

GWS-Kurzmitteilung 2026/2

Same Same but Different: Similarities and Differences in Regional Conditions for the Energy and Heating Transition

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Key outcomes

- The paper aims at using indicators derived from the research project Info-EW to cluster regions (Kreise) according to their starting conditions for the energy and heating transition.
- The applied method is a combination of Principal Component Analysis and cluster analysis.
- The 400 German Kreise can be grouped into five clusters based on different starting points, challenges and investment needs for the energy and heating transition.
- The five clusters differed mainly in renovation need, renewables/storage capacity and private investment capacity.
- The typology aims to target policy and investment and enable cross-regional learning and best-practice exchange.

1 Introduction

The decarbonisation of energy systems, as in the clean energy transition or green transition combined with the targeted transformation of the heating sector, is essential to meet national and international climate targets and to restructure energy systems for resilience and affordability. Integrated decarbonisation requires coordinated action across the electricity, heating and transport sectors, and planning that recognises strong spatial heterogeneity in energy demand, infrastructure, resource potentials and socio-economic capacities (IEA 2021).

In Germany, local and district-level conditions, such as building stock composition and age, urban density, existing district-heating networks, local renewable potentials, the availability of land for renewables, grid constraints, and the economic prosperity substantially influence which energy technologies and system designs are technically and economically appropriate (Agora Energiewende et al. 2024; Thelen et al. 2024; dena 2025).

Given this diversity, policy design and investment planning benefit from systematic methods that identify groups of regions with similar starting conditions. Exchanging information among regions facing comparable conditions and challenges can help to identify practical solutions and potential pitfalls. In this context, immediate neighbours do not necessarily provide an appropriate basis for comparison or for identifying suitable solution approaches. Cluster analysis offers a means of uncovering patterns and identifying regions with similar characteristics.

The aim of this study is to identify regions with similar structural and socio-economic conditions relevant to the green transformation using cluster analysis. Our results support regions in the identification and implementation of appropriate measures and suitable fields of action.

Cluster analysis is a broadly used quantitative approach for this purpose: it partitions observations into relatively homogeneous clusters based on multiple indicators, enabling targeted policy packages, tailored business models and more efficient allocation of technical and financial support (Kaufman & Rousseeuw 1990; Jain 2010). Compared with single-indicator ranking, multivariate clustering captures complex interactions among demographic, technical and economic variables (e.g. age of building stock, local renewable potentials, or socio-economic capacity), thereby producing groupings that are more informative for integrated energy-system decisions.

The method of cluster analysis has previously been applied in the context of the green energy transition for different research foci. One focus in the application lies on the European level: European countries are clustered to detect similarities and patterns in order to develop more effective energy transition policies (e.g. Borozan 2022, Strielkowski et al. 2024).

For studies with a regional focus on Germany, we found only three studies with a similar research direction. Lutz et al. (2017) focus on the German “Energiewende” with grouping regions according to their renewable energy potentials. The authors identified nine energy context types. However, the results can only be used for limited comparison purposes, as the number of districts has fallen from 412 to 400 since publication. This means that the

cluster allocation may no longer apply to all districts. Additionally, the content focuses solely on green energy production. Therefore, it is not possible to transfer the clusters to other conditions of the energy and heating transition. Schmid-Petri & Elschner (2024) analysed the role of municipal energy companies in facilitating the green transition and introducing green innovations. The authors find three communication types, which are the transitionalists, the traditionalists, and the pioneers. The results only refer to company level, regional clusters and socio-economic conditions were not considered. In the publication of Breitschopf & Burghard (2022) the research focus lies on individuals, that means the different attitudes and preferences of citizens for design elements of the energy transition. The authors used cluster analysis to identify two groups with different preference patterns. Again, spatial patterns were not addressed.

This study uses cluster analysis to identify German Kreise that have similar conditions for the energy and heating transition. This analysis is based on municipal and regional data sources, such as censuses, federal and state statistical offices, the Federal Employment Agency and the Federal Network Agency. The set of indicators used for clustering is intended to represent different aspects of the feasibility of the energy and heating transition. It therefore contains the following indicators: (a) demand characteristics (energy demand, heating type and energy-intensive industries); (b) building and land use characteristics (renovation needs and population density); (c) supply and technical infrastructure (existing district heating, energy storage capacity and local renewable energies); and (d) socio-economic and structural factors (energy poverty, investment capacity and the availability of the construction industry). This approach follows the established methodological steps for robust clustering: selecting relevant indicators; normalising them; reducing their dimension; and choosing a suitable clustering algorithm (Kaufman & Rousseeuw 1990; Jain 2010).

The principal contributions of the analysis are threefold. First, it provides a reproducible, multivariate typology of Kreise that highlights spatial patterns relevant to heat decarbonisation pathways. Second, by combining technical and socio-economic indicators it offers a basis for designing differentiated policy and regulatory interventions (e.g., where to prioritise district heating expansion, building retrofit subsidies, or market support for heat pumps). Third, the cluster framework supports further modelling and stakeholder engagement by indicating which districts can be meaningfully addressed with similar measures and which require bespoke approaches. The following sections describe data sources and indicator construction, the clustering methodology and validation procedures, present the resulting typology, and discuss implications for planning and policy.

2 Methodological Approach: Cluster Analysis based on Info-EW Indicators

This section outlines the methodological approach applied to identify groups of regions with similar structural characteristics. The analysis is based on a set of indicators drawn from

the Info-EW project¹, which capture key dimensions relevant to the comparative assessment. An overview of the variables included in the data set and their main characteristics is provided in Table 1. The data is based on official sources and is available for all 400 districts in Germany. The indicators were calculated as part of the Info-EW project. The indicators cover the following dimensions of the energy transition:

- Energy demand: Electric cars, energy-intensive industries, fossil heating, private energy consumption.
- Building stock and land use characteristics: Population density, rehabilitation need
- Infrastructure: Capacity of battery storage, district heating, renewable energies.
- Socio-economic and structural factors: Construction industry, energy poverty, private capacity to invest.

Table 1: Variables of the data set and their characteristics

Variable	Description	Max.	Mean	Min.
Capacity of battery storage²	Storage capacity of large-scale, commercial, and home energy storage systems (MWh)	358.9	54.4	4.7
Construction industry¹	Share of employees in the construction sector (%)	14.1	6.5	1.6
District heating³	Share of district heating in energy carriers for space heating (%)	93.2	12.5	1.2
Electric cars⁴	Share of electric vehicles in the passenger car stock (%)	9.1	3.1	1.0
Energy poverty³	Share of households affected by energy poverty (%)	9.8	6.6	4.0
Energy-intensive industries¹	Share of employees in energy-intensive industries (%)	19.2	3.8	0.0
Fossil heating³	Share of oil and gas heating systems (%)	97.6	75.9	6.2
Population density³	Inhabitants per sq. km	4844.0	541.1	35.0
Private capacity to invest³	Share of households with capacity to invest in the heat transition (%)	17.1	6.2	0.4
Private energy consumption³	Share of energy expenditure in household income (%)	8.3	7.3	6.3
Rehabilitation need³	Share of households living in potentially refurbishment-needy buildings (%)	95.8	87.3	71.2
Renewable energies²	Installed capacity of solar and wind energy (W per capita)	21577.3	2308.7	80.2

Data sources: ¹Bundesagentur für Arbeit, ²Bundesnetzagentur, ³Federal Statistical Office, ⁴Kraftfahrt-Bundesamt; Indicators: Info-EW project results, estimated by GWS and PIK; Descriptive statistics: own calculation.

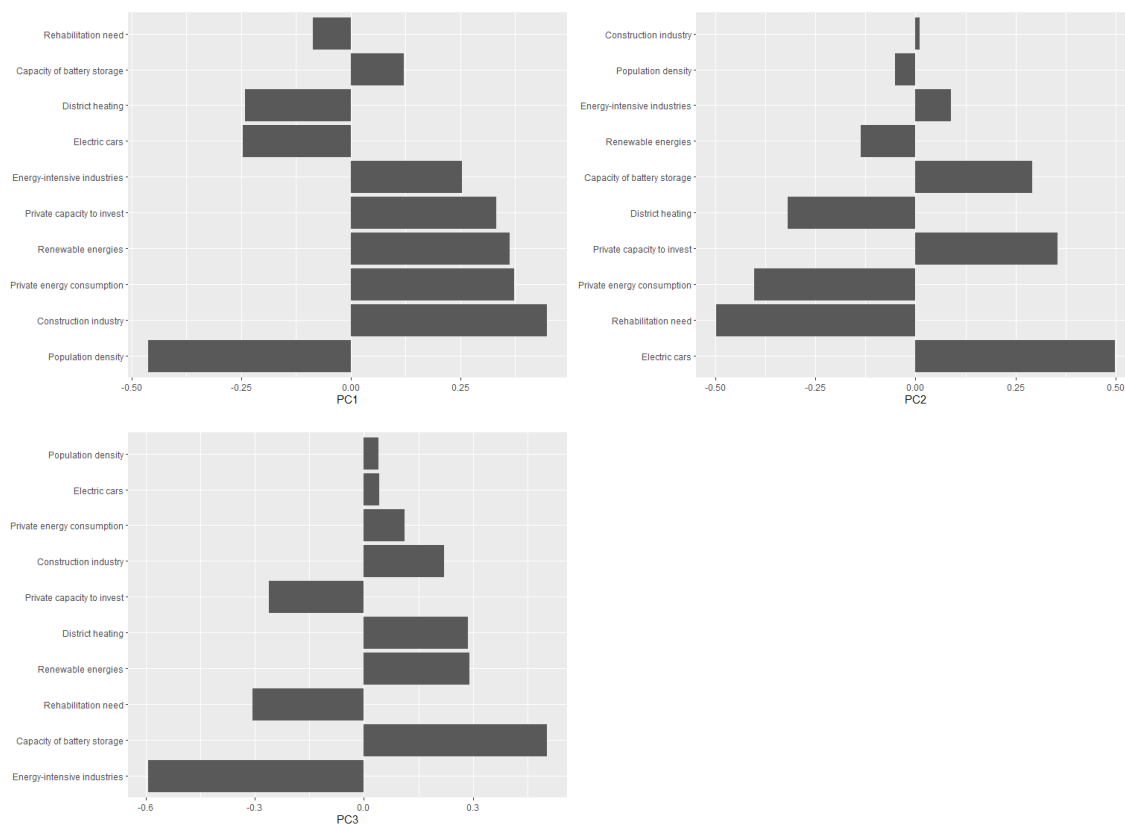
To account for heterogeneity across regions and to move beyond purely geographic comparisons, cluster analysis is employed as a systematic, data-driven method for grouping regions according to their initial conditions. This approach facilitates the identification of

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comparable cases and provides a robust basis for cross-regional learning and policy analysis. The cluster analysis was done in R (R Core Team 2024) using especially the libraries `data.table` (Barrett et al. 2024), `tidyverse` (Wickham et al. 2019) and `mclust` (Scrucca et al. 2023).

Cluster analysis is sensitive to correlated indicators and high-dimensional data sets (Aggarwal et al. 2001; Jain 2010). Firstly, the data was checked for correlation. The indicator energy poverty correlates with several other indicators and was therefore excluded in the clustering process. District heating and fossil heating are correlated. District heating is chosen as an indicator because there is a fundamentally different need for action here than in regions without district heating. Secondly, the dimensions were reduced using principal component (PC) analysis. A principal component is a new variable formed as a linear combination of the original indicators, capturing as much of the variation in the data as possible. Each subsequent component explains the remaining variance while being uncorrelated with the previous ones. According to the Kaiser criterion the optimal number of PCs can be established by choosing those PCs with eigenvalues larger than 1. This was the case for PC1, PC2 and PC3. Choosing the first three principal components, the dimension could be reduced from 10 to 3. The contribution of each variable to the respective principal component is displayed in Figure 1. The Hopkins statistic with a value of 0,777 for the first three PCs and a value of 0.838 for the original data suggests that the data is clusterable.

Figure 1: Contribution of indicators to the first three principal components (PC1 to PC3)



Source: Own estimates.

3 Results of the Clustering Analysis

For the clustering, three different procedures were applied: hierarchical clustering, K-Means Clustering and Model Based Clustering. All three methods suggested 5 clusters. The method Model Based Clustering and its cluster result was chosen. The Model Based Clustering fitted a gaussian finite mixture model with the characteristics ellipsoidal, equal volume and equal shape, a BIC of -4141.233 and a log-likelihood of -1959.775. Of the 400 regions 146 were in Cluster 1, 93 in Cluster 2, 87 in Cluster 3, 49 in Cluster 4, and 25 in Cluster 5. The characteristics of the identified clusters are summarized in Table 2. The following analysis highlights the main patterns and differences among clusters, providing a basis for comparative assessment and further policy interpretation.

Table 2: Mean indicator values of the different clusters

Indicators	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Mean
Capacity of battery storage	59.9	27.4	50.5	70.6	105.4	54.4
Construction industry	6.7	4.2	7.8	6.6	9.4	6.5
District heating	6.2	25.3	15.3	5.8	5.4	12.5
Electric cars	3.4	3.4	2.2	3.2	3.7	3.1
Energy poverty	6.6	5.6	7.9	6.7	6.7	6.6
Energy-intensive industries	3.7	2.4	3.3	7.4	5.0	3.8
Fossil heating	79.3	70.3	74.7	78.2	75.9	75.9
Population density	308.2	1537.4	131.4	267.4	157.8	541.1
Private capacity to invest	8.3	2.0	4.4	9.3	10.7	6.2
Private energy consumption	7.2	7.0	7.8	7.3	7.2	7.3
Rehabilitation need	86.2	90.2	88.9	86.9	78.6	87.3
Renewable energies	2028.2	469.8	4616.6	1881.6	3592.7	2308.7

Source: Own estimates.

Cluster 1: Average starting conditions with potential

In contrast to the other clusters, Cluster 1 consists of regions that have many values close to the mean, representing typical conditions for energy storage, the capacity of the construction industry, industrial energy use and renovation needs. A key challenge is the high proportion of heating that relies on fossil fuels. However, favourable economic and social conditions provide a good starting point, due to high investment capacity, low energy poverty and low household energy demand. The area is predominantly rural, with a decentralised heating structure. Given these starting conditions, it can be assumed that investment requirements for the expansion of energy storage facilities and technologies for a more energy-efficient, low-emission industry will be high on average, while greater investment will be needed in the areas of renewable energies and private heating systems.

Cluster 2: Urban with challenges in the existing infrastructure

Regions in Cluster 2 have no values close to the mean, with all indicators deviating from the average. Above average are district heating, electric vehicles, very high population density and renovation need. Those below average include battery storage capacity, construction industry activity, energy poverty, energy-intensive industries, fossil heating, private

investment capacity, private energy consumption and renewable energies. The cluster has a favourable base, with few energy-intensive industries and low reliance on private, fossil-based heating systems, as well as low household energy demand. Challenges include low private investment capacity, extensive mainly fossil-based district heating networks, an ageing building stock, and limited potential for renewables. The area is urban with a decentralised heating structure. Investment needs are likely to focus on converting district heating systems, renovating buildings and expanding renewables, including storage.

Cluster 3: Challenges on private household level

Cluster 3 is characterised by a high need for change among the local population. The main challenges are few electric vehicles, high private energy demand, high private energy poverty and low private investment capacity. Nevertheless, the cluster also has some favourable conditions that it can benefit from: substantial renewable energy resources, a strong construction sector and existing district heating networks. The cluster is predominantly rural with a centralised heating structure. Investment needs will focus on building renovations and converting district heating networks.

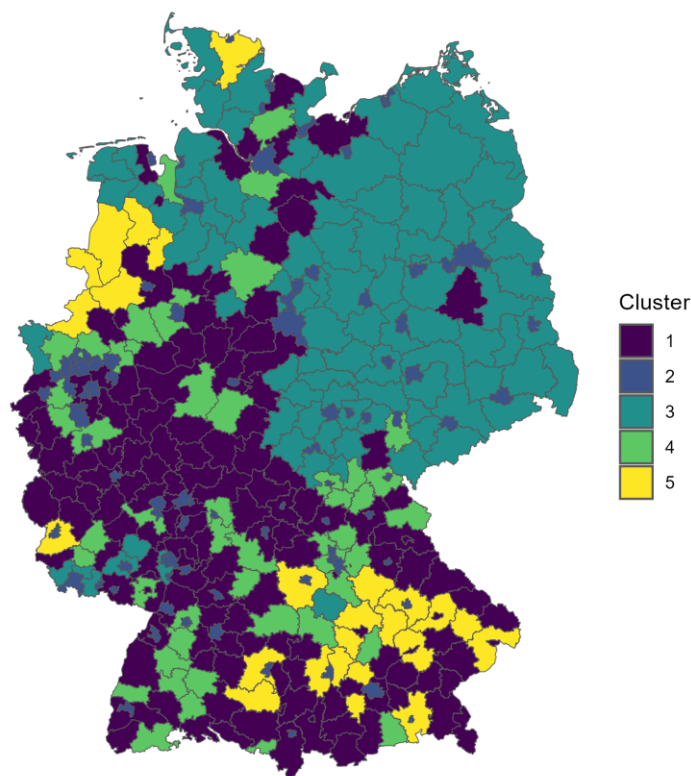
Cluster 4: Still a lot to do

Regions in Cluster 4 face many challenges due to a large energy-intensive industrial presence, widespread fossil fuel heating systems, and low deployment of renewables. However, the cluster has potential in the form of strong private investment capacity, existing capacities of energy storage, and low household energy demand. The cluster is rural, with a decentralised heating structure. Investment needs are likely to focus on private heating systems, converting energy-intensive production processes, and expanding renewable energy sources.

Cluster 5: Progressive green transformation with high demand

Cluster 5 has already developed a strong renewable energy generation and storage capacity, as well as a high uptake of electric vehicles, and shows comparatively low renovation needs. Private households have strong investment capacity, and the area is very rural, with heating remaining decentralised and consisting of many individual systems. At the same time, the cluster is home to a large number of energy-intensive industries, which keeps the overall energy demand high and creates a substantial need for additional green energy and a low-carbon supply. Investment priorities therefore are likely to focus on industrial decarbonisation. Moreover, it is anticipated that investment in renewable generation and storage will persist.

The spatial distribution of the five clusters is shown in Figure 2. The different cluster types are not distributed evenly across regions. Cluster 1 occurs particularly in the southwest, while Cluster 3 is mainly present in the north and east. Cluster 2 mainly comprises independent cities and is distributed across all of Germany. Clusters 4 and 5 are found almost exclusively in western Germany.

Figure 2: Distribution of Clusters

Source: Own estimates.

4 Conclusion

The results of the cluster analysis show that the 400 German districts, the so-called Kreise, can be clearly grouped into distinct clusters according to their starting conditions for the energy and heating transition. These clusters differ in their starting points and the challenges they face, which leads to different investment requirements. There is potential to develop best practice solutions and identify suitable case studies, enabling Kreise that are not immediate neighbours but belong to the same cluster to learn from each other and support one another in their transformation efforts.

However, there are also challenges and limitations to consider. Some clusters may contain outliers for which certain findings and conclusions do not fully apply. Hence, alongside general action options based on cluster assignment, regional knowledge of local conditions should always be included when assessing investment decisions or policy measures. Furthermore, the analysis represents a snapshot in time and does not account for dynamic changes over time. Past developments and previous transformation efforts are therefore not reflected in the clusters, which describe only to the present situation. For continuous monitoring, the indicators should be updated regularly and the clusters recalculated.

Finally, the choice of variables directly influences the clustering results, and the inclusion of irrelevant indicators or the omission of important metrics could adversely affect cluster formation. In this study, the indicators were selected through a comprehensive process within

the Info-EW project and evaluated by stakeholders, ensuring that all relevant variables for assessing the starting conditions of the energy and heating transition were considered. Correlated values were excluded, providing a robust basis for cluster determination.

Overall, this cluster analysis provides an overview of different stages in the energy and heating transition and enables classification. It supports discussion of various policy options, promotes exchange between districts with similar challenges and facilitates the comparison of recommendations and best practice examples.

Within the Info-EW project, the clusters will be made available as reference values in a dashboard, enabling regions with similar starting conditions to compare their progress more easily and contextualize the regionally differing effects of investment efforts in the energy and heating transition. The results are thus made accessible to regional decision-makers and support the evidence-based refinement of local and regional strategies.

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