Conditions for local adaption of building policies in German cities according to their building structure and demography

Judit Kockat & Clemens Rohde
Fraunhofer ISI
Breslauer Str. 38
76139 Karlsruhe
Germany
+49 721 6809-147

Keywords
urban planning, policy-induced savings, demographics, energy saving potential, energy demand

Abstract
Building properties and the demographic growth of major German cities, both affect the energy demand and the need for energetic retrofit that local effort needed to achieve long-term climate protection targets. On one hand, with increased population the demand for residential units increases in growing cities. Hence, the energy demand may rise, while it probably shrinks in shrinking cities. On the other hand, prices for living space increase in growing cities. Therefore, people are willing to satisfy with less living space, which may reduce the energy demand. In this paper we analyse both of these factors to answer the question: How is the energy demand changed by migration and how much energy is still needed to be saved and what does that cost? The answers are deemed to provide for political action on energetic retrofit to be locally adapted to the local migration trend.

In our approach, German cities are initially clustered with regard to their age, size and attachment. Therefore, we use the algorithms proclus and k-means combined with a principle component analysis. Secondly, we calculate the energy savings of model cites based on this clustering, assuming constant specific savings for similar buildings derived from modelling approaches. The comparison of these energy savings amongst clusters shows whether the similarity of cities within a cluster and the differences amongst clusters, are significant. Finally, we amend the saving potential of the city clusters based on their current and future growth, so as to assess that demographic influence.

Nine clusters covering 40 % of the analyzed cities were identified. The biggest and most robust cluster is formed by eight main eastern German cites. Not surprisingly, the separation of the country has left significant traces within architecture and age distribution, which are both energy relevant properties.

We found that most of the migration impact can be directly linked to the population growth, however about 10 % to 22 % is linked to change the building structure. This means, with respect to energy savings and such targets, that not every city can reach the same energy demand reduction.

Furthermore, we found that positive and negative migration effects are easily diminished or even reverted by the rebound effect of use intensity. For example, low housing prices in shrinking cities cause people to afford more living space that consumes more energy for heating.

Due to the different modernization level in each city, the effects of migration need to be assessed in detailed. However, this study quantifies the impacts of migration and the resulting change in use intensity on energy demand, savings and investments. Subsequently it also reveals starting points for local adaption of policies to demographic growth.

Introduction

THE ROLE OF ENERGETIC RETROFIT
The EU and national governments – and supporting them many scientists – are discussing how energy can be saved in buildings and what political measures or mixes are best to facilitate those efforts.

Currently there are numerous policy instruments implemented in Germany. They encompass minimum requirements

Table 1. Mapping of attachment type and apartment units to the building types of IWU 2010.

attachment	units	building type	building type description
attached	1 and 2	rh	row house
	3–6	smh	small multifamily house
	6–12	mmh	medium multifamily house
	13–	gmh	grand multifamily house
detached	1 and 2	sfh	single family houses and semi-detached homes
	3–6	smh	small multifamily house
	6–12	mmh	medium multifamily house
	13–	gmh	grand multifamily house
semi-detached	1 and 2	sfh	single family house
	3–6	smh	small multifamily house
	6–12	mmh	medium multifamily house
	13–	gmh	grand multifamily house
Other	1 and 2	sfh	single family house
	3–6	smh	small multifamily house
	6–12	mmh	medium multifamily house
	13–	gmh	grand multifamily house

Source: own mapping.

for new buildings and renovations, financial support varying with ambition level, and a variety of information tools and consulting offers for building owners and inhabitants.

Therewith, politicians react to the fact, that 22 %[1] of the final energy in Germany is consumed for heating residential buildings and most of it can be saved using the current available technology. The energy that can technically be saved by retrofitting German buildings at a medium standard, for example, is between 260 and 500 TWh (Repenning et al., 2014b; Schlomann et al., 2012).

BUILDING STOCK PROPERTIES IN DIFFERENT CITIES

According to Banse and Effenberger, 2006, p. 7 the residential buildings stock in eastern and western Germany is different and influenced by the second world war and the subsequent separation of the country. The destruction created an increased need for living space and for building material, which led to poorer energetic quality. In addition, the conditions were different in eastern and western Germany. With respect to climate protection targets, we want to find out, how these differences in the buildings stock affect the energy demand, the amount of energy that can be saved through energetic retrofit and the investment needed for these measures?

INTERACTION WITH DEMOGRAPHIC GROWTH

With increasing population the demand for residential units rises in growing cities. Hence, the energy demand will probably rise, too. However, as the demand for housing grows prices for living space increases as well. Therefore, people may be willing to satisfy with less living space, which may subsequently reduce the energy demand. In this paper we analyse both of the described triggers to answer the question: How is the energy demand changed by migration and how much energy is still needed to be saved and what does that cost? These answers are deemed to provide for the adaption of political action on energetic retrofit to the local migration trend.

Methods

Before the demographic influence is considered, we analyse the building stock of Germanys' major cities, which form the scope of this paper. These German cities with 100,000 and more inhabitants are first clustered based on their building stocks' properties. This allows us to assess, which cities could be grouped together for policy design. In a validation step we also determine how similar and different the clusters and the cities are. This validation reveals, if conclusions for one city could be transferred to another. Secondly, we calculate the energy demand, the technical energy savings potential and the investment needed to realize this potential. Finally, these key figures are amended by the demographic growth triggers, population change and use intensity.

BUILDING STOCK DATA

The building stock data in this analysis are a synthesis of data coming from 4 sources. The official population census of 2011, updated in May 2014, supplied the number of buildings in each city by attachment type, number of apartment units, building age and owner. These properties form the building stock dataset of 200 dimensions resulting from 10 building periods, four attachment types and five different sizes for each of the 76 major German cities under review.

The second data batch provided for the demographical data(wegweiser-kommune.de, 2012). It includes the population growth for the past and expectations for the future, the living space per area ratio from 2005 through 2011, as well as the living space of the cities in 2011.

The third source is the German building typology study (Institut Wohnen und Umwelt GmbH, 2003) that identified 44 representative building types for Germany with their properties, as geometry, living space and energetic quality, specified as the u-values of windows and walls. This study was updated several times (Diefenbach and Loga, 2011) and in 2010 the same institute published data on the retrofit rate and quality in Germany (Diefenbach et al., 2010). These two studies provide for the calculation of energy demand in the buildings stock in 2011 that was performed in EE-LAB/Invert[2]. To assess the energy savings rate, further assumptions, as the future retrofit rate and quality with underlying energy and technology price developments, were needed. These energy parameters were taken from the fourth source the energy projection Klimaszenarien 2050 (Repenning et al., 2014a). From this study, the "climate protection scenario 80" targets 80 % greenhouse gas reduction as politically targeted in the energy concept (Bundesministerium für Wirtschaft und Technologie and Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, 2010). The energy demand, savings and investments in the cities are calculated based on the specific values per m² that were derived from the "climate protection scenario 80", see Table 4. These

1. Considering 2012 data from RWI (2013) and AGEB (2012).

2. http://www.invert.at/, Kranzl et al. (2013).

Table 2. Mapping of building ages among source data and this analysis.

Building period census 2011	Building period, building typology	Building period in this analysis	Historic events – with effect on building stock and construction
before 1919	before 1919	before 1919	First world war
1919–1948	1919–1948	1919–1948	Second world war
1949–1978	1949–1957	1949–1978	Germanys' separation: East: establishment of mainly big mfh, sfh only 10 % West: strong demand for living space, that doubled with almost half of new buildlings in owner-occupied sfh and semid-etached buildings
	1958–1968		
	1969–1978		
1979–1986	1979–1983	1979–1986	West: first ordinance on thermal insulation
1987–1990	1984–1994	1987–1995	West: second ordinance on thermal insulation 1982
1991–1995			
1996–2000	1995–2001	1996–2011	Third ordinance on thermal insulation 1982
2001–2004	2002–2009		Energy Savings Ordinance 2002
2005–2008			
2009 and later	2010–		Energy Savings Ordinance 2009

Source: Statistisches Bundesamt, 2014, Diefenbach and Loga, 2011, own mapping, Banse and Effenberger, 2006.

datasets from the four sources mentioned are aggregated using the assumptions described below.

The attachment type (row house, single family house[3], multifamily house) and the number of apartment units are condensed to match building types according to the German building typology issued by Diefenbach et al., 2010. This aggregate was used for the calculation of the energetic values while the clustering was performed on the original spread of data described in Table 3.

The building age classes from the population census 2011 and the building typology (Diefenbach and Loga, 2011; Institut Wohnen und Umwelt GmbH, 2003) are mapped and aggregated for this analysis, as depicted in Table 2. According to Banse and Effenberger, 2006, p. 7 ff the residential buildings stock was influenced by the second world war and the subsequent separation of the country as shown in Table 2. The aggregation of building age classes, i.e. 1949 until 1978, leads to rougher estimate of the buildings energy demand than the building typology would allow.

CLUSTERING THE CITIES

The cities were clustered according to their building stock. The underlying data were queried on the census data updated in 2014. The 200 dimensions result from combining 10 building ages, 5 buildings sizes (apartment units) and 4 attachment types. Of these dimension or variables 111 (9×4×3) are independent.

High dimensional data is not easily illustrated or interpreted. Thus we illustrate the clustering approach with simply two dimensions, see Figure 1. In the illustrated excerpt of the data, there are cities with a low share of small multifamily buildings built between 1948 and 1978 while holding a high share of single family buildings of building period 1919 to 1948 forming one cluster (green). The other cities have oppositely distributed shares and yet different shares of each dimension. Hence, they belong to different clusters, as indicated by the colours that reveal the clusters the cities were robustly assigned to, based on all dimensions.

The clustering algorithms perform comparisons similar to this visual approach for all 200 clustering dimensions. When working with high dimensional data the curse of dimensions appears. This phenomenon causes data with a clear cluster assignment in few dimensions not to be as clearly clustered, when the number of dimensions increases. The reason for this behaviour is that each new dimension increases the space between all data points, but does not keep similar data points close in the same way. The dimensions that don't contain a lot of differences between the data points will spread them. Hence, similarity measures like the Euclidean distance lose their expressiveness. To counteract the loss of differences, the influence of the significant dimensions can be increased, i.e. through principle component analysis. It decreases the number of dimensions by compressing the variance into few orthogonal components. The resulting principle components are not easy to be read or interpreted by themselves. However, they serve as a basis for the following cluster analysis (Backhaus, 2011).

A variety of cluster algorithms and settings were used to obtain a robust assignment of cities for the clusters. Starting with the k-means algorithm the seed and number of clusters was varied.

K-means is an iterative algorithm and it starts by distributing the selected number of cluster centres randomly. In a second step each data point is assigned to the closest centre. After that

3. As single family homes, we aggregate detached houses with one unit and semi-detached houses with two units.

Table 3. Dimensions of the cluster analysis and their structure.

building age	age ID	number of units	building attachment	att. ID	clustering dimension	building class	City 1 number of buildings	…	City 76 number of buildings
before 1919	**1919**	**01**	detached	**dt**	1919_01_dt	**sfh_1919**			
before 1919	**1919**	**01**	semi-detached	**sd**	1919_01_sd	**sfh_1919**			
before 1919	**1919**	**01**	row house	**rh**	1919_01_rh	**rh_1919**			
before 1919	**1919**	**01**	other house	**oh**	1919_01_oh	**sfh_1919**			
before 1919	**1919**	**02**	detached	**dt**	1919_02_dt	**sfh_1919**			
before 1919	**1919**	**02**	…	…	…				
before 1919	**1919**	…	…	…	…				
…	…	…	…	…	…				
2009 and later	**2009**	**13** and more	other house	**oh**	2009_13_oh				
Based on the number of buildings the share of each dimension is then calculated per city; totalling to							100 %	…	100 %

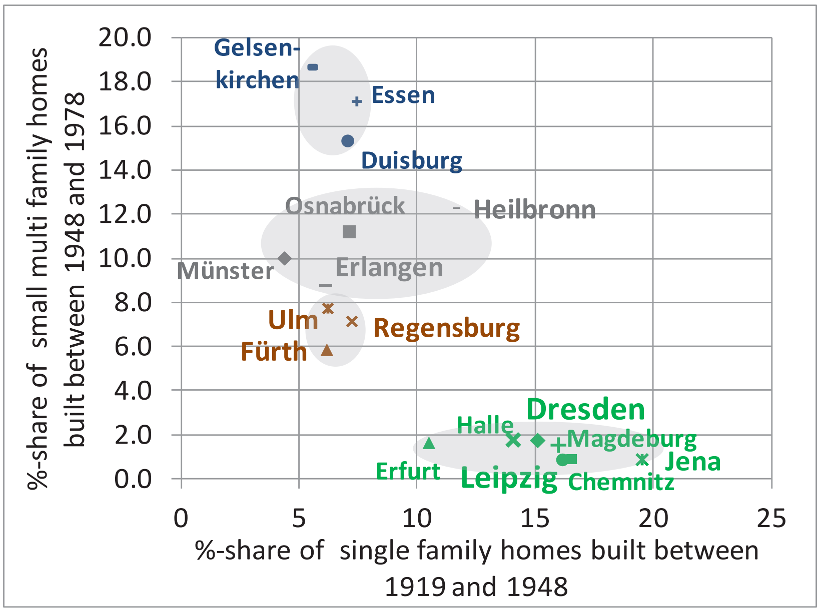

Figure 1. Two-dimensional clustering sample showing the shares of large multifamily buildings built between 1948 and 1978 and single family buildings built in 1919–1948.

the centres are updated and moved to the centroid position of the data points assigned to it. The centroid is the mean position of all the points in all of the coordinate directions. Subsequently, the assignment and updating of centroids is repeated until stability is achieved i.e. the cluster assignments of individual records are no longer changing. Apart from the number of clusters, the result is also dependent upon the chosen seed. The seed determines the location of the initial cluster centres. The results may vary with a different seed (Bacher, 1994, p. 309).

This algorithm was performed on the original data as well as on principle components, since it is not specifically designed for high dimensional data, as opposed the Proclus algorithm. The latter approaches high dimensions by spanning a subspace through attributes with low variance for each guessed medoid. Points are then assigned to the closest medoid based on that subspace. To perform the clustering we used different tools: KNIME (Michael R. Berthold et al., 2007), Elki (Elke Achtert et al.) and Real Statistics (Zaiontz, 2013). For comparison the data were also clustered by their attributes, i.e. by age and geometry. Finally the different clustering results were compared and the common, robust clusters identified.

The cities that are robustly assigned to the clusters thus have similar building properties, i.e. age, attachment and size. In the next step these properties are used to determine the energy demand, the technical energy savings potential and the investments needed to realize this potential.

Table 4. Assumptions of energy demand, energy savings and investments based on Repenning et al., 2014a.

building class	energy demand kwh/m²	energy saving kwh/m²	invest-ment EUR/m²	building class	energy demand kwh/m²	energy saving kwh/m²	invest-ment EUR/m²
sfh_1919	162	94	394	mmh_1919	111	81	300
sfh_1948	158	90	385	mmh_1948	119	60	297
sfh_1978	144	81	371	mmh_1978	92	68	336
sfh_1986	127	78	410	mmh_1986	93	53	376
sfh_1990–sfh_1995	124	37	428	mmh_1990–mmh_1995	96	33	321
sfh_2000	104	17	379	mmh_2000	75	9	255
sfh_2004–sfh_2011	100	10	366	mmh_2004–mmh_2011	70	14	236
lmh_1919	118	54	412	rh_1919	142	82	243
lmh_1948	97	64	387	rh_1948	144	64	280
lmh_1978	82	49	398	rh_1978	128	80	255
lmh_1986	79	48	388	rh_1986	110	53	278
lmh_1948–lmh_1978	83	24	386	rh_1990–rh_1995	118	38	210
lmh_2000–lmh_2011	61	13	339	rh_2000	95	15	175
smh_1919	133	88	325	rh_2004–rh_2011	86	11	171
smh_1948	136	72	323				
smh_1978	109	79	358				
smh_1986	91	66	381				
lmh_1990–lmh_1995	106	37	381				
smh_2000	83	11	346				
smh_2004–smh_2011	81	12	256				

Source: own mapping.

DETERMINING THE ENERGY DEMAND, THE TECHNICAL ENERGY SAVINGS POTENTIAL AND THE INVESTMENTS IN ENERGETIC RETROFIT TO ACHIEVE THE SAVINGS

The current energy demand, savings and investments in the cities are calculated based on the specific demand per m², see Table 4, derived from a political target oriented scenario simulated in the bottom-up building model, INVERT/EE-Lab (Kranzl et al., 2013). This simulation included space heating and warm water generation with methodical assessment of user rebound and investment behaviour (Steinbach, eingereicht).

These parameters are extracted from the energy projection in Klimaszenarien 2050 based on the building properties. To calculate the savings the energy demand projected in 2050 is compared to the current one. Whilst, the current energy demand reflects past modernization, as assessed in Diefenbach et al. (2010). This projection assumes technical energy savings measures to be applied in the future, if they are available and feasible. At the same time, the objective is to fulfil Germany's targets as detailed in the Energy Concept (Bundesministerium für Wirtschaft und Technologie and Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, 2010)

Hence, in the scheme of Schlomann et al., 2015, the calculated potential is rather a technical potential, since it considers the economic diffusion of energy saving measures until 2050. Therefore, assumptions for the development of price levels for measures and energy carriers, as well as cost for saving measures are taken from the "climate protection scenario 80" in Repenning et al., 2014b.

In this analysis we amend the energy demand and the technical saving potential for growing and shrinking cities. This amendment is based on two triggers.

DISTRIBUTION OF POPULATION CHANGE ACROSS THE BUILDING STOCK

Firstly, the population change itself leads to an increased or diminished demand for residential units. Therefore, in growing cities new buildings are assumed to be built to fulfil that demand. In our analysis the distribution of new buildings equals the distribution of the latest building period (2011) in the typology data Diefenbach and Loga, 2011. That means, we assume the new building trend will be continued, which reflects the trend suggested by Banse and Effenberger, 2006, p. 29. However, it could be argued, that cities may become denser and may not be able to grow in the same way, as they did in the past.

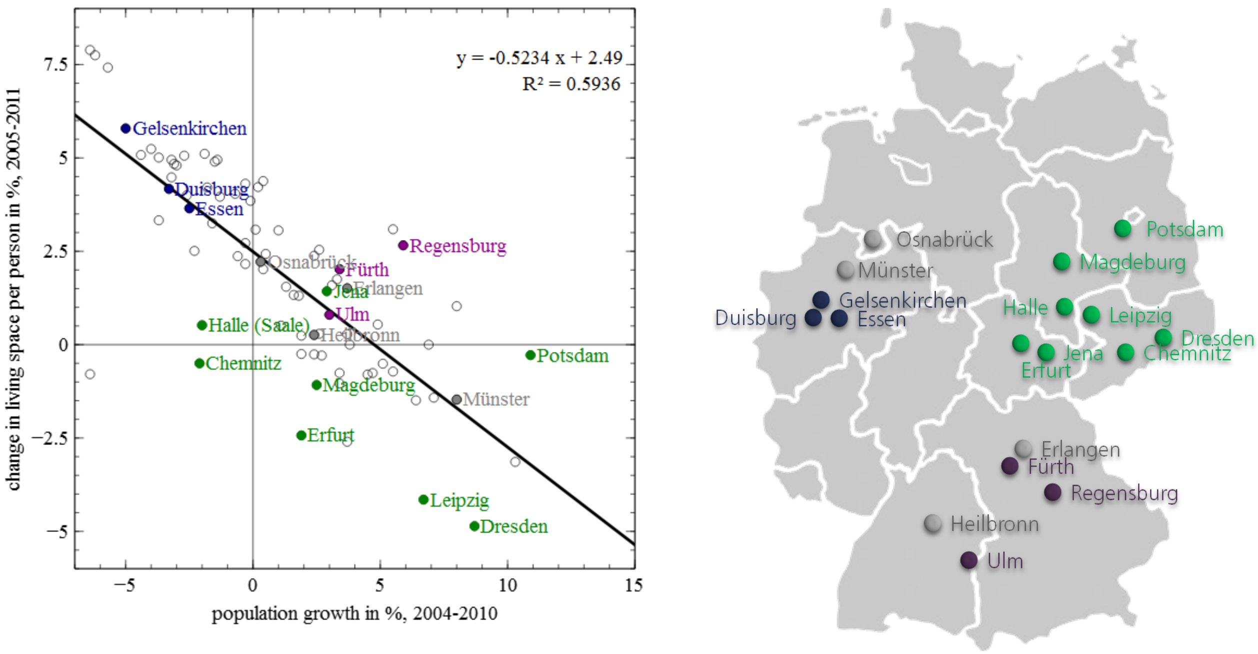

Figure 2. Left: correlation of population growth and space use intensity, own analysis based on wegweiser-kommune.de, 2012. Right: geographical distribution of cities for the four biggest, robust clusters.

As opposed to the construction in growing cites, buildings become vacant when population decreases in shrinking cities. Since the unused living space is assumed not to be heated, the population reduction triggers a decrease in energy demand. An interesting question is, which buildings will be vacant and which will be continued to use? Banse and Effenberger, p. 16 and Braun et al., 2014, p. 7 found that more than 80 % of vacant living units are within multifamily buildings[4]. Apart from the building size, the vacancy is also differently distributed over construction periods. A reduction of vacancy in older multifamily buildings (construction before 1918) and increased vacancy in younger buildings was observed, in eastern Germany comparing 1998 and 2002, see Banse and Effenberger, 2006, p. 16. Based on that, we distributed the newly vacant living space across multi-family buildings older than 25 years and younger than 100 years will become vacant.

USE INTENSITY (M²/CAP)

The second trigger for changing the energy demand is the change in space use intensity. The living space per person is adjusted based on how much the city grows or shrinks, as suggested by the results of Bräuninger and Otto, 2006, p. 537. Therefore, we analyzed the correlation of population growth and living space per capita using the data from Bertelsmann Stiftung, 2014. Figure 2 shows that a correlation can be approximated through linear regression.

However, the data provide a comparison of different cities and not a timeline for one city. Moreover, the coefficient of determination of 0,59 is moderate. However, both data dissadvantages seem acceptable considering that existing research, like Monkkonen et al., 2012 provides empirical evidence in favor of the correlation. Therefore, we decided to use the current and local data for german cities to amend the growth of living space demanded. The linear approximation of this correlation is, however, only valid within boundaries, since living space use is cost driven and utility costs increase with space as explained in Spars, 2006, p. 29. The resulting living spaces per person for the cluster cities, are within that boundary of 45 m²/cap.

LIMITS OF THE ANALYSIS

Two factors remain unconsidered, since they cannot be estimated robustly. Firstly, the vacancy may not affect the complete house. In that case the kWh/m² increases since the number of surrounding non-heated walls rises. However, in this analysis we assume that the vacancy will progress fast within one house, since living becomes more inconvenient and expensive when neighbours move out.

Secondly, partial heating of apartments is not considered. In older buildings with a high energy demand people tend to heat partly, i.e. only the living room. That is not the case in newer buildings. Again imagining people moving from newer multi-family buildings in the surrounding in the old city centre, people may want to reduce their energy bill, by not heating rooms that are rarely used or have many outer walls. This effect may be caused by an increased energy bill. However, there is yet empirical evidence needed on where people move, when a city shrinks and how their heating behaviour changes.

Results

ROBUST CLUSTERS

The application and comparison of several different clustering algorithms resulted in the formation of 9 robust clusters, i.e. those clusters that PCA and kmeans as well as proclus had in

4. Further evidence of dominant vacancy in multi-family buildings can be found in Simons (2005).

Table 5. Overview of assumptions.

	Assumption	Reference	Source
energy and investment	*determined for each building class, constant across cities*		
Energy demand	const. kWh/m²	Table 4	KS80 in Repenning et al., 2014a
Energy savings	const. kWh/m²	Table 4	
Retrofit in vestment	const. EUR/m²	Table 4	
migration and building			
migration development (M)	2009–2030	Table 5	Bertelsmann Stiftung, 2014
use intensity (UI)	UI = -0.5234 M + 2.49%	Figure 2	own calc based on Bertelsmann Stiftung, 2014
growth	continued trend based on latest building age in building typology		own assumption based on Banse and Effenberger, 2006
shrinkage	evenly distributed across multi-family buildings		own assumption based on Banse and Effenberger, 2006 and Braun, 2007
partly heated buildings and apartments	not considered		

Table 6. Robust clusters from the cluster analysis.

#	Cluster name	mean share of biggest buildings segments biggest	2nd biggest	3rd biggest	4th biggest		average growth rate	cities
1	prewar + prefabricated	sfh_1948: 15.2 %	sfh_1919: 7.0 %	mmh_1978: 6.8 %	sfh_2000: 6.0 %	shrinking	-7.3 %	Chemnitz, Erfurt, Jena, Halle, Magdeburg
						growing	10.6 %	Dresden, Leipzig, Potsdam
2	Rapid growth until 80s	sfh_1978: 23.3 %	smh_1978: 10.6 %	rh_1978: 10.2 %	sfh_1948: 7.3 %	shrinking	-2.2 %	Osnabrück
						growing	2.2 %	Erlangen, Heilbronn, Münster
3	Moderate but durable growth	sfh_1978: 17.2 %	rh_1978: 9.2 %	smh_1978: 6.9 %	sfh_1948: 6.5 %	growing	5.1 %	Fürth, Ulm, Regensburg
4	60s peak Ruhr	smh_1978: 17.0 %	sfh_1978: 11.0 %	mmh_1978: 8.3 %	rh_1978: 7.9 %	shrinking	-7.0 %	Duisburg, Essen, Gelsenkirchen

common. These clusters contain 28 cities, representing 37 % of the 76 major German. 18 of those 28 cities (24 % of 76) are assigned to the four biggest that contain more than 2 cities. These biggest clusters contain 6 % of the German population and 8 % of the living space in Germany. These four biggest clusters were chosen for further analysis.

TECHNICAL ENERGY SAVINGS POTENTIAL

Comparing the energy demand and savings of the clusters the impact of the different building stock structure becomes obvious. Firstly, the dark bar on the left shows a different average energy demand per m² for the 4 clusters under review. In addition, the energy that can be saved through retrofit measures – light bars – also varies amongst clusters. Finally, it is remarkable that the cities have different remaining energy demands. This means, not every city can reach the same level of energy demand per m².

The average energy demand of the buildings in clusters 1 through 4 varies by about 5 % around the mean. Reason for this divergence is that the different clusters have a different energy demand per living space. The specific energy demand depends on the distribution of the building categories: single family home (sfh), multi-family home (mfh) and row house (rh).

The impact of the migration on the energy demand is influenced by the migration rate. In cluster 1 there are 5 shrinking cities, Chemnitz, Erfurt, Halle, Jena, Magdeburg, with their similar building stock properties with an average initial energy demand of 187 kWh/m²a, see Figure 4 and Figure 5. This demand can be reduced through renovation by 58 % leading to 79 kWh/m²a when no change in population is assumed. However, when the shrinking population is considered the energy demand shrinks by another 4 kWh/m²a, which is 5.6 % of the energy demand after retrofit.

Comparing this energy saving to the negative population growth of -7.3 % the energy demand shrinks by 1.7 % pts less than the population. Since every other parameter in the energy demand calculation is constant, this allows the conclusion that the 1.7 % pts, which are 23 % of the migration impact, can be explained by the change in building stock. For clusters 2 and 4 the impact of the building stock is similar with 22.7 % and 19 %, respectively.

The fact that the energy demand shrinks at a lower rate than the population, means that buildings with less energy demand than the average building stock are falling out of use. These unused multi-family houses have a better volume-to-surface ratio and thus consume less energy than the average building stock, which consists largely of single family homes. Hence, the fact that vacancy is mainly happening in multi-family buildings leads to less energy savings.

The impact of decreased use intensity is directed in the opposite direction. In detail, this means for cluster one and four that energy demand is back to its original level, despite the population decrease. In the second cluster the energy demand

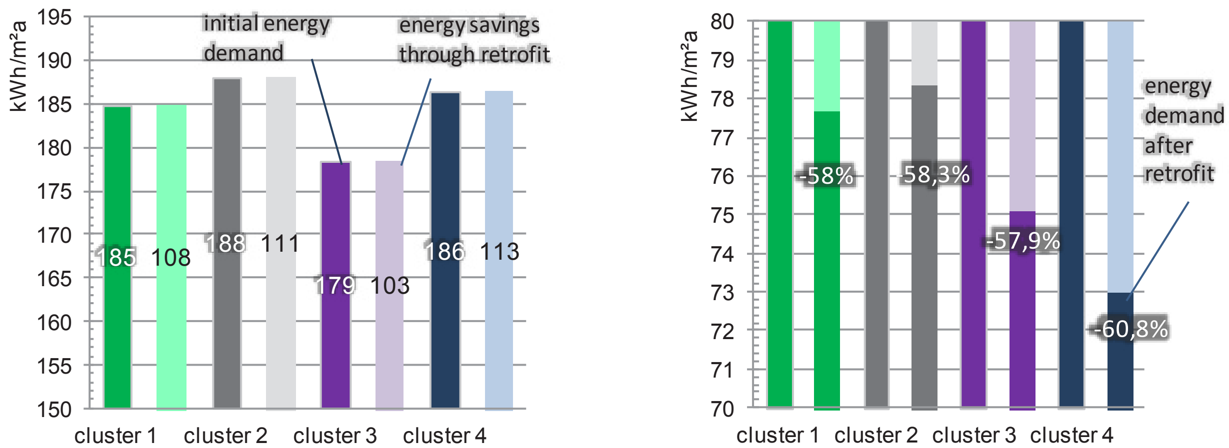

Figure 3. Energy demand and energy savings through retrofit compared across the four largest, robust clusters.

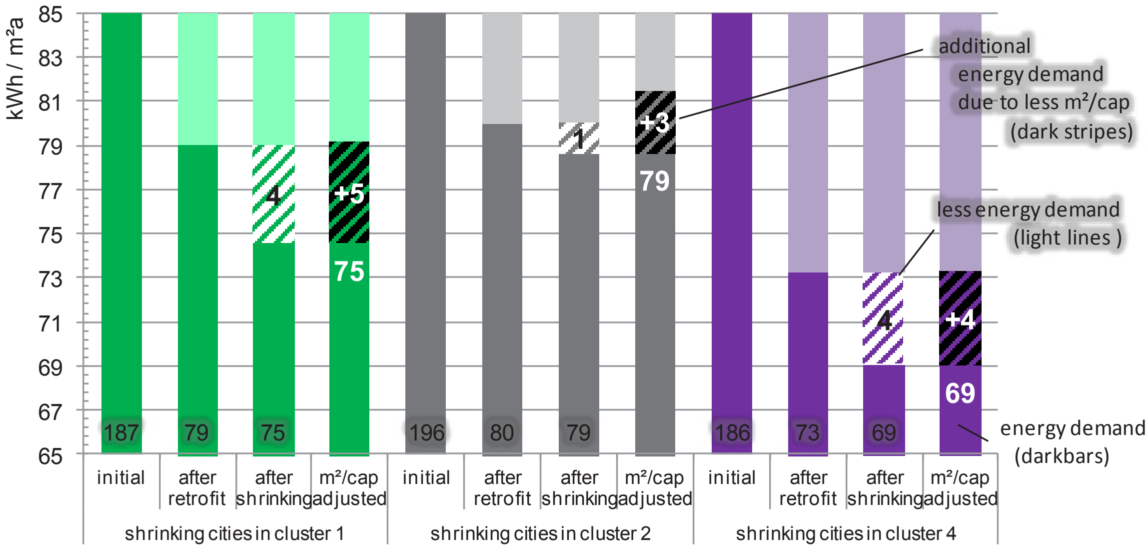

Figure 4. Energy demand before and after retrofit, separating the migration effect and the effect of use intensity for the shrinking cites of the four largest, robust clusters.

even increases. This increase is triggered by and thus dependent on the reduced price level. These lower prices cause people to afford more living space and a subsequent rebound in energy demand.

The energy savings potentials, compared in Figure 5, are similarly affected by the migration effects, meaning the cities will not gain energy savings just through a population drop. On the contrary, about the same retrofit efforts will be necessary to achieve the goals. Hence, against our expectations energy saving targets, if defined for a city, will hardly need to be adjusted due to migration.

The assessed impact of population growth on a cities energy demand is also very different amongst the clusters. For example, the first clusters growing cities of cluster one: Dresden, Leipzig and Potsdam, are expected to grow at an average rate of 10.6 % until 2030. As a consequence, new buildings need to be established and we found that the energy demand increases by 9.9 % equalling 7.7 kWh/m²a. Again comparing the growth rates, we noted now that the increase of energy demand is lower than the increase of living space caused by population growth. This can be explained since the new buildings are more energy efficient than the average building stock in the city.

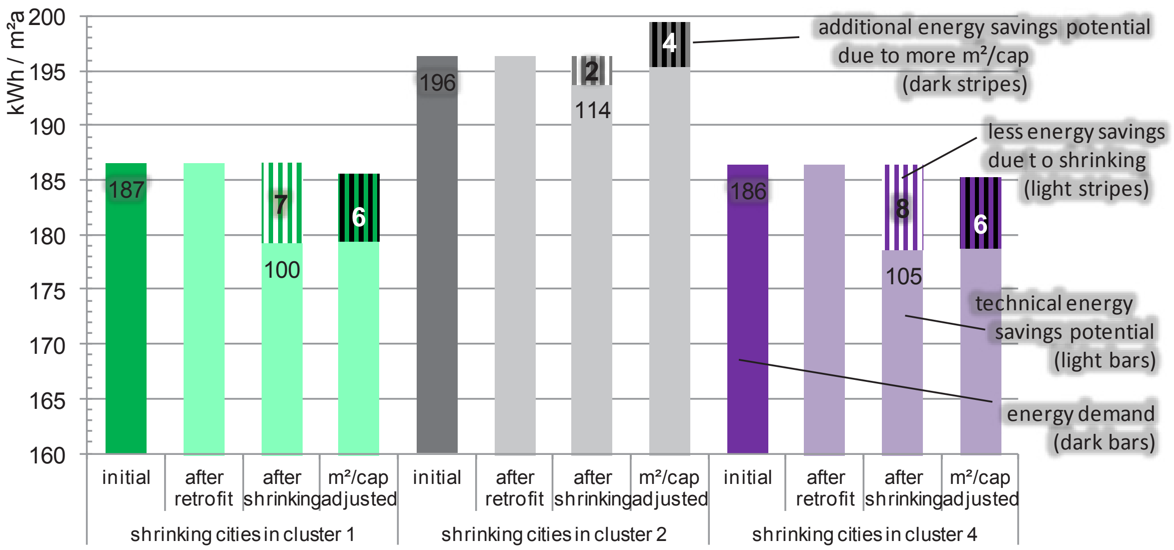

Figure 5. Energy savings, before and after retrofit, excluding and including migration effects for the shrinking cites of the four largest, robust clusters.

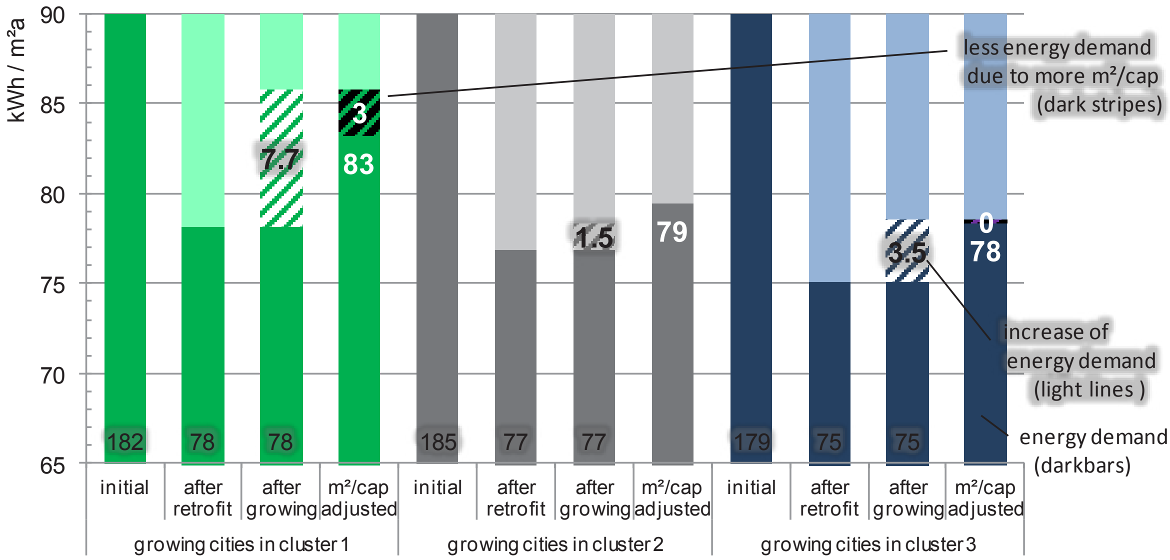

Figure 6. Energy demand before and after retrofit, excluding and including migration effects for the growing cities of the four largest, robust clusters..

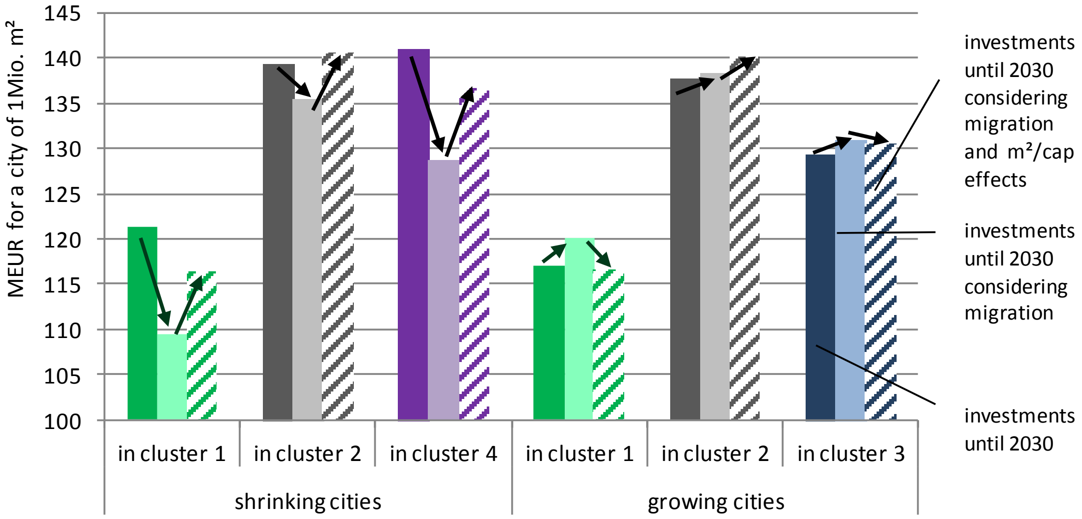

Figure 7. Change in investment including migration effects for the shrinking and growing cities.

However, the increase of energy demand is partly diminished when we include the intensified use of space in our calculation. As opposed to that, in cluster two, the population growth is rather low and according to Figure 2 the living space per person continues to rise at that growth rate. Hence, the energy demand grows further.

A similar effect can be observed for the growing cities of the clusters. The building stock properties cause the increase in energy demand after retrofit and growth to vary by a standard deviation of 5.3 % around the average.

Figure 6 shows how different model cities have a different change in energy demand due to migration. This effect varies between 1.6 and 8.3 GWh representing 2 to 10 %. The big variance in the additional demand is, of course, related to the different growth rate with some influence of the building stock properties.

INVESTMENTS

Figure 1 shows that a shrinking population is initially linked with a reduction in investment in energetic retrofit. However, when considering the subsequent increase in m²/cap, the investment rises again, which is explained mainly due to the change in population, see Table 7. Despite the upward impulse, in cluster 1 and 4 there is still a saving compared to the original investment. In cluster 2, however, the increased use of space leads to more investments.

For the growing cities the investment rises due to the growth, and then shrinks again when space consumption is reduced. Again cluster 2 forms an exception, the population grows by up to 3 % only, which leads to an increased use of space per person and thus more investment for retrofit.

The comparison of the change in energy demand to the change in investment in Table 7 shows that the building stock structure has a bigger effect on investments than on energy demand. For example, in the first cluster the energy demand shrinks by 5.6 %, while the population decreases by 7.3 %. At the same time, the investment shrinks by 9.8 %. In growing cities, the retrofit investment is hardly affected, since additional living space is covered by investments in new buildings that are not considered here.

Discussion

This analysis focuses on the impact of energetic retrofit and growth on the energy demand and savings of a city. However, the following aspects were either not within the scope or could not be considered with a decent level of certainty.

The energy savings rate per area (kWh/m²) stays constant for each building class and the buildings remain within the same building class. Thus, in the calculation of energy savings the replacement of old buildings by new buildings is not considered. We also don't consider the improvement of energy standards of new buildings over time.

In the same manner we assume constant energy demand rates per area (kWh/m²) and constant density rates (m²/cap) over time. Hence, the calculated energy demand does neither account for a higher energy demand in partly inhabited buildings, nor does it reflect a possible intensified use of space in growing cities.

Due to a lack of data, the past retrofit activity in the different cities could not be considered. However, the specific energy demand rates include the average retrofit that was assessed in Diefenbach et al., 2010. What is the impact of this non-city specific consideration of retrofit activity? On one hand, some cities may have undergone more retrofit activities than the average. The buildings in these cities, thus, have a better energetic quality and a lower demand, regardless of their other properties. For these cities, our calculation overestimates the initial energy demand and the energy savings. One the other hand, some cities might have a lower retrofit rate leading to the reverse effect. Starting from there, the energy saving potential will be lower than before.

The energy demand of the buildings is assumed based on the buildings age, its size and attachment type. Size and attachment

Table 7. Comparing retrofit investments with and without the influence of migration and resulting across the four biggest robust clusters.

	%	difference to mean investment	change in population	change in energy demand due to migration	change in investment due to migration	change in investment due to adjusted m²/cap	change in energy demand due to adjusted m²/cap
shrinking cities	in cluster 1	-7.3	-7.3	- 5.6	-9.8	5.6	6.2
	in cluster 2	6.4	-2	- 1.7	-2.7	3.5	3.6
	in cluster 4	7.6	-7	- 5.7	-8.6	5.6	6.2
growing cities	in cluster 1	-10.6	11	9.9	2.6	-3.1	-3.2
	in cluster 2	5.1	2	2.0	0.4	1.4	1.3
	in cluster 3	-1.2	5	4.6	1.2	-0.2	-0.2

Source: own calculations.

influence the volume to surface ratio with impact on energy demand. In the analysis of (Aksoezen et al., 2015), buildings constructed before 1921 performed better than the average, whereas buildings built between 1947 and 1979, performed worse. This effect can be generalized for German cities, i.e. due to the recovery from World War II living space was needed urgently and building material was scarce. Also in the following years the economies recovered and grew vastly, again increasing the need for living space especially in the cities. This urgent and increased need for living space caused fast solutions lacking quality and energetic performance.

Finally, when thinking ahead, especially with some uncertainty within the growth rate, it is worth considering the energy saved during the time that the retrofitted building is used, even though it might become vacant later.

Conclusion

Considering the 1–11 % impact on the energy demand we found in Figure 6, the impact of migration on the technical energy saving potential is tangible. However, when looking at multifamily buildings, the impact rises to 14 %. When narrowing the building periods to 1949–1978 the share increases to 25 %. As specified in the methods, multifamily houses built after the war in times of scarcity, until the late 1970s with rapid growth and need for living space, are especially impacted. Hence, their energy performance is relatively low – sometimes lower than in earlier years – and they are situated within a suburban multifamily house belt with a high share of living space. In most big cities there is such a belt, rather far from the old town centre, consisting of mostly publicly owned multifamily houses. In accordance with past developments, see Banse and Effenberger, 2006, we assume that people will start to move away from these areas first; since they are distant to the city centre and their energetic quality is relatively low.

If the effect of migration concentrates in this assumed way, housing companies that own most of the multifamily buildings in the suburban belts are affected significantly. These actors will need support by the local or regional authorities to gain the data on migration and align with the plans of the urban planning department, concerning the density of the living areas.

Another anchor for local political action could be the prevention of rebound of the space use per person. We found that the change in living space per person, as deducted from the current cities, will reverse the direct migration effect, which results from more/fewer households. For shrinking cities this is a form of rebound that could be avoided by keeping the price level high by reducing the living space available. Thus, there is a perspective for political action to take on.

The assumption of a growth rate over a long time like 20 years holds several complications. The first one is the uncertainty that growth or shrinking will become real over such a long time. Secondly, the growth rate may vary and in between even reverse over such a long time span. For a long term investment like a retrofit it will reduce recovery risk if growth rates are steady and can be predicted with a decent certainty.

When considering the time frame a retrofit needs to recover the cost (or as much of the cost as possible) the question of the uncertainties of a growth forecast become inevitable. Can one rely on the growth rates forecast for 20 years in the future to base our investment risk calculations on? The migration rates in Germany are commonly analyzed and forecasted by the urban planning department, if such a department exists. Unfortunately, especially for smaller cities, those units often don't exist. In addition, the urban planning is often not connected to the department(s) that handles climate change and energy matters. The results laid down above show an interaction between growth and energy demand/ savings. Hence, the cooperation of these city units is needed to facilitate the political guidance on a local level for investment in buildings. Then, the value of the integrated assessment of buildings' energy savings and demographic growth are possible where authorities and institutions are set up and working in a progressive and integrated way.

In addition, further advantages arise from linking the renovation considerations to the demographic growth analysis. The planning horizon of renovations might get adjusted to the demographic analysis' dimensions, allowing i.e. a longer payback period. The time under consideration might thus implicitly increase. Furthermore, the local authorities become aware of solving several problems with one measure i.e. the need for homes of elderly people or social housing may be solved by energetic renovation of city owned buildings. Both of these effects may affect the profitability calculation in a way, where more and more ambitious renovations become economically feasible.

References

AGEB, 2012. Energieflussdiagramm. http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=ageb_energieflussbild_2012_pj.pdf. Accessed 11 March 2015.

Aksoezen, M., Daniel, M., Hassler, U., Kohler, N., 2015. Building age as an indicator for energy consumption. Energy and Buildings 87, 74–86. 10.1016/j.enbuild.2014.10.074.

Bacher, J., 1994. Clusteranalyse: Anwendungsorientierte Einführung. Oldenbourg, München, 424 pp.

Backhaus, K., 2011. Multivariate Analysemethoden: Eine anwendungsorientierte Einführung, 13th ed. Springer, Berlin [u.a.], X, 583 S.

Banse, J., Effenberger, K.-H., 2006. Deutschland 2050: Auswirkungen des demographischen Wandels auf den Wohnungsbestand. IÖR.

Braun, R., 2007. Auswirkungen Der Demographie Auf Den Wohnungsmarkt–Regionalprognosen. Empirica Paper 149.

Braun, R., Heising, P., Schwede, P., 2014. Aktuelle und zukünftige Entwicklung von Wohnungsleerständen in den Teilräumen Deutschlands: Datengrundlagen, Erfassungsmethoden und Abschätzungen. http://www.bbsr.bund.de/BBSR/DE/Veroeffentlichungen/Sonderveroeffentlichungen/2014/DL_Wohnungsleerstaende.pdf?__blob=publicationFile&v=2. Accessed 11 March 2015.

Bräuninger, M., Otto, A., 2006. Die zukünftige Entwicklung auf den Wohnungsmärkten in Deutschland. Wirtschaftsdienst 86 (8), 532-537. 10.1007/s10273-006-0554-4.

Bundesministerium für Wirtschaft und Technologie; Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, 2010. Energiekonzept: für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung, 36 pp. http://www.bundesregierung.de/Content/DE/_Anlagen/2012/02/energiekonzept-final.pdf?__blob=publicationFile&v=5.

Diefenbach, N., Cischinsky, H., Rodenfels, M., Clausnitzer, K.-D., 2010. Datenbasis Gebäudebestand: Datenerhebung zur energetischen Qualität und zu den Modernisierungstrends im deutschen Wohngebäudebestand 0049. Institut Wohnen und Umwelt GmbH, Darmstadt, 150 S.

Diefenbach, N., Loga, T., 2011. Basisdaten für Hochrechnungen mit der Deutschen Gebäudetypologie des IWU. Neufassung August 2011.

Elke Achtert, Hans-Peter Kriegel, Erich Schubert, Arthur Zimek. Interactive data mining with 3D-parallel-coordinate-trees of Data, SIGMOD 2013, New York, NY, USA, June 22–27, 2013, pp. 1009–1012.

Institut Wohnen und Umwelt GmbH, 2003. Deutsche Gebäudetypologie: Systematik und Datensätze 05/03, Darmstadt, 9 pp. http://www.iwu.de/fileadmin/user_upload/dateien/energie/klima_altbau/Gebaeudetypologie_Deutschland.pdf. Accessed 22 August 2013.

Kranzl, L., Hummel, M., Müller, A., Steinbach, J., 2013. Renewable heating: Perspectives and the impact of policy instruments. Energy Policy 59, 44–58. 10.1016/j.enpol.2013.03.050.

Michael R. Berthold, Nicolas Cebron, Fabian Dill, Thomas R. Gabriel, Tobias Kötter, Thorsten Meinl, Peter Ohl, Christoph Sieb, Kilian Thiel, Bernd Wiswedel, 2007. KNIME: The Konstanz Information Miner, in: Studies in Classification, Data Analysis, and Knowledge Organization (GfKL 2007). Springer.

Monkkonen, P., Wong, K., Begley, J., 2012. Economic restructuring, urban growth, and short-term trading: The spatial dynamics of the Hong Kong housing market, 1992–2008. Special Section on Asian Real Estate Market 42 (3), 396–406. 10.1016/j.regsciurbeco.2011.11.004.

Repenning, J., Emele, L., Blanck, R., Döring, U., Förster, H., Haller, M., Harthan, R., Henneberg, K., Herrmann, K., Jörß, W., Kasten, P., Ludig, S., Loreck, C., Matthes, F.C., Scheffler, M., Schumacher, K., Braungardt, S., Eichhammer, W., Elsland, R., Fleiter, T., Hartwig, J., Pfluger, B., Schade, W., Schlomann, B., Kockat, J., Sensfuß, F., Athmann, U., 2014a. Klimaschutzszenario 2050. Studie im Auftrag des Bundesministeriums für Runde 1. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, Berlin. http://www.oeko.de/oekodoc/2065/2014-638-de.pdf. Accessed 19 January 2015.

Repenning, J., Emele, L., Blanck, R., Döring, U., Förster, H., Haller, M., Harthan, R., Henneberg, K., Herrmann, K., Jörß, W., Kasten, P., Ludig, S., Loreck, C., Matthes, F.C., Scheffler, M., Schumacher, K., Braungardt, S., Eichhammer, W., Elsland, R., Fleiter, T., Hartwig, J., Pfluger, B., Schade, W., Schlomann, B., Kockat, J., Sensfuß, F., Athmann, U., 2014b. Klimaschutzszenario 2050: Zusammenfassung. Studie im Auftrag des Bundesministeriums für Runde 1. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, Berlin. http://www.oeko.de/oekodoc/2019/2014-604-de.pdf. Accessed 19 January 2015.

RWI, 2013. Erstellung der Anwendungsbilanzen 2011 und 2012 für den Sektor Private Haushalte: Endbericht. Oktober 2013. AGEB. http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=rwi-anwendungsbilanz_haushalte_2011-2012.pdf. Accessed 11 March 2015.

Schlomann, B., Eichhammer, W., Rohde, C., Bürger, V., Becker, D., Kockat, J., 2012. Kosten-/Nutzen-Analyse der Einführung marktorientierter Instrumente zur Realisierung von Endenergieeinsparungen in Deutschland. Endbericht an das Bundesministerium für Wirtschaft und Technologie (BMWi). Fraunhofer ISI; Ecofys Germany GmbH; Öko-Institut e.V. http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/kosten-nutzen-analyse-einfuehrung-marktorientierter-instrumente-endenergieeinsparung,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf. Accessed 24 September 2014.

Schlomann, B., Rohde, C., Plötz, P., 2015. Dimensions of energy efficiency in a political context. Energy Efficiency 8 (1), 97–115. 10.1007/s12053-014-9280-8.

Simons, H., 2005. Wirtschaft und Wohnen in Deutschland: Regionale Prognosen bis 2015, Wohnungsmarktentwicklung bis 2030. Empirica, Forschung und Beratung; DKB, Berlin, Berlin, IV, 94 S.

Spars, G., 2006. Makrotrends für die Wohnungsmärkte in Deutschland, in: Spars, G. (Ed.), Wohnungsmarktentwicklung Deutschland, vol. 58. Universitätsverlag der TU Berlin, pp. 15–42.

Statistisches Bundesamt, 2014. ZENSUS 2011 (2014) – Gebäudezahlen nach Baualtersklasse, Wohneinheiten, Außenwände und Eigentümerstruktur: database query on demand.

Steinbach, J., eingereicht. Modellbasierte Untersuchung von Politikinstrumenten zur Förderung erneuerbarer Energien und Energieeffizienz im Gebäudebereich,: Eingereichte Dissertation bei der Fakultät für Wirtschaftswissenschaften. Dissertation, Karlsruhe.

wegweiser-kommune.de, 2012. Gemeindetypisierung – Wegweiser Kommune: Methodisches Vorgehen und empirische Befunde. Faktor Familie GmbH, Bochum. http://www.wegweiser-kommune.de/datenprognosen/demographietypen/Demographietypen.action?redirect=false. Accessed 27 March 2014.

wegweiser-kommune.de, 2014. Datenlieferung für deutsche Großstädte. www.wegweiser-kommune.de.

Zaiontz, C., 2013. The data analysis was generated using the Real Statistics Resource Pack software (Release 3.5). Copyright (2013–2015) Zaiontz. www.real-statistics.com. www.real-statistics.com. Accessed 16 March 2015.