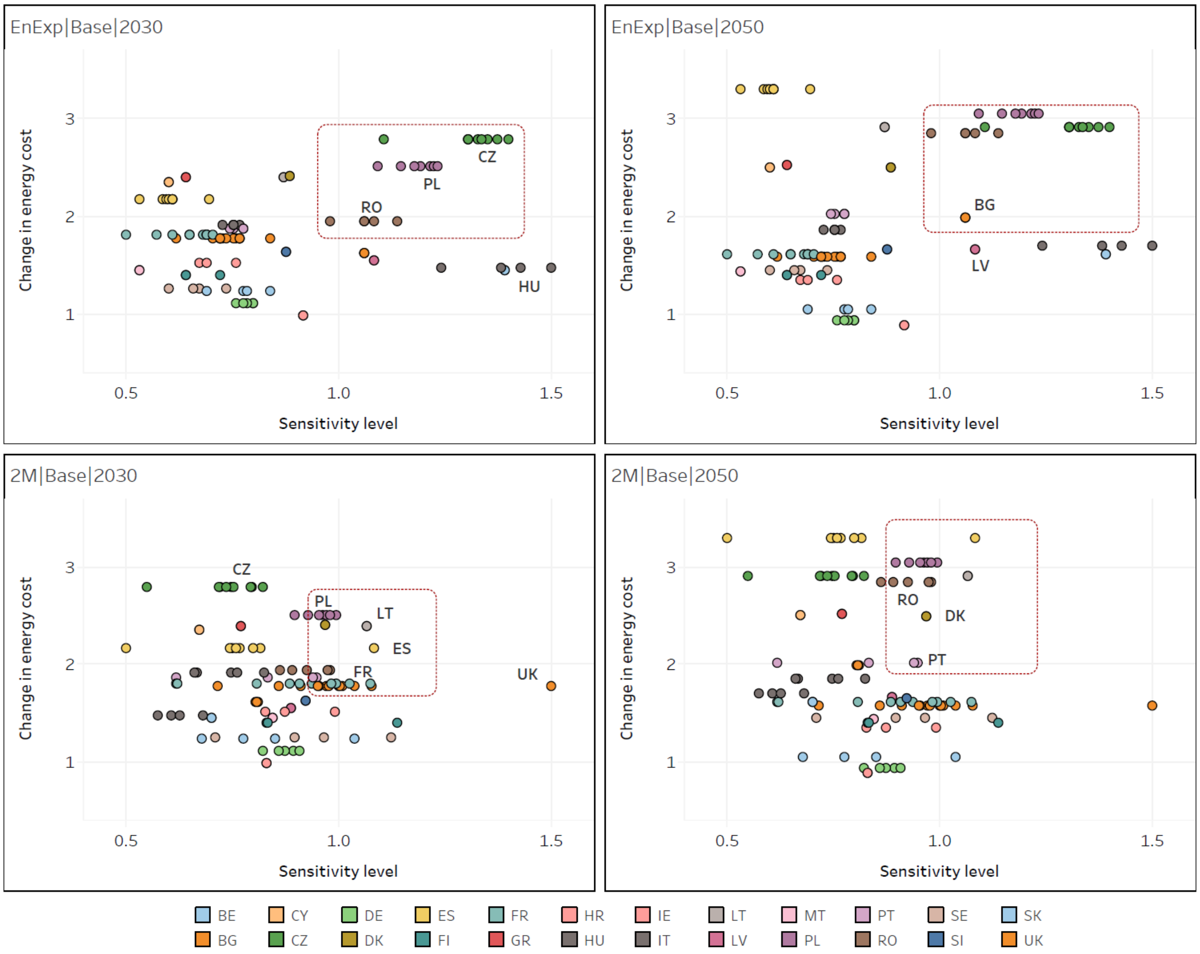


Figure 38. Change in energy cost level in 2030/50 (relative to 2015) under Base pathway versus current household sensitivity as measured by expenditure indicators, EnExp and 2M.

The sensitivity indicators are for the average household in a region i.e. not for a given decille. Red boxes highlight those regions who are both sensitive and see high levels of cost. MS not represented include AT, NL, EE, and LU.

Appendix 5. Approach to combining exposure and sensitivity metrics

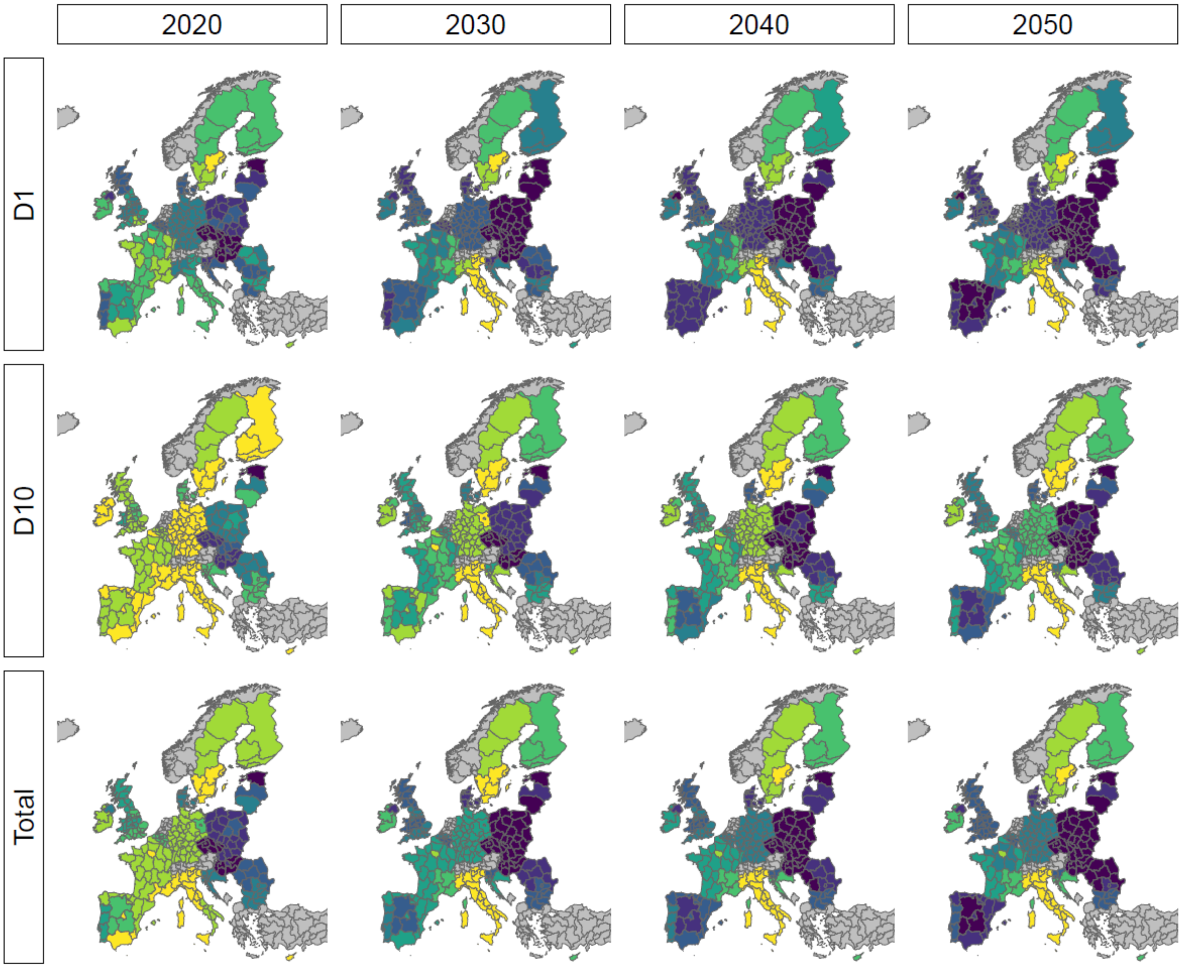


Figure 39. Combining vulnerability (sensitivity) with scenario (exposure) metrics.
This figure shows the combining of both metrics (by multiplying values together) under the Base scenario; the increasingly dark shades over time are a function of increasing investment levels and levels of vulnerability, based on proportion of expenditure on energy. The problem with such an approach of combining metrics is that the information underpinning the scores becomes obscured.