International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0621

ESTIMATING THE ATTRACTIVENESS OF GERMAN COUNTIES FOR ENERGETIC RETROFITTING: A CONJOINT-ANALYSIS APPROACH

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ABSTRACT

With climate change threatening the status of affairs, governments have initiated counter-measures aimed at severely reducing energy consumption. This necessitates increasing the energy efficiency in the real estate sector. However, real estate owners often refuse to carry out profitable energetic retrofitting investments, a phenomenon referred to as the energy efficiency gap. To better understand which regional factors may influence individual investment decisions, a conjoint analysis comprising 104 policy makers, commercial property owners and private home owners was conducted, allowing to infer implicit preferences for four county-based attributes with respect to energetic retrofitting. Based on these results, an indicative energetic retrofitting attractiveness score is estimated for all 401 German counties. Furthermore, a comparison of the responses of the different stakeholder groups reveals that policy makers, commercial property owners and private home owners differ in their decision-making regarding energetic retrofitting.

Keywords: energy efficiency, energy efficiency gap, energetic retrofitting, conjoint analysis, decision support

1. INTRODUCTION

The real estate sector consumes around 40% of global energy and causes almost a third of global greenhouse gas emissions [1]. There is an overwhelming consensus that such human actions are the cause for global warming and other adverse consequences [2]. In recognition of this situation, the German government has initiated the energy efficiency strategy for buildings. Accordingly, an 80% reduction of the real estate sector's energy consumption should be achieved by 2050, requiring extensive energetic retrofitting measures. However, energetic retrofitting rates remain far below this target, which can possibly be ascribed to insufficient investments by third parties, i.e. commercial property owners and private home owners. The reluctance of these decision-makers to invest in energetic retrofitting can, however, not merely be explained by economic reasoning. In fact, the practice of rejecting profitable energy efficiency investments is widespread to such an extent that it has been coined the energy efficiency gap [3]. Barriers to investments in energetic retrofitting such as inattentiveness or imperfect information have been proposed as causes of this economic conundrum. This study aims to contribute towards overcoming these barriers in the context of heating energy by identifying and analyzing available data on a regional level. It identifies the relevance of factors impacting the perceived attractiveness of energetic retrofitting in Germany through a conjoint analysis with 104 respondents. These insights are used to assign an attractiveness score to each German county. Furthermore, this study examines the preferences of three stakeholder groups that are instrumental in this context, namely commercial property owners and private home owners as well as policy makers.

2. THEORY AND DATA SELECTION

While the decision-making of home owners regarding energetic retrofitting has been the subject of many analyses, this study will consider four established meta-factors impacting the profitability and realization of energetic retrofitting: meteorology, energy intensity, construction sentiment and socioeconomics [4]. To assess German counties based on these meta-factors, the following prerequisites must be fulfilled:

1) *The meta-factor has a quantifiable county-level representation or proxy measure.*
2) *A meta-factor's proxy measure is available for each county in Germany.*
3) *A meta-factor's proxy measure exhibits some variation across German counties.*

These criteria led to the following selection of proxy measures for the mentioned meta-factors. The inclusion of additional factors is not feasible given the methodology of conjoint analyses, which requires limiting the scope of information presented to respondents to avoid overstraining them.

Meteorology: There is a broad consensus in literature that climate conditions impact building energy consumption [5]. Since German residential buildings usually do not employ energy for cooling purposes, this study employs a meteorological proxy related to heating energy. The concept of heating degree days quantitatively captures heating activities by measuring daily negative deviations from a reference temperature. To approximate county-level data for this proxy, information was retrieved from 54 weather stations of the German Meteorological Office. Each county was assigned the figure of the closest weather station.

Energy intensity: Energy intensity describes how similar buildings vary in their energy consumption, usually expressed as consumed energy per m² per year. The estimated annual reduction of carbon dioxide emissions and the estimated pay-back period rely on the current energy intensity of a building [6]. Building age can be used to approximate the energy intensity of real estate objects in GermanyFurthermore, the year 1990 is often used to categorize buildings due to historical differences in construction methods. Thus, the fraction of buildings constructed before 1990 in a given county was identified as a fitting proxy measure for energy intensity. Corresponding data are based on a census conducted in 2011 [8].

Construction sentiment: The sentiment in the construction market, i.e. construction and renovation costs, is considered an important determinant regarding the profitability of energetic retrofitting [9]. Institutions such as the Association of German Architects compute a yearly index comparing relative construction costs for different zip codes in Germany. For instance, a value of 90% would indicate that construction costs in a given county are 10% beneath the German average. Their non-public data are based on several thousand aggregated construction bills.

Socioeconomics: Socioeconomic factors evidently affect energetic retrofitting [4, 9]. Rent prices are especially relevant since home owners often recoup investments in energetic retrofitting via rent increases. Hence, average rent per m² in a given county was considered a fitting socioeconomic proxy measure [10].

Summary descriptive statistics for the resulting regional data set can be found in Table 1. The data set comprises 401 county-level observations. As can be seen, all factors exhibit a sufficient amount of variation.

Proxy measure	***Mean***	***St. Dev.***	***Min.***	***Int.***	***Max.***
Heating degree days [C°]	3477.5	230.29	3,102.4	3562	4021.8
Buildings constructed before 1990 [%]	77.63	6.26	57.13	74	91.14
Relative construction costs [%]	97.8	9.27	69.7	107	144.7
Average rent [€/m²]	6.66	1.69	4.25	10	15.65

Table 1 Descriptive statistics for the four proxy measures (N=401)

3. METHODOLOGY

To estimate the perceived importance of these four proxy-measures for energetic retrofitting in Germany, a conjoint analysis was conducted with 104 respondents, comprising of policy makers, commercial property owners and private home owners. Policy makers are defined as high-ranking members of a county's building or environmental authority. Commercial property owners consist of respondents working for real-estate investment firms as well as energy consultants, engineering experts and academics of the field who often advise investment professionals regarding energetic retrofitting. Private home owners are respondents that themselves own real-estate property.

The respondents were confronted with a set of nine hypothetical counties. These mock counties differed only in terms of the mentioned proxy measures. More specifically, each mock county was assigned a unique combination of the minimum (Min), intermediate (Int) or maximum (Max) levels from Table 1 according to established fractional factorial design patterns. Since the proxy measures exhibit sufficiently low correlation and are considered to be relevant and feasible, the necessary requirements of conjoint analyses are satisfied [11].

Respondents were asked to rank these nine mock counties based on their attractiveness for energetic retrofitting. By aggregating all 104 rankings, two crucial insights into the respondents' preferences were derived:

1) Each proxy measure was assigned a relative importance value, which indicates the extent to which it impacts the respondents' decision-making.
2) Each level of each proxy measure was assigned a part-worth utility. These part-worth utilities are normalized between -1 and 1. The higher the part-worth utility, the more attractive the corresponding attribute level was to the respondents. This results in three part-worth utilities for each proxy-measure, which are linearly interpolated to form aggregate part-worth utility curves.

Computing of relative importance values and part-worth utilities was done in accordance with established frameworks for conjoint analyses [11].

4. RESULTS

4.1 Aggregate relative importance values

Aggregate relative importance values for all 104 respondents are as follows: Heating degree days (30.14%), average rent per m² (25.40%), relative construction costs (24.57%) as well as fraction of buildings constructed before 1990 (19.89%) The results indicate that all four proxy measures play a decisive role in the respondents' decision-making processes, confirming the conclusions of the literature review.

Furthermore, some minor tendencies can be inferred from the relative importance figures. Evidently, the heating degree days of a given county are a crucial indicator for many respondents, with a relative importance of 30.14%. It suggests that supplying climate data to home owners in attractive regions, e.g. via local building authorities, might benefit energetic retrofitting.

Moreover, the respondents assigned 25.40% to a county's average rent per m². Its relative importance thus slightly exceeds the corresponding figures for relative construction costs (24.57%), while the fraction of buildings constructed before 1990 was only weighted with 19.89%. The latter finding may seem surprising. It is conceivable, however, that respondents assign a higher importance to cash flow-oriented proxy measures.

4.2 Aggregate part-worth utility curves

The interpolated aggregate utility curves of the four proxy measures are illustrated in Figure 1. Minimum (Min), maximum (Max) and intermediate (Int) attribute levels as indicated in Table 1 are highlighted as black points.

Evidently, the utility curves exhibit different shapes and steepness. Interestingly, both heating degree days and average rent per m² possess distinctly non-monotonic utility curves. In both cases, the highest part-worth utility is assigned to the intermediary level. Clearly, respondents preferred moderate levels for both proxy measures. Regarding heating degree days, this preference is especially noteworthy. One might have expected respondents to prefer high values, seeing them as an indicator for large possible energy savings. However, some participants might regard initial energy efficiency levels to be high in counties with a lot of heating activity, thus leading to lower potential savings.

With respect to average rent, respondents again clearly preferred the intermediate attribute level. Potentially, raising rents to cover the costs of energetic retrofitting was perceived to be difficult in places where rents are very low or very high. After all, low rents indicate that tenants are hard to find or non-affluent. Conversely, rental costs that are already very high might inhibit home owners from conducting non-essential investments.

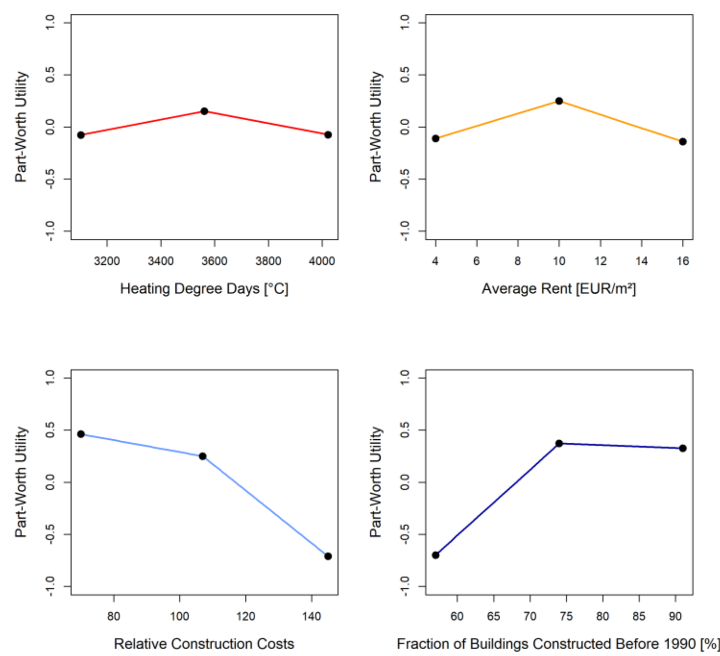

Fig. 1 Part-worth utility curves

The utility curve of relative construction costs is monotonically decreasing with high steepness. Most respondents thus found low values for relative constructing costs to be a necessary precondition for assigning a high rank to the corresponding mock county. This is not surprising, since high construction costs increase the initial investment needed to perform energetic retrofitting and thus directly impact profitability.

Finally, the utility curve regarding the fraction of buildings constructed before 1990 displays a non-monotonous shape. Respondents evidently considered counties with a relatively low percentage of buildings constructed before 1990 as unattractive for energetic retrofitting. However, they only marginally distinguish between counties with moderate and very high percentages. This indicates that counties with relatively old buildings are to a certain extent more attractive for energetic retrofitting.

4.3 Sensitivity analysis

In order to assess the robustness and variability of these results, the sensitivity of the relative importance values to additional respondents with randomly generated rankings was examined. At least 41 additional random rankings are required to shift the relative importance values by 5% over all attributes. A change of 10% could not be realized through random additions. Similar sensitivity analyses were conducted by considering hypothetical respondents with a pre-defined preference for a particular attribute. In this case, the marginal effect of one such respondent on the utility curves is limited for all attributes, while the respective preferred attribute gains at most 0.76% in relative importance. At least seven identical respondents with fixed preferences are required to shift importance values by 10%. Thus, the derived insights appear to be robust.

4.4 County-specific energetic retrofitting attractiveness score

The above results can now be utilized to estimate the implicit attractiveness of every German county. For this purpose, define $\boldsymbol{x_i} \in \mathbb{R}^4$ as the input vector of county i, in particular the vector including four county-specific data points x_{ij} relating to the four proxy measures j. The respective relative importance values RI_j enumerated in Section 4.1 are represented in a vector $\boldsymbol{RI} \in \mathbb{R}^4$. The interpolated part-worth utility functions from Figure 1 are denoted as $f_j(x_{ij})$. The vector of part-worth utilities for a certain county can now be computed by entering the county-specific attribute data into the respective interpolated functions. This leads to utility vector $\boldsymbol{u_i}$ for county i, defined as follows:

$$\boldsymbol{u_i}(\boldsymbol{x_i}) = \begin{pmatrix} u_{i1} \\ u_{i2} \\ u_{i3} \\ u_{i4} \end{pmatrix} = \begin{pmatrix} f_1(x_{i1}) \\ f_2(x_{i2}) \\ f_3(x_{i3}) \\ f_4(x_{i4}) \end{pmatrix}$$

To calculate an energetic retrofitting attractiveness score, each county-specific part-worth utility u_{ij} will initially be scaled on an interval of $[0,1]$. Each scaled value u_{ij}^* thus represents the percentage share of the maximum utility that county i achieves with respect to attribute j. Finally, the product of relative importance vector and the adjusted part-worth utilities accounts for the differing overall impact of each proxy measure on the respondents' decision-making. The result is the energetic retrofitting attractiveness score S_i:

$$S_i = S_i(\boldsymbol{x_i}) = \boldsymbol{RI}^T \cdot \boldsymbol{u_j^*}(\boldsymbol{x_i}) = \sum_{j=1}^{4} RI_j \cdot \frac{f_j(x_{ij}) - \min_i f_j(x_{ij})}{\max_i f_j(x_{ij}) - \min_i f_j(x_{ij})}$$

These raw scores are scaled on an interval between 0 and 100, where higher levels imply a higher average attractiveness for energetic retrofitting. The resulting energetic retrofitting attractiveness scores of all 401 German counties are visualized as a heat map in Figure 2.

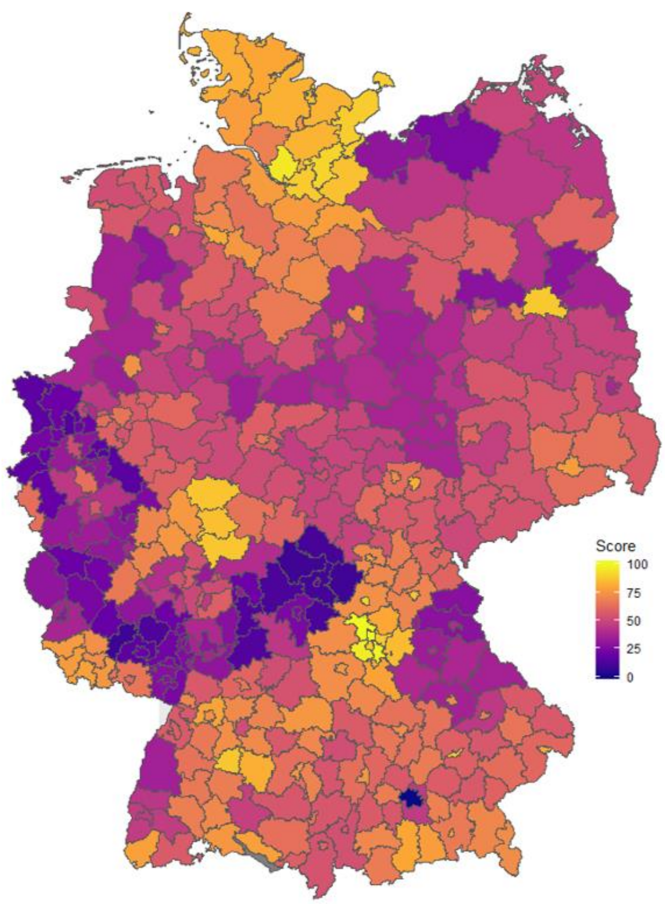

Fig. 2 Energetic retrofitting attractiveness score visualized as a heat map

Most German counties received average attractiveness scores close to 50, implying that they are considered equivalent in terms of energetic retrofitting attractiveness. However, there is a clear trend towards higher scores in Southern and Northern Germany. Large parts of Bavaria and Baden-Wuerttemberg in the south along with Hamburg and Schleswig-Holstein in the north appear to be particularly attractive. Conversely, Western, Central and Eastern Germany mostly exhibit low scores. However, this is only a broad categorization. The heat map illustrates high variation and significant differences between many bordering counties. This emphasizes the importance of analyzing energetic retrofitting on a county-level, or even more granularly. Further illustrating this finding, the highest score is achieved by the city of Erlangen while the city of Munich, due to its high rents and high construction costs, ranks at the very bottom. Both counties are located in Bavaria.

4.5 Stakeholder comparison through cluster analysis

Finally, this study aims to identify whether distinct preferences were exhibited by policy makers, commercial property owners and private home owners. However, it should be noted that respondents were not confined to a single category (e.g. private home owners who were also policy makers). Thus, a k-means cluster analysis was performed to group respondents with the same preferences into three categories. These were especially noteworthy regarding their diverging preferences on average rent per m². Relative importance values across clusters regarding average rent per m² were as follows: Cluster 1 (13.31%), Cluster 2 (27.63%) and Cluster 3 (31.48%). Furthermore, Figure 3 shows how utility curves differ across three clusters regarding average rent per m².

The first cluster (n=24) mainly comprises of commercial property owners (including academics in the field). There is little overlap with policy makers and among all clusters, it has the lowest percentage of private home owners. Members of this cluster placed the lowest relative importance on average rent per m². This suggests an expectation to be able to increase rent regardless of the current level.

Members of the second cluster (n=51) mostly identified as energy advisors, energy engineers and policy makers. There is only little intersection with commercial property owners. Most members of this cluster are also private home owners. Here, the proxy measure average rent per m² received the second highest relative importance. The corresponding utility curve is monotonously decreasing, with high steepness. This shows a definitive preference for counties with lower rent costs. It might be that members of this cluster feel uncertain about the ability to raise rents in counties were rents are already on a higher level.

Lastly, the third cluster (n=29) consists mainly of policy makers and commercial property owners. A high percentage of these are also private home owners. In contrast to the other clusters, average rent per m² was perceived as the decisive proxy measure with a relative importance of 31.48%. Here, members agreed with the first cluster, preferring high rent costs. Thus, they perceived affluent regions as more attractive for energetic retrofitting.

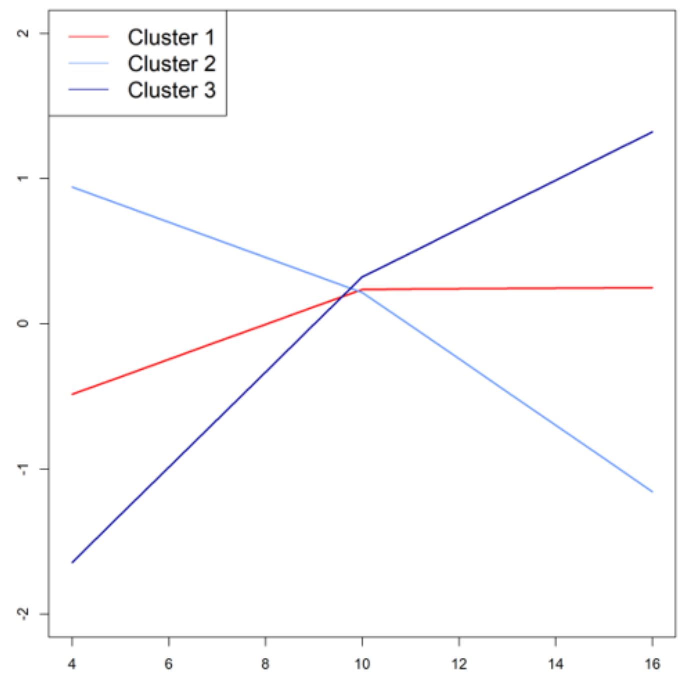

Fig. 3 Utility curves regarding average rent per m² across clusters

In summary, the cluster analysis reveals heterogeneous and not clearly identifiable preferences. Policy makers and private home owners were part of both the second and the third cluster but disagreed on the utilities associated with different rent levels. Commercial property owners concentrated in clusters one and three also disagreed on the relative importance of average rent per m².

Several implications can be drawn from these results. To begin with, engineers and real-estate investors might benefit from sharing their domain knowledge regarding the impact of socioeconomic factors when collaborating on energetic retrofitting. Furthermore, home owners' doubts regarding the ability to recoup investments in energetic retrofitting by increasing rents manifests in the differing relative importance associated with the average rent per m² proxy measure. Policy makers could address this through transparent legal guidelines and local subsidies. Incidentally, governmental subsidies were frequently mentioned by the respondents when asked which additional information would have impacted their decision-making.

5. CONCLUSION

This study analyzes the perceived attractiveness of energetic retrofitting on county-level in Germany based on several influence factors. The results are derived from a conjoint analysis conducted with 104 respondents comprising of policy makers, commercial property owners and private home owners. The input of those stakeholders was the basis of an energetic retrofitting attractiveness score for all German counties.

Commercial property owners might use these results as a decision-support tool in order to assess energetic retrofitting investments. Policy makers relying on independent third parties to carry out energetic retrofitting can use these findings to advertise highly attractive counties and offer increased subsidies in counties with low attractiveness. Moreover, a cluster analysis determined that policy makers, commercial property owners and private home owners do not have uniform preferences. Even within the stakeholder groups themselves, respondents differed on whether high or low average rents are beneficial for energetic retrofitting. This emphasizes the need for stakeholders to communicate and share domain knowledge.

This study is subject to certain limitations, which should be addressed by future research. As is the case with any conjoint analysis, the results are based on the input of a limited number of attributes and respondents. While these respondents are stakeholders in the field of energetic retrofitting, it cannot be claimed that they fully represent the totality of decision-makers. Furthermore, due to availability issues, data regarding the four proxy measures were issued at different points in time within a seven-year time-period. Nevertheless, this study offers an in-depth analysis regarding the perceived attractiveness of energetic retrofitting on a county-level, and thus contributes towards bridging the energy efficiency gap.

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