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Resilience of German regions to climate change

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Abstract

There is broad agreement in the scientific community that climate change has already advanced significantly compared to pre-industrial times and will continue to increase due to past emissions of greenhouse gases (GHGs). As a consequence, extreme weather events will become more probable, more frequent and more severe affecting all areas of life, the environment and the economy. Additionally, extreme weather events occur on a local level forcing regions and cities to advance the impacts of climate change. One important concept to measure the robustness of a city or smaller geographic area towards climate change is resilience. Though the term and concept of resilience is not uniquely defined it is often used in this context to express the ability of the local identity to cope, withstand and adapt to the challenges posed by an extreme event.

The objective of this paper is to assess the resilience of German regions to extreme weather events caused by climate change. Scenario results depicting the impact of climate change from the national macro-econometric model INFORGE were linked to the regional model QMORE. The model results were used to derive indicators that assess the resistance of German regions against climate change. The regions were divided into groups using cluster analysis to detect determinants that explain higher or lower sensitivity towards climate change. Finally, the implementation of climate change adaptation measures were assessed with regard to resistance as an indirect measure for recovery.

It shows that there was a clear division with regard to sensitivity to climate change: Regions in the north-west and south-east were considerably less resistant to climate change impacts. However the determinants for high resistance were not that clear cut. Regions seem to be more resistant if they were only confronted with one challenge, i.e. if labour market shortages does not add to the impact of climate change and if the agricultural sector is of lower importance. Climate change adaptation helps in strengthening resistance against climate change. However, the measures should be tailored to the specific local situation to be more effective. Otherwise, with an unspecific distribution, the regions that need adaptation and an increase in resilience most were not necessarily addressed.

Keywords: resilience, regions, climate change, climate change adaptation

JEL: R11, R15, Q51, C67

1 INTRODUCTION

There is broad agreement in the scientific community that climate change has already advanced significantly compared to pre-industrial times and will continue to increase due to past emissions of greenhouse gases (GHGs). As a consequence, extreme weather events will become more probable, more frequent and more severe affecting all areas of life, the environment and the economy. Additionally, extreme weather events occur on a local level forcing regions and cities to advance the impacts of climate change. One important concept to measure the robustness of a city or smaller geographic area towards climate change is resilience. According to Pendall et al. (2010) the concept of resilience is useful to illustrate different types of regional stress and change, but the term resilience is fuzzy and needs therefore to be carefully specified regarding space and time.

Though the term and concept of resilience is not uniquely defined it is often used in this context to express the ability of the local identity to cope, withstand and adapt to the challenges posed by an extreme event. At the European level the term resilience was established as a concept at the European level as part of the Strategic Foresight Report 2020 and has since been used intensively. Resilience is defined as "the ability not only to withstand and cope with challenges but also to undergo transitions, in a sustainable, fair, and democratic manner".[1] The IPPC also uses resilience in the context of climate change and climate change adaptation, with a similar definition (IPCC 2022): "Resilience [...] is defined as the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation. Resilience is a positive attribute when it maintains such a capacity for adaptation, learning, and/or transformation." The Federal Environment Agency refers to the 2007 IPCC definition of resilience:[2] The capacity of a social or ecosystem to absorb disturbance while maintaining the same basic structure and functioning, capacity for self-organisation, and capacity to adapt to stress and change. These definitions are each relatively broad and can be applied to individuals and ecosystem services as well as to regions.

In order to measure regional economic resilience there are three basic concepts according to Martin and Sunley (2015): engineering resilience, extended ecological resilience and adaptive resilience. Applied to economic theories, the definition of engineering resilience is the most restrictive, as it assumes that the economy in the region follows an equilibrium path that must be regained after a shock (Martin and Sunley 2015). The associated resilience measures how quickly the return is possible under the given free market forces. Lack of resilience is therefore a sign of market failure. The second concept, based on ideas of extended ecological resilience, is less restrictive in that multiple equilibria are allowed and the regional economy does not necessarily have to return to the old equilibrium path. The point of criticism and challenge here, however, is the identification of the multiple possible equilibrium paths (Martin and Sunley 2015). Often they are set a priori and therefore provide only limited information about the actual response and regional resilience (Martin and Sunley 2015). Both kind of resilience analysis concepts are also grouped under the term equilibrium analysis (Pendall et al. 2010). The last concept of adaptive resilience is the most open, since it is not assumed that an original state will be reached again, i.e. that it must be returned to (Martin and Sunley 2015). Rather, structural change and adaptation can restore and secure economic prosperity in the region. The region thus leaves its original development path and goes beyond the original development and structure. Resilience is then measured by using input-output analysis or indicators. This concept also falls under the term of complex adaptive systems analysis (Pendall et al. 2010).

With the beginning of the 2000s, the concept of regional resilience was started being used in the context of climate change (Albers and Deppisch 2013). However, many authors have focused primarily on defining or classifying resilience in the context of climate change (Adger et al.; Bahadur et al. 2013; Cannon and Müller-Mahn 2010), or have placed the concept of resilience in relation to climate change adaptation (Nelson et al. 2007; Nelson

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[1] https://joint-research-centre.ec.europa.eu/scientific-activities-z/resilience_en

[2] www.umweltbundesamt.de/service/glossar

2011; Pelling 2011).

Since then, the concept of resilience has been used successfully in assessing and evaluating how cities and communities are confronted and adapting to climate change (Cobbinah 2021; Feldmeyer et al. 2019; GDV 2022b; Satterthwaite et al. 2020; https://smr-project.eu/). Other research focus on the resilience of selected economic sectors to climate change such as the tourism sector (Dogru et al. 2019), agriculture (Meuwissen et al. 2019) or fishery (Holsman et al. 2019).

The objective of this paper is to assess the economic resilience of German regions to extreme weather events caused by climate change. Scenario results depicting the impact of climate change from the national macro-econometric model INFORGE were linked to the regional model QMORE. The model results were used to derive indicators that assess the resilience of German regions. Finally, the regions were divided into groups to represent different types of resilience and to find regional patterns.

We add to the field of resilience in the context of climate change to assess the vulnerability or resistance respectively of regions regarding climate change impacts. However, we did not conduct an ex-post study of past resilience but were forward looking applying scenario techniques. Thus, the focus of this study is to assess the future sensitivity of German regions against the climate change impacts to come. We complemented the results regarding resilience by clustering the regions in order to find determinants for high or low resistance. We intended to give insights of initial parameters favouring a high future resistance against climate change impacts. Additionally, we tried to find a measure of recovery for the ongoing process of climate change by computing resistance under the implementation of climate change adaptation measures. Finally, this study is no case study in focusing on just one city or region or one economic sector but provides a complete integrated picture of the resilience in all German districts taking all economic sectors into account.

Our results show a clear spatial pattern with respect to regional resilience to climate change. However, the initial conditions favouring higher resilience were not clearly the same for all more resilient regions. That is, higher resilience cannot be attributed to the combination of a few factors. Our results also highlight the importance of applying tailored, area-specific adaptation measures to support regions with lower resilience to climate change.

The remainder is organised as follows. Section 2 provides a description of the economic model and the scenario methodology. It defines the concept of resilience in the context at hand as wells as the estimation procedure. Section 3 encompasses the results, i.e. the spatial distribution of resistance against climate change, a discussion on commonalities and differences between regions with high and low resistance as well as the effects of climate change adaptation on resilience. Section 4 concludes.

2 METHODOLOGY

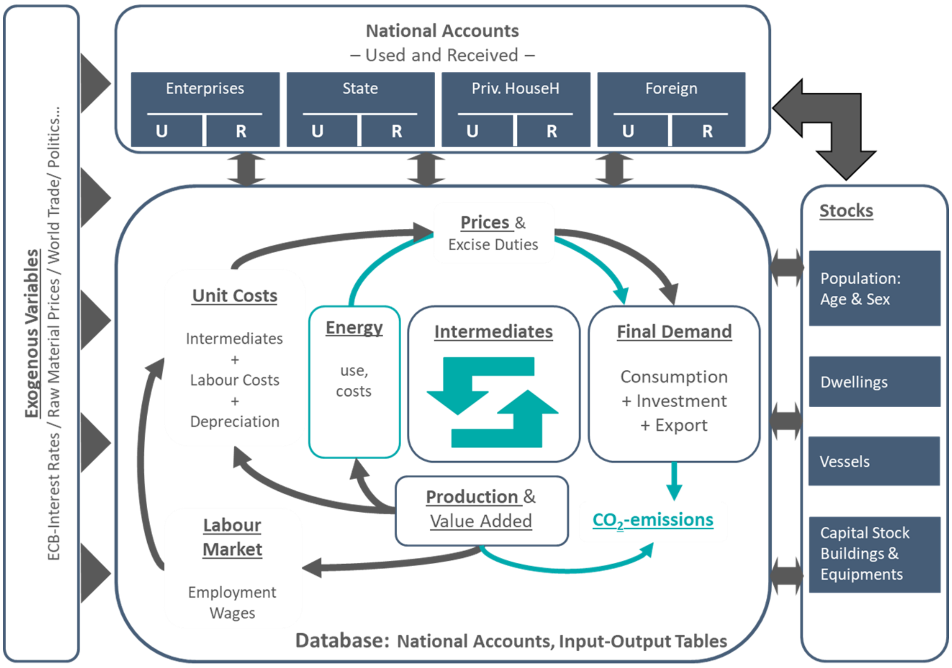
For the analysis of regional resilience, a reference development has to be defined, which represents the regional development without disturbance (Jakubowski et al. 2013). This reference development is affected by a shock, which can have a wide variety of causes. This can range from extreme weather events such as the flood disaster 2021 in the Ahr Valley and pandemics such as Covid-19 to supply chain bottlenecks caused by global trade disruptions such as the Ukraine war. However, the shock does not necessarily have to be a one-off short-term event, but can also proceed over a longer period, as in the case of climate change or profound structural changes such as the departure from the coal industry in the Ruhr region. Resilience then results from the response to the shock, i.e., the deviation from the reference.

The reference or baseline and the shock development representing the impact of climate change were estimated using the macroeconomic-model INFORGE in combination with scenario techniques. Subsequently, the resulting economic developments from the baseline and the climate scenario were linked to the regional model QMORE to assess the impact of the shock on regional level. The results were translated into indicators that illustrate the extent of resilience in German regions. The model structure and the scenario details are described in the following section. The local resilience is assessed by using indicators described in section 2.2.

2.1 MODELLING AND SCENARIO BACKGROUND

The models used in the GWS are macro-econometric input-output models that do not follow equilibrium theory, but uses approaches from evolutionary economics, i.e. explain developments from the past via estimating equations and parameters and extrapolate them into the future (Lehr and Lutz 2020). Therefore, the model methodology allows for myopic behaviour among market actors as well as imperfect markets such as incomplete competition, partially rigid prices and market dependencies, and determines mark-up prices (Becker et al. 2022).

Figure 1: The model structure of INFORGE

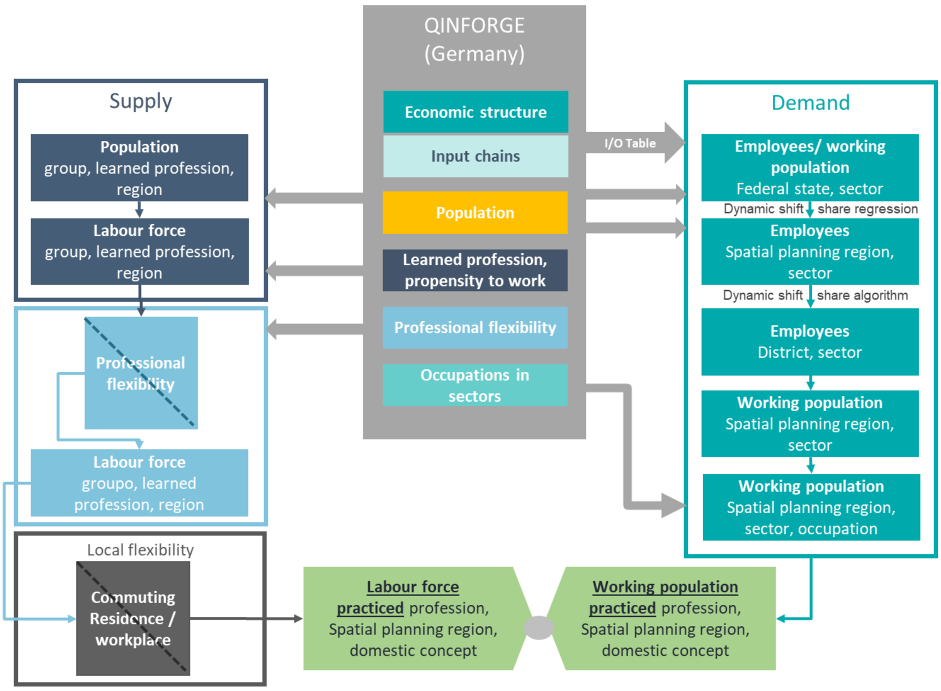


Source: own figure.

The model INFORGE is a country model for Germany being fully integrated into the System of National Accounts including input-output interdependencies (see Figure 1 and Becker et al. 2022). Thus, interactions, indirect effects and other cause-effect relationships are mapped at a high sectoral level of detail. It is designed to analyse complex socioeconomic and economic structures including their dependencies and assess economic, energy, climate and environmental policies up to the year 2050.

INFORGE has been used for projections of labour demand, sectoral development and the overall economic development (Zika et al. 2022; Mönnig et al. 2021; Zika et al. 2021). Additionally, the model has been applied in many ways for scenario analysis: to calculate the macroeconomic effects of the socio-economic impact of the NECP (Lutz et al. 2021b), rebound effects of energy taxes (Lutz et al. 2021a; Ahmann et al. 2022), the net employment effects of the transition to a green economy (Ulrich et al. 2022), or the macroeconomic effects of climate change and adaptation to climate change (Lehr et al. 2016; Lehr et al. 2020; Flaute et al. 2022).

Figure 2: Overview over the regional model QMORE and its interaction with INFORGE



Source: own figure.

The QMORE model that contains the spatial levels of the federal states, spatial planning regions as well as rural districts and independent cities, can be linked to the national model INFORGE. The regional modelling is empirically based as well, uses regional econometric approaches and includes the following methodological principles for updating local industry-specific employment (see Figure 2 and Zika et al. 2023):

1. Detailed coverage of regional economic structures, currently with a breakdown into 37 economic sectors or main occupational groups.
2. Systematic analysis of industry-specific growth differences between the respective spatial level and the superordinate region
3. Assessment of specific inter-regional and intra-regional effects and development relationships, e.g. influences of population development, commuting patterns and supply chains within the region.

4. Consistency of the projections with the values of the superordinate territorial unit and the federal government.

The regional projections are thus embedded in a consistent macroeconomic framework that enables development comparisons with other regions.

This model system provides empirically based long-term development and offers the possibility of scenario based analysis. According to Martin (2012), long-term development is a necessary component in determining resilience, as it is the deviation from an initial development that determines the degree of sensitivity against the shock and the speed of recovery after the shock. Using scenario based analysis it can be shown what a shock triggers and means for the region compared to the reference or baseline development.

The scenario analysis consisted of three model-based estimations:

1) A baseline, in which climate change does not proceed
2) A climate change scenario, in which a likely development of climate change in form of extreme weather events and their impacts is assumed
3) A climate adaptation scenario, in which the impact of climate change is weakened by investment in adaptation measures.

The scenario structure is based on Flaute et al. (2022) and is described in more detail in Wolter et al. (2023). The climate change scenario addresses the climate fields agriculture, forestry, fishery, water management, buildings and infrastructure, transport, and health. Table 1 gives an overview of the parameter settings in the climate change scenario.

Table 1: Climate change impacts considered and parameter settings

Field / Sector	Climate impact	Entry points INFORGE	Sources of the scenario assumptions
Agriculture	Yield losses in agriculture	Higher import prices for intermediate products for agricultural sector, higher domestic producer prices for agricultural sector, higher import prices for food products (food industry), higher agricultural land leases and prices (competition for land)	Schlenker and Roberts (2009), Lesk et al. (2016), Brasseur et al. (2017), Mäkinen et al. (2018), Ren et al. (2018) Tigchelaar et al. (2018), Wang et al. (2018), Li et al. (2019), Beillouin et al. (2020), Knittel et al. (2020)
Buildings and infrastructure	Damages to buildings and infrastructure due to heavy rain and river flooding and damages to or destruction of coastal settlements and infrastructure on the	Higher saving rate of private households (less private consumption), higher accruals in housing sector, more insurance payments and higher insurance costs, more accruals in economic activities (other than housing sector)	GDV and DWD (2019), Bubeck et al. (2020), Fritsch et al. (2021), GDV (2021), Voß et al. (2021), GDV (2022a), Trenczek et al. (2022a), Trenczek et al. (2022b)

	coast		
Fishery	Species extinction, fish diseases, algae	Higher import prices	
Forestry	Lower Timber yield in forestry	Higher import prices for forestry industry, higher domestic producer prices for forestry industry, higher import prices for wood products, higher forestry land leases and prices	Augustynczik et al. (2017), Brasseur et al. (2017), Tei et al. (2017), Alegria et al. (2020)
Health	Effects on the healthcare system	Changes in public expenditure	Karlsson and Ziebarth (2018); Pfeifer et al. (2020)
Transport	Impairment of goods traffic via inland waterways (low water)	Changes in the production cost structure (sector-specific)	Hänsel et al. (2020); Nilson et al. (2020)
Water management	Higher usage and need of water due to heat and drought	Increasing share of water management services in intermediate inputs, higher domestic producer prices for water industry (changes in way of production)	

Quelle: Own evaluation based on KWRA 2021 (Kahlenborn et al. 2021)

For the adaptation scenario it was assumed that agriculture and forestry in particular will undertake specific adjustment measures. The accruals in the buildings and infrastructure sector will be used for higher investments made in adaptive equipment and buildings. Furthermore, it was assumed that the need of the planning sector (specifically the economic sector " architectural and engineering activities as well as technical testing and analysis ") will increase significantly. Especially the public administration and the construction industry were expected to make increased use of these services. In addition, accompanying public research was supposed to be subcontracted. All assumptions regarding climate change adaptation are summarised in Table 2. It is important to note, that no regional differentiation was made in the adopted adaptation measures. This means that the measures were enforced at the federal level and distributed evenly among the regions.

Table 2: Climate change adaptation and parameter setting

Field / Sector	Climate change adaptation measure	Entry points INFORGE
Agriculture	Investments in digitalization, crop production systems, agricultural technology, technical equipment, irrigation systems etc.	Higher investment in gross fixed capital formation, higher labour intensity, increase in production prices, domestic price increase is lower than that of import prices, higher yields and output
Buildings and infrastructure	Structural engineering solutions for climate-resilient, especially flood-adapted	Reversal of provision, investment in infrastructure, equipment and buildings, lower

	construction, such as hydraulic engineering measures, dike construction, flood retention basins, flood plains or polders. Insurance policies with coverage of natural hazards.	depreciation
Forestry	Investments in new equipment and other facilities to improve forestry infrastructure in the face of climate change and to more quickly and efficiently repair damage from extreme weather events for reduced or no pest infestations.	Long-term processes, lower depreciation starting in 2040, government subsidies for reforestation, higher labour intensity, higher technical planning requirement (demand of services of architectural and engineering activities as well as technical testing and analysis)
Planning and Research	Investment in research for new knowledge as well as development of new technologies for improved adaptation to climate change, programs in building design for climate-smart construction.	Higher demand from the construction industry and public administration for planning services, significant increase in public administration investment in intellectual property (research and development, software, databases)

Quelle: Own elaboration and settings.

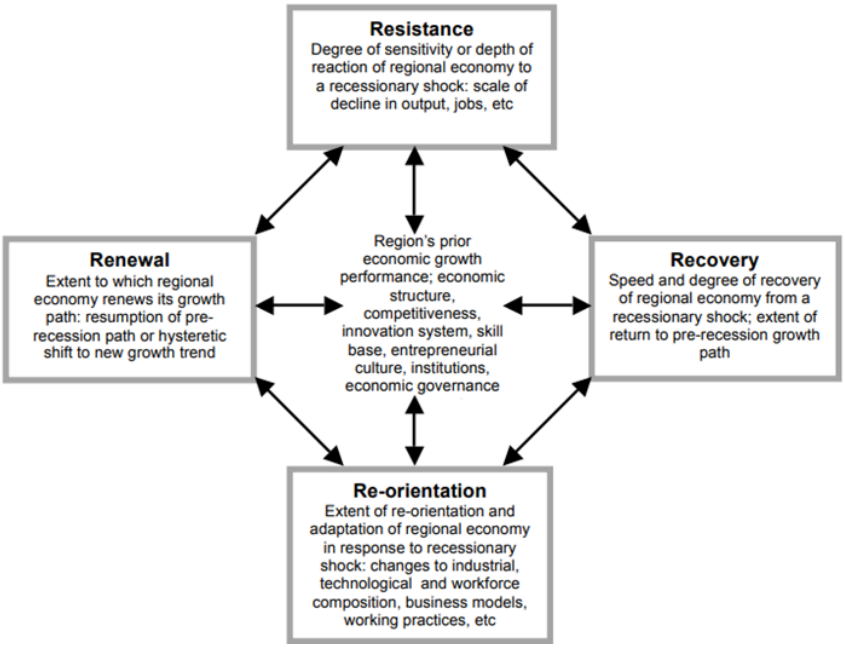
2.2 ESTIMATION OF RESILIENCE

Resilience results from the response to the shock, i.e., the deviation from the reference. As an immediate response to the shock, it takes two dimensions: temporal and structural. The temporal indicates how quickly the region responds to the shock and recovers. The structural dimension indicates how strongly the region responds to the shock through its structures, i.e., how resistant it is to the shock (Martin, 2012). These two dimensions are complemented by Martin (2012) with two more dimensions that focus on development and change after the shock: Reorientation and Renewal (see Figure 1). Reorientation encompasses the extent to which a region adapts to the shock, i.e., with which fundamental structural changes it responds. Renewal measures the extent to which the new reference development obtained through reorientation deviates from the original reference development.

For the analysis at hand we focused on the dimensions resistance and a special form of recovery. The other dimensions, i.e. re-orientation and renewal, could be analysed at a later point in time.

The reference development can be measured in different units, e.g. in employment, economic output or an indicator reflecting the economic structure of the region. Based on the variables available at local level, their related robustness and quality as well as the modelling focus of QMORE we selected the number of employed persons as indicator.

Figure 3: The four dimensions of regional resilience according to Martin (2012)



Source: Martin (2012, p. 12)

The sensitivity index β_R proposed by Martin (2012) and already applied to German regions by Jakubowski et al. (2013) relates the response to the shock of a regional unit R to the average macroeconomic response A. We adapted this approach to the scenario systematics by not choosing the start and end time of the shock, but by putting the two different developments in relation to each other. The relative difference between the two scenario runs shows the climate change-related deviation and thus the specific "cost" of climate change or specific response of the region to climate change. This will be compared to the specific average response in Germany. The reference year was 2050, the end of the projection period.

$$\beta_R = \frac{R_{S=1}/R_{S=0}}{A_{S=1}/A_{S=0}}$$

$S = 0$ denotes the baseline and $S = 1$ the climate change scenario.

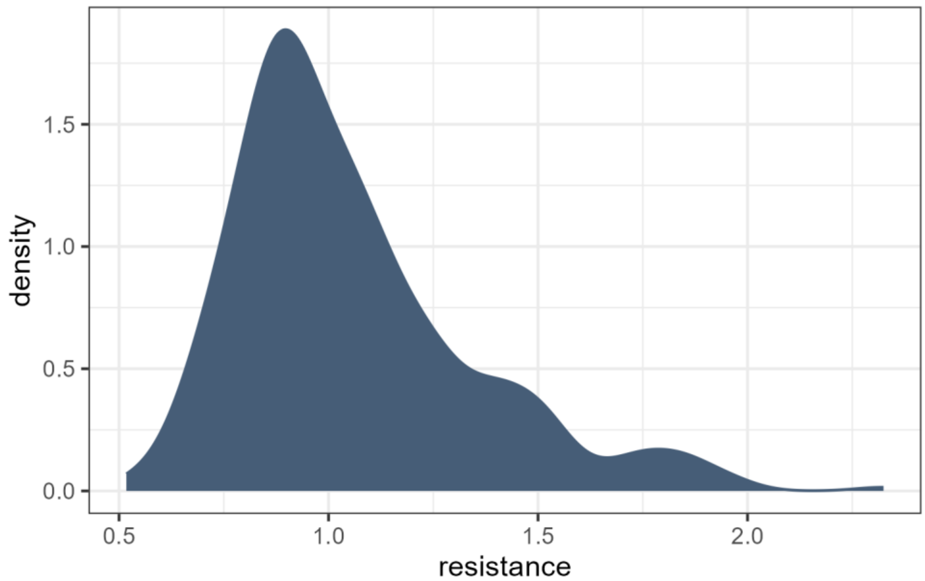
Values of β smaller than 1 imply lower sensitivity to the shock, that is a higher resistance towards the shock, while values larger than 1 imply higher sensitivity and consequently represent a lower resistance. The index alone only provides information on the local resistance, as it only measures the degree of reaction to the shock.

For both dimensions of resilience, i.e. resistance and recovery, the speed and degree of recovery must be added. Thus, the sensitivity index must be supplemented by a temporal component. However, the challenge at hand is not characterised by a one-time acute shock making it impossible to identify a reference point where the challenge stops. Climate change does not impose a singular shock on the economy but is an ongoing process with continuous shocks or impacts. Therefore, the regions were continually penetrated with the effects of climate change making a recovery in the original definition impossible. Thus, the challenge of time in this context is to identify resilience within adaptive cycles in response to the continuous shocks of climate change (Pendall et al. 2010). As a consequence, recovery is defined in this context as the ability of a region to soften the negative impacts of climate change by climate adaptation. The above equation of β_R also applies, but $S = 1$ is a scenario imposing climate adaptation measures. According to the matrix for evidence of resilience by Pendall et al. (2010), in which the character of resilience is systematized according to the type of challenge and resistance lens, the present case is continual adaptation. The nature of the challenge is continuous, i.e., a chronic slow down, and resilience is measured in a complex adaptive system.

3 RESULTS

Figure 4 shows that the resistance of German counties to climate change impacts ranged from 0.52 to 2.32. The results thus illustrate that the local sensitivity towards climate change could differ significantly. On average, the value of 1.05 was close to 1, so it can be concluded that, on average, the regions are similarly resistant to climate change as Germany as a whole. Nevertheless, there was a significant number of outliers, especially in the high value range, which were characterised by a comparatively high sensitivity to climate change impacts.

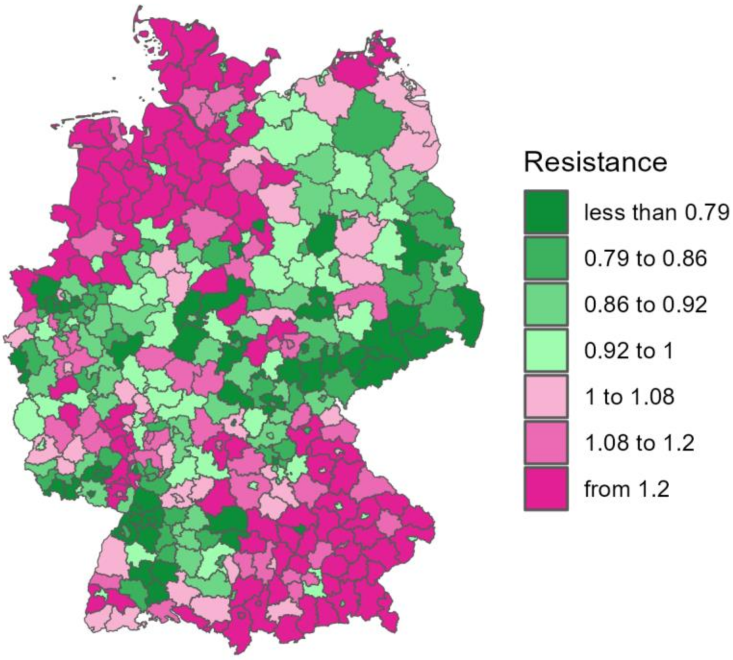
Figure 4: Distribution of the local resistance against climate change



Source: Own calculation and figure.

On a spatial level, shown in Figure 5, it can be seen that the north-west and south-east in particular were sensitive to climate change impacts, while the centre of Germany and the east were less affected. Especially counties in Saxony were characterised by a high value of resistance. The highest resistance with values of about 0.5 could be found for the city Schweinfurt and the county Tuttlingen. Least resistant against climate change with values of about 2 were the counties Cloppenburg, Oldenburg, Rhein-Pfalz-Kreis, and Ammerland.

Figure 5: Resistance against climate change impacts in German counties



Source: Own calculations and figure. Geodata: ©GeoBasis-DE / BKG 2021

We performed a cluster analysis (model-based, k-means, and hierarchical) to analyse the structure behind regional resistance. We used the indicators from Table 3 to delineate the clusters. Depending on the method we got 3 to 7 clusters. In the following the 5 clusters resulting from hierarchical clustering were used.

Table 3: Indictors for cluster analysis

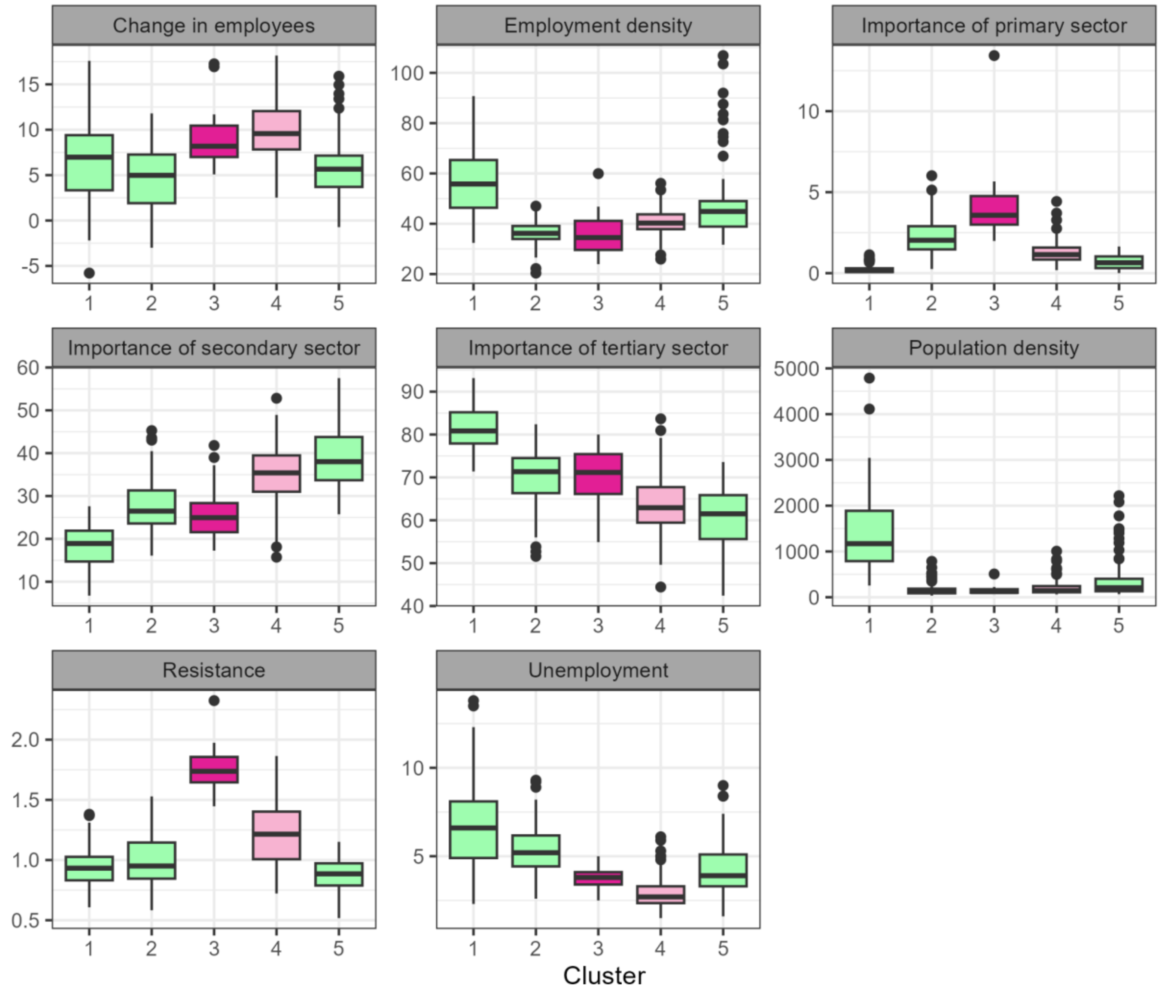
Indicator	Variable	Time
Change in employees	Change in employees in pre-Covid 19 period	2014-2019
Population density	Inhabitants per 100 qkm	2021
Employment density	Employees per 100 inhabitants	2022
Importance of primary sector	Share of employees in agriculture, fishery and forestry in total employment	2022
Importance of secondary sector	Share of employees in industries in total employment	2022
Importance of tertiary sector	Share of employees in services in total employment	2022
Unemployment	Unemployment rate	2022
Resistance	Sensitivity index	2050

Source: Own selection.

Figure 6 summarizes the different values of the indicators for the individual clusters. Clusters with above-average resistance to climate change are marked in green, those with below-average resistance in red. At first glance, there are no clear characteristics for resistance. Rather, different combinations of various indicators appear to have a positive influence on resistance.

High population density, high employment density and higher unemployment rates seem to favour resistance to climate change. This suggests that these labour markets do not appear to be facing extreme shortages. Thus, the effects of climate change were not amplified by additional other challenges. In contrast, increasing demand for labour, low employment density, low unemployment coupled with a relatively high share of agriculture seem to have a negative impact on the region's resistance. The importance of industries or services, however, does not seem to have a significant impact on resistance.

Figure 6: Cluster characteristics by indicators



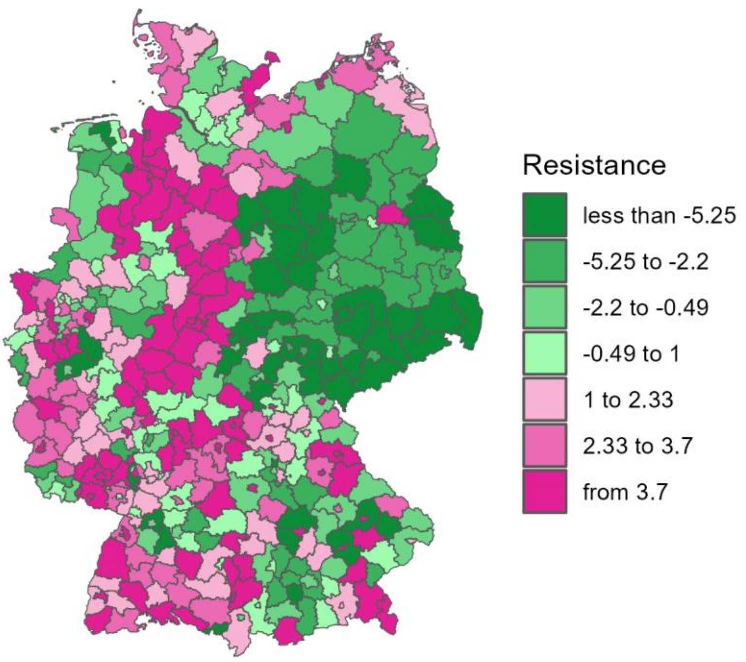
Source: own calculation and figure.

Figure 7 shows the recovery from climate change represented by the sensitivity index when adaptation measures were applied. It measures resistance against climate change with climate change adaptation. It compares the development with climate change adaptation under climate change to the development without proceeding climate change. For Germany the difference is still negative, i.e. even with investments in climate change adaptation the labour market development is lower than in the baseline without climate change. Negative values of the sensitivity index hence means that the difference between both developments within the region is positive and contrary to the overall development.

The spread of resistance between the regions was much larger when climate change adaptation measures were applied. The sensitivity index ranged from -55 in the county Gifhorn to 11.4 in the city Amberg. The mean value is centred at 0, implying that resistance against climate change increased. Thus, it could be concluded, that climate change adaptation favour resistance and strengthen recovery.

The downside is that it were not necessary the most vulnerable regions that would profit most. Due to the mixed characteristics in the sensitive and less sensitive regions and the non-specific distribution of the budget and the unfitted type of adaptation measures the positive effects of adaptation could not address equally effective all regions. Moreover, an east-west divide can be noticed. This suggests that these investments in climate change adaptation work more as an economic stimulus plan.

Figure 7: Recovery by climate change adaptation (resistance under climate change adaption), 2050



Source: Own calculations and figure. Geodata: ©GeoBasis-DE / BKG 2021

4 CONCLUSION

Scenario based analysis in combination with the concept of resilience provides an opportunity to classify and compare how regions are affected in the context of climate change. Our results show that the different levels of resistance were not equally distributed across regions. Especially, outliers can be found in the high value range implying that some regions are considerable less resistant to climate change impacts than the average. These regions could be mainly found in the north-west and south-east.

When looking at determinants or parameters that favour resistance, the picture is not that clear cut. Regions seem to be more resistant if they were only confronted with one challenge, i.e. if labour market shortages does not add to the impact of climate change. A focus on the agricultural sector could also be seen as less favourable for a higher resistance against climate change, as the agricultural sector and related industries were highly affected by climate change.

Climate change adaptation helps in strengthening resistance against climate change. To be most effective the measures should be tailored to the specific local situation. This means that the measures should be designed on local level where knowledge is available to address the specific challenges and characteristics. A broad distribution of the adaptation investments, on the other hand, should be avoided, as then the desired positive effects are not necessarily achieved. This point is supported by the findings of Adger et al. (2011) who analyse long-term resilience in the background of policy responses to climate change, such as global expansion of biofuels or decentralised water planning in Brazil. Their results suggest that many policies to enhance adaptation negatively impact resilience without careful planning and implementation.

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