Database tools for policy development – presenting building stock renovation programme potentials through Energy Saving Cost Curves

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Abstract

The use of buildings databases has an enormous potential to inform decision-making in order to decarbonize the building stock by 2050. This paper showcases the potential of databases and, by using the example of Germany, it presents a methodology for appraising the economic and energy reduction outcomes of building renovation policies. A dynamic bottom-up simulation model, the Invert/EE-Lab, evaluates the effects of three scenarios of economic and regulatory incentives for three different renovation packages oriented towards the standards defined by the German building code (EnEV) as well as the support programmes of the Federal Development Bank (KfW). Results are presented visually through Energy Saving Cost Curves which communicate the energy savings and avoided energy costs following renovation programmes of the German building stock. The results show that under a range of realistic scenarios to 2030, the total economic energy saving potentials range from 60 to 170 TWh/y, and correspond to financial savings that range from 1.2 to 6.2 bn€/y. Energy Saving Cost Curves provide a means to compare the impact of different policy options from the perspective of the investor for different building categories, and can thereby feed directly into the design of renovation strategies -whether at national, regional or city level- taking into consideration economic parameters ranging from subsidies and energy prices, to transaction costs, learning curves and discount rates.

Introduction

In order to mitigate climate change, the European Union (EU) has set a long-term aim to reduce greenhouse gas (GHG) emissions by 80-95% below 1990 levels by 2050. The European Council decided, in October 2014, to adopt a 40% goal for the reduction of GHG emissions by 2030 compared to 1990 levels, together with targets of at least 27% for renewable energy and 27% for energy efficiency (European Council 2009, 2014).

In Germany, the building sector accounts for 40% of final energy demand and is the source of 30% of GHG emissions (BMWi, 2015a). Adopted as part of the "Energiewende"[1] (energy transition) in 2010/2011, the German Federal Government has set national goals to reduce energy consumption for heating by 20% by 2020 and non-renewable primary energy consumption for space heating and hot water by 80% by 2050, compared to 2008 levels (BMWi, 2015b). In addition, it aims for a 14% share of heating and cooling generated from renewable sources by 2020 (Wärmegesetz, 2009). The central piece of German building performance policy is the 2014 version of the building code required by the Energy Saving Ordinance (EnEV) which applies to new and existing buildings, both

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[1] In September 2010 the German government decided to restructure the country's energy system by 2050 and adopted the "Energiekonzept" (energy concept). It was speeded up and further developed after the Fukushima-disaster in the spring of 2011 and the subsequent decision to phase out nuclear power by 2022, but is in essence still valid today. http://www.bmwi.de/DE/Mediathek/Publikationen/publikationen-archiv,did=573670.html

private and public, as well as to the installations required for space heating & cooling, domestic water heating, and indoor air quality (plus lighting for non-residential buildings).

Energy efficiency investments in buildings

Germany has a financial support scheme, administered by the KfW development bank, which provides low interest loans and grants for both highly efficient new buildings and the renovation of existing buildings. The requirements of this support go beyond the EnEV standards. Currently, one in three renovations, together with half of all newly constructed buildings, is supported by the KfW programme, which provides progressively higher levels of support according to the resulting energy performance (BMWi, 2015c). Since 2006, more than 3.8 million dwellings and over 2,100 social or municipal buildings have been built or renovated with these funds, bringing the total investment in building energy performance improvement to €187 billion (BMWi, 2015c). Despite the above-mentioned initiatives, the overall German renovation rate is just at the level of the European average, of around 1% per year (Government of the Federal Republic of Germany, 2014).

Research Questions

This paper outlines a methodology and provides a policy tool able to assess the effectiveness of a number of economic levers in improving the attractiveness of renovation, specifically from the perspective of the investor. The use of such tools can inform policy design regarding the combination of policies and measures that could be used to improve the economic attractiveness and hence the rate and degree of renovation across the full range of building categories. Therefore, the main research question of this paper is:

- How can database-based tools inform the policy-making process for buildings renovations?

From this main question follows a set of three sub-questions that address significant concerns of policy-making. These supporting research questions are:

- How to represent the economically attractive energy savings potential?
- How do economic parameters influence the outcome of renovation policies?
- How could policy be designed to realise significant energy savings at no net cost?

Methodology

Description of the German building stock

The starting point for the analysis is the categorization of the German building stock according to a number of representative building typologies. The building stock database is based on different surveys on the residential and non- residential building sector[2]. The German building stock database is an input to the Invert/EE-Lab model, where the buildings are clustered according to three levels:

- Building Categories: This top level summarizes buildings based on fundamental building characteristics such as type of usage.
- Building Classes: The second level distinguishes a Building Category to sub-groups that have broadly the same energy needs, defined by the following criteria: geometry, types and properties of the building façade elements and mechanical ventilation system, climate region

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[2] Diefenbach and Born 2007; Diefenbach et al. 2010; Dirich et al. 2011; Schlomann et al. 2013

and user profiles. Residential buildings are represented by 285 different classes and non-residential buildings by 70 classes.

- Building Segments: The most detailed level clusters all buildings to 4459 segments according to building class, heat supply system and as availability of energy carriers.

Definition of renovation packages and calculation of investment costs

This study applies energy refurbishment according to three efficiency standards oriented towards the requirements defined by the German building code (Energy Savings Ordinance, EnEv) as well as the support programmes of the KfW Development Bank[3]. These renovation packages are:

- The ***Standard*** refurbishment package is defined by the requirements of the *Energy Saving Ordinance* on existing buildings in case of major renovation.
- The ***Moderate*** refurbishment package meets the target of a *KfW efficiency house 100* with regard to the energy performance of the building envelope.
- The ***Ambitious*** package corresponds to the highest *KfW efficiency house 55* level of performance.

The renovation packages are provided as input to the Invert/EE-Lab model and represent standards of energy efficiency. There are degrees of freedom in the choice of building components to be retrofitted as well as in the applied level of insulation thickness and windows quality. An optimization model, developed by Fraunhofer ISI, is used to determine the specific investments of the refurbishment packages for each reference building while minimising the required investments[4]. These costs vary according to each building's original energy efficiency level, its geomorphology, its orientation and so on. The area-weighted average investments of the renovation packages per m^2 of gross floor space are shown in Table 1. It should be noted that the values shown below only include investments for measures on the building envelope, excluding the heat supply system.

Table 1: Average specific investments for envelope renovation measures (€/m² net floor area)

Renovation Level:	Standard	Moderate	Ambitious
Total investments including required maintenance measures	208	273	432
…of which investments in energy efficiency	142	213	366

Calculation of final energy demand

The Invert/EE-Lab model is a dynamic bottom-up simulation tool that evaluates the effects of different settings of economic and regulatory incentives on the energy carrier use, costs for renewable heat and renovation support policies. Furthermore, it simulates scenarios and their impact on future trends of renewable as well as conventional energy use on a national and regional level.

The basic idea of the model is to describe the building stock, heating, cooling and hot water systems on a very detailed level, calculate related energy needs and delivered energy, determine reinvestment cycles and new investment of building components and technologies and simulate the decisions of various agents (i.e. owner types) in case that an investment decision is due for a specific building segment. A detailed description of the model is given in (Müller 2015), (Kranzl et al. 2013).

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[3] The KfW programme *Energy Efficient refurbishment* provides grants, or soft loans with repayment bonuses, for refurbishment to the so-called *KfW efficiency houses*. The financial support depends on the achieved energy-performance

[4] For a description of the calculation model see Steinbach and Schultmann 2015.

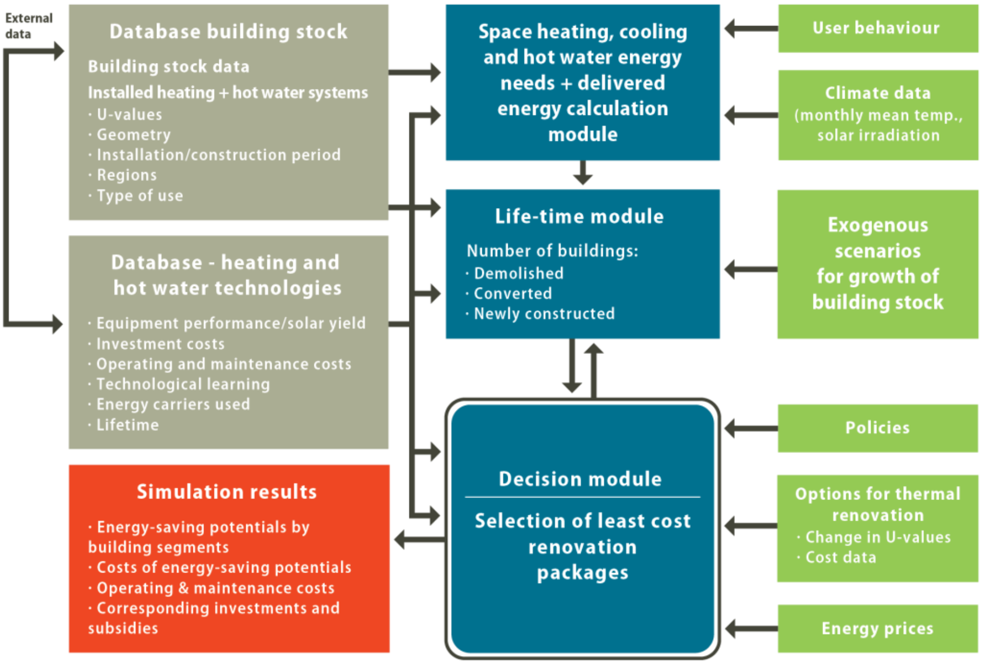

Figure 1: Structure of the Invert/EE-Lab model as applied in this study for deriving Energy-Saving Cost Curves (Source: Kranzl et al 2014)

Figure 2 shows the results of the model with regard to the final energy demand of the building sector in Germany based on the building stock database described above.

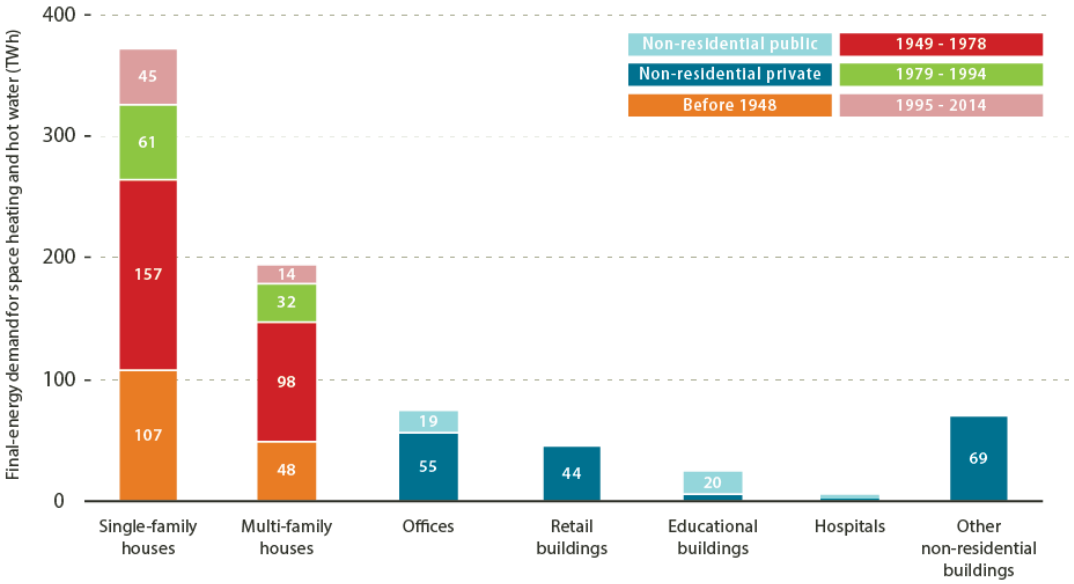

Figure 2 Final annual energy demand for space heating and hot water.

Deriving energy saving cost curves

The tool for deriving Energy Saving Cost Curves (ESCC) makes use of the results generated by the Invert/EE-Lab model. The ESCC plot tool has been developed by BPIE as an add-on to the Invert/EE-Lab. The horizontal axis (x-axis) displays projected annual energy savings for each building category (e.g. offices). The vertical axis (y-axis) shows the net costs or savings, discounted over the measures' lifetime, divided by the total lifetime energy savings. If the bar is above the horizontal axis, there is a cost for investors in that building category. Conversely, if the bar is below the axis, there are net savings. The total cost or total saving for a building category is represented by the area of the bar.

Bundling policy simulation

Bundling is an approach to maximize energy savings at no net cost, whereby monetary savings from cost efficient building categories are transferred to building categories that are not profitably renovated. The transfer of funds allows these marginally cost-inefficient categories to be included in the renovation program. These calculations are not included in the ESCC graphs, but are applied separately and presented for each scenario's total energy and cost savings.

Scenario parameters and boundary conditions

The cost-effectiveness from the investors' perspective is estimated in a number of scenarios based on permutations of economic factors, to illustrate different policy measures that could stimulate the renovation market. The factors influencing the outcome of scenarios are described and summarized in Table 2.

Table 2: Economic variables used in the modelling of scenarios

Variable	**Description**	**Range applied in the modelling**
Energy-price evolution	Increase in the real retail price of energy from 2015 to 2030	1.1% - 2.6% per annum (equivalent to 19% - 50% total increase to 2030)
Subsidy levels	Grants, implicit value of loan, or other external financial support as a % of total capital investment	0-40%. Varies according to technology and renovation package
Transaction costs	Costs associated with preparatory work, planning costs, approvals, etc., including staff time	2.5-5% of total capital investment
Discount rates	Cost of borrowing to finance energy saving investment	2-4%
Learning and cost reduction	The impact of future price reductions resulting from factors such as increased sales volumes, more efficient installation procedures, improved productivity or R&D resulting in new and better ways of saving energy	6-38%, depending on technology

Technological learning reflects the cost reduction due to technology diffusion and increased sales volumes. Historical evidence of such reductions is plentiful, with perhaps the best known example being the reduction in the cost of photovoltaic panels (PV). In the model, technological learning is used in the form of cost reduction. A differentiation has been made according to technology, reflecting its maturity.

Table 3: Cost reduction applied for specific technologies (Sources: Manteuffel et al (2014); Henning et al (2013); Fernandez-Boneta (2013))

Technology	**Cost reduction in 2030 compared to 2015 prices**	
Scenario assumption	*moderate*	*high*
Solar thermal	6%	9%
PV	25%	38%
Heat pumps	6%	9%
Ambitious renovation of building envelope	15%	23%
Moderate renovation of building envelope	10%	15%

Scenario definition

Based on the above-mentioned, variable parameters, the present analysis has modeled a large number of exploratory scenarios of various combinations. A representation of these can be found in the discussion section. For the purpose of this paper, three scenarios are selected to represent a range of outcomes. The Business As Usual scenario, models the current state of affairs without additional policies; the High Subsidies scenario examines the measure of increased subsidies; and the Best Case scenario examines the effect of high subsidies combined with other favorable economic conditions such as discount rates. An overview of the scenario parameters is offered in the following table.

Table 4: Overview of parameters defined in the scenarios

	Subsidies	Energy Price Increase	Transaction Costs	Discount Rates	Cost Decrease to 2030
Business As Usual	10-25%	1.1% /y	5%	4%	6-25%
High Subsidies	20-40%	1.1% /y	5%	4%	6-25%
Best Case	20-40%	2.6% /y	2.5%	2%	9-38%

Boundary Conditions

The modelling and analytical approach set out to present the economic attractiveness of building renovation under a certain set of economic conditions, and hence the *potential* savings if building owners acted in an economically rational manner. Not every feasible energy-saving measure has been considered in this study. For example, the important role that district heating, co-generation (heating and electricity) and tri-generation (heating, cooling, and electricity) can play in reducing GHG emissions has not been explored. The energy uses covered are for heating cooling and domestic hot water. In terms of renovation depth, the approach taken in this study has been to select the renovation package for each building segment that incurs the lowest overall cost. Only comprehensive renovations, which result in installation of both fabric and heating measures, are considered. Partial renovations, or the installation of single heating or envelope measures, are not considered. All scenarios run to 2030. It is a sufficiently long timescale for the full impact of policies to be witnessed and for realistic assumptions to be made. Results on investments and subsidies represent the total requirement for all renovations to 2030 at today’s prices. The property value increase due to renovations is not valued in this analysis.

Results

The following results identify the ESCC approach to representing one of the most important parameters in policy making, namely, the economically attractive energy savings potential. The ESCC graphs allow for good communication of which building categories are economically attractive: If a category is located below the line, then there are potential energy savings for the investor. Contrasting between scenarios, it is possible to observe how the variation of key parameters affects the economic potential and therefore the outcome of renovation policies. When favorable economic conditions are set in place, the bars progressively move below the axis, and even cover more potential energy savings. Finally, the bundling approach shown only in Figure 6 considers the recycling of investment returns and provides the upper limit of total cost effective energy savings possible under each scenario.

Business As Usual scenario

The Business As Usual scenario models the effect of current policies taking into account the level of subsidies, the prevailing discount rates and so on. The following Figure presents the results in the ESCC format.

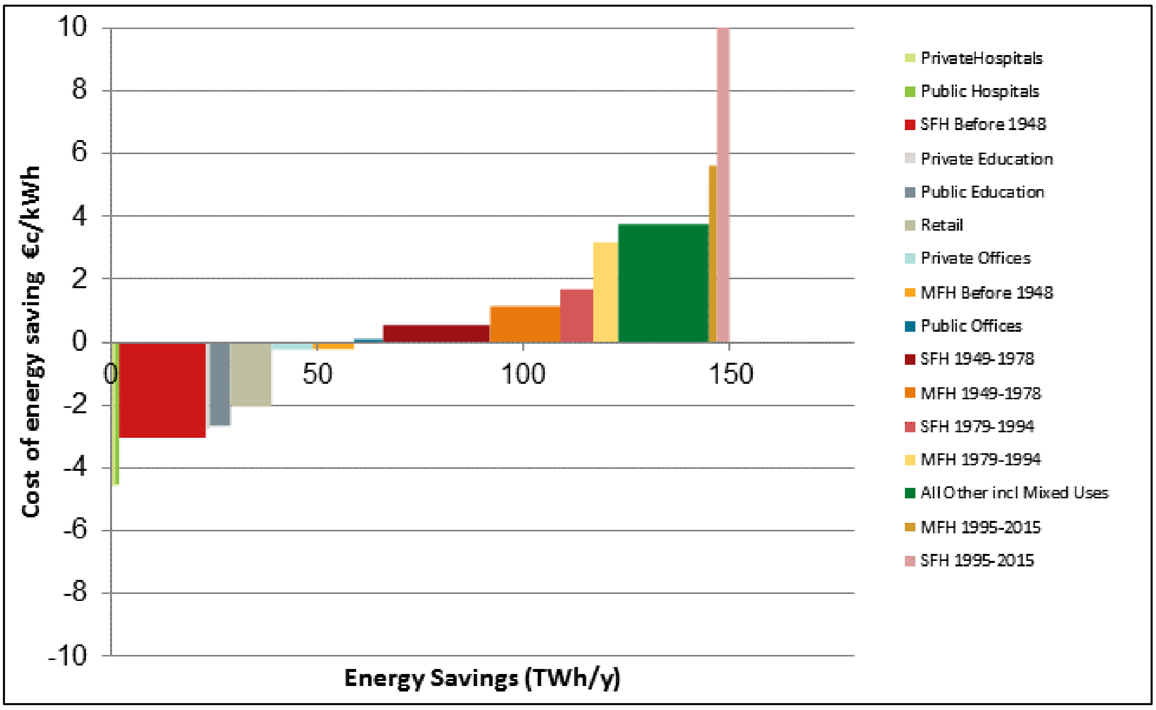

Figure 3. ESCC curve for the Business As Usual Scenario

Under current trends, by 2030 this scenario can lead to 60TWh/y of energy savings per year from profitable categories, represented in the following graph as blocks below the line. This figure could drop to around 40TWh/y considering that the last two cost effective categories are only marginally below the line. It is noticeable that only the most energy intensive building categories are renovated under this scenario, namely: hospitals, education buildings, retail shops and very old single family houses. If the remaining residential buildings were included, then the estimated potential savings could be in the order of 150TWh/y. It is obvious that the current policy landscape and economic conditions are not adequate to encourage enough private investors to undertake renovations. Under this scenario, the government would spend €19bn in subsidies in order to mobilize €78bn in private investments, just for the profitable building categories. It is expected that subsidies would not be directed to any category above the line since subsidies would not be enough to make the investment economically attractive. The programme targeting the building categories below the line would lead to net cost savings for the investors valued at €1.2bn. It would also potentially incentivize 13% and 38% of renovations in the residential and non-residential building categories respectively to correspond to KfW55 standards.

High Subsidies scenario

The High Subsidies scenario differs from the Business As Usual scenario only in the increased share of subsidies. Increasing subsidy levels from 10% - 25% to the order of 20% - 40% causes significantly more building categories to become economically profitable to renovate. While the Business As Usual scenario targeted mainly non-residential categories, under the High Subsidies scenario, a significant number of older residential categories are include as well, namely single and multifamily houses built before 1978. The difference between Figures 3 and 4 is noticeable.

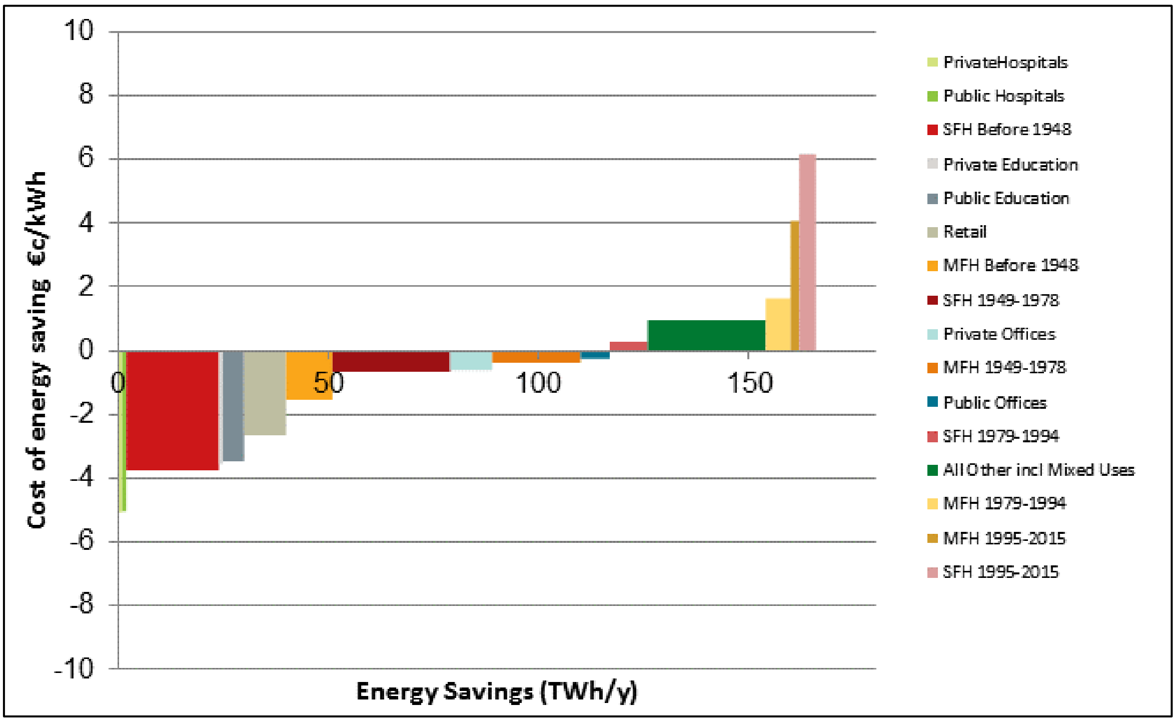

Figure 4. ESCC curve for the High Subsidies Scenario

The energy savings from building categories that can be profitably renovated are, under this scenario, significantly increased to 118TWh/y (compared to 60TWh/y for the Business As Usual scenario). The economic strain on public budgets is increased, while their leverage to attract investments is decreased, considering that €65bn of subsidies provided by the government can leverage private investments worth €189bn. Under this scenario, for every 1€ in subsidies, private investments contribute another 3€, while in the Business As Usual scenario, this leverage effect was 1 to 4. Considering however that the aim of renovation policies are to decrease energy demand, the High Subsidies scenario is overall much more effective than the Business As Usual scenarios, especially since the net monetary cost savings for investors are valued at €1.9bn.

The increased government subsidies are therefore effective in mobilizing further investments and increasing energy savings. This scenario also incentivizes 34% and 47% of renovations in the residential and non-residential building categories respectively to meet the ambitious KfW55 standards. Contrasting these figures with the corresponding 13% and 38% rates of the Business As Usual scenario, it becomes immediately apparent that the High Subsidies scenario leads to better cost and energy savings predominantly because it is able to incentivize deep renovations and bring building categories to very high energy efficiency levels.

Best Case scenario

The energy efficiency potential of the German building stock is almost fully captured in the Best Case scenario. Increased subsidies, lower discount rates and transaction fees, increased energy prices and steeper learning curves for technologies create the most favorable investment conditions and incentivize renovations in all but the most recent building categories. The Best Case scenario runs to 2030 and, as depicted in Figure 5, once all profitably renovated building categories are renovated, it delivers 170TWh of energy savings every year.

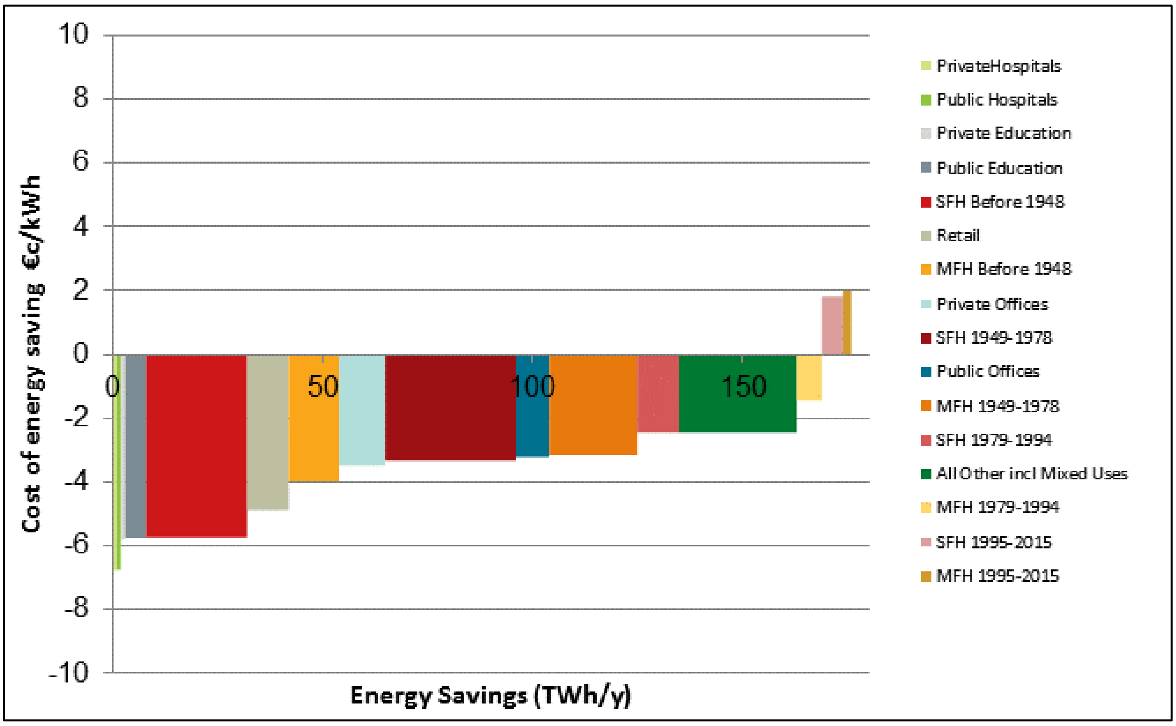

Figure 5 ESCC curve for the Best Case Scenario

Compared to the High Subsidies scenario, if state support is roughly doubled to €114bn and in combination with the above-mentioned favorable economic conditions, the renovations programme mobilizes €313bn of private investments for the cost effectively renovated building categories. The leverage effect of the Best Case scenarios (1 to 2.7) is less than the Business as Usual Scenario (1 to 4) and similar to the High Subsidies scenario (1 to 3). Despite the decrease of the leverage effect, the Best Case scenario is delivering significantly more benefits than the other two since the net monetary cost savings for investors are valued at €6.2bn. This figure ensures that investors will be more attracted by the higher economic opportunity compared to the other two scenarios that only offer returns of 1 to 2 bn. The explanation of the effectiveness of the Best Case scenario lies in the fact that 57% and 89% of renovations in the residential and non-residential building categories respectively could be undertaken under the ambitious KfW55 standards. Under the Best Case scenario, the German government could incentivize investments that within 15 years could transform more than half of the residential buildings and the majority of the non-residential building stock to nZEBs (nearly Zero Energy Buildings), at a profit.

Bundling

A bundling policy stimulates equitable investment and overcomes the issue of investor preference for the most economic building categories. This policy transfers surplus economic gains from building categories with a high energy saving potential to building categories whose economic benefit is marginally negative. The following graph portrays the additional benefits in terms of total annual energy savings and shows that they do not need to lead to losses for investors.

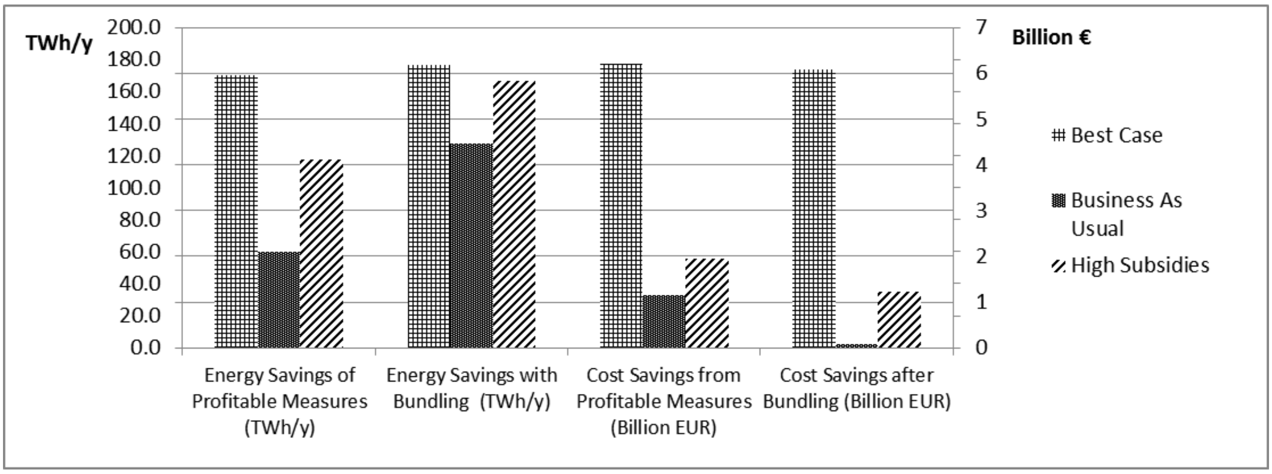

Figure 6 The effect of bundling on energy and cost savings

Discussion

In order to test the range of results as well as the influence of each parameter on those, a large number of scenario runs were conducted. The flowing figure compares the ESCC outlines deriving from a range of possible parameter combinations, while the limits of the parameters tested are presented in Table 5.

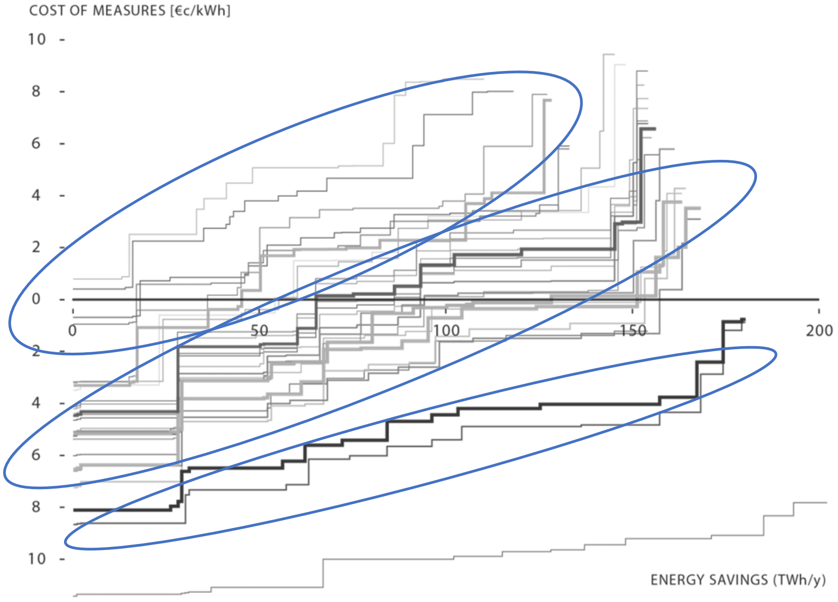

Figure 7 Sensitivity Analysis

Table 5 Sensitivity analysis parameter ranges

Limits	Subsidies	Transaction costs	Discount rate	Learning curve	Energy Price increase
Lower	0%	2.5%	2%	3-13%	1.1% /y
Upper	20% -40%	10%	10%	9-38%	2.6% /y

The sensitivity analysis identifies three areas of possible policy outcomes with their associated maximum and minimum costs and benefits of energy efficiency renovations. The top ellipse groups scenarios whose parameter combinations make energy efficiency renovations to cost between -1 cent and up to 8 cents per kWh of saved final energy annually. The cost effective energy savings are negligible, and if anyone would bear that cost, the energy saved would not surpass 100TWh annually. The middle ellipse identifies a second group, which is the most populous and displays a variation of costs normally between – 6 cents and 5 cents per kWh. The cost effective energy savings of this group may range from about 100TWh to roughly 150TWh annually. The lower ellipse groups just two scenarios which optimally combine parameters and save about 180TWh annually. The energy costs range from -8 to -2 cents per kWh of final energy and lead to the deep renovation of all buildings. Lastly, there is an isolated curve which assumed an unrealistic increase in subsidies combined with very favorable values for all parameters.

Bundling policies adopted in a renovation programme should also be taking into account social factors, which are excluded from the scope of our analysis. The economic evaluation of the subsidy levels under the KfW requirements could pass through a centralised system that would allow for a readjustment of the grant according to the bundling approach and based on the registered economic status and energy savings potential of the participating owners and buildings. Attention should be placed in the structure of the bundling system and its adjustment criteria in order to avoid irrational and socially unacceptable transfers of funds.

Renovation rates in the Invert/EE-Lab Model are derived based on the lifetime of buildings and building components, and the corresponding age structure of the building stock. Thus, different age bands show different renovations rates. The cumulated share of renovated buildings in the period from 2015 to 2030 varies as a model output between about 15% and 37% for different building segments. This is equivalent to an annual renovation rate from below 1% for newer building segments and up to 2.3% for older building segments.

Conclusion

In conclusion, this paper presents, in terms of energy savings and avoided energy costs, the benefits of investing in renovations on the German building stock for the next 15 years. Its main message is that an ambitious renovation strategy, tailored to specific building categories, has the potential to transform the building stock while offering financial returns to investors. Under the scenarios presented here, it becomes obvious that the present economic conditions do not sufficiently incentivize investors to act. An increase in subsidies and an improvement in other parameters such as discount rates, innovation, transaction costs and energy prices, have the potential to drive the transformation of the building stock's energy performance. Energy savings could triple from the current trajectory's levels and reach 170TWh/y. Financial returns to investors would increase fivefold to over €6 bn annually in the best case scenario compared to the business as usual scenario.

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