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## Policy options for climate policy in the residential building sector: The case of Germany

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# Policy Options for Climate Policy in the Residential Building Sector: The Case of Germany

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HWWI Research

Paper 117

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# Policy Options for Climate Policy in the Residential Building Sector: The Case of Germany

Sebastian Schröer†

January, 2012

## Abstract

In order to achieve the climate protection goals in the building sector, a higher rate of building refurbishment is necessary to improve the energy standard of residential building stock in the European Union. Although subsidisation seems to be necessary, optimal measures concerning cost effectiveness are unclear. Using a stylised model of the German residential building stock, we analyse different refurbishment measures by simulating every relevant investment until 2030. In particular, we compare two different options that are relevant for political measures: first, comprehensive refurbishments that are expensive but achieve the greatest reductions in energy consumption and GHG emissions and second, partial refurbishments which include only low-cost improvements but can be achieved on a wide scale. We conclude that comprehensive refurbishments will require the least amount of investment costs per ton GHG emissions and provide the highest reductions in energy consumption in 2030. Hence, partial refurbishments are never optimal. However, in terms of cumulated GHG emissions in the period considered, the difference between both options is very small. This is due to their different dynamics: comprehensive refurbishments achieve fewer results in the first years but catch up quickly, which means that the higher the refurbishment rate the higher the advantage of comprehensive refurbishments.

JEL classification: C60, H30, O33, Q40, Q58

Keywords: Residential building sector, Refurbishment, Climate policy, Energy saving, Policy scenarios

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# 1 Introduction

The European Union and Germany have established very ambitious targets on climate protection. To cut greenhouse gas emissions by 80 per cent of 1990 levels by 2050, the residential building sector cannot be ignored. In Germany, private households account for 28.5 per cent of final energy consumption and cause 14.2 per cent of all energy-related greenhouse gas (GHG) emissions – mainly for space heating. At the same time, up to 90 per cent of space heating is based on fossil energies.

There are three ways for national governments to reduce GHG emissions in the residential building sector: first, the minimum performance requirements for new buildings could be increased and the demolition of old and energy-inefficient buildings encouraged. Second, energy-related refurbishments could be promoted, and third, the share of biofuels could be increased.

In past decades, the average annual demolition rate was 0.5 per cent of the entire housing stock. At the same time, about 1 per cent of the housing stock was built, which means that housing stock increases annually by 0.5 per cent. This is by far too little to reduce GHG emissions in order to reach the target. In addition, the capacities for producing biofuels in a sustainably way are limited. Therefore, the climate targets cannot be achieved without increasing the rate of energy-related refurbishments.

Currently, the refurbishment rate is at approximately 1 per cent in Germany. Rational house owners and landlords will invest in energy-related refurbishments only if there is a pay-off. The costs of refurbishment must be overcompensated by decreasing heating costs, higher rental income, increase in value, etc. The German government has therefore decided to promote energy-related refurbishments by reducing the costs for house owners and landlords.

While it is obvious that the refurbishment rate must be increased, it is unclear what specific measures the national governments or the European Union, respectively, should implement. This question is not a trivial one, since there are a lot of trade-offs and dilemmas to be considered. In general, the definition of energy-related refurbishments is vague. In principle, due to technological progress, a lot of conservation measures produce energy savings and therefore could be considered as an energy-related refurbishment. Hence, funding such measures that would have been taken anyway would be a misuse of subsidies. Since refurbishments are long-term investments, promoting cheap measures could result in failure to achieve the targets. This is so because refurbishments are long-term investments, and once the investment is made, it will prevent further investments until it has paid off even if it hardly reduces energy consumption and GHG emissions. Given the fact that costs increase exponentially with emission reductions, it is possible for comprehensive measures that public funding would have to be very high to ensure

investments. Also, from a social perspective, refurbishment measures could entail a new cost burden for tenants. Especially for comprehensive measures, the subsidising must be very high to prevent significant increases in rents. Furthermore, an unclear funding scheme could cause investment decisions to be delayed and thus prevent an increase of the refurbishment rate.

The definition of the GHG emission reduction target may also be considered. Usually the target is defined as a reduction at a certain point in time, for example the year 2030. However, it could make more sense to consider the emission budget in the sense of cumulated emissions until 2050.<sup>1</sup> These two approaches could make a difference for policymakers.

As a result, policymakers can, in principle, choose between two options: to promote comprehensive refurbishments that are expensive but achieve the greatest reductions in energy consumption and GHG emissions or also to promote partial refurbishments which include only low-cost improvements but can be achieved on a wide scale.

Although the topic is important and of current interest especially for policymakers, there is very little literature on optimal policy measures.<sup>2</sup> One of the very few exceptions is Uihlein and Eder (2010). They aim at a replacement of building elements (roofs and windows) rather than major refurbishments. They conclude that these measures offer the potential for substantial additional energy savings. Furthermore, they conclude that, on the one hand, a replacement of energy-inefficient windows and roofs that have not reached their end of life leads to additional costs at comparably low energy savings. On the other hand, the installation of energy-efficient building elements comes at negative net cost. However, Uihlein and Eder (2010) calculated a period of 25 to 30 years for net costs to become negative. This might be too long for house owners to present a substantial incentive to invest in energy-efficient measures.

In this paper, we analyse the efficiency of different refurbishment measures in the residential building stock by evaluating the basic options for comprehensive and partial refurbishments. Using a stylised model of German housing stock, we compare the investment needed to reduce energy consumption and GHG emissions, but ignore the gains of lower energy consumption. We therefore do not calculate GHG abatement costs. We also analyse the effect of biofuels on GHG emissions and find a small but significant benefit. Since our paper is the first to offer a detailed model of German residential building, it provides a reliable basis for analysing refurbishment measures, which, in turn, can be used to derive efficient policy options for the achievement of the climate targets in residential building stock.

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<sup>1</sup> See Meinshausen et al. (2009).

<sup>2</sup> However, there is an extensive body of literature on willingness to pay for energy-related refurbishments, which is important in order to understand the dynamics of investment decisions of house owners. See Achtnicht (2011) for a recent literature overview.

## 2 The Model

### 2.1 Methodological Background

The energy demand of private households for heating purposes is basically determined by the building efficiency, i.e., heat engineering and heat insulation, and by the living space to be heated. As the central standard for the model, we use the space-related final energy consumption, i.e., the actual energy consumed per living space within one year. The living space in question is divided up according to the source of heating energy. Subsequently, efficiency classes are formed within the respective source of heating energy. These classes differ based on building efficiency and heat producer and therefore have different levels of specific energy consumption.

For the scenarios, refurbishment methods are defined that either illustrate present trends or appear to be plausible in the future. A refurbishment method may mean a change of efficiency classes within an energy source or a change of energy source.

The living space-related energy consumption is determined by the refurbishments methods and refurbishment rate. The total energy consumption for 2030 can be calculated from this in combination with an assessment of the living space to be heated. This refers only to heating in rooms and does not include the energy used to produce hot water.

The emission of greenhouse gases for the energy sources and for the total energy consumption both per year and for the total period under consideration is calculated on the basis of energy source-specific greenhouse gas factors. The applied emission factors take into account not only the direct emissions, but also the individual pre-chain emissions of the fuel supply including conversion losses.

For the economic evaluation of refurbishment options, investment costs for the relevant refurbishment steps are determined on the basis of the current estimates in technical publications. Macroeconomic investment needs can then be extrapolated from the refurbishment steps and the annual refurbishment rate. These are put in relation to the saved greenhouse gas emissions in order to estimate the cost efficiency of the individual refurbishment options. This estimation concerns only the fixed investment for the refurbishment, however, and not the variable earnings resulting from the refurbishment, for example, through energy conservation.

By adjusting the refurbishment methods that can currently be observed and the present refurbishment rate of approximately 1 per cent, a trend scenario can be calculated for 2030 and another scenario of “2%”, which assumes the same refurbishments methods but a refurbishment rate of 2 per cent as desired by the German government. Subsequently, the opposite refurbishment options Quick and Comprehensive are reviewed for a basic evaluation of

refurbishments. For each relevant refurbishment rate, the emissions, energy saving, and incurred costs are compared for both options.

Another way to reduce emissions is to feed in biogenic oil or biogas in addition. For this reason, this possibility is also tested. Since the costs for this are difficult to quantify, the analysis is confined to the illustration of emission reductions.

## **2.2 Data**

### **2.2.1 Living Space**

Housing markets are influenced by the economic and demographic development of the region in question. High economic growth tends to lead to rising housing prices and to a delayed increase in available housing. The demographic development affects the housing demand through population and age structure.

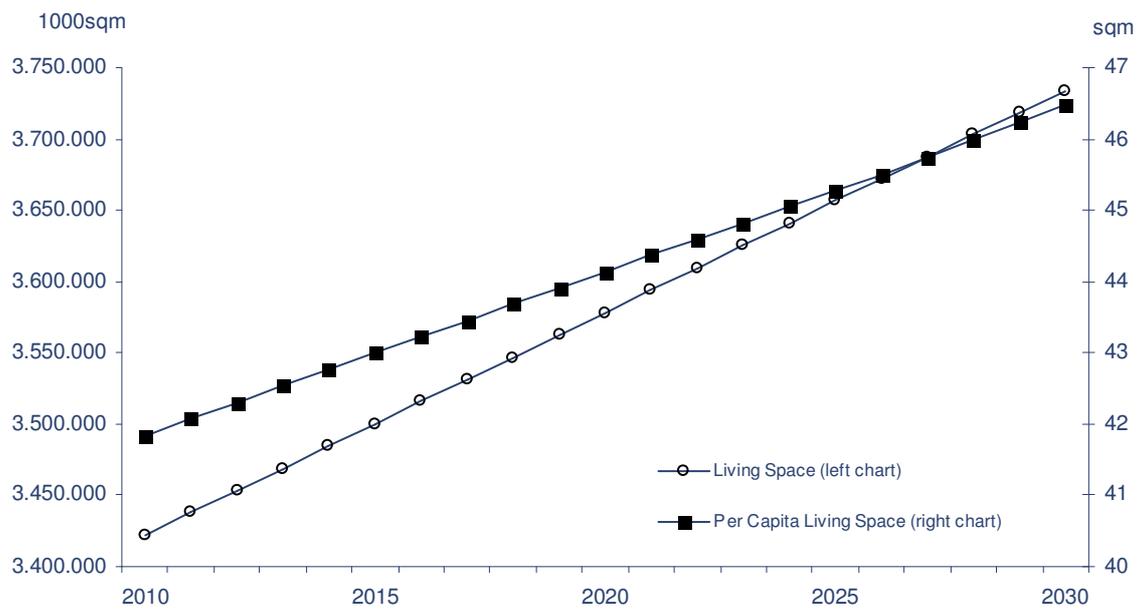
The model used here is based on the historically observed supply and demand in the regional housing market.<sup>3</sup> Assuming that the behavioural pattern of market players is consistent over time and considering forecasts on the development of the regional framework conditions and economic growth, conclusions can be drawn for the future development of real estate markets and combined to obtain a pan-German result.

As a result of an ageing population, there will be an increase in one-person and two-person households; therefore, the per capita living space will exceed 46 m<sup>2</sup> by 2030 compared to less than 42 m<sup>2</sup> in 2010. Assuming a moderate annual economic growth of 1.25 per cent on average at the same time, the German living space will increase by 9 per cent from 3.42 billion m<sup>2</sup> to 3.73 billion m<sup>2</sup> between 2010 and 2030 according to our model, despite a decrease in population over the same period of time.

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<sup>3</sup> For further explanations see Shell (2011).

**Figure 2.1: Projection of Living Space in Germany**



Source: HWWI.

### 2.2.2 Heating Structure

In Germany, there are about 17.8 million central heating systems. The association of German chimney sweepers estimates that 6 million are oil-fired heating systems (5.7 million oil standard and low-temperature boilers and 0.3 million oil condensing boilers) and 7.7 million gas standard and low-temperature boilers.<sup>4</sup> Additionally, approximately 3 million gas condensing boilers are not included in the statistics of the association of German chimney sweepers because they have to be inspected only once after first-time operation. Gas and oil-fired heating systems thus make up the majority of the all existing central heating systems. In contrast, the 400,000 heat pumps account for only roughly 2 per cent and the 700,000 biomass boilers account for approximately 4 per cent of all existing heating systems.

The energy consumption of private households is illustrated in different limits and classifications depending on the source. If possible, the data of the environmental-economic accounting of the German Federal Statistical Office serve as a basis. According to our calculations for the base year 2008, we calculated the following specific consumption depending on the source of heating energy and distribution of the different sources of heating energy on the living space.

<sup>4</sup> See Brennstoffspiegel (2011).

**Figure 2.2: Distribution of Sources of Heating Energy on Living Space in 2008<sup>5</sup>**

Source of Heating Energy	Share of Living Space in %	Average Consumption in kWh/m <sup>2</sup> a
Oil	25.6	171.7
Gas	53.6	144.35
District heating	12	102.55
Electricity	3.6	135.56
Coal	0.7	175.11
Biomass	3.6	619.5

Source: Federal Statistical Office (2010).

The efficiency classes of the energy sources are made up of different combinations of heat engineering and building efficiency standards, which is why they differ in specific energy consumption. The classification and the distribution of living space among the efficiency classes follow a wide range of sources, expert interviews, and plausible estimates.

#### Oil and Gas-Fired Heating Systems, District Heating

For oil and gas-fired heating systems, there are four classes each. For spaces heated with district heating, there are just three classes, because homes heated with district heating differ only in building efficiency. Furthermore, it does not make any sense to connect houses with very high efficiency standards and thus very low energy needs to district heating grids.

In Efficiency Class 1, the energy source oil has a consumption rate of 270 kWh/m<sup>2</sup>a, whereas gas rates 5 per cent higher with a consumption rate of 283.5 kWh/m<sup>2</sup>a. Older gas boilers are slightly less efficient than old oil boilers, because the unused condensation energy of steam contained in flue gas has a greater effect.<sup>6</sup> For district heating, the energy consumption amounts to 159.28 kWh/m<sup>2</sup>a. In this class, a standard boiler with an indirectly heated drinking water reservoir is installed. Typically, these houses are heated with constant temperature boilers, and the insulation is very poor.

In Efficiency Class 2, low-temperature boilers or modern condensing boilers are used. The top floor ceiling, the distribution pipelines, and the basement ceiling are insulated. A hydraulic compensation takes place, and single glazing has been replaced by double glazing. In addition, new thermostatic valves and possibly a solar drinking water heater and a support heating system have been installed. Oil-fired heating systems consume 150 kWh/m<sup>2</sup>a and gas-fired heating systems 157.5 kWh/m<sup>2</sup>a.<sup>7</sup> The energy consumption of district heating is 100 kWh/m<sup>2</sup>a.

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<sup>5</sup> Federal Statistical Office (2010).

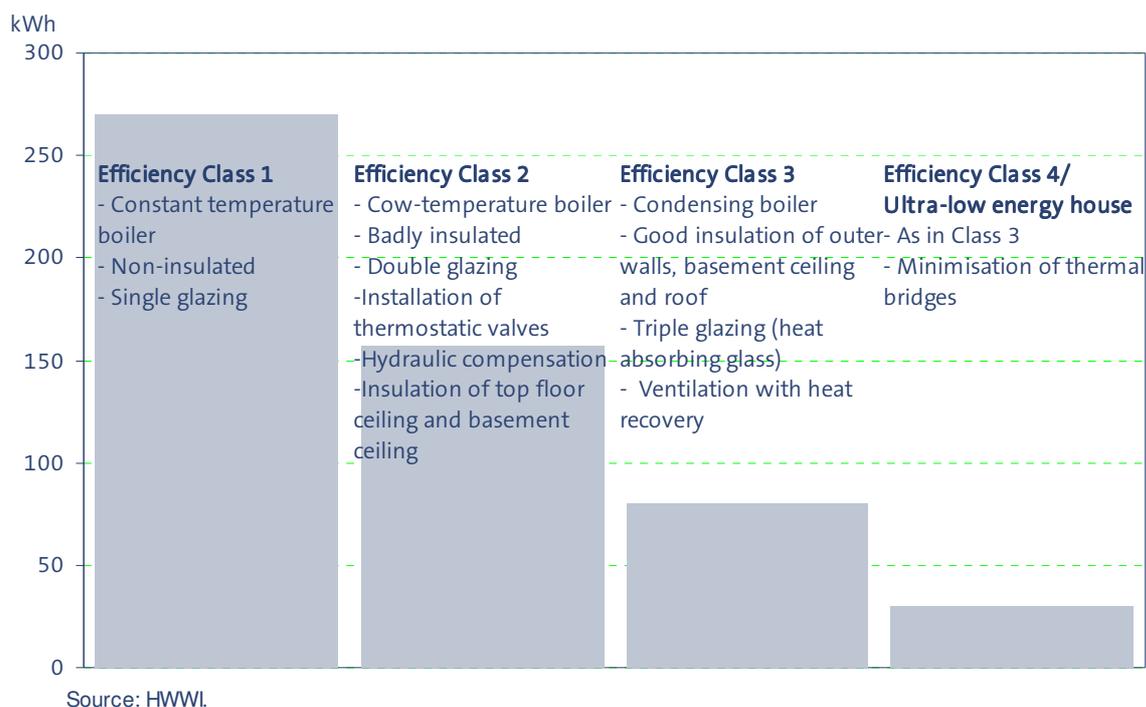
<sup>6</sup> See Dena (2011b); Interessengemeinschaft IG Energie Umwelt Feuerungen GmbH (2011); IWO (2010).

<sup>7</sup> See Prognos/EWI/GWS (2010), p. 61-76; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.

In Efficiency Class 3, only boilers with condensing heating technology are installed in the buildings. In addition to the Efficiency Class 2 measures, there is a controlled ventilation system with heat recovery in some cases. The outer walls, the basement ceiling, and the roof are very well insulated, and the windows are fitted with triple glazing. The energy consumption amounts to 80 kWh/m<sup>2</sup>a<sup>8</sup> for oil and gas and 65 kWh/m<sup>2</sup>a for district heating.

In Efficiency Class 4, energy consumption is only 30 kWh/m<sup>2</sup>a. Only buildings with very high overall energy efficiency are included. On the European level, these ultra-low energy houses aim at covering their energy needs primarily with renewable energy sources. In addition to having a controlled ventilation system with heat recovery and, if applicable, solar heat for additional room heating, thermal bridges are minimised, for example, where the outer walls are connected to the roof structure.<sup>9</sup>

**Figure 2.3: Efficiency Classes of Heating Energy Sources Using Oil as an Example**



In the distribution of the living space among the efficiency classes, the number of houses in the respective efficiency classes serves as an approximation of the living space, and the age structure of the gas-fired and oil-fired heating systems in German houses is used.<sup>10</sup> Since district heating and gas are grid-bound and the connection took place simultaneously, we assume that the output

<sup>8</sup> See IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.

<sup>9</sup> See HMUELV (2011); Official Journal of the European Union, Directive 2010/31/EU (2010).

<sup>10</sup> A current estimation can be found in BEI/IWU (2010), p. 98.

distribution of district heating lies between oil and gas. We disregard the currently available housing in Efficiency Class 4 and assume that such housing will consist only of new buildings as of 2021.

**Figure 2.4: Share of efficiency classes in houses heated with oil, gas or district heating**

	Oil	Gas/District heating
Efficiency Class 1 high energy demand	21.7%	14.6%
Efficiency Class 2 medium energy demand	72.1%	44.7%
Efficiency Class 3: low energy demand	6.1%	40.7%
Source Bremer Energieinstitut (2010); compiled by the author.		

#### Solid fuels: Coal and Wood

Coal-fired heating systems are typically old and inefficient. Average consumption is 175.11 kWh/m<sup>2</sup>a. We assume that houses with coal-fired heating systems will be torn down and that such systems will be neither refurbished nor installed in new buildings, which will lead to a continuous decrease in houses with coal heating.

A large number of wood-fired heating systems or fireplaces are used in addition to other heating systems. Our focus is on primary heating sources, and we differentiate between old (inefficient) and new (efficient) systems. We assume that half of all existing houses heated with wood as primary heating source have been rebuilt and are efficient by 2008. According to statistics, houses heated with old systems consume 1,194 kWh/m<sup>2</sup>a. Like houses heated with coal, the inefficient wood-fired heating systems are simply demolished. New biomass heating systems are installed only in efficient buildings and thus consume an average of 45 kWh/m<sup>2</sup> per year.

#### Electricity

Houses heated with electricity are divided into three classes. About 75 per cent of houses heated with electricity are fitted with night storage heaters. These are comparatively inefficient and use 169.08 kWh/m<sup>2</sup>a. The other 25 per cent are heated via heat pumps. Both new and refurbished buildings using heat pumps are highly efficient.

However, heat pumps differ in efficiency. The most efficient heat pumps are brine-water heat pumps used in new buildings. Since installation in existing buildings is often difficult, air-water heat pumps are primarily installed in such buildings. This is why heat pumps consume

35 kWh/m<sup>2</sup>a in refurbished buildings, whereas their consumption is only 20 kWh/m<sup>2</sup>a in new buildings.

### 2.2.3 New Buildings and Demolition

Since technical standards are getting ever higher, demolishing old buildings and constructing new buildings lead to an energetic improvement. During the last decades, an average of about 0.5 per cent of existing houses was demolished per year.<sup>11</sup> This figure is reflected in the scenarios. The construction forecasts presented above show that available housing will increase by an average of 0.5 per cent per annum over the next few years. Hence, new buildings will account for approximately 1 per cent of existing houses. Based on current technological trends and building law, we assume the following distribution of new buildings up to 2030:

**Figure 2.5: Distribution of new buildings**

Efficiency class	Share until 2020	after 2021
Oil class 3	5%	0%
Oil class 4	0%	5%
Gas class 3	45%	0%
Gas class 4	0%	25%
District heating	5%	0%
Electricity (heat pumps)	40%	60%
Biomass	5%	10%

Source: HWWI

Assuming that older and non-refurbished houses, in particular, are torn down, demolitions always take place in the lower efficiency classes. The energy sources are affected in proportion to their shares in living space heated by them in the lower efficiency classes.

### 2.2.4 Refurbishment Methods

Refurbishment generally implies structural or technical modernisation of a building in order to repair damages or to raise the standard of living. Energetic refurbishment refers exclusively to reducing energy consumption and/or energy-induced emissions. This is achieved by improving the heating system, changing the energy source or refurbishing the building. We define energetic refurbishment as a residential building's upgrade to at least one higher efficiency class. We distinguish between small and large refurbishments. A small refurbishment improves the efficiency class by one class, and a large refurbishment implies an improvement by at least two classes.

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<sup>11</sup> Calculations on the basis of the Federal Statistical Office (2011).

### The Trend scenario

A mixture of smaller and larger refurbishments at approximately 1 per cent average annual refurbishment rate can currently be observed.<sup>12</sup> In order to evaluate the current refurbishment measures, we therefore develop a trend scenario with the following assumptions:

- There are refurbishments improving the energy class by one or two classes, refurbishments improving the energy class by two classes being carried out only half as often.
- Within oil/gas, refurbishments take place up to Class 3, thus from Class 1 to Class 2 and Class 3 and from Class 2 to Class 3. At most, the average current new building standard is achieved.
- During refurbishments of oil-heated living spaces, 25 per cent switch to gas.
- Due to the absence of a boiler, there are only three categories, differing only in insulation, for district heating. It is therefore assumed that no refurbishments to outdated insulation standards are carried out. Refurbishment is therefore possible only from Class 1 to Class 3 or Class 2 to Class 3.

### The Quick scenario

The scenario “Quick” consists of measures that can be implemented quick in terms of cost-effectiveness. It builds on the scenario Trend, but differs in the following:

- Each refurbishment for the energy sources oil and gas allows only for changes into one higher class, thus from Class 1 to Class 2 and from Class 2 to Class 3.

### Comprehensive

This scenario can be regarded as the opposite to the scenario “Quick”. In this case, priority is given to maximum energy conservation or emission reductions per refurbished housing unit. Therefore, the most inefficient housing units are brought into the best condition. This scenario differs in two points from Trend:

- Half of each refurbishment for the energy sources oil and gas leads to the biomass or heat pump efficiency class.
- It is begun in the most inefficient classes, until they no longer exist, and then continued in the next, thus first from oil/gas Class 1 and then oil/gas Class 2.

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<sup>12</sup> BEI/IWU (2010), pp. 69-74.

## 2.2.5 Costs

Distinguishing refurbishment costs from normal maintenance costs is difficult, since it is not clear whether refurbishments are energy-related or not.<sup>13</sup> The replacement of a heating system for reasons of age becomes necessary someday, but it cannot be determined whether the costs for a new heating system are energy-related or would have been incurred anyway. In light of increasing energy prices, heating systems are sooner replaced by heating systems with less consumption. However, only the costs for making the exchange earlier and for the improved heating system are energy-related as such.

Furthermore, it should be considered whether to factor in the expected variable savings and additional expenditure, in addition to the fixed investment costs. We disregard the variable costs, since it is difficult to predict them and consider only the fixed investment costs. In this sense, we neither include GHG abatement costs in the calculation. At the same time, we do not consider any costs for new buildings and demolition. Although this can be regarded as the maximum refurbishment, heating costs, for one thing, are usually not the decisive criterion for demolition and, for another, every new building implies an energetic improvement even without an energetic motive. We also assume that refurbishment costs will remain steady until 2030. Although it is true that technical developments may lead to a decrease in costs, refurbishments are dominated by labour costs, which are more likely to increase in Germany.

Our cost assumptions are based on different studies and expert opinions. In particular, these include:

Refurbishment Efficiency Class 1 to 2: €100 per m<sup>2</sup>.

This is equivalent to installing a condensing boiler plus additional smaller measures, possibly a solar thermal water heating system, total costs approximately €15,000.<sup>14</sup>

Refurbishment Efficiency Class 1 to 3: €480 per m<sup>2</sup>.

This approximates the refurbishment of a not or only little refurbished house to a KfW-100-standard. The costs result from the average refurbishment costs for different house types (single-family home, multi-family house, etc.) and age group.<sup>15</sup>

Refurbishment Efficiency Class 2 to 3: €430 per m<sup>2</sup>.

This intermediate step builds on the measures from the first refurbishment. Basically, only the boiler (approximately €7,500) and possibly the solar thermal water heating system can be used.

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<sup>13</sup> See, e.g., DENA (2010a), pp. 32-37; Neuhoff et al. (2011), pp.7-11.

<sup>14</sup> See ITG (2010), p. 28; ARGE (2011), pp. 73-81; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.

<sup>15</sup> See ARGE (2011), loc. cit., pp. 64-69.; IG Energie Umwelt Feuerungen (2011), loc. cit.

Plus the additional expenses, we assess that half of the costs (€7,500) can be included, thus 480-50=€430.

#### Refurbishment to Heat Pump

It is generally possible to install heat pumps in existing buildings. However, this is economically and ecologically feasible only if the installation of heat pumps is part of an extensive refurbishment of the building. For this reason, heat pumps belong to the most efficient class in existing buildings and new buildings, although they differ considerably in terms of efficiency. Relatively high refurbishment costs, €600 per m<sup>2</sup>, irrespective of the previous efficiency class, are the consequence.<sup>16</sup>

#### Refurbishment to Biomass

Generally, biomass installations (usually wood-fired heating systems) can be installed in buildings with different refurbishment standards. Since the conversion of the heating system is expensive, this is economically and ecologically feasible only if the installation of biomass systems is part of an extensive refurbishment of the building. In the scenarios, it is therefore assumed that a refurbishment with biomass is always done into the most efficient class. Refurbishment costs amount to €600 per m<sup>2</sup>, irrespective of the previous energy efficiency class of the building.<sup>17</sup>

### 2.2.6 Specific Greenhouse Gas Emissions Factors

GHG emissions are calculated on the basis of the IFEU data.<sup>18</sup> The entire life cycle, including the pre-chain and emitted greenhouse gases during the utilisation phase, are included in the calculation. In the transport sector, the concepts Well-to-Wheels (WTW) for the entire life cycle, Well-to-Tank (WTT) for the pre-chain and Tank-to-Wheels (TTW) for the utilisation phase have been established.<sup>19</sup> Analogously, the Well-to-Warmth concept is the concept for fuels (also WTW), i.e., from the raw material source to the release of thermal heat in a building.

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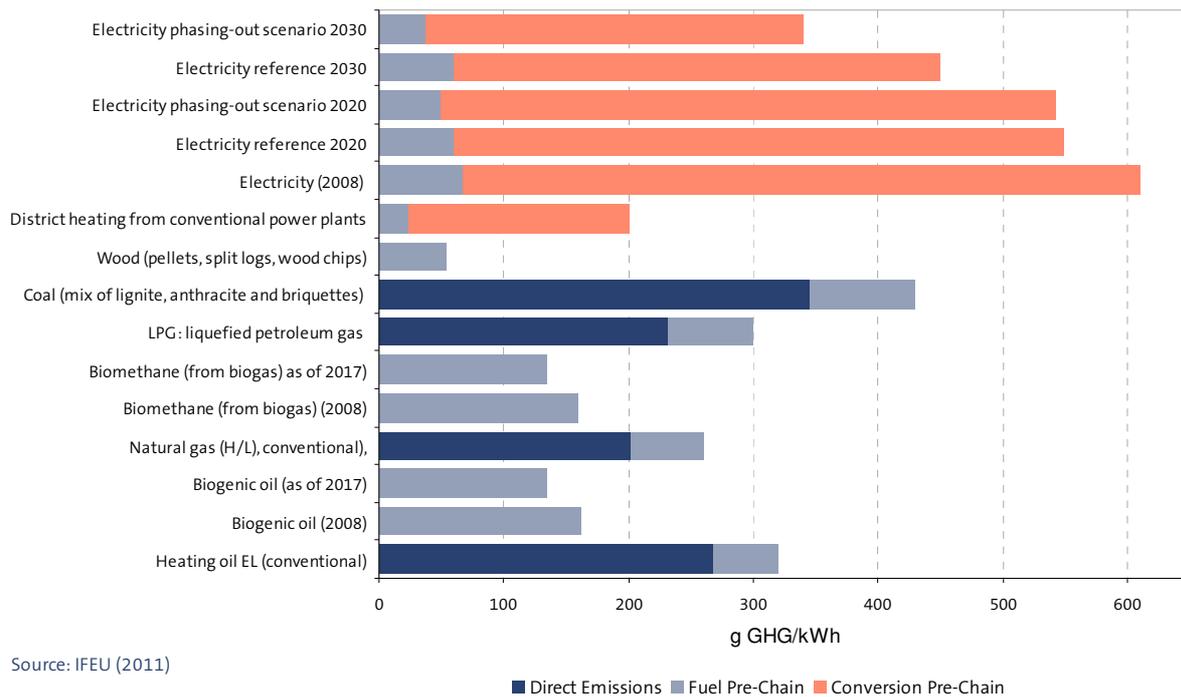
<sup>16</sup> See ARGE (2011), loc. cit., pp. 73-81; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.

<sup>17</sup> See ARGE (2011), loc. cit., pp. 73-81; IG Energie Umwelt Feuerungen GmbH (2011), loc. cit.

<sup>18</sup> See IFEU (2011).

<sup>19</sup> See EUCAR, CONCAWE, JRC/IES, (2008).

**Figure 2.6: GHG Factors**



Source: IFEU (2011)

### 3 Results

In this section, we will present the results of the scenario Trend. Additionally, we calculate the effect of a doubled refurbishment rate, as desired by the German Federal Government, i.e. the scenario “2%”.<sup>20</sup> Then, we show the results of the comparison of Comprehensive and Quick. The last part presets the effects of biofuels.

#### 3.1 Trend and “2%”

If this trend is to be continued in the long run, thus an annual refurbishment rate of approximately 1 per cent of the living space by 2030, the specific energy consumption for the entire living space (including new buildings) would drop from an average of 162.04 kWh/m<sup>2</sup>a to 108.6 kWh/m<sup>2</sup>a. This is a decrease of 33 per cent. In the event of a doubled refurbishment rate, as desired by the German Federal Government, energy consumption would fall to 93.2 kWh/m<sup>2</sup>a or 42.5per cent.

<sup>20</sup> See BMWi/BMU (2010).

**Figure 3.1: Results of the Scenarios “Trend” and “2%”**

		Consumption in kWh/m <sup>2</sup> a	Emissions Reduction Compared to 2008 in %	Total Refurbishment Costs in Billions of Euros	Refurbished Space in sqm	Share of Refurbished Space of Total Space in %	Average Annual Investment Costs in EUR/t GHG
Scenario “Trend”	2008	162.04					
	2020	126.40	18.53	252.2	511,241	1.13	9,297
	2030	108.56	26.97	385.8	815,707	1.00	10,474
Scenario “2%”	2008	162.04					
	2020	114.08	27.33	511.3	1,083,908	2.40	15,017
	2030	93.16	39.18	743.5	1,623,990	2.00	14,561

The specific consumption figures should not be overrated, since the total living space is likely to increase by 10.1 per cent compared to 2008 by 2030. The absolute consumption figures make this clear: in 2008, total consumption was at 549 billion kWh. If refurbishments were not to take place by 2030, then about 493 billion kWh would still be necessary to supply the German heating sector. This is equivalent to a reduction of 10.4 per cent. In the “Trend” scenario, this would be tantamount to a reduction of 26.2 per cent (405 billion kWh) and 33.7 per cent in the “2%” scenario (348 billion kWh).

There are only slight differences among the energy sources. This is because during most current refurbishments, it is about heat producers being modernised and insulation being improved, but energy sources are not changed. Houses heated by oil are the exception, and some buildings are switched to gas. In this respect, the share of heat producers is changed mainly when new buildings are built, where gas and electricity currently dominate, the importance of electricity resulting from the installation of heat pumps. Since the living space increases at the same time, the share of gas in new buildings is not sufficient for its already dominant position to be expanded. Figure 3.2 illustrates the shares and the total energy consumption of the energy sources.

GHG emissions are also reduced owing to technological progress. By 2030, they would amount to 9.5 per cent compared to 2008 due to demolitions and new buildings without any refurbishments taking place. Savings would be at 27 per cent in the “Trend” scenario and at 39 per cent in the “2%” scenario. Considering the absolute GHG emissions, these figures seem to be low given the objective to achieve almost zero emissions by 2050.

Figure 3.2: Energy Consumption of Trend in billions of kWh

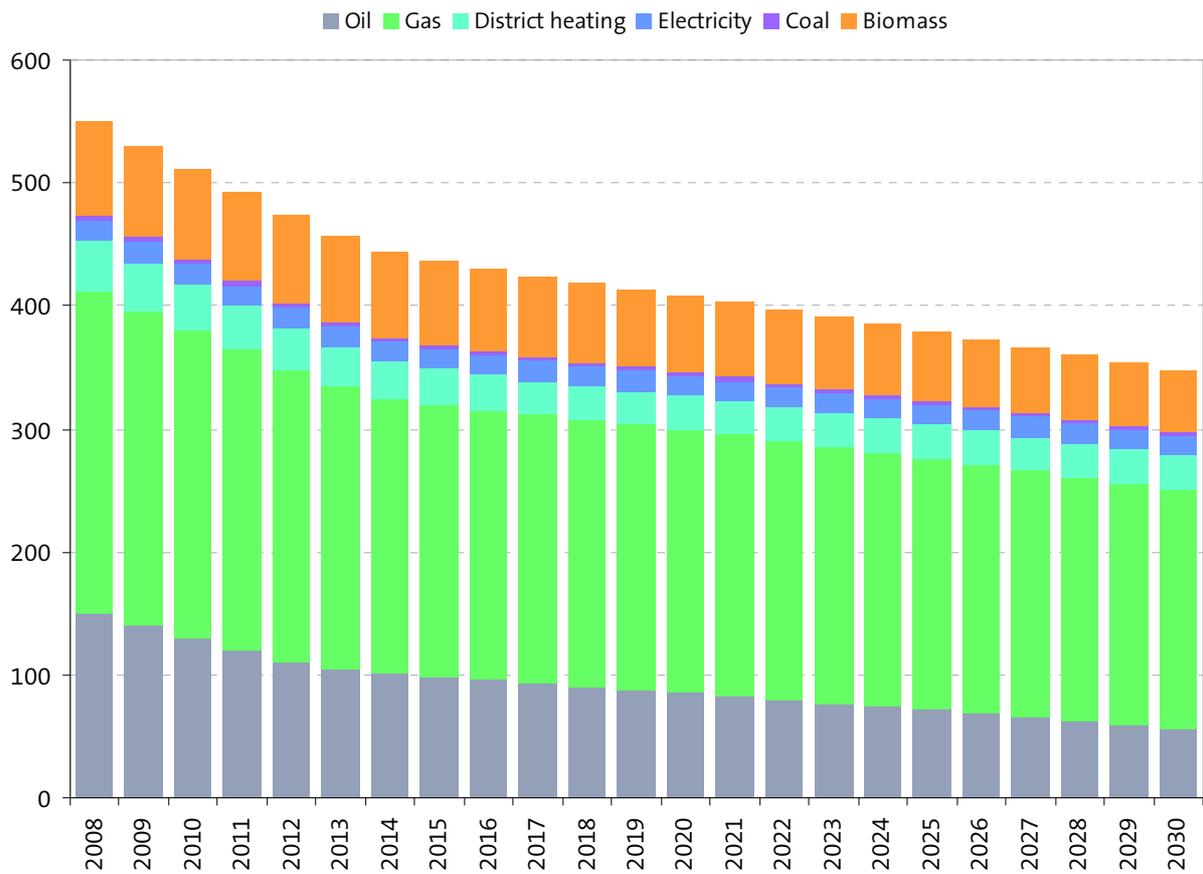
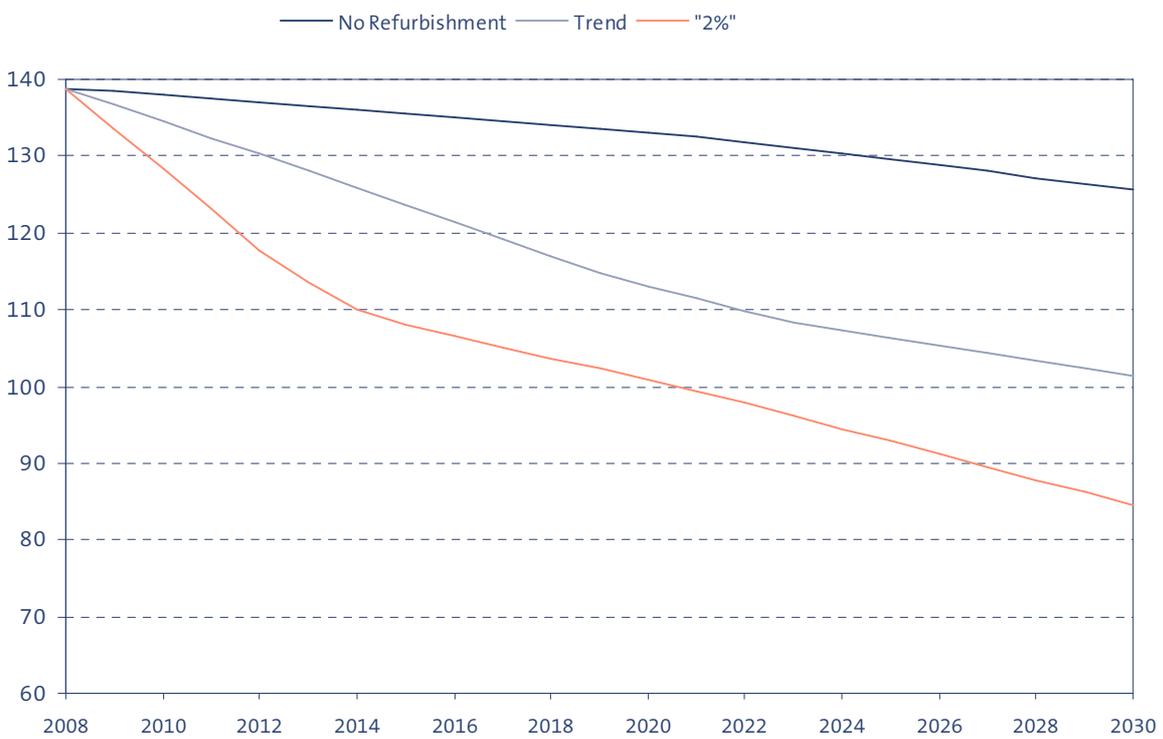


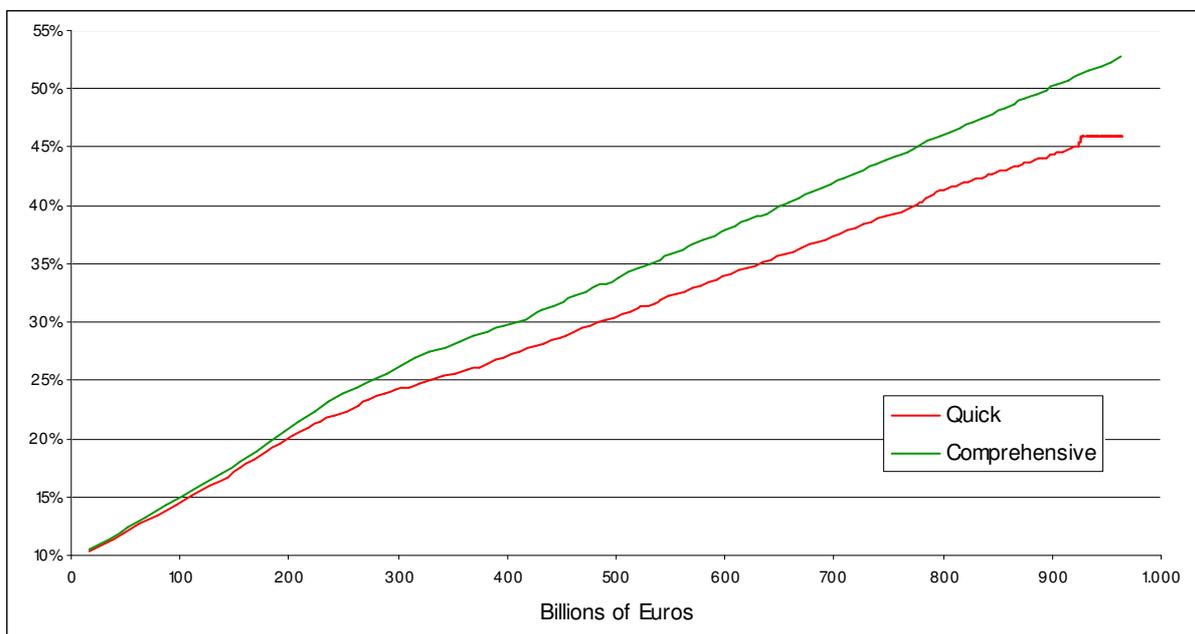
Figure 3.3: GHG Emissions in Millions of Tons



### 3.2 Quick vs. Comprehensive

Figure 3.4 shows GHG emissions reduction in 2030 compared to 2008. We simulated the reduction for every relevant investment in refurbishments.<sup>21</sup> It can easily be seen that Comprehensive is optimal for every investment cost since GHG reduction in the case of Comprehensive is always higher than in the case of Quick. Both options are nearly equal with very low investment costs, i.e. up to 150 billion euros. If more than 150 billion euros are invested in refurbishments, the advantage of Comprehensive increases. At 900 billion euros, the difference is more than 5 per cent.

Figure 3.4: Reductions of GHG Emissions (2030 compared to 2008)



Furthermore, it can be easily seen that the reduction of Quick stabilises at 925 billion euros. At this point, which corresponds to 3.13 per cent annual refurbishment rate, the maximum possible refurbishment of Quick is reached, since Efficiency Class 1 or 2 of oil, gas or district heating no longer exists. As defined in our model, the amount of 925 billion euros is therefore the limit of stepwise refurbishments. In fact, this is a considerable investment level, as it equals 40.2 billion euros per year, which is 2.4 times higher than the current investment level of 16.7 billion euros in Trend.

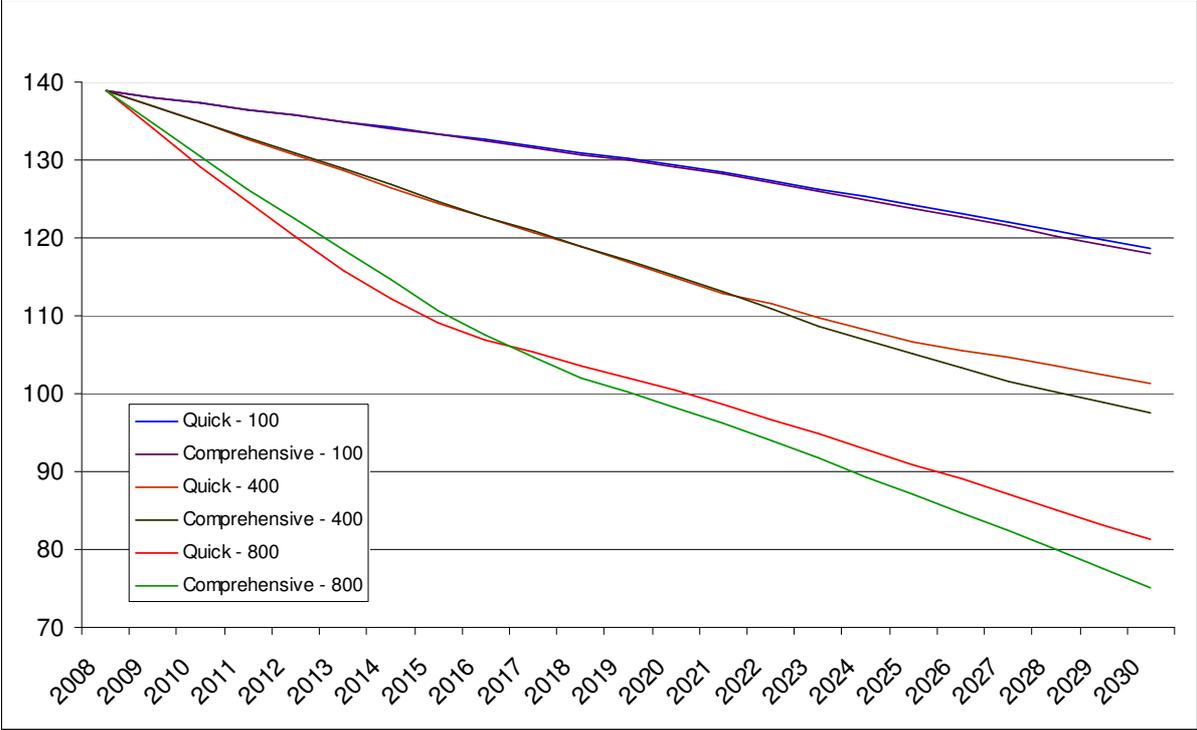
The difference between Quick and Comprehensive becomes clearer when examining the GHG emissions per year. Figure 3.5 shows the emissions per year at three different investments levels.

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<sup>21</sup> The investment levels are equivalent to refurbishment rates. Since the refurbishment rates are different for both options, we compare every outcome to the investment of refurbishments.

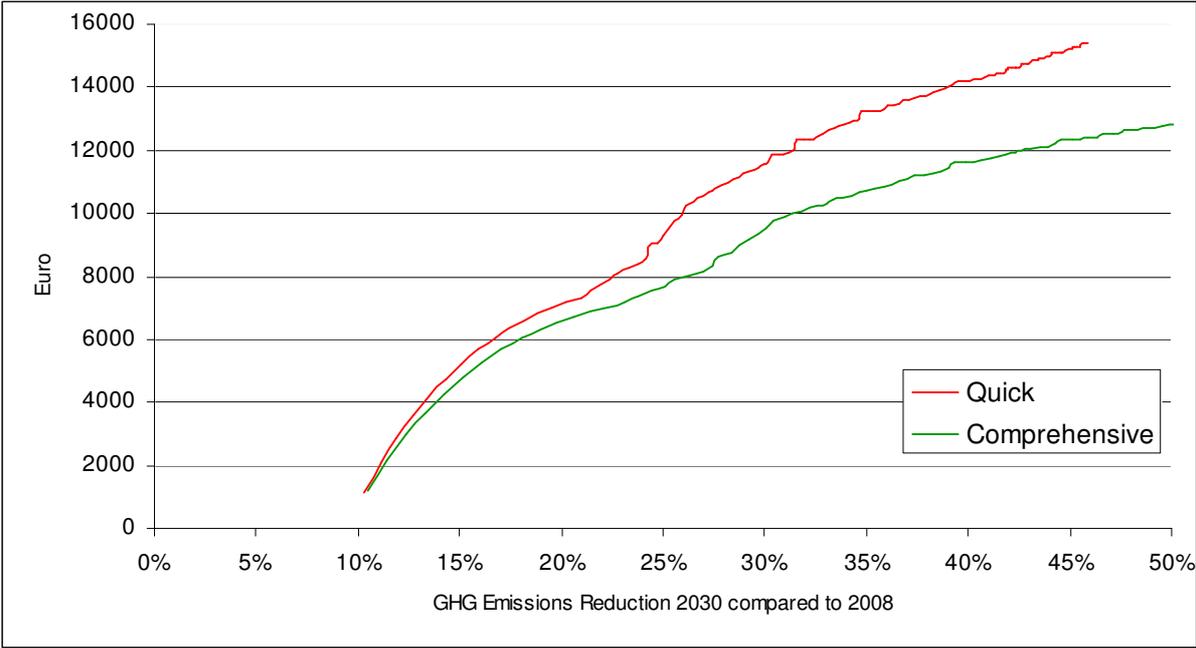
If 100 billion euros are invested up to 2030, the difference between Quick and Comprehensive can be neglected. If 400 billion euros are invested, Comprehensive will emit more until 2020 and will afterwards quickly improve. The same dynamics can clearly be seen at an investment level of 800 billion euros: Comprehensive makes less progress than Quick in the first years but catches up quickly. The explanation is simple: with increasing refurbishment rates, Quick needs to refurbish living space twice, i.e. from Efficiency Class 1 to Efficiency Class 2 and then to Efficiency Class 3. It is assumed that it is always efficient to reach a certain energy standard in one big step rather than step by step. However, the time period of 23 years considered in our model is too long for Quick to benefit from the advantage of the first years. This leads to the conclusion that stepwise refurbishments are only optimal if the time period is relatively short or, in other words, it is always optimal to apply comprehensive measures if long periods of time are considered.

**Figure 3.5: GHG Emissions per Year in Millions of Tons GHG**



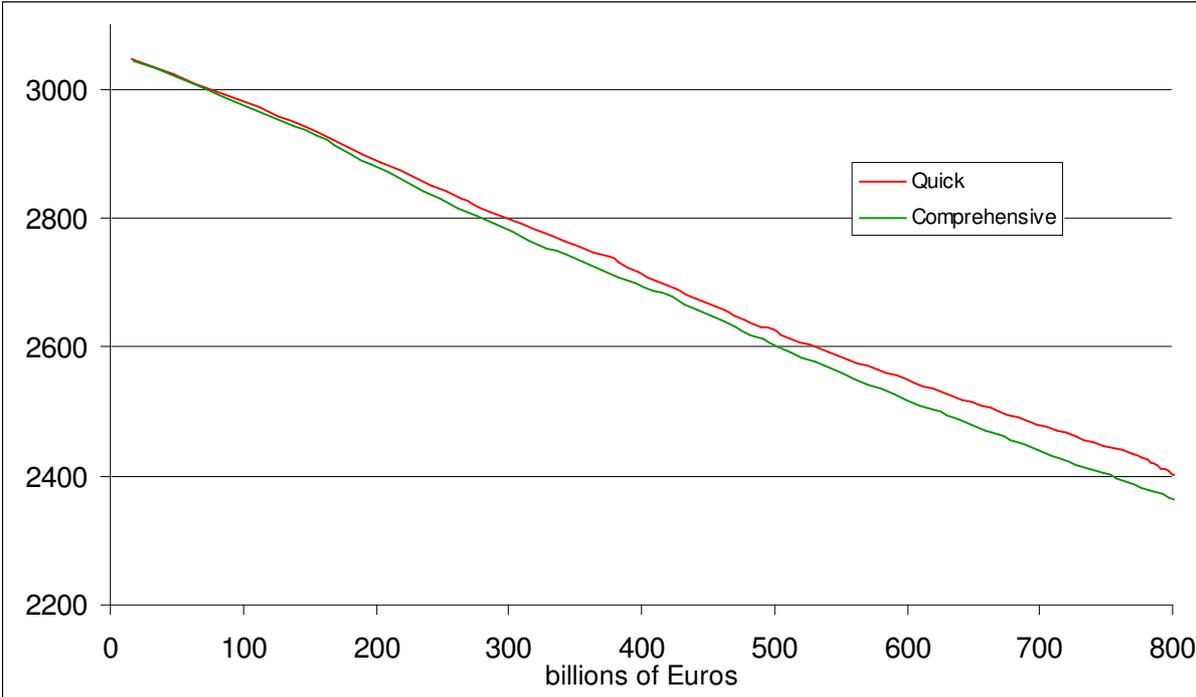
As a result, the investment costs per ton GHG emissions are always lower if comprehensive refurbishment measures are applied. Figure 3.6 shows the investment costs per ton GHG for any possible amount of GHG reduction in 2030 compared to 2008. It should be noted that these costs are not abatement costs, since we do not calculate the variable benefits of the reduction. Instead, we only calculate the fixed investment costs that are required to reduce GHG emissions.

Figure 3.6: Investment Costs per Ton GHG Emissions



However, a different conclusion might be drawn when considering cumulated GHG emissions. Figure 3.7 shows the cumulated GHG emissions for all relevant investments. Obviously, the difference can be neglected, since the maximum difference is less than 2 per cent for an amount of 800 billion euros. This result may seem surprising, but is, in fact, entirely in line with our findings above. While the period of 23 years is enough to create a significant advantage for Comprehensive in terms of emission reduction, it is not long enough in order to create a clear distinction when considering cumulated emissions.

Figure 3.7: Cumulated Emissions (2008- 2030) in Millions of Tons GHG

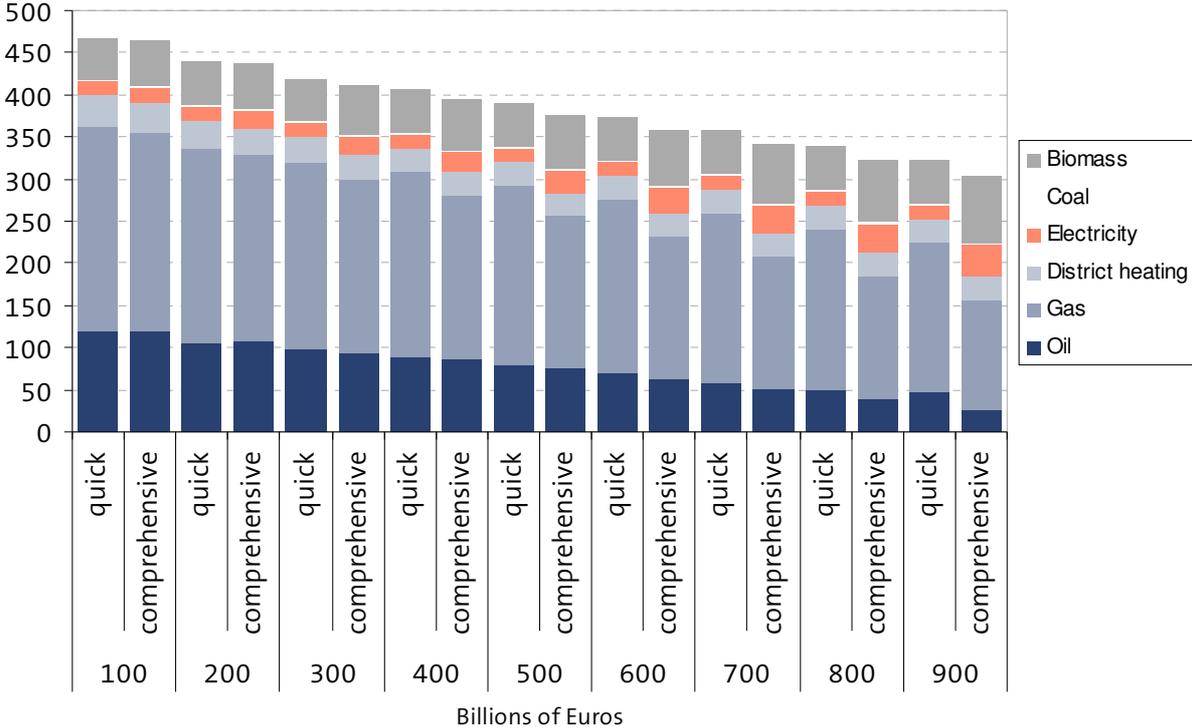


Energy consumption is another indicator revealing the small difference between the two options. Figure 3.8 shows the energy consumption of all energy sources for both options at different investment levels. In accordance with the emission reductions, the difference between the two options increases with increasing investment levels, but remains very small. However, the different structure of energy consumption in both options is evident. The larger share of fossil energy sources, especially gas, can be easily seen in Quick. Hence, the share of renewable energies, i.e. biomass and heat pumps<sup>22</sup> is larger in Comprehensive. This shows the general difference of both options: While Quick is based mainly on increasing energy efficiency of the established fossil technologies with a slight shift from oil to gas, Comprehensive, in contrast, implies a shift from fossil energy sources to renewable energy sources.

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<sup>22</sup> Note that, in this case, heat pumps are considered a renewable energy source, even if they are powered by electricity that is not generated from renewable energy sources. The GHG emission factor of electricity will decrease with the increasing share of renewable electricity in the electricity mix.

Figure 3.8: Energy Consumption in Billions of kWh



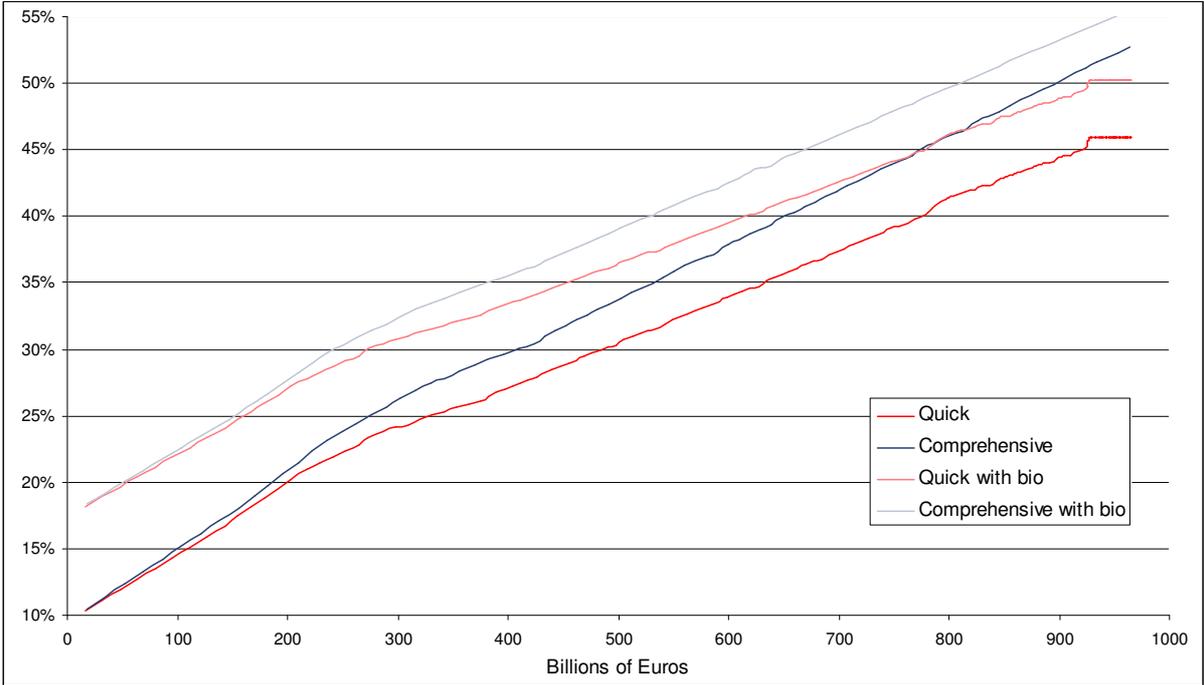
### 3.3 Biofuels

As an alternative to refurbishment measures, the reduction of GHG emissions is also facilitated by using renewable energies. Besides biomass, there are biogenic oil and biogas, insofar as they are produced sustainably. Given the increasing significance of heat pumps, an improved electricity mix can have a positive impact. These measures make sense if they are more cost-effective than refurbishments. This does not apply to the electricity mix since the climate protection goals concerning electricity generation are already very ambitious.

Since costs are difficult to forecast, we focus on investigating the potential GHG emissions reductions, assuming an admixture of 2 per cent of biogenic oil and biogas as of 2012 and an annual increase of 1 per cent, which leads to a 10 per cent share in 2020 and 20 per cent in 2030.

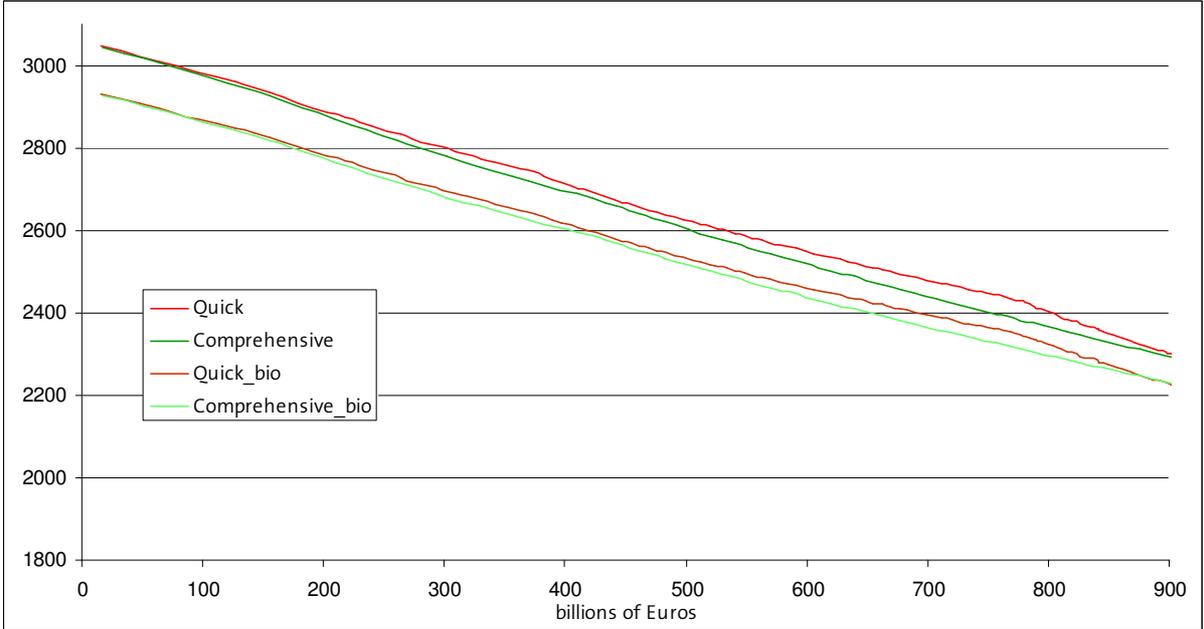
Figure 3.9 shows the results biofuels have on GHG emissions reductions in 2030 compared to 2008. A significant difference for both options is obvious. Biofuels have an effect of 8 percentage points with no refurbishment and this effect decreases slightly as the share of fossil fuels decreases with increasing refurbishment rates. Since the share of oil and gas is smaller, the effect of biofuels is obviously smaller for Comprehensive than for Quick. It should be noted that we assume no additional costs for biofuels in this figure in order to compare the potential of biofuels.

**Figure 3.9: Comparison of GHG Emissions Reductions (2030 to 2008) of the Two Options with and without Biofuels**



The same result can be seen for cumulated GHG emissions. There is a small but significant effect of biofuels.

**Figure 3.10: Comparison of Cumulated GHG Emissions of the Two Options with and without Biofuels**



## 4 Discussion

Since residential building stock is of great importance for achieving the climate protection goals in the European Union and Germany, policymakers have to take appropriate measures in order to increase the refurbishment rate. Given the large amount of investment that is needed, efficiency is essential in this context. Furthermore, habitation is a basic human need and should therefore be affordable. Since refurbishments will lead to higher rents, there is a potential trade-off between social policy and climate policy in the residential building sector. Inefficient funding schemes with distorted effects could worsen this trade-off.

In terms of GHG reductions in the period from 2008 to 2030, our model shows a clear advantage of comprehensive refurbishments compared to partial refurbishments. This outcome applies for any level of investment. Hence, it can be concluded that policymakers should prefer comprehensive refurbishments over partial measures.

However, when placing emphasis on the cumulated GHG emissions, one can come to another conclusion. In the period considered in our model, the advantage of comprehensive refurbishments is recognizable but very small. Since the GHG budget is more important for climate protection policies than GHG reduction at a specific point in time, the advantage of comprehensive refurbishments decreases. On the one hand, one can argue that the small difference in the period considered here is not important, since the advantage of comprehensive refurbishments increases with the period considered and since climate protection policy in the residential building sector is a long-term project. On the other hand, uncertainty also increases with the time period considered and hence makes precise forecasts difficult.

Moreover, being aware of optimal refurbishment options does not necessarily imply being aware of optimal funding schemes. Many papers on house owners' preferences on energy-related refurbishments exist, pointing out different drivers of investment behaviour.<sup>23</sup> It is obvious that house owners have different investment incentives than landlords, for example.<sup>24</sup> Another essential point that has to be taken into account is that house owners are often elderly. Hence, the payback period of refurbishment investments might bias investment decisions towards partial refurbishments. Our results are therefore a first step to frame policy recommendations. Therefore, further research on optimal funding schemes in order to achieve the desired objective is necessary.

In addition, the above-mentioned social aspect of refurbishments is an important issue for policymakers. By raising the energy standard of buildings, the housing price will increase, which is

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<sup>23</sup> See Achtnicht (2011).

<sup>24</sup> See Rehdanz (2007).

counterproductive from a social perspective. Firstly, rents will increase and secondly, it may reduce the number of people building a detached house. Hence, policymakers will have to face a trade-off between climate protection and social policy. The option of comprehensive or stepwise refurbishments therefore also has a social dimension, since the investment costs per unit of space are very different. For comprehensive refurbishments, few people will face high costs and for stepwise refurbishments, a lot of people will face lower but significantly increasing costs. This situation is complicated for policymakers, because both options could be favourable.

To conclude, we cannot recommend only subsidising comprehensive refurbishments in order to reach the climate protection targets because of the minor advantage of comprehensive refurbishments in terms of cumulated GHG emissions, on the one hand, and because of the uncertainty about optimal funding schemes, on the other hand. The advantage of comprehensive refurbishments is at most 2 per cent, which is too little given the time period of 23 years considered in our model. Also, optimal measures to promote comprehensive refurbishments have not been identified. In view of the high costs per unit of space, concentrating on comprehensive refurbishments could result in failure to achieve the climate targets, as house owners hesitate to invest in energy-related refurbishments.

## 5 Conclusion

We analysed different energy-related refurbishment measures that can be taken in order to achieve climate protection targets. Although subsidisation seems to be necessary to increase the refurbishment rate, optimal measures concerning cost effectiveness have not been identified. We used a stylised model of the German residential building stock to analyse different refurbishment measures by simulating every relevant amount of investment until 2030. In particular, we compared two refurbishment options in order to derive policy recommendations: first, we took a look at comprehensive refurbishments that are expensive but achieve the most reductions in energy consumption and GHG emissions and second, we examined partial refurbishments, which include only low-cost improvements but can be achieved on a wide scale.

We found that, at any amount of investment, comprehensive refurbishments provide the highest reductions of GHG emissions and energy consumption in 2030. Hence, partial renovations are never optimal. This result can be explained as follows: typically, it is always efficient to reach a certain energy standard in one big step rather than step by step. Although partial refurbishments have an advantage in the first years, comprehensive refurbishments catch up quickly, since partially refurbished living spaces have to be refurbished again. To conclude, partial refurbishments are only optimal if the time period is relatively short or, in other words, it's always optimal to apply comprehensive measures if long periods of time are considered.

Furthermore, we analysed the potential of biofuels as an alternative to energy-related refurbishments and found a small but significant impact on GHG emissions reductions. Provided that the production costs of biofuels are lower than refurbishment costs and that biofuels are produced sustainably, this option should not be ignored.

However, when considering cumulated GHG emissions during the entire period, the difference between both options is very small, i.e. less than 2 per cent at the highest refurbishment rate. This is completely in line with the explanation above: comprehensive refurbishments make less progress in the first years but catch up quickly. Hence, the advantage of comprehensive refurbishments increases with the refurbishment rate. However, the fact remains that the time period considered is too short to create a significant difference.

Therefore, it may be a mistake for policymakers subsidise only comprehensive refurbishments for two reasons: first, the emission budget, defined as the cumulated emissions, is more important than reductions at a specific point in time. However, the calculated advantage of comprehensive refurbishments seems too small, particularly given the uncertainty caused by the time period considered in our model. Second, even if the reduction at a specific point in time is more important to policy makers, due to the high investment cost per unit of space, landlords and house owners could possibly hesitate to invest in energy-related refurbishments, which may prevent the necessary rate of refurbishment. Hence, it could be more sensible to also subsidise stepwise refurbishments in order to increase the rate of refurbishment. Moreover, due to the long-term investments in the residential building sector, reliable policy measures seem to be essential to avoid reluctant investment decisions and therefore may be more important than specific refurbishment options.

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