Behavioural Response to Investment Risks in Energy Efficiency

D 3.4 SUMMARY REPORT WP3

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1 Objective and approach

This report is submitted as Deliverable 3.4 in the BRISKEE project and aims at summarizing the methodological, results and policy recommendations derived from the meso-level modelling approach conducted in work package 3.

The BRISKEE project has the objectives of providing evidence-based input to energy efficiency policy-making by investigating the role of household decision-making on three levels:

1) On the micro level, the project provides empirical evidence on the factors that influence investment decisions for energy efficiency technologies in households, in particular focusing on the role of household preferences for time discounting and risk, accounting for possible differences by technologies, household types, and countries.

2) On the meso level, the project explores the impact of time discounting and risk preferences, and of policies affecting those factors on technology diffusion and energy demand in the residential sector in Europe up to 2030. The project uses inputs from the micro-level analysis in order to improve the representation of investment decisions in energy demand modelling tools.

3) On the macro level, BRISKEE explores the long-term macroeconomic impacts of changes in micro-economic decision-making and of energy efficiency policy on employment, GDP and exports in the EU up to 2030.

This report focuses on findings derived from 2) meso-level modelling which is mainly based on modelling final energy demand for heating and cooling as well as appliances in the European residential sector. Two bottom-up models (Invert/EE-Lab and Forecast) have been applied to model energy demand and supply developments for different policy scenarios and assumptions on the behavior of building occupants.

The main results discussed in this report are:

i. Development of final energy demand for space heating, hot water, space cooling and for appliances in the residential sector until 2030 in EU28 member states including the use of final energy carriers
ii. Costs related to space heating, hot water, space cooling and appliances including investment, operational and energy costs
iii. Estimation of the deployment of efficiency measures including investments into thermal refurbishment, efficient heating systems and efficiency improvements of appliances
iv. Quantification of the potential impact of different discount rates attributed to investing agents (e.g. home owners) on the final energy demand and deployment of energy carriers

v. Quantification of the impact of intensified policy measures for three scenarios with a focus on the effect of policy measures that would reduce discount rates and investment barriers.

The report is structured as follows. Section 2 gives a brief overview of the findings of WP2 (details in Deliverable 2.2), their relation to model inputs in WP3 and a general discussion on the impact of interests rates on the models used in WP3. Section 3 provides an introduction on the modelling approach and scenario definition within WP3 (details in D 3.1). In section 4 we describe the modelling results for the development of energy demand and supply in buildings and appliances for EU 28 until the year 2030 under current policy assumptions. Those results serve as a basis to evaluate the potential impact of intensified additional energy efficiency measures and in particular the potential of policies addressing user behavior to reduce energy demand and fossil fuel use in the European Union which is discussed in section 5. Section 6 concludes this report with a summary of the findings from the quantitative scenarios calculated in WP 3.

2 WP2 results summary and impact on modelling

This chapter outlines the methodological approach of the two energy models and presents some additional findings from the survey in addition to the findings described in BRISKEE (2016), presenting descriptive results of the survey, and BRISKEE (2017), presenting a multivariate analysis of the survey results regarding the adoption of energy efficiency technologies and determinants of risk and time preferences.

The BRISKEE survey is a representative online survey conducted in households in eight EU countries (FR, DE, IT, PL, RO, ES, SE, UK) in July/August 2016, with 1500 to 2000 observations per country. These countries account for about 75 % of EU population, energy use and CO2-emissions. The survey covered a variety of technologies influencing residential energy demand including household appliances, lighting, building insulation, heating technologies. This chapter outlines the methodological approach of the two energy models and presents some additional findings from the survey in addition to the findings described in BRISKEE (2016), presenting descriptive results of the survey, and BRISKEE (2017), presenting a multivariate analysis of the survey results regarding the adoption of energy efficiency technologies and determinants of risk and time preferences. For more details we would like to refer to BRISKEE 2017b (forthcoming). The chapter also discusses the impact of discount rates on modelling and describes how the results of the BRISKEE survey were implemented in the energy demand models INVERT/EE-Lab (for buildings) and FORECAST (for residential appliances).

2.1 Methodological approach for data analysis

The analysis presented in this chapter focuses on the decision criteria that investors apply in energy efficiency investments. For purchase decisions for household appliances, investments in energy efficiency measures in buildings, and purchase decisions for light bulbs participants were asked to rate the following nine decision criteria regarding their importance in their most recent purchase decision on a five-point scale ranging from “played no role” (numerical value 1) to “very important” (numerical value 5):

Table 1: Overview of purchase criteria

Household appliances and lighting	Buiding technologies
Purchase price	Investment costs
Energy cost	Energy cost
Performance (quality, reliability, durability, functionality)	Performance (quality, reliability, durability, functionality …)
Financial support (e.g. tax rebates, subsidies)	Existing governmental financial support measures (e.g. subsidies, rebates, tax refund)
Recommendations by friends and family (social influence)	Recommendations by friends and family
Recommendations by professionals (e.g. retailers)	Recommendations by professionals
Environmental friendliness	Environmental friendliness
Energy label	Increase in property value or rental receipts
Design, look, fit with current interior	Indoor comfort

We analyse how various population groups differ in their rating of the various criteria across the eight EU member states included in the survey. The different population groups were selected based on the literature review (BRISKEE, 2015) and include age, income, gender, environmental identity, among others.

In order to identify the influence of different attributes on energy efficiency investment behaviour, for each attribute the sample is split in subgroups (e.g. male vs. female) and the mean values of the ratings of the different purchase criteria (see Table 1) are compared.

The mean values (arithmetic mean, $\bar{x}$) were calculated by adding the individual results ($x_1 + x_2 + \cdots + x_n$) within one group of interest and dividing by the number of group members (n):

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

The corresponding sample variance (v) was calculated as follows:

$$v = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

The sample standard deviation (SD) is equal to the square root of the variance of the sample:

$$SD = \sqrt{v} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Differences of resulting mean values were tested using the independent two sample t-test.

In order to meaningfully analyse the influence of the attributes on the stated relevance of the purchase criteria and to compare between different countries, attributes and criteria, a three dimensional visualisation approach was developed.

First the raw data were ordered by sub-groups e.g. gender, country, etc. (Figure 1a). For each sub-group the mean value and standard deviation was calculated. The resulting mean values are shown for the sub-group gender and country as an example in Figure 1b. The three dimensional colour maps show the eight countries and the mean value for all countries together on the x-axis. The eight purchase criteria are listed on the y-axis, arranged according to their rating values of the average of all countries. The mean values are colour coded. In order to compare two sub-groups (e.g. female and male), the ratio of the mean values was calculated and plotted in percentage in the three dimensional colour map approach (Figure 1c). Finally, a two parameter t-test was performed between the two sub-groups with a 5 % significance level, in order to verify the significance of the differences between the mean values and the resulting ratios. The values with no statistically significant difference were marked in white in the colour maps (Figure 1d). The final three dimensional colour maps allow an easy and quick comparison between the different purchase behaviour of the two sub-groups.

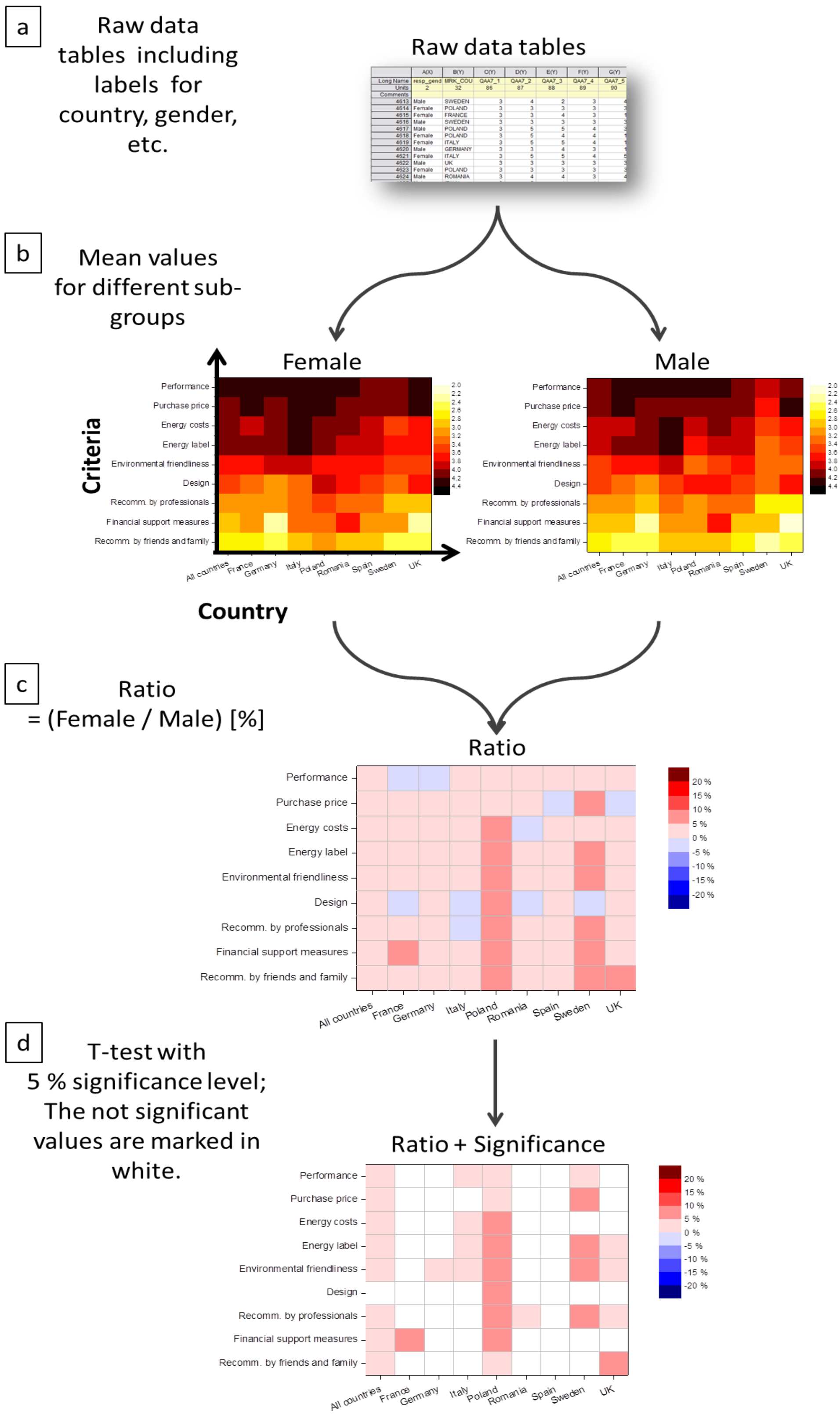

a
Raw data tables including labels for country, gender, etc.
Raw data tables
b
Mean values for different sub-groups
Female
Male
Criteria
Performance
Purchase price
Energy costs
Energy label
Environmental friendliness
Design
Recomm. by professionals
Financial support measures
Recomm. by friends and family
All countries
France
Germany
Italy
Poland
Romania
Spain
Sweden
UK
Country
c
Ratio = (Female / Male) [%]
Ratio
20 %
15 %
10 %
5 %
0 %
-5 %
-10 %
-15 %
-20 %
d
T-test with 5 % significance level; The not significant values are marked in white.
Ratio + Significance

Figure 1

2.2 Residential buildings

In this section we illustrate important findings from the survey from the perspective of residential buildings, briefly discuss the role of discount rates for investment decisions in the area of heating and cooling, illustrate the decision making approach of the building stock model INVERT/EE-Lab including the impact of survey findings on model assumptions and provide a sensitivity analysis on the effect of discount rates on modelling results.

2.2.1 Descriptive Statistics of Survey

In this section, we elaborate the question based on the results of the survey, if we can find empirical evidence that different population groups display systematic differences in their behavior, when they are confronted with the decision, whether or not to refurbish the building which they live in. Since our bottom-up model relies on statistical data regarding the building stock, the owner and the occupation status, we focus on indicators, for which statistical data are available, at least for many European countries: type of building, income distribution and the age group of occupants.

When and why do people refurbish their buildings?

The Reason, when and why people refurbish their buildings, plays an important role in modelling the future evolution of energy efficiency measures in the building stock. Therefore, we asked participants in the survey, for the main reason why they did decide to refurbish their building. The question was put as follow:

- *What made you decide to install insulation or new windows? Please mark the single most important factor only.*

For their answer, they could choose from these four given reasons:

1. Modification or expansion of building
2. Refurbishment of building was needed due to other technical or visible reasons - leaking roof, necessary repairing/ repainting of facade, broken windows, air leakage etc.
3. Energy costs
4. Other

The results from the survey show (Figure 2) that the most important primary reasons are either the necessity due to other technical or visible reasons (38 %) or the energy costs (44 %). Only 10 % stated that the refurbishment was done in the course of a modification or expansion of building, 8 % of the participants reported that primary driver was another reason. These findings underlie the importance that bottom-up need to consider both, the lifetime of building components, commonly defined by survival rates, as well as the economics of different refurbishment options and their impact.

Furthermore, the results indicate, that for participants, who are living in their primary residence for less than 10 years and refurbished their home, a large share reported that the refurbishment was done in the course of modifying or expanding the building. On average, although not consistently throughout all countries, energy costs become more important for participants who have been occupying their home for more than 10 years.

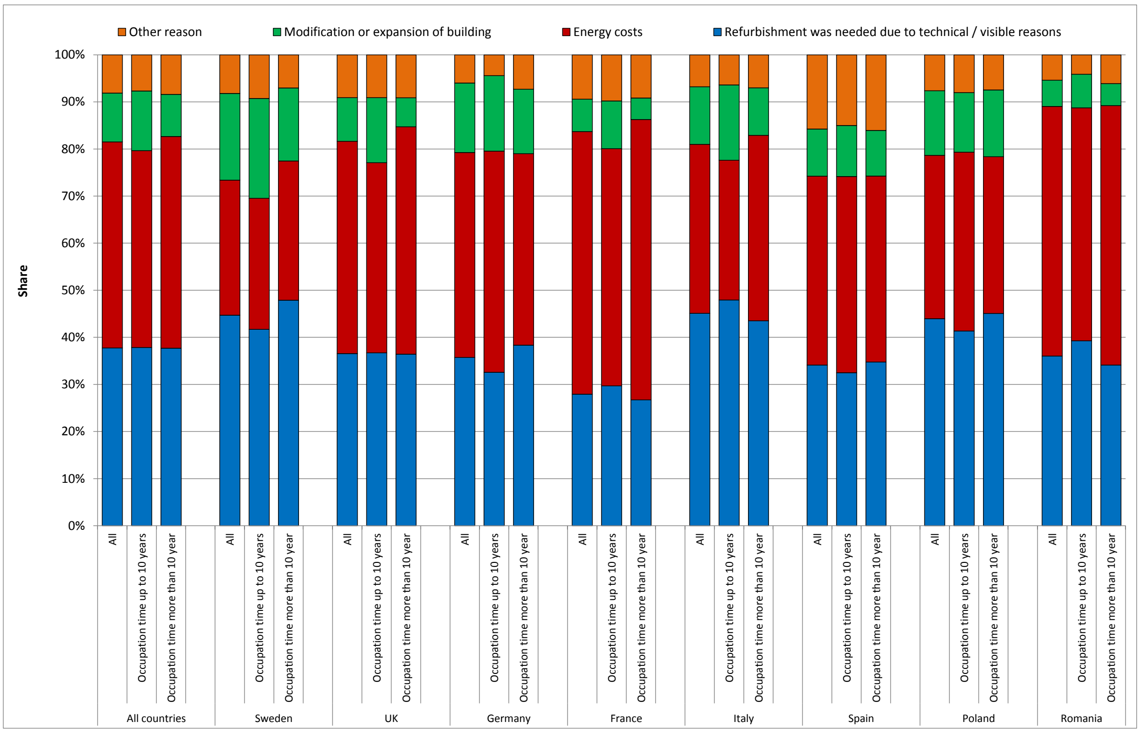


Figure 2: Survey results: most important factor, why participants decided to refurbish their building. The results are clustered by country and whether or not the participants were living in their primary residents for more than 10 years or not.

Another finding is, that the relevance of the criterion "Modification or expansion of the building" decreases with an increasing number of apartments within the building. At the same time, the criterion "Energy costs" gains in importance (Figure 3).

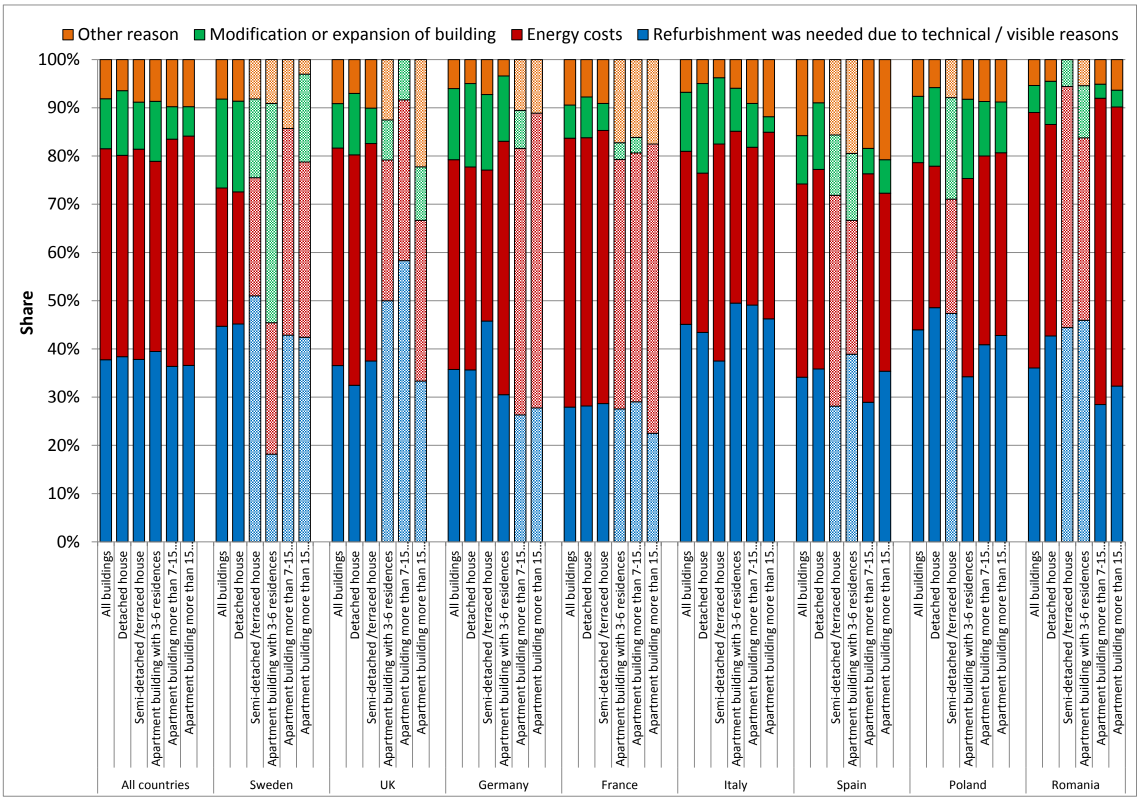


Figure 3: Survey results: most important factor, why participants decided to refurbish their building. The results are clustered by country and building type. The checked (bright) bars indicate the sample with a low sample size (<50).

The evaluation of the income of the participants indicates that the criterion “Energy costs” loses importance with increasing household income (Figure 4). If compared against the reason “Refurbishment was needed due to other technical / visible reasons”, we observe a statistical significant trend for the full dataset that the criterion “Energy costs” is less often stated as main reason with increasing income. However, this trend is weak and not consistent if analyzed on the level of individual countries. At the same time, with increasing income modification or expansion of the building becomes more of an issue.

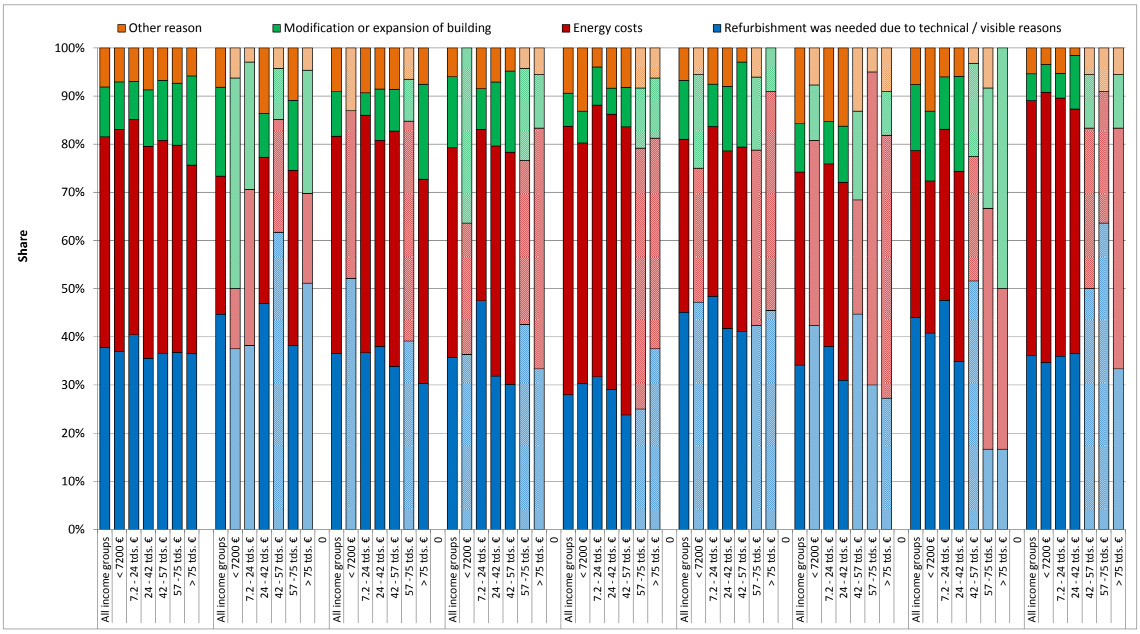


Figure 4: Survey results: most important factor, why participants decided to refurbish their building. The results are clustered by country and income group. The checked (bright) bars indicate the sample with a low sample size (<50).

Relevance of purchasing criteria for investing in heat supply technologies and building refurbishments per population group

If decision makers would act like the so called "homo oeconomicus", the decisions would be taken based on the total costs of ownership only. In fact, this assumption is often presumed in techno-economic driven bottom-up models. However, we can observe that this assumption does not hold in realty. First, we have to acknowledge that decision makers have individual preferences, identify themselves with certain attitudes and are exposed to social norms. Second, we also have to keep in mind that investors act in a situation where they often face some sort of information deficits. In order to get empirical evidence which aspects are more relevant in the decision making process, we asked the survey participants about the importance of certain criteria in their decision process.

The survey question[1] was put as follows:

- *For the decision to invest in insulation measures or heating systems in general, how important are the following criteria?*

The following criteria were given:

1. Investment costs
2. Existing governmental financial support measures (e.g. subsidies, rebates, tax refund)
3. Energy costs
4. Indoor comfort
5. Environmental friendliness
6. Performance (quality, reliability, durability, functionality …)
7. Increase in property value or rental receipts
8. Recommendation by professionals (e.g. installer, architects, energy consultants)
9. Recommendation by friends and family

When we look at the absolute average values per decision criteria (Figure 5, Figure 6, upper graph), we observe that countries with lower income tend to attach the given decision criteria with higher importance then countries with higher income. At the first glimpse it looks as the results from the survey support that the hypothesis that strong differences in the decision criteria between countries were observed. However, if we look only at the relative differences (Likert scale values per decision criteria divided by respondent-average Likert scale value of all criteria) between decision criteria (Figure 6, lower graph), we can see that this effect is mainly due to a systematic shift of the average Likert scale value. As shown in the later graph, we cannot falsify the hypothesis that no (average income-related) country specific differences of the importance of different decision criteria exist.

1 5-point Likert scale: (1) Plays no role / (2) Not very important / (3) Neither important nor unimportant / (4) Important / (5) Very important

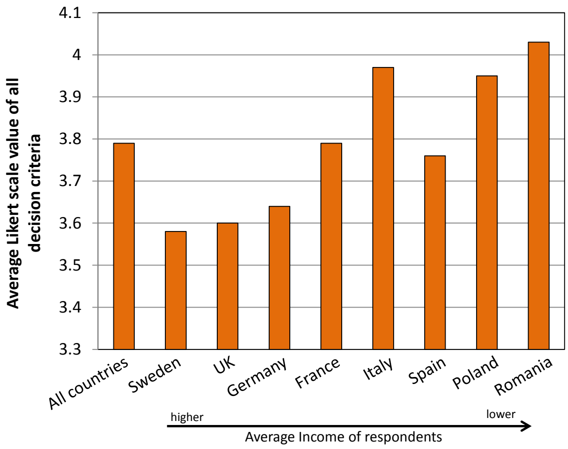


Figure 5: Average Likert scale of decision criteria for investing in building related energy efficiency measures per country

The results shown in Figure 6 reveal that on average, the most important criteria are the technical properties and performance of the system. On average, the given weight of this criterion is about 12 % above the total average. The second most important criterion are the energy costs (+10 % above the total average), followed by indoor comfort (+8 %) and investment costs (+7%). In all eight countries, these criteria are, on average, rated as the top four criteria. The criteria environmental friendliness and financial support measures were given an average importance. Lower weight was put on the increase in property value (-8 %) and recommendations by intermediaries (-9%). The lowest value received the criterion recommendation by friends and family (-19 %).

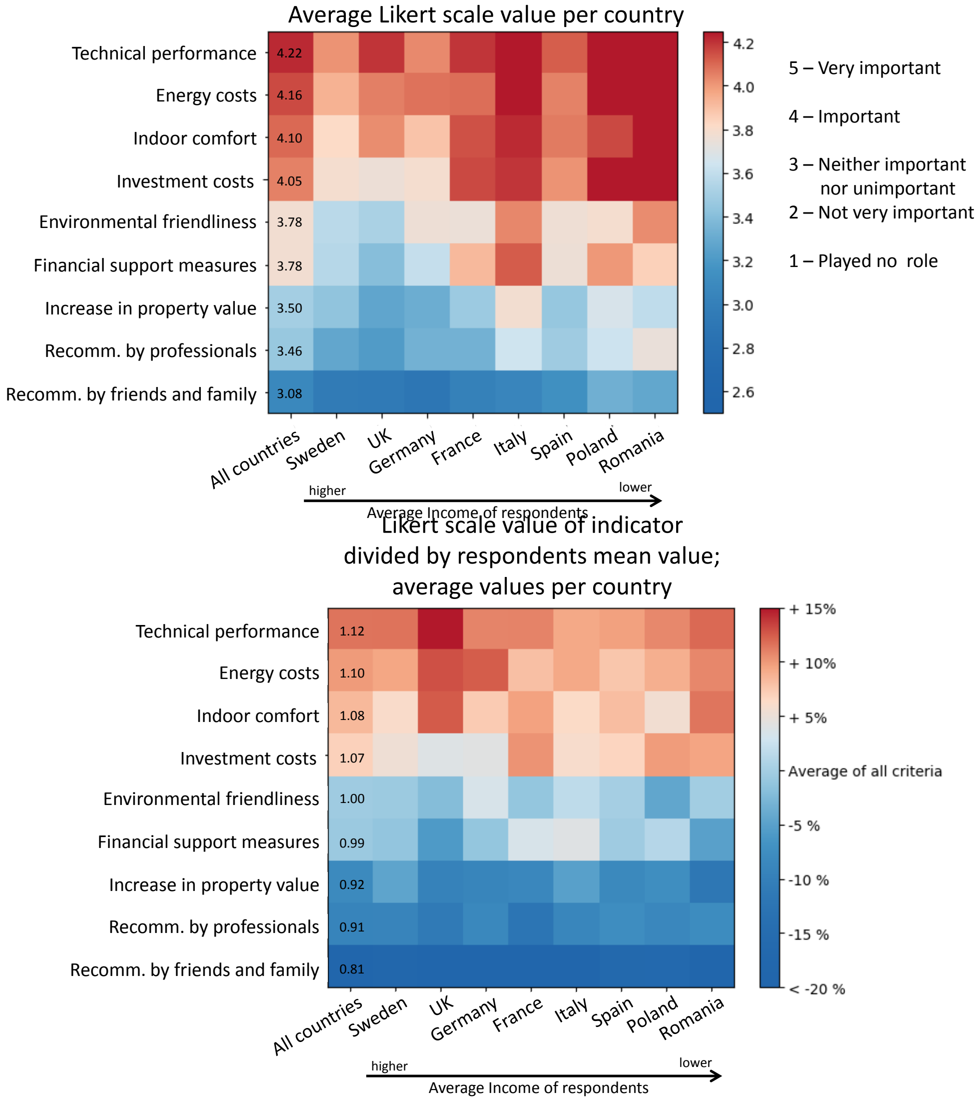


Figure 6: Importance of decision criteria for investing in heating systems and building refurbishment

Furthermore, we tested whether or not we can observe a correlation between the relevance of investment costs and the relevance of energy costs. If those indicators are positively correlated this would strengthen the hypothesis that in general, participants would look the total cost of space heating – upfront investments as well as running energy costs during the service period. If, one the other hand, the indicators would be negatively correlated, the finding would support the hypothesis that the set is composed of (at least) two subgroups: one group that focuses on the initial investment costs, the other group that looks more at the annual energy expenditures during the service lifetime. Figure 9 depicts the findings of the analysis. In the majority of countries we can observe a positive (and statistical significant on a 10 % level), only for the UK a negative correlation is measured; for Germany the results are statistical not significant.

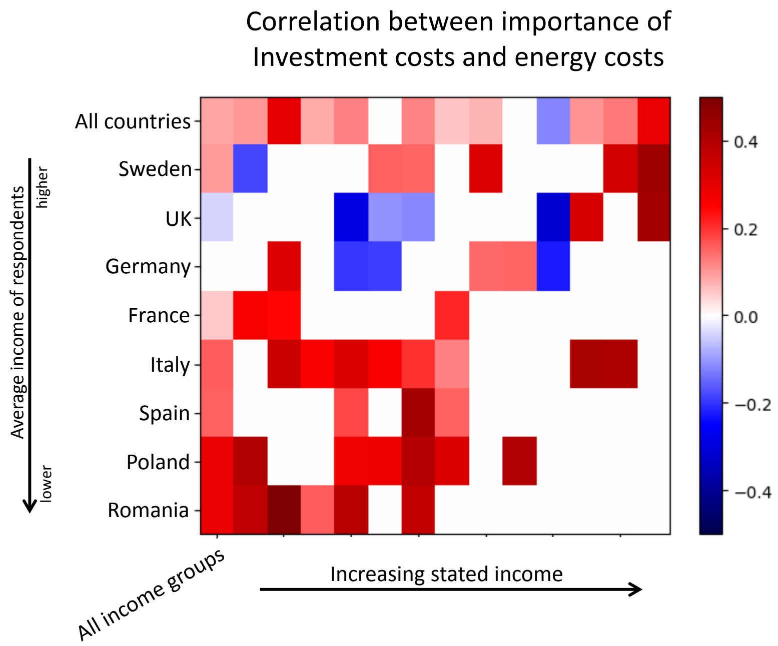


Figure 7: Correlation between the weight of the decision criteria investment cost and energy costs. The red squares indicate a positive correlation, blue squares a negative correlation. Results, which are not significant according to the t-test on a 10 % significance level are left in white.

Further data on the correlation between the relevance of decision criteria and the participant's income and age are shown in the appendix. General speaking, for most criteria we couldn't observe a strong trend between the participant's age or income and the relevance of decision criteria.

2.2.2 Impact of discount rates on thermal renovation and choice for heating systems

Before describing the decision making process implemented in the model INVERT/EE-Lab we will briefly discuss the impact of discount rates (r) on the choice for thermal renovation and efficient heating systems. In general, the higher the discount rate of a decision maker, the lower the weight of future energy expenditures in the investment appraisal and the higher the weight of initial investment costs will be. This holds for both, investment decisions related to the building envelope and heating systems, which is illustrated in Figure 8. The figure on the left shows the development of the net present value of an investment in thermal renovation assuming a decrease of annual heat demand from 150 kWh/m^2 (Q_old) to 70 kWh/m^2 (Q_new), investment costs of 150

€/m² (I) and a constant energy price of 100 €/MWh$_{heat}$ (p_heat). Assuming constant heat demand savings and energy prices, the net present value of a renovation option for a given investment horizon N can be calculated as follows:

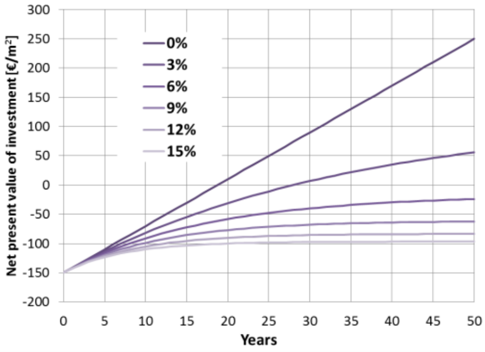
$$NPV_{renovation} = -I + \sum_{n=1}^{N} \frac{(Q_{old} - Q_{new}) \cdot \text{p\_heat}}{(1+r)^n}$$

As illustrated in Figure 8 (left) the chosen discount rate (r) significantly affects the investment appraisal and in effect the decision on thermal renovation which in theory will only be realized if the net present value of the investment is positive. In the illustrative example below, the investment would only be realized for discount rates below 3% and investment horizons above 30 years. With investors with discount rates above 5% the investments appraisal leads to negative NPVs even for very long investment horizons above 50 years as the expected savings in the future are strongly discounted. Note that for a discount rate of 5% the denominator $(1+r)^n$ for savings in year 30 already amounts to 4.3 and increases to 11.5 in year 50. Given the long life time measures related to thermal renovation the discount rates heavily affects the outcome of investment appraisals in building stock models and in the real world.

The same applies to the decision for heating systems. Consumers have to choose between various options of technologies. Typically, less energy efficient options require less upfront investment costs but lead to higher energy costs in the future compared to energy efficient solutions. This is illustrated in Figure 8 (right) for a comparison of net presents costs for heating with a direct electric heating system (inefficient technology with conversion efficiency (η) of 95% and investment costs (I) of 4000 €) and a heat pump (more efficient technology with a COP of 3 ($\eta = 300\%$) and investment costs of 16000 €). With simplified assumption of a constant annual heat demand (Q) of 10 MWh and a retail electricity price of 150 €/MWh the net present costs (NPC) of both heating systems can be written as:

$$NPC_{heating\ system} = I + \sum_{n=1}^{N} \frac{\text{Q} \cdot \text{p\_electricity} \cdot \frac{1}{\eta}}{(1+r)^n}$$

Similar to thermal renovation, the discount rate heavily effects the investment appraisal. In this example, we show NPC of both heating systems for investment horizons of 1 to 20 years and discount rates of 3% and 9%. It can be seen that under those assumptions, heat pumps appear to be more expensive if a discount rate of 9% is assumed even for long investment horizons of 20 years. Homeowners with high discount rates would therefore opt for less efficient direct electric heating systems instead of heat pumps. For relatively low discount rates of 3 % heat pumps appear to be the more cost efficient options for investment horizons of more than 12 years and homeowners might therefore opt for the more efficient option.



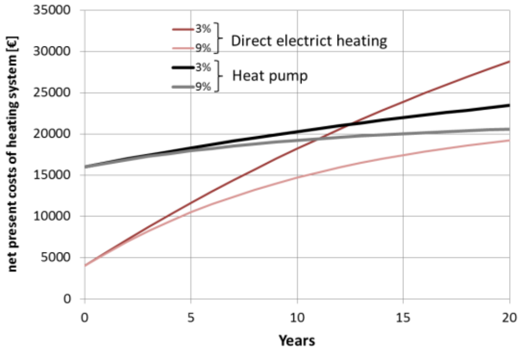


Figure 8: Left: Net present value per m^2 floor area for an investment in thermal renovation and discount rates from 0% to 15%. Right: Net present costs of direct electric heating versus heat pumps for discount rates of 3% and 9%.

It is clear that in reality the decision making process of homeowners for thermal renovation measures and heating systems is more complex. It includes several non-monetary factors (e.g. comfort, environmental considerations) and the way in which the monetary investment appraisal is conducted varies between investing agents. The approach that models decision making implemented in INVERT/EE-Lab which incorporates those influencing factors is described in the following section. Irrespective of those additional aspects the discount rate attributed to agents in the model is still one of the main drivers for decision making in the model.

2.2.3 INVERT/EE-Lab decision approach

On the meso level, the Invert/EE-Lab Model (Müller, 2015; Steinbach, 2016) is used to derive scenarios for the possible development of the European building stock and the related heating and cooling demand under three different framework conditions. The Invert/EE-Lab model is a bottom-up (with some top-down elements) techno-socio-economic simulation model, which has been developed to evaluate the effects of different policy packages on the total energy demand, energy carrier mix, CO2 reductions and costs for space heating, cooling, domestic hot water preparation and lighting in buildings.

Two calculation procedures constitute the core calculation kernel of the model. First, a sound energy-calculation tool is implemented. This is done based on the Austrian implementation (ÖNORM B8110 1-6) of the energy calculation standard ISO 13790 and the energy demand of the technical building equipment (ÖNORM H5055). This allows the Invert/EE-Lab tool to derive the energy needs and energy consumption consistent with the procedure that is applied for the Energy Performance Certificates of buildings. Second, a calculation procedure has been developed and implemented which endogenously anticipates decisions of investors in building related energy efficiency technologies (thermal renovation) and heating systems (including PV and solar thermal collectors).

In the model, the decision process is implemented as a two-step procedure. In the first step, the decision of whether or not to replace, refurbish or maintain an existing system (e.g. heating system or building envelope). These decisions are mainly taken on the observed survival rates of building components using Weibull distributions. However, if only such a technical approach where any economic criteria do not factor in at all is considered, it might result in poor results for policies that increase the average price of available options. In such case one could argue that people could keep their equipment longer than observed in place and are willing to use them for a longer period of time. Therefore a feed-back from the results economic assessment has been implemented in the model. A full description of the calculation process and equations are given at Mueller (2015).

In the second step, the net utility (perceived utility minus perceived costs) of each available alternative is calculated for each investor type and building set. Market shares are then derived by a nested logit model. In this process not only hard factors, such as investment costs, saved energy expenditures, subsidies or financing costs are considered, but also soft factors such as historic decisions made by peer groups, environmental attitudes, expectations regarding comfort levels, perceived access to capital or willingness to take loans or time preferences. A more detailed but general description of the implemented process is described in deliverable 3.1, discussion paper of the BRISKEE project (Kranzl et al., 2016[2]), a comprehensive set of equations and detailed description are given at Müller (2015) and Steinbach (2016).

In order to derive results, which reflect real world observations, this procedure heavily depends the calibration of parameters. While these parametrization of variables was done based on expert guesses and the interpretation of data provided by literature in previous projects, we are using the survey performed in the BRISKEE project to review and/or recalibrate some of our core assumptions in the Invert/EE-Lab model. The reviewed assumptions address the cause why people decide to set some actions and whether or not there is empirical evidence that the weights of different decisions criteria vary strongly between different demographic groups (age and income) and countries of homeowners, or if a more general and universal pattern emerges from the survey results.

The following equations briefly describe the parameters influencing the decision algorithm implemented in Invert /EE-Lab. A Nested Logit approach defines the core of the Invert/EE-Lab's

2 Deliverable 3.1: Discussion paper on scenario definition and integration of WP2 in modelling

decision algorithm. For each alternative, the model calculates a utility V (see 7A.1.1) based on a implemented utility function and weighting factors for different criteria. The Utility V for a technology option j (which is part of the nest n) in a certain building type b at a given period t is then derived by the weighted sum the Utilities U_c for considered decision criteria i.

$$V_{j,b,t} = \sum_{c=1}^{C} w_{c,a} \cdot \frac{U_{c,j,b,t}}{\widehat{U}_{c,j,b,t}}$$

$\widehat{U}_{c,j,b,t}$	…Mean value of all $U_{c,j,b,t} \leq 3 \cdot \widehat{U}_{c,j,b,t}$
C	…Set of decision criteria, e.g. rentability, investment costs, comfort, environment
U_c	…Utility of criterion c
$w_{c,a}$	…Weight of criterion c for agent a

Note that the discount rate is therefore not the only parameter influencing the decision making process of agents in the model. Different weights can be attributed to each parameter and agent group. The discount rate defines the interest rate on which the agents monetary investment appraisal is based. Then there are different weights for each agent for different attributes of renovation measures and heating systems. For renovations the model distinguishes weights for investment costs, profitability and comfort. If an agent would purely decide based on the overall profitability of a renovation measure including future energy savings and investment costs the weighting factor for “profitability” would be set to 1. However, we know from WP2 survey results and previous projects such as Entranze[3] that building occupants also take the expected level of living comfort into account. On top agents typically put more weight on investment costs rather than on the overall profitability, which can be included by assigning weights to the parameter “investor” for an agent. The weights of all renovation parameters have to add up to 1. Note that the effect of putting more weight on investment costs has similar effects as increasing the implicit discount rate of an agent. The discount rate of the INVERT/EE-Lab model can therefore not directly be compared to implicit discount rates of other models.

The choice for heating systems is modelled in a similar way distinguishing between economic weights and non-economic weigths for the investment appraisal of agents. On the economic side weights can be attributed to investment costs, payback time of the investment and the overall profitability of a heating system. Non-economic parameters distinguish between sustainability (environmental friendliness) and comfort.

Due to the fact that the surveys in WP2 did not show significant differences between most of the agents with regard to the weighting of parameters implemented in INVERT/EE-Lab only the

[3] http://www.entranze.eu/

discount rates of low income agents compared to median income agents were adjusted. The survey results also reveal that agents typically rate several criteria as import or very important in their decision making process. The top five criteria are Performance, Energy costs, Indoor comfort, Investment costs and Environmental friendliness (see deliverable 5.1, Figure 4). In INVERT/EE-Lab this is reflected by assuming relatively equal weights for those criteria. As significant differences between agents with regard to those weights were hard to justify from WP2 survey results, they do not differ between median income and low income agents in the model. In the project ENTRANZE it was found that discount rates between agents from different countries can differ substantially. The results from the BRISKEE survey confirm these differences between low, medium and high income countries. (see deliverable 2.2 Figure 2 and Figure 3) Relatively high differences between discount rates for the low income countries Poland and Romania were observed, while the difference between medium and high income countries is less pronounced. We set 4%, 5% and 8% for high, medium and low income countries respectively as default discount rates for median income agents per country. Table 2 provides an example for parameters assumed for the majority of central European member states. Assumption for all member states can be found in Annex 7A.4.

For a discussion on the influence of changes in discount rates on the model results please see section 2.2.4.

Table 2: Example for parameters used to model the decision of agents in INVERT/EE-Lab

Agent group	**discount rates**	**Renovation weights**			Heating systems weigths						
		Investment	**profitability**	**comfort**	**Economic weight**	investment	payback time	profitability	**non-economic weight**	sustainability	comfort
Median income agent	**4%**	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Low income agent	**7%**	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55

2.2.4 Sensitivity analyses of discount rates and other investment barriers in INVERT/EE-Lab

In this section, we describe the impact of discount rates and other investment barriers in the model INVERT/EE-Lab. Before defining the policy scenarios illustrated in 3 we conducted a sensitivity analysis to estimate the general impact of changes in discount rates. Table 3 shows an overview of assumptions for the scenario runs calculated for the sensitivity analysis performed with INVERT/EE-Lab. The first run is based on the default assumptions for discount rates for investments in thermal renovation and heating systems, which are assumed to be between 2% and 9% in most EU member states. Discount rates of low income agents are assumed to be between 2% and 5% higher than discount rates of median income home owners. Next we define a set of additional parameters to estimate the sensitivity of final energy demand development with regard to changes of discount rates which are shown in Figure 9. We vary the discount rate between 1% and 20% for all agents and add scenarios in which we only reduce discount rates of low income agents to the level of median income building occupants. Additionally we also test the impact of an additional parameter in INVERT/EE-Lab which indicates how much weight the agents attribute to initial investment costs instead of the overall profitability of the investment.

Table 3: Overview of assumptions for sensitivity analysis on the impact of discount rates in INVERT/EE-Lab

Sensitivity Scenario name	Description
Default discount rates (DR)	Default assumptions for discount rate for all agents
High DR including barriers	Discount rate of 20 % for all agents
Low DR + no other barriers	Discount rate of 1 % for all agents
Default DR + low weight on investment costs	Default assumptions for discount rate for all agents and lower weight on initial investment costs
Lower DR for low income agents	Discount rate of low income agents is lowered to discount rate of median income agent
Lower DR for low income agents + low weight on investment costs	Discount rate of low income agents is lowered to discount rate of median income agents and lower weights on investments

We observe a significant impact of the assumptions of discount rates on the overall model outcome. Final energy demand is expected between 10% lower for the low discount rates of 1% compared to the high discount rate run of 20% as thermal renovations appear to be less attractive for agents. Note that still thermal renovation takes place as in most countries the agents have to fulfill required building performance standards in most countries. The difference varies between 5% and 20% within the simulated EU 28 member states. Figure 9 shows the results for the sensitivity analysis for Belgium and France. For high interest rates the final energy demand in Belgium is expected to be decline from around 80 TWh in 2012 to around 60 TWh in 2030. For low discount rates final energy demand for space heating and hot water declines to around 52 TWh. In France the final energy demand declines from around 380 TWh in the year 2012 to 330 TWh in the high discount rate scenario and 290 TWh for low discount rates.

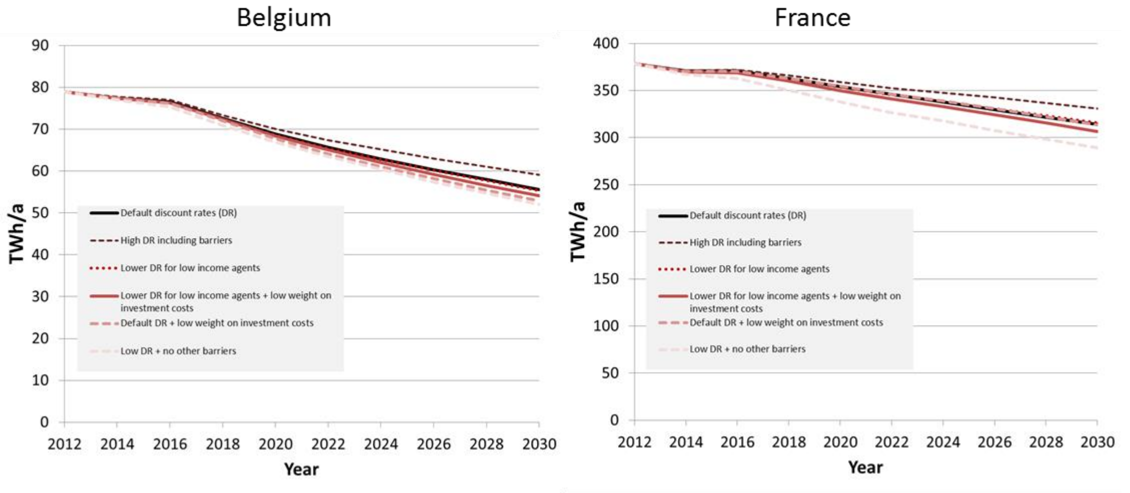


Figure 9: Results for sensitivity analysis of the impact of discount rates on final energy demand

Figure 10 illustrates the development of specific heat demand of building classes including the service sector in Belgium between 2015 and 2030 simulated in INVERT/EE-Lab for the high and low interest rate scenario. The blue areas indicate the buildings that have been thermally renovated within this period, while the grey area indicates buildings where only maintenance measures have been performed. The red area illustrates the heat demand of new buildings. It can clearly be seen that under the assumption of low interest rates significantly more buildings are renovated while in the high interest rate scenario the majority of agents would choose to only perform minimum maintenance measures. It can also be seen that the thermal efficiency of new buildings is significantly lower for the low interest rate assumptions as investors tend to opt to invest more in the building envelope. The average specific heat demand for high interest rate assumptions in Belgium in 2030 is estimated to be 98 kWh/m^2 versus 84 kWh/m^2 for very low interest rate assumptions. Similar simulation results are observed for the other EU 28 member states and it can be confirmed from a modelling point of view that the discount rate of consumers significantly affects the uptake of efficiency measures.

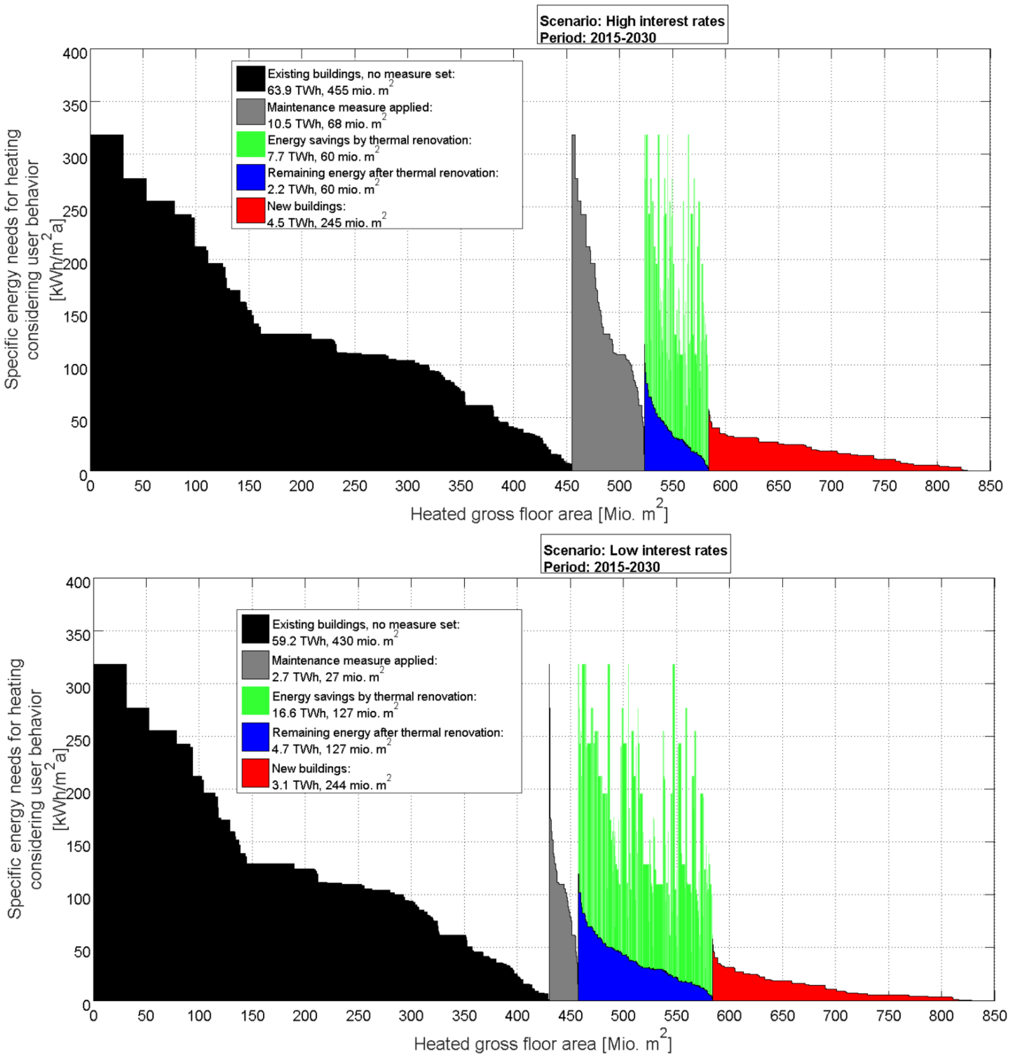


Figure 10: Results for sensitivity analysis of the impact of discount rates on renovation activities

The other sensitivity runs, which have been conducted, all lie within those two extremes of very high and very low discount rates. They also reveal that other barriers and also assumptions on the way in which agents conduct their investment appraisals affect simulation results. From a policy perspective, it seems to be unrealistic to influence the discount rates of all agents in the building stock. However certain measures can be taken (special loans, information campaigns etc.) to specifically address agents with expected high discount rates. Those measures can influence the attitude and expectations towards efficiency measures of households. Within the sensitivity analysis it was found that if policy measures would be able to reduce the discount rates of low income agents, energy demand of the EU 28 building stock could be around 1.5% lower compared to an intensified policy scenario. This scenario will be further discussed in chapter 5 of this report.

2.3 Residential appliances and lighting

2.3.1 FORECAST approach for decision-modelling

For calculating the energy demand projections of residential appliances, the model FORECAST-Residential[4,5] is used. FORECAST is a bottom up energy demand model covering the EU-28 as well as Norway, Switzerland and Turkey, in which the energy demand is simulated on individual member state level, distinguishing a variety of energy demand end-uses. For residential electricity use, the model covers large appliances (refrigerator, freezer, dishwasher, washing machine, and dryer), cooking, lighting, ICT appliances (television, set top boxes, laptop and desktop computers, monitors, routers/modems), air conditioning and small appliances (not distinguished due to a limited data basis).

FORECAST-Residential is a vintage stock model allowing a detailed modelling of the stock turnover, taking into account the development and diffusion of autonomous and policy-driven innovations in energy efficiency of appliances, lighting and air conditioning over the years. For each year, the end-use types that are available on the market are exogenously specified, taking into account policy requirements. The alternative choices that are available on the market differ both in energy efficiency and in their respective purchase prices.

The market share of each appliance type is modelled as a result of individual investment decisions. The investment decisions are modelled as a discrete choice process, where household decision makers choose among alternative technologies competing with each other (see e.g. (Revelt & Train, 1997)). Labelling has an influence on the investment decisions of consumers, directing preferences towards more energy-efficient devices (Bull, 2012). Without Energy Labelling (or when most products have reached the highest Labelling class), consumers lack information about the life-cycle costs of appliances. A number of recent studies show that information on life-cycle costs has a significant effect on the investment decisions of consumers and contributes to lowering the discount rates for residential appliances (Kaenzig & Wuestenhagen, 2009; Consumer Focus, 2012).

Figure 1 provides a schematic overview of our modelling approach. The global parameters setting the framework for electricity demand modelling are the end consumer prices and the number of households. The ownership rate is projected using a Bass model. The annual electricity demand

4 FORECAST (FORecasting Energy Consumption Analysis and Simulation Tool) is a modelling platform that captures the final energy demand of the industry, residential, tertiary, transport and agriculture sector (http://www.forecast-model.eu).

5 In addition, FORECAST-Residential also captures the useful and final energy demand for heating purposes, which are not part of this study (Elsland, Bradke, & Wietschel, 2014).

is calculated as the product of the specific consumption per end-use and efficiency category and the corresponding stock.

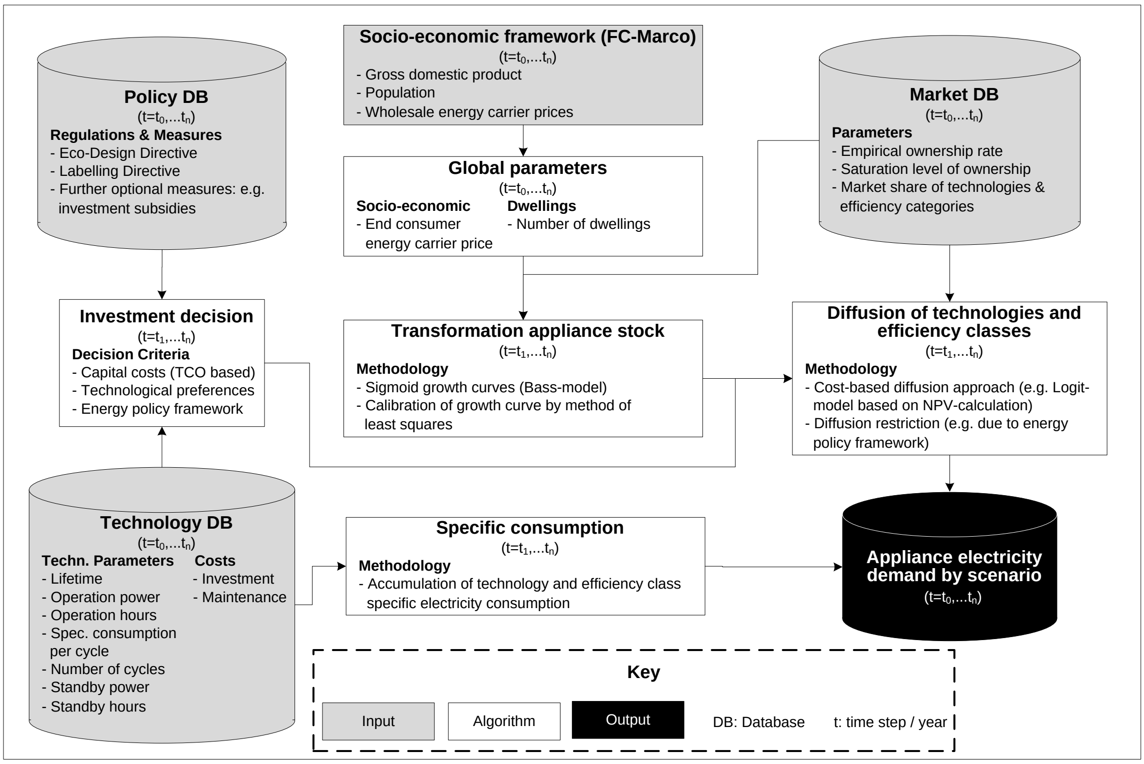


Figure 11: Overview over the modelling approach. Source: (Elsland, Schlomann, & Eichhammer, 2013). The key elements of the modelling of technological change include the policy database, the technology database and the investment decisions. These aspectsare discussed in more detail in the text.

The diffusion of energy efficiency technologies is determined by the consumers' investment decisions, which in turn depend on the technological specifications of the appliances that are on the market (technology database) and the policy measures (Policy DB) that are in place. Each of these parameters is discussed in detail in the following.

- Technology database: The technology database contains the technological specifications of the appliances including their lifetime, specific power in operation and stand-by mode, operation and stand-by hours and investment as well as maintenance costs. For the historical years, the data is collected from the Ecodesign documents, market research institutes and manufacturer data. The data is defined on an annual basis, such that technological innovation is reflected in the time that new, high-efficient appliances enter the market. Prices are determined based on the current price and learning curves derived from historical data. Due to a lack of empirical data, the stand-by and operation hours are assumed to remain constant over the projection time period

- Policy database: The policy database defines the policy measures that are in place. For residential appliances, the two most relevant policy measures are the Ecodesign directive and the Energy Labelling directive. The Energy Labelling directive influences the decision-making processes both at firm level and consumer level. For firms, Energy Labelling provides an incentive to develop and commercialize energy efficient products. For consumers, Energy Labelling provides transparency regarding the electricity consumption, thus enabling consumers to take into account the total cost of ownership approach in their purchase decisions. The impact of Energy Labelling on the development of new technologies has been subject to an increasing number of studies in recent years (Edler, 2013) (Schiellerup & Atanasiu, 2011). Labelling policies have an effect on appliance manufacturers, whose direct innovation efforts towards the development of products in higher efficiency classes. The evidence suggests that the rate at which appliances with higher efficiency classes enter the market increase when Labelling policies are in place (PSI & BIOIS, 2011). In our modelling approach, the range of different options on the market is specified exogenously in the technology database. The assumption to what extent Labelling enhances the speed at which new appliances appear is therefore a critical input parameter that influences the evolution of electricity demand. Minimum energy performance standards (MEPS) are modelled by restricting the market share of new appliances starting in the year the standards come into force (Elsland, Schlomann, & Eichhammer, 2013). In our modelling approach, MEPS are implemented by restricting the exogenously specified range of different options on the market. The Ecodesign and Labelling legislations are designed to act in a combined way, where Ecodesign "pushes" the lower end of the market whereas Labelling "pulls" the higher end. Our modelling approach takes into account the interactions between the two policy measures, such that the total electricity savings calculated by the combined implementation of the two measures differ from the savings when implementing the measures in two consecutive runs of the model. Our results in the diffusion scenario therefore display the combined savings of Ecodesign and Labelling, taking into account their interactions.

- Investment decision: Labelling has an influence on the investment decisions of consumers, directing preferences towards more energy-efficient devices (Bull, 2012). Without Energy Labelling (or when most products have reached the highest Labelling class), consumers lack information about the life-cycle costs of appliances. A number of recent studies show that information on life-cycle costs has a significant effect on the investment decisions of consumers and contributes to lowering the implicit discount rates for residential appliances (Kaenzig & Wuestenhagen, 2009; Consumer Focus, 2012). The implementation of the investment decision process in FORECAST-Residential follows a multinomial logit-approach, where the market share Sk for a given technology option k is calculated using equation (1), with U denoting the utility function and the sum over Uk running over the N available alternatives. The logit model also includes a parameter v representing the heterogeneity in the market.

$$S_k = \frac{e^{-\nu U_k}}{\sum_{j=1}^{N} e^{-\nu U_j}} \tag{1}$$

The utility function is determined by the annuities of the different available options, the energy cost (Ec) and the maintenance cost (Mc) and is calculated by eq. (2). The annuities are calculated using the discount rate i, the investment cost Ik and the lifetime T.

$$U_k = \beta_{0k} + \beta_{1k} \cdot \sum_{t=1}^{T} \frac{I_k}{(1+i)^t} \frac{(1+i)^T\, i}{(1+i)^T - 1} + \beta_{2k} \cdot Ec + \beta_{3k} \cdot Mc \tag{2}$$

2.3.2 Descriptive statistics of survey

Market shares of energy efficiency technologies

The BRISKEE survey is a representative online survey conducted in households in eight EU countries (FR, DE, IT, PL, RO, ES, SE, UK) in July/August 2016, with 1500 to 2000 observations per country. The survey participants were asked if they had purchased one of the following four appliances within the past five years: refrigerators, freezers, dishwashers, washing machines. They were then screened for their most recent purchase, such that the subsequent questions addressing the participants' criteria for energy efficiency investments are based on their real purchase decision. Table 4 displays the number of participants that resulted from the screening, reflecting the most recent investments.

Table 4: Survey appliances and sample sizes by energy end-use

	FR	**ES**	**DE**	**IT**	**PL**	**RO**	**SE**	**UK**	**Total**
Total sample	2000	2001	2002	2000	2008	1529	1515	2000	15055
Appliances bought within the past 5 years (2012-2016), most recent purchase:									
Refrigerator	522	485	436	519	483	502	224	539	3710
Freezer	149	121	155	106	77	93	94	155	950
Washing machine	583	629	642	744	753	604	294	630	4879
Dishwasher	387	278	328	274	310	65	259	183	2084
Appliances, total	1641	1513	1561	1643	1623	1264	871	1507	11623

The market shares of lighting technologies in the survey countries are shown in Figure 11. The share of LEDs is particularly low in Romania (only 25 % market share). Despite the Ecodesign requirements that removed incandescent light bulbs from the market from 2013, respondents still stated purchases in 2014 and later, especially in Romania (26 %).

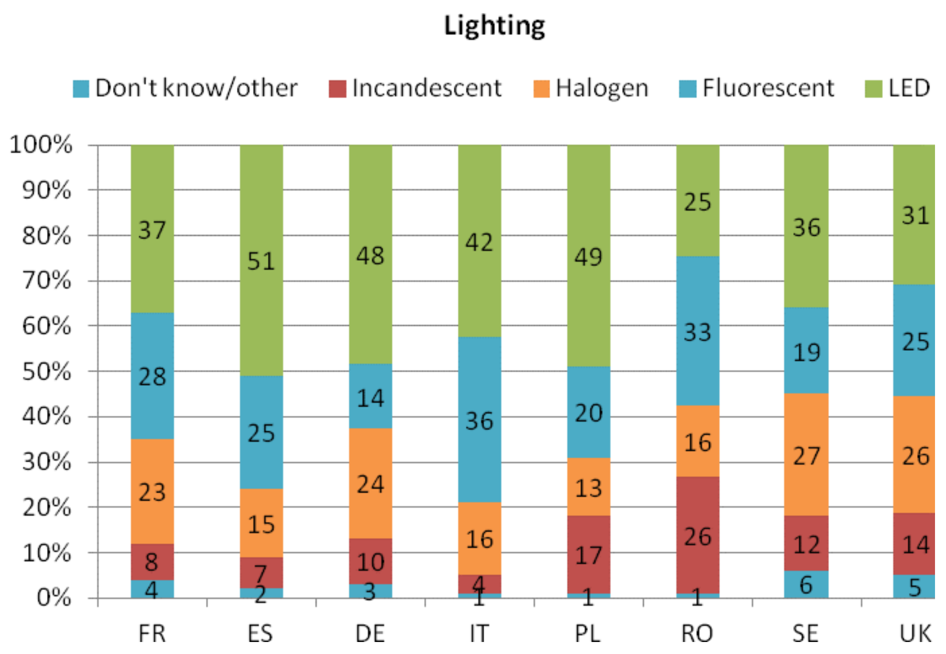


Figure 12: Lighting technology shares in the eight survey countries (last purchase in 2014-2016)

According to US DOE 2014, LEDs reach a market share of 84 % in 2030, which was used as a projection node of market shares in the survey countries. The market shares in the survey countries were transferred to their analogy countries in the model.

The shares of EU efficiency classes for the four appliances included in the survey (refrigerator, freezer, washing machine, dishwasher) in the respective periods are shown in . In France, the UK and Sweden, top efficiency classes have a lower market share than in the other countries, and the share of households that do not know the efficiency class is higher.

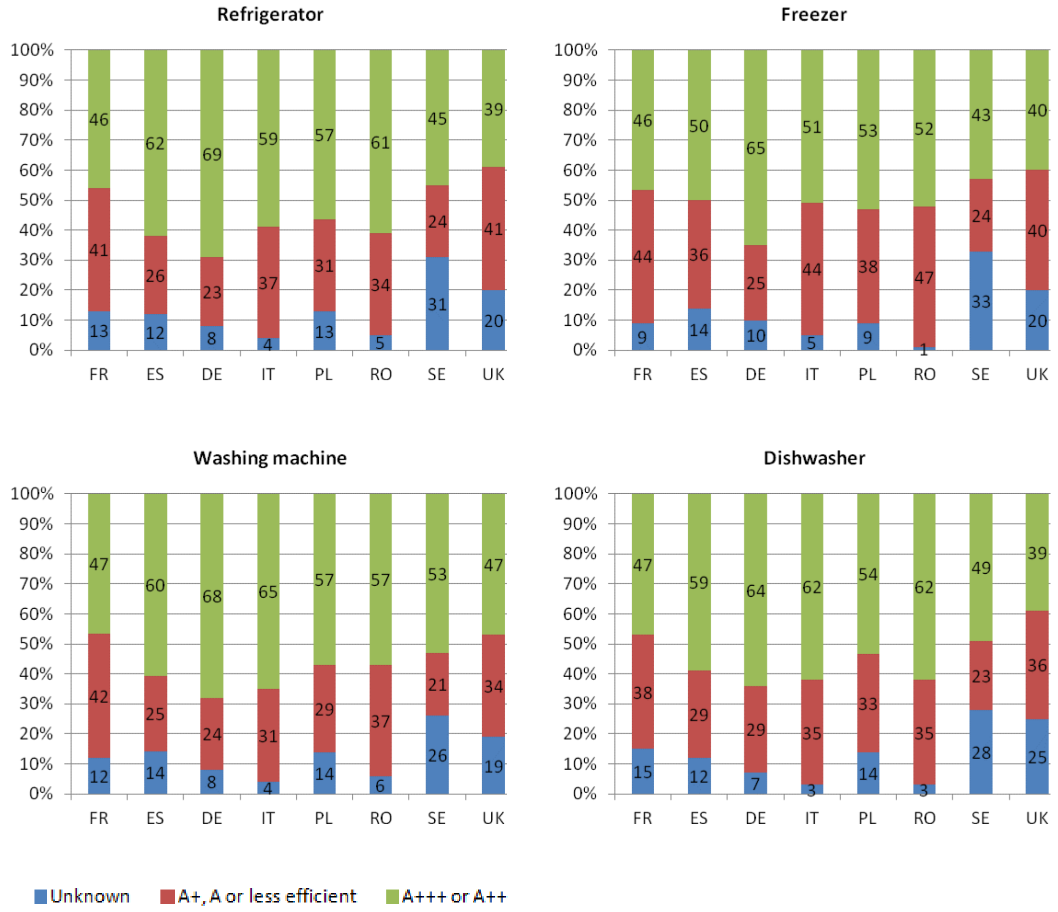


Figure 13: Market shares of efficiency classes for the four appliances included in the survey

Share of enivronmentally conscious households

A population group with high environmental identity was defined for one scenario in each country using the BRISKEE survey. The survey included a scale by Cardiff University (Whitmarsh and O'Neill 2010) with four statements on respondents' environmental identity (rated from “strongly disagree” with value 1 to “strongly agree” with value 5):

- To save energy is an important part of who I am.
- I think of myself as an energy conscious person.
- I think of myself as someone who is very concerned with environmental issues.
- Being environmentally friendly is an important part of who I am.

Respondents who gave an "agree" answer for all statements with at least two"strongly agree" answers were defiend as environmentally conscious. The shares of environmentally conscious households in the model are shown in Figure 14.

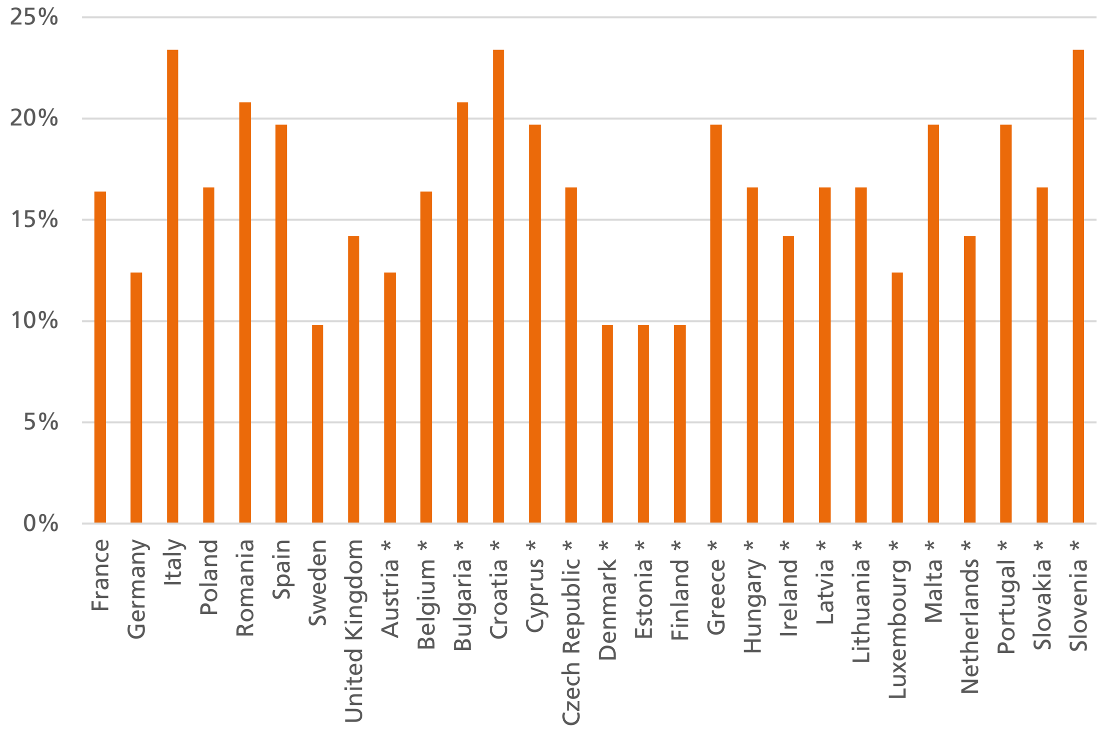


Figure 14: Share of environmentally conscious households in the scenario, data from the BRISKEE survey, definition above. Countries included in the survey without *. For countries with * share transferred from analogy country

Purchase criteria by different population groups

This section presents our analysis of the BRISKEE survey data considering the factors that influence purchases of enregy efficient household appliances using the methodological approach outlined in Section 2.1. The following attributes were covered in the analyis: 1) Differences between countries, 2) gender, 3) income, 4) environmental identity and 5) age.

Relevance of EU member state

The relevance of different purchase criteria was analysed for all participating countries and for each country individually. Figure 15 shows the ratings of the criteria.

Performance and *purchase price* are considered to be important or very important purchase criteria. *Energy cost, energy label, environmental friendliness, design* and *recommendations by professionals* are rated in between important and neither important nor unimportant. The least importance was found in the criteria *financial support measures* and *recommendations by friends and families*.

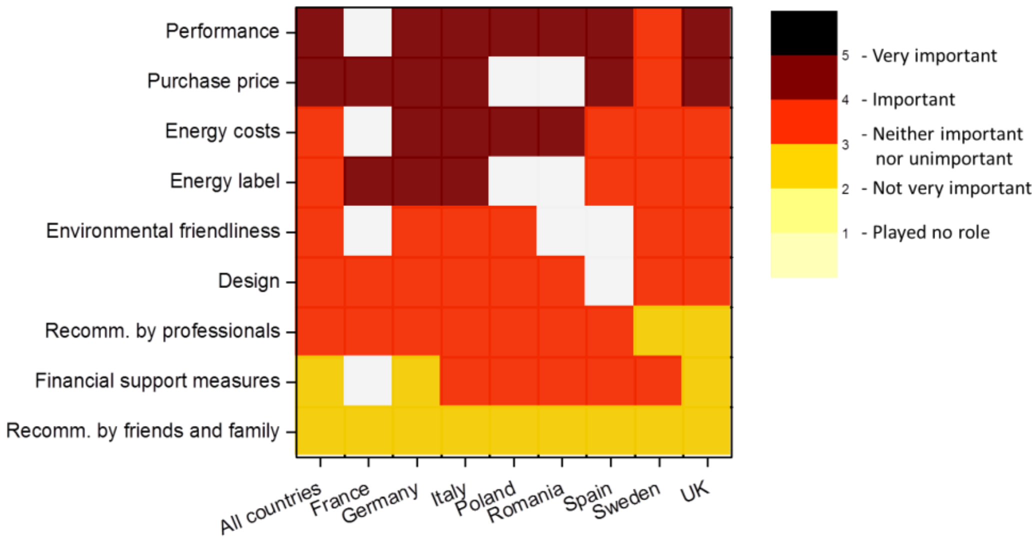


Figure 15: Mean value of purchase criteria for appliances between all participants and different counties. According to the t-test, **not** significantly different results of the different countries compared to the overall countries mean value are left in white.

The differences between the mean values in individual countries and the mean values of all countries was calculated (Figure 16).

The biggest differences were found for the rating of the criteria *financial support measures*. Further, it can be seen, that in general participants from Italy, Poland and Romania rated most of the criteria more important, while participants from Sweden and UK rated most of the criteria less important.

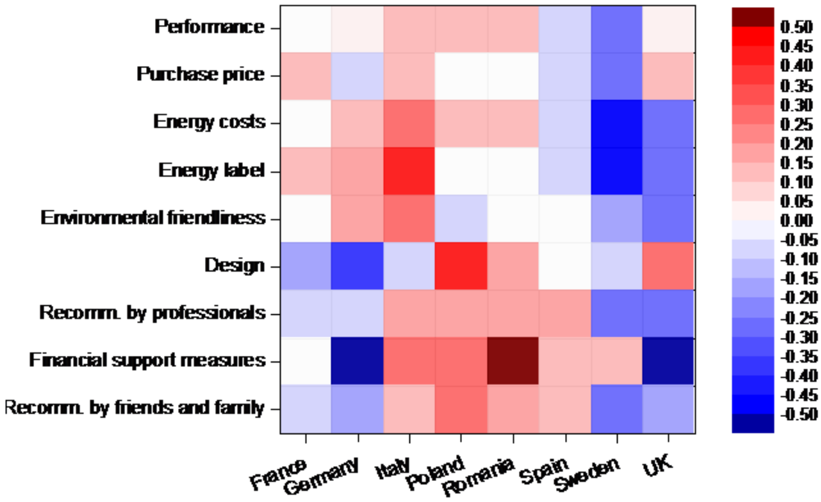


Figure 16: Difference between the results of an individual country divided by the result of all countries. A higher (lower) importance for a purchase criteria of participants of a country is indicated in red (blue). According to the t-test, *not* significantly different results are left in white

Relevance of gender

The difference between the mean values of the rating of purchase criteria by female and male participants is shown in Figure 17. In general, women tend to answer more positive, which is in good agreement with other studies (Dalen & Halvorsen, 2011). Dalen et al. found gender differences in how people respond to questions about hypothetical policy measures, where females tend to be more positive on average (Dalen & Halvorsen, 2011). However, our findings show, that gender does not contribute substantially to the purchase criteria for appliances.

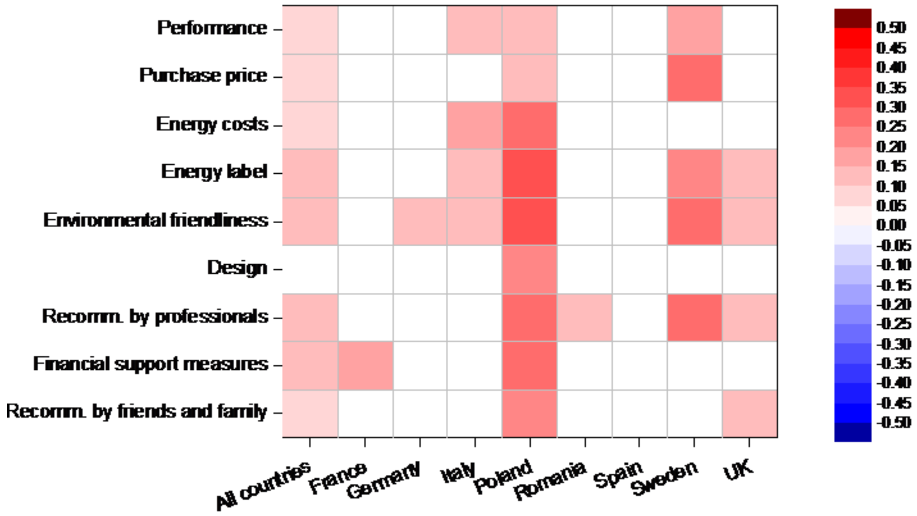


Figure 17: Difference between mean values of purchase criteria for the different countries for female and male participants. In red (blue) are shown more positive ratings by female (male) participants. According to the t-test, *not* significantly different results are left in white

Relevance of income

In order to analyse the role of income, the survey participants were divided in two groups: high-income and low-income households. For the High-income group, households with more than 49000€ income per year were considered. For the low-income group households with less than 7200€ income per year were considered. Due to the difference in income distribution in the participating countries, the groups differ in size (Figure 19). The threshold values were chosen in a way that each group consists of a minimum of 70 members

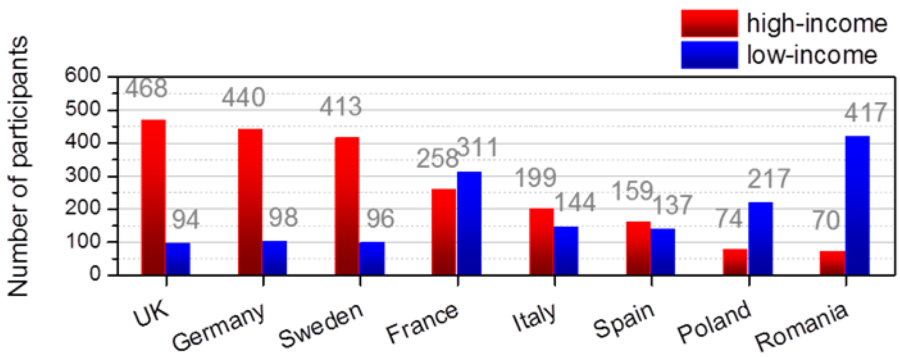


Figure 18: Income distribution for high- and low-income participants in the different countries.

The relevance of the different purchase criteria between participants of all countries with high- and low-income varies for several criteria (Figure 19, All countries). The biggest difference in the mean value concerning all countries was observed for *financial support measures*.

Concerning the different countries, the criteria *performance and energy label* were rated more import by high-income participants in all countries except France. For the low-income participants, the criteria *financial support measures* was rated more important in all of the individual countries. *Recommendations by friends and family* was rated more important by high-income participants in Poland and the UK. In the other countries the criteria was rated less important by high-income participants.

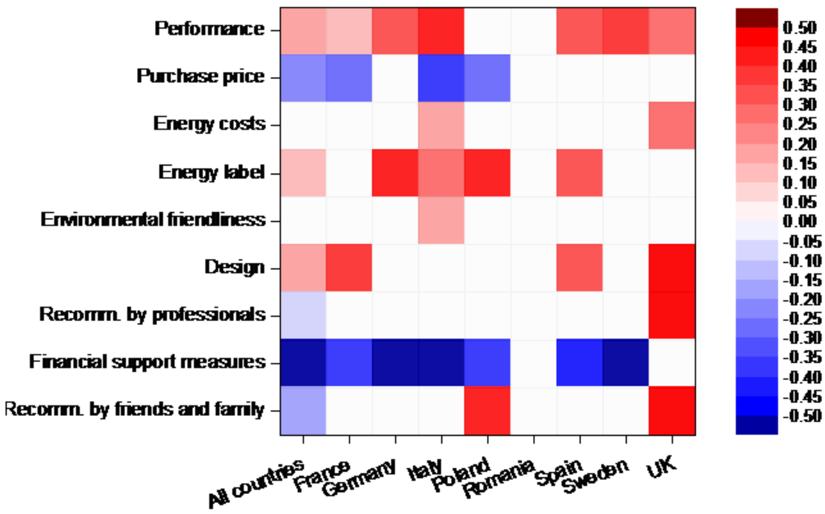


Figure 19: Difference between mean values for purchase criteria for appliances comparing *high-income and low-income* participants. In red (blue) are shown more positive ratings by high-income (low-income) participants. According to the t-test, *not* significantly different results are left in white.

The findings show, that the income of the participants contributes rather strongly to the purchase criteria for appliances. Especially directly payment influencing criteria (e.g. *purchase price* and *financial support measures*) are rated more important by low-income participants. The higher relevance of financial support measures may be explained by the fact that several countries have implemented support schemes that are accessible only to low-income households, such as e.g. the German program "Stromspar-Check" (Seifried & Albert-Seifried, 2015). Criteria which influence the payment in a long term (e.g. *energy costs*) are not considered as important by low-income participants. The results agree with earlier studies in which low-income and lack of capital are seen as barriers which inhibit EE investments (Ugarte et al., 2016). Low-income households are more likely to lack both savings to cover the higher initial investment costs for EE technologies and access to credit. These barriers are likely to be much less relevant for higher-income individuals (Ameli & Brandt, 2015). Further, high-income households might have the financial flexibility to invest in better performing products. Therefore, as our findings show, the criteria *performance* was rated with more importance for high-income participants than for low-income participants.

Relevance of environmental identification

In the following, the purchase criteria of consumers with different environmental concern were analysed by comparing participant with a stated high environmental identification and a stated low environmental identification. The groups were defined according to the survey question if saving energy is an important part of who they are. Participants who stated that they agree or strongly agree were considered in the group of strong environmental identification, while participants who stated, that they strongly disagree, disagree or neither agree not disagree were considered in the group of weak environmental identification. The numbers of participants of each group are shown per country in Figure 20.

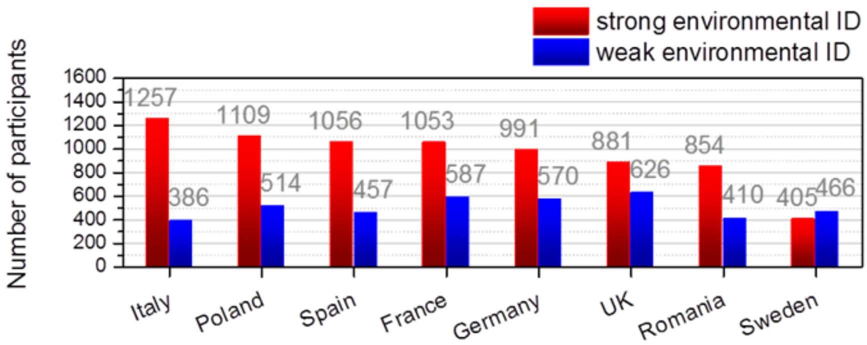


Figure 20. Distribution for participants with strong and weak environmental identification (ID) for the different countries

The difference in rating the purchase criteria between the two groups is shown in Figure 21.

The analysis shows that the group of stronger environmental ID gives in general more importance to all purchase criteria. The criteria *energy costs*, *energy label* and *environmental friendliness* show the largest differences.

Survey participants that state that energy saving is an important part of who they are rate *energy label*, *energy costs* and *environmental friendliness* significantly more important than consumers with lower environmental identity. However, the effect of higher ratings is seen, to a lesser extent, also for the remaining purchase criteria. This indicates that part of the effect is due to the fact that, in general, some participants tend to provide higher ratings than others (independent of the question).

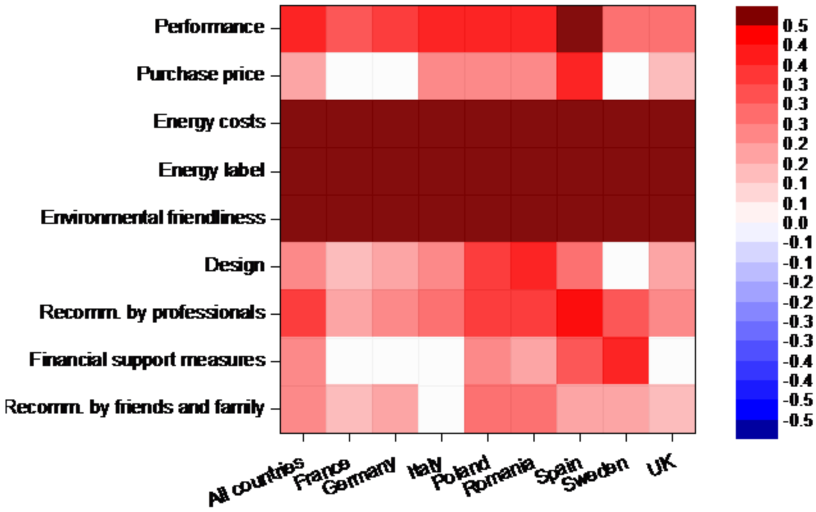


Figure 21. Relevance of environmental identification. In red are shown more positive responds by participants who have strong environmental identification. According to the t-test, *not* significantly different results are left in white.

Relevance of age

The relevance of age was analysed for the different purchase criteria by dividing participants in 12 groups (see Figure 22): 18-21 years, 22-25 years, 26-29 years, 30-33 years, 34-37 years, 38-41 years, 42-45 years, 46-49 years, 50-53 years, 54-57 years, 58-61 years and 62-65 years. Differences between the mean values per age group compared to the total average mean values are shown inFigure 23.

The results suggest that age is not a main parameter for the relevance of purchase criteria.

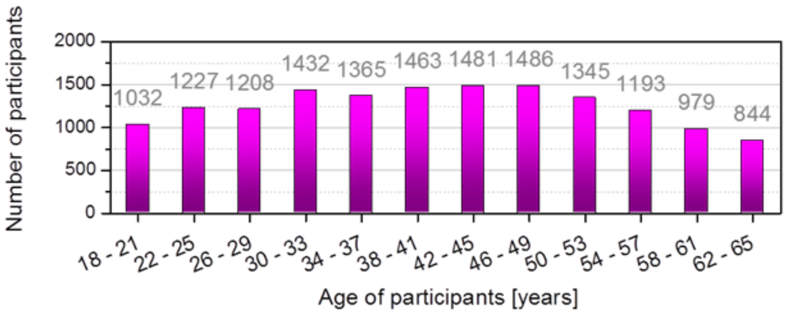


Figure 22: Number of participants with repsect to their age, divided in 12 groups

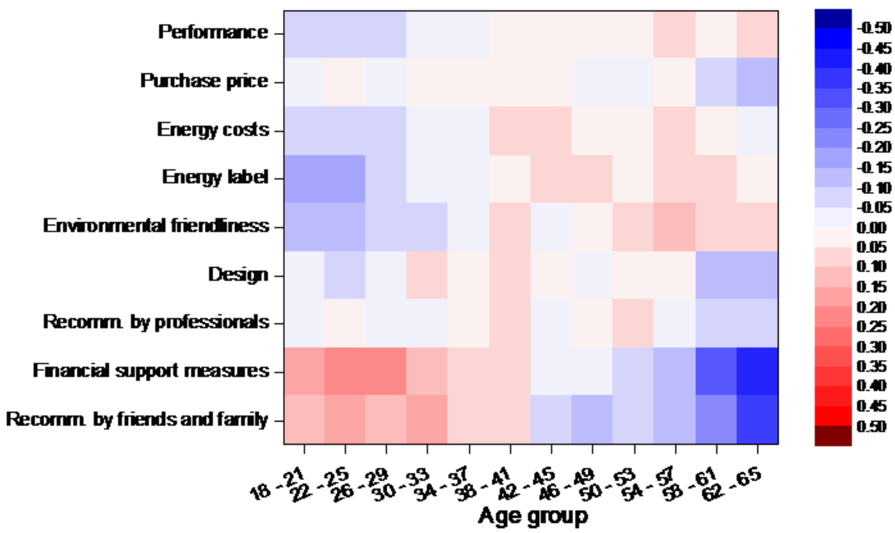


Figure 23: Differences between ratings of purchase criteria of age groups as compared to the mean value of all participants. In red (blue) are shown more positive (negative) ratings by the age group as compared to the overall mean value.

Relevance of number of children

The relevance of different purchase criteria were analysed for the number of children of the participants for all countries. The participants were divided in five groups with no children, one child, two children, three children and more than three children. The distribution among the groups is shown in Figure 24.

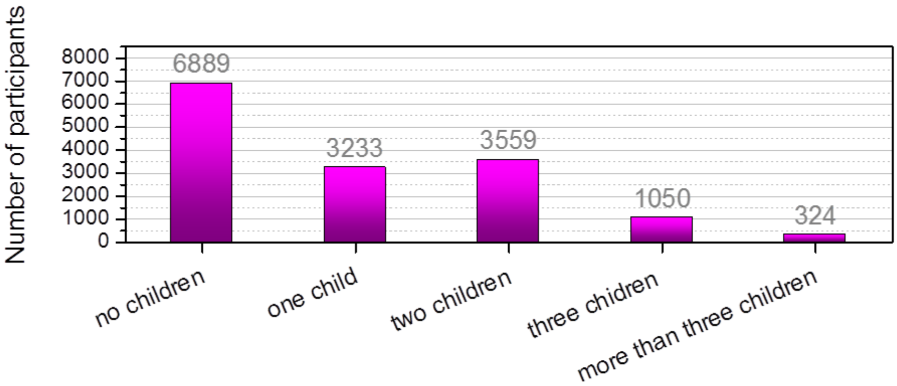


Figure 24: Distribution of participants having no children, one child, two children, three children or more than three children.

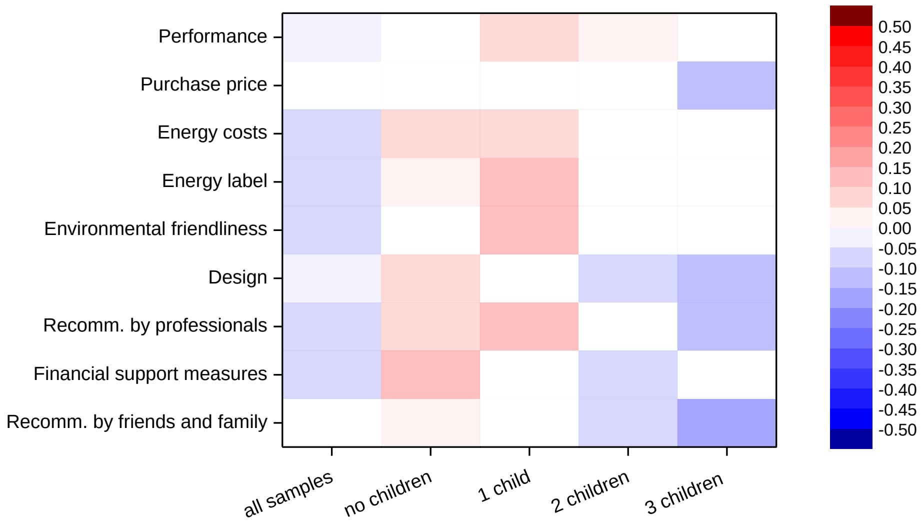


Figure 25: Differences in ratings for purchase criteria for appliances depending on the number of children compared to the overall mean values. In red (blue) are shown more positive (negative) ratings by a group as compared to the overall mean value of the other participants. According to the t-test, not significantly different results are left in white

The differences in ratings, depending on the number of children compared to the overall mean values, are displayed in Figure 25. Generally, the effects of the number of children in the households purchase criteria are very weak.

2.3.3 Impact of discount rates on the choice of appliance efficiency levels

Appliances are available in varying levels of energy efficiency and high-efficiency appliances tend to be more expensive at purchase than less efficient appliances. The service delivered by an appliance can be considered identical for white goods appliances and lighting across all efficiency levels. Therefore energy costs are assumed to be a major decision criterion when purchasing these appliance types. This was also confirmed in the BRISKEE survey as presented in section 2.3.3.

Similar to the discussion for building technologies, a high discount rate (DR) in the choice process means preferring a lower up-front cost and accepting higher energy costs during the usage period after that. A lower discount rate puts more emphasis on low energy costs and directs the choice towards products with a higher purchase price but higher efficiency.

The fundamental ideas regarding the impact of discount rates presented for the buildings in section 2.2.2 are valid for appliances as well. The major differences in the impact result from the differing lifetime of appliance investments and the different ratio of investments and energy costs. For example, the average appliance price in Germany for A++ fridges is only half of that of A+++ refrigerators with 35 % less energy consumption, according to BRISKEE research. Due to the often large difference in purchase price, more efficient appliance options tend to be less attractive financially than in the buildings sector. This also limits the effect of a lower discount rate.

An indicative analysis illustrates this. A comparison between one scenario (intensified-measures scenario defined below) with discount rate 20 % and the same scenario with discount rate 2 % shows the effect of the discount rate for washing machines in France and refrigerators in Germany. Figure 26 shows more efficient energy classes gaining slightly higher market shares with a lower discount rate. In 2030, the difference in specific energy consumption is 1.1 %. Figure 27 shows more efficient energy classes gaining slightly higher market shares with lower discount rate. The difference in specific energy consumption is 2.7 % in 2030.

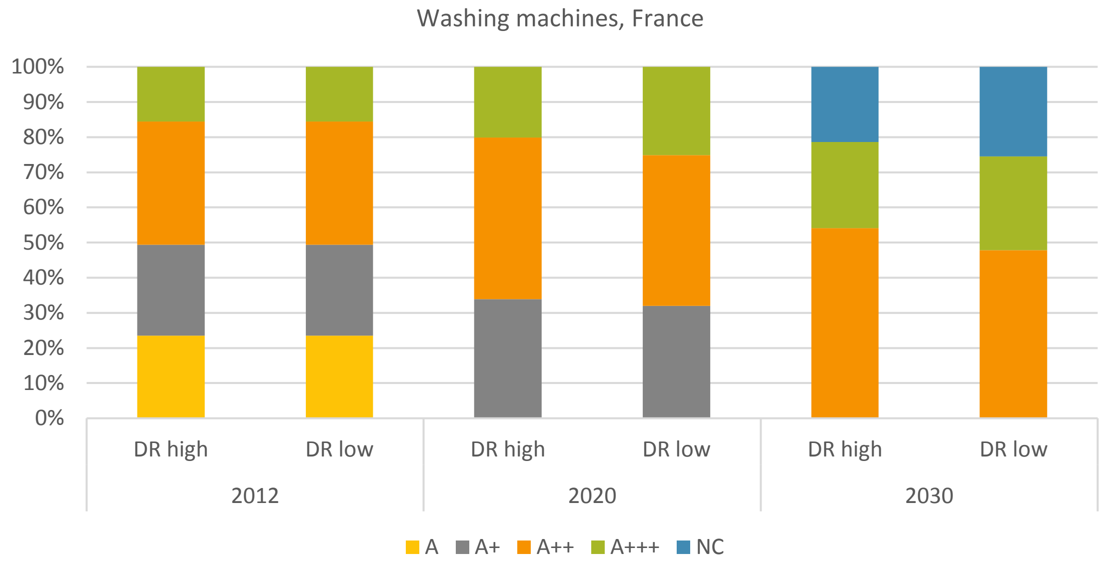


Figure 26: Market shares of energy classes for washing machines in France in scenarios with high or low discount rate (DR)

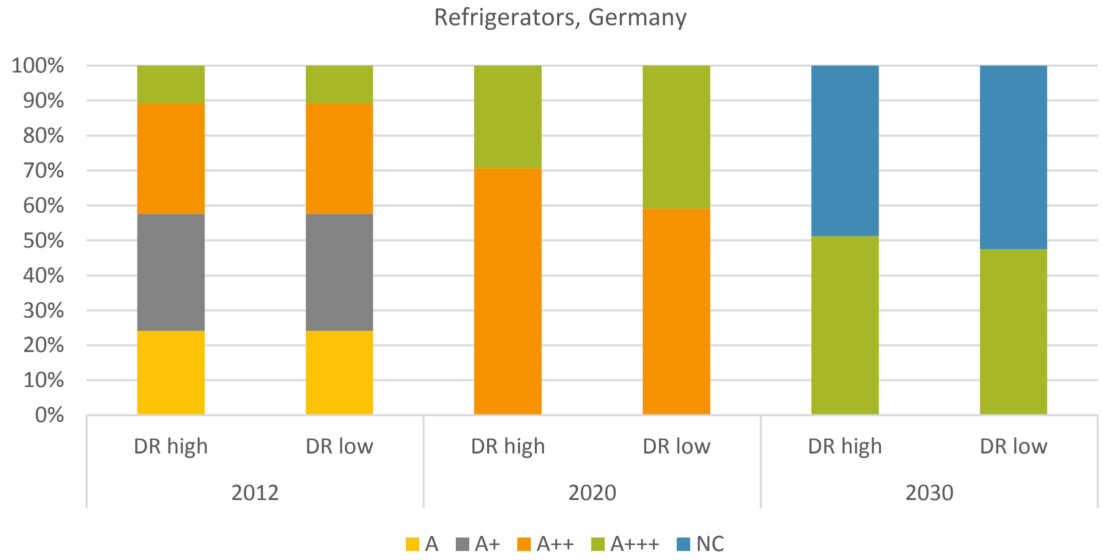


Figure 27: Market shares of energy classes for washing machines in France in scenarios with high or low discount rate (DR)

3 Modelling approach and scenario definition for the quantification of final energy demand and investments in the residential sector

In this chapter we present the approach of the BRISKEE project to quantify final energy demand and related costs in the residential sector until 2030. Figure 28 provides an overview of the modelling work in WP3. In general the analysis is split between heating and cooling including investments in the thermal efficiency and appliances. The starting point was the analysis of WP2 results focusing on relevant parameters for modelling agents. (please see the previous chapter 2). Based on the analysis the parameters defining agents behavior were implemented in the models INVERT/EE-Lab and FORECAST.

For the development of investments and energy demand in the building stock the Invert/EE-Lab model and it's building stock and technology database is used. The algorithm simulating consumer decisions has already been explained in chapter 2 and a detailed description of the methodology of INVERT/EE_Lab can be found in the Annex of this report or online at www.invert.at. The energy demand for household appliances, lighting, air conditioning and electronic devices is projected with the FORECAST model using a bottom-up approach that distinguishes individual technologies (see Annex or http://www.forecast-model.eu).

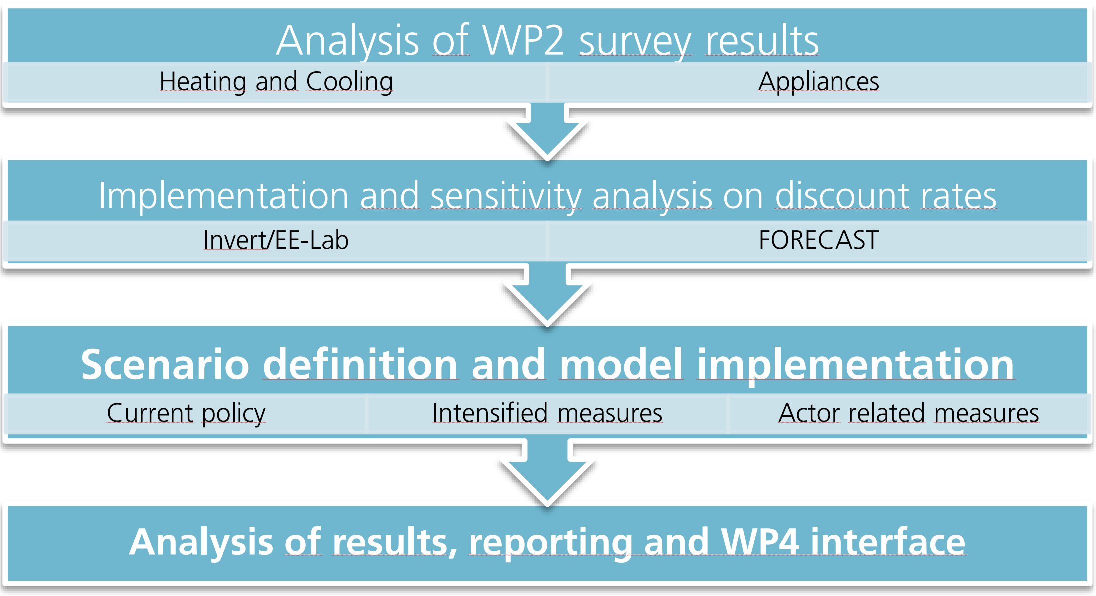


Figure 28: General approach of modelling work in WP3

Within the BRISKEE project we defined three scenarios for the which will be presented in chapter 4 and 5 of this report. All scenarios are calculated on country level for EU 28 member states until the year 2030. The first scenario is defined as a current policy scenario in which we assume that all measures implemented at present or foreseen in the near future will be in place until 2030. Please see the following sections on policies in buildings and appliances for details. In the second scenario we assume that existing measures are intensified (e.g. through higher subsidies, stricter building codes or labelling requirements). Both scenarios are based on the assumptions on default discount rates derived from previous projects and WP2 survey results. Finally we define a third scenario in which new actor-related measures are assumed. We keep the same assumptions on policies including monetary measures from the intensified scenario but assume that policy measures are applied that affect the discount rates and decision behavior of low-income agents. We chose those assumptions for the 3rd intensified scenario because 1) it seems to be a more realistic policy measure to address the discount rates of certain agents rather than of all agents in the building stock and 2) because WP2 results suggest that low income groups typically have higher implicit discount rates than other investing agents. The 3rd new actor related scenario therefore shows the impact of policies that would lead to lower discount rates of low income agents which could consist of information campaings, contracting or special loans or other non-monetary support schemes.

Within this report the results will be presented first for the current policy scenario to give the reader an overview of most likely developments and provide him with a feeling for the magnitudes of developments in the building stock and for appliances. Finally the results of each scenario are exchanged with the macro-economic model ASTRA to provide inputs for the macro effects of different discount rates and policy measures. The outcome of this analysis will be shown in upcoming deliverables of WP4 by the end of 2017.

In order to ensure comparability with the PRIMES projections, drivers such as the international fuel prices, the energy wholesale prices, the number of dwellings and the carbon prices were adapted from the most recent PRIMES projections, the EU Reference Scenario 2016.

3.1 Assumptions for residential buildings

For space heating and domestic hot water related energy efficiency measures, three policy sets (as described above) regarding energy efficiency were specified. The model INVERT/EE-Lab allows for wide range of policies to be defined for each country. For existing policies a major data source for defining the inputs for the model is the MURE database which includes descriptions of polices measures such as:

- Minimum energy performance standards (MEPS) set by the ecodesign directive

- Minimum energy performance standards for major refurbishments and newly constructed buildings, including the definition of Nearly Zero Energy Buildings (NZEBs) defined in the national implementations of the Directive on Energy Performance of buildings.
- Energy taxes for different energy carriers
- Investment subsidies, grants, soft loans (considering constrains regarding the absolute support level either per building or dwelling as well as restricted national budgets per country and support instrument) for different types of refurbish measures and building types as well as investments into technologies to utilize renewable energy carriers.
- “Soft measures” such as reducing the information barrier and increasing the compliance rate through the introduction of energy performance certificates, information campaigns, or reducing the diffusion barrier through workforce education, etc.

The policy descriptions lead to the following implementation in the simulation:

- Investment subsidies for building renovation (three options for building envelope refurbishment)
- Investment subsidies for heating supply systems
- Investment subsidies for solar thermal systems
- Country specific public budgets for subsidies
- Obligations regarding the implantation of renewable heating supply systems
- Building codes: improvement of technical building standards for new and renovated buildings (building envelope)

Building renovation

The INVERT-EE-Lab model consists of three renovation options, which are standard renovation and two intensified renovation options, as well as a maintenance option without any improvement of the building envelope. The quality and costs of the different options vary between the designed scenarios.

Specific heating energy-uses covered

In the INVERT/EE-Lab model, the following building related energy usage types and energy carriers are covered:

- Space heating: oil, gas and coal powered heating systems, biomass heating systems, electricity convectors and heatpumps
- Domestic hot water: oil and gas systems, biomass powered water heating, electrical converters and heatpumps
- Auxiliary energy: technology related auxiliary energy demand of heating systems
- Cooling: energy demand for cooling

Scenario-independent drivers

The energy demand of residential buildings and for the usage types mentioned above depends on a variety of exogenous drivers, which are the same for all scenarios. These drivers include, number of buildings/dwellings, floor area, climate development, solar yield, fuel prices.

Scenario implementation for residential buildings

The current policy scenario definition for BRISKEE was done based on the policy descriptions described above. The intensified scenario consists of a more ambitious set of measures in the same manner as the current policy set. For the New actor-related measures scenario, the policy set from the intensified scenario is adopted, but a different consumer behaviour concerning investment behaviour and information awareness especially for low income groups is assumed. Table 5 provides an overview on all three scenarios for residential building.

Table 5: Overview of the scenario definition for residential buildings

Scenario name	Implementation for residential buildings
Current-policy scenario	Scenario with current policies while including more detailed modelling of the decision-making of households based on survey data. The "Current-policy scenario" considers targets and measures concerning RES-H/C and energy efficiency which have been decided or already implemented. On the European level, the relevant policy implications are particularly set by the Renewable Energy Directive, the Energy Efficiency Directive, the Directive on Energy Performance of buildings, and the Ecodesign Directive.
Intensified-measures scenario	The intensified measures scenario assumes that the policies that are implemented currently are intensified; however, the policy approaches remain the same. For example, a country that currently relies on minimum efficiency standards would continue to use this approach; however, the standards would be defined in a more ambitious way.
New actor-related measures scenario	The new actor-related measures scenario assumes that energy efficiency policy is complemented by new policy measures affecting the discount rate of low income agents.

Current-policy scenario

The current policy scenario incorporates decided or already implemented targets or measures concerning the diffusion of renewable heating and cooling and energy efficiency measures in building envelopes.

The implementation of the policy measures are specified per country and therefore depend on the country specific implementation of the policy programs shown in Table 6. (e.g.: favouritism of investment subsidies for renovation actions or mandatory building codes).

The monetary measures for building renovation include investment subsidies, ranging from about 10% to 40% of the investment among member states, as well as commonly defined public budget restrictions. The definition of these country specific measures was done by incorporating the policy implementations developed during the projects *Mapping and analyses of the current and future (2020-2030) heating/cooling fuel deployment (fossil/renewables)* and *ZEBRA 2020*. For countries, which were not within the scope of the conducted surveys, or which have a rather small impact on overall scope of the EU28 the measure definition was done by scaling of measures from focus countries with similar characteristics.

Intensified building codes, reflecting the improvement of technical building standards for new and renovated buildings (building envelope), were implemented by adjustment of the thermal quality of the main parts of buildings through tightening of the u-value definition. Policy driven changes of building codes were implemented on country level, covering about 80% of the European building stock, which includes the countries within the scope of WP2 surveys.

Monetary measures for heating systems were implemented as investment subsidies, for each heating system, ranging from about 20% to 40%, restricted by overvall public budget per member state.

In some member states also renewable heating obligations were implemented as share on the final energy demand per household which has to be covered by renewable sources, ranging from 20% to 50%.

An overview of the different policies targeting energy efficiency and RES in the end-uses categories space heating and cooling as well as domestic hot water heating considered in the current-policy scenario is given in Table 6.

Intensified measures scenario

In the intensified-measures scenario, policy measures implemented in the current-policy scenario were intensified in order to evaluate the potential of the existing measure scheme by outlining a more ambitious pathway. The policy approach regarding the applied set of instruments remain the same. No additional instruments were introduced.

With regard to the model implementation of policy instruments described above, the modifications were done by increasing investment subsidies and corresponding budgets on country level, tightening the obligations for renewable heating, and intensifying the building codes by reducing the heat transfer coefficient of the building components after refurbishment and for new buildings.

Table 6: Overview of policy measures implemented in the current policy scenario

	EU leg.	Current-policy scenario
Regulations / Information		
Energy efficiency standards for renovation	EPBD	National building code requirements, 2015 or planned tightening as far as data available
Energy efficiency standards new buildings	EPBD	National implementation of NZEB standards after 2018 (for public buildings) and 2020 (for all buildings). Development of building codes until 2018/2020 according to national action plans for nZEBs.6
Increase of renovation rate	EED	3% renovation rate achieved until 2020 in central government buildings. Renovation obligations in case of real estate transactions as far as they are currently implemented.
RES obligation	RED	Current implementation in Member States (only for new buildings in few countries)
Technology standards	EDD	MEPS for all lots for which regulations have been implemented before 29 February 2016:
Support of CHP and DHC	EED	Realization of lower limit of economic feasible CHP and DHC potentials
Energy labelling	ELD	Mandatory for new H/C devices
Financial policies		
Energy saving obligation	EED	Current implementation in Member States with regard to applicable and supported technologies
Energy and CO2 taxation	ETD	Taxes varying by fuel and sector
Subsidies for building renovation	National	Ongoing subsidy programs (MURE-DB)
Subsidies for efficient fossil fuel technologies	National	Ongoing subsidy programs (MURE-DB)
Subsidies for RES technologies	National	Ongoing subsidy programs (MURE-DB)

New actor-related measures scenario

The new actor-related measures scenario was designed in order to evaluate the potential and impact of actor related measures. The decision module of the INVERT/EE-Lab model can distinguish between several agents representing different types of investor behaviour, as it was briefly discussed in 2.2.3 The actor-related measures scenario assumes that energy efficiency

6 Detailed nZEB definitions are very hard to compare and to implement on a detailed level. Simplifications are necessary regarding the specific definition of indicators and national calculation methodologies.

policy, consisting of investment subsidies, building codes and renewable heat obligations, is complemented by new policy measures affecting the discount rate and decision behavior of low income agents. Changes in the parameters defining agent behaviour were therefore only done for low income agents. The scenario therefore shows the potential impact of policies that would lead to lower implicit discount rates of low income agents such as information campaigns, contracting or special loans or other non-monetary support schemes.

In the input assumptions for the model we make two changes for each member state: 1) we set the discount rates of low income agents to the lower level of discount rates for median income agents; 2) we reduce the weight that low income agents attribute to investment costs by half compared to default assumptions and add more weight on the overall profitability or cost efficiency of renovation actions and changes of heating systems. Table 7 provides an example for parameters of low income agents in the actor related scenario compared to default assumptions for the majority of central European member states. Note that the parameters of median income agents do not change between the scenarios.

Table 7: Example for default and 3rd scenario parameters used to model the decision of agents in INVERT/EE-Lab

Agent group	**discount rates**	**Renovation weights**			Heating systems weights						
		Investment	**profitability**	**comfort**	**Economic weight**	investment	payback time	profitability	**non-economic weight**	sustainability	comfort
Median income agent	**4%**	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Low income agent - *default*	**7%**	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Low income agent – *new actor-related scenario*	**4%**	0.13	0.45	0.42	0.43	0.22	0.27	0.5	0.57	0.45	0.55

3.2 Assumptions for residential appliances and lighting

For household appliances, the main energy-efficiency policies are implemented in the FORECAST model as follows.

- Minimum energy performance standards (MEPS) set by the ecodesign directive are modelled by restricting the market share of new appliances starting in the year the standards come into force.
- The effect of Energy Labelling policies is modelled in two ways: On the one hand, Labelling policies have an effect on appliance manufacturers, who direct innovation efforts towards the development of products in the highest efficiency class. This effect is modeled through the introduction of new Labelling classes in the market. On the other hand, Labelling has an influence on the investment decisions of consumers, directing the preferences towards more energy-efficient devices. This information-based effect is modeled by adjusting the discount rate and thus assuming less emphasis on the costs in the near future, in particular initial purchase costs. This way, a higher share of consumers will select an appliance with a higher initial cost but lower total cost of ownership.
- Non-monetary barriers, discount rates and logit parameter:
    - *Barriers related to the lack of information:* Without Energy Labelling (or when most products have reached the highest Labelling class), consumers lack information about the life-cycle costs of appliances. A number of recent studies show that Energy Labelling has a significant effect on the awareness of consumers on the life-cycle costs and contributes to lowering the discount rates for residential appliances. However, especially for low-income households the lack of capital for investing in appliances with higher efficiency leads to purchases with higher than optimal life-cycle costs.
    - *Lack of interest/preferences in product features:* For products where the purchase decision depends strongly on product features and is influenced only marginally by life-cycle-cost considerations (e.g. ICT appliances), a low logit parameter is chosen to reflect the limited sensitivity on life-cycle-costs.

Scenario-independent drivers

The energy demand of household appliances depends on a number of exogenous drivers such as the number of households, the appliance ownership rates, electricity prices and the lifetime of appliances. These drivers are the same for all scenarios. Table 8 provides an overview over the main drivers and the data sources used in this project.

Table 8: Main scenario-independent drivers

Driver	Source
Number of households	EU Reference Scenario 2016
Rate of ownership	Odyssee and own projections
Appliance Stock in base year	GfK
Appliance lifetime	Ecodesign implementing measures
Electricity and gas wholesale prices	EU Reference Scenario 2016
Appliance investment price in base year	GFK, Eurostat
Yearly operation hours	Eco-design documents

Scenario implementation for residential appliances

BRISKEE includes three scenarios for energy demand in the residential secotr. The same approach is translated to the energy demand for appliances. The definition of the three appliance scenarios is presented as an overview in Table 9 and in more detail below.

Table 9: Overview of the scenario definition for appliances

Scenario name	Implementation for residential appliances
Current-policy scenario	All Ecodesign and Labelling measures that are adopted are explicitly modeled for refrigerators, washing machines, freezers, dryers, dishwashers, stoves and lighting and are modelled as an average over technologies for televisions, set-top boxes, laptops, desktop computers, computer screens, modems/wifi-routers and air conditioning
Intensified-measures scenario	Includes all measures implemented in the current-policy scenario and assumes that minimum standards are intensified and the label is rescaled. The rescaling of the energy label is assumed to increase its effectiveness affecting both consumers and suppliers so that more efficient appliances become available earlier.
New actor-related measures scenario	New instruments affecting actors are implemented in the model (and existing actor-relevant policies increased) taking into account findings from survey

Current-policy scenario

The current policy scenario includes currently available energy classes and foreseeable improvements. This scenario includes all measures that were decided upon until the year 2016. This includes various MEPS (see Table 10). In the current policies scenario, energy demand for New & Others is assumed to grow by 1.5 % per year over the entire period.

The current energy label allows consumers to include energy costs in their purchase decisions and this way contributes to a faster development of more efficient appliances. Subsidies for the purchase of very efficient applianes are not included in the current policy scenario.

Table 10: MEPS for white goods in the BRISKEE scenarios (actor-related measures scenario like intensified-measures scenario)

Appliance	Scenario	MEPS
Refrigerators	Current-policy scenario	EEI ≤ 55 from 2010 EEI ≤ 44 from 2012 EEI ≤ 42 from 2014
	Intensified-measures scenario	EEI ≤ 38 from 2020 EEI ≤ 28 from 2025
Freezers	Current-policy scenario	EEI ≤ 55 from 2010 EEI ≤ 44 from 2012 EEI ≤ 42 from 2014
	Intensified-measures scenario	EEI ≤ 38 from 2020 EEI ≤ 28 from 2025
Washing machines	Current-policy scenario	EEI ≤ 68 from 2011 EEI ≤ 59 from 2013
	Intensified-measures scenario	EEI ≤ 51 from 2019
Dryers	Current-policy scenario	EEI ≤ 84 from 2013 EEI ≤ 76 from 2015
	Intensified-measures scenario	EEI ≤ 64 from 2021 EEI ≤ 52 from 2022
Dishwashers	Current-policy scenario	EEI ≤ 80 from 2011 EEI ≤ 71 from 2013 EEI ≤ 63 from 2016
	Intensified-measures scenario	EEI ≤ 56 from 2021 EEI ≤ 52 from 2025
Lighting	Current-policy scenario	EEI ≤ 80 from 2010-2013 depending on technology EEI ≤ 60 from 2016
	Intensified-measures scenario	EEI ≤ 24 from 2019

Intensified-measures scenario

In the intensified policies scenario, ecodesign standards are made more ambitious betwen 2019 and 2025 (see Table 10). More efficient appliances become available faster due to the intensified measures.

Generally New & Others develop as in the current policies scenario while, from 2019, a share of 20 % of New & Others energy demand is taken to be affected by regulations. This share develops like the sum of the other end-uses, meaning slower growth or decreasing energy demand.

New actor-related measures scenario

The actor-related policies scenario includes all ecodesign measures included in the intensified policies scenario. Additionally, an information campaign, which includes a very strong energy label, decreases the discount rate of households from 20 % to 2 % so that energy-efficient appliances are more attractive.

The actor-related policies scenario for appliances includes three different population groups in each country. The majority of households has only a changed discount rate. Two smaller groups are low-income households and environmentally conscious people, which were identified as the most relevant groups in the BRISKEE survey. Low-income households in the scenario can receive a subsidy of 150 EUR when purchasing a white-goods appliance with energy class A+++ or better. In each country, it is assumed that half of the low-income households (shown in Figure 29) are aware of this programme and consider it in their purchase decisions. However, the difference in purchase price remains fairly large despite the subsidy and does not have a major effect on market shares for this population groups.

Environmentally conscious households (see Figure 14) are very responsive to the information campaign and improved energy label. These households from 2020 only buy the most efficient white-goods appliances and televisions. This strongly decreases the energy demand for this population group, making the main contribution in this scenario to the decrease in energy demand compared to the intensified policies scenario. In these households, also New & Others from 2019 develop much slower as energy consumption plays a stronger role for the household group also in this area.

General remarks

The scenarios do not include changes in the usage of the appliances. For future energy demand, the number of households and the rate of ownership are crucial. The number of households depends on the development of the population but also strongly on the age structure and changing lifestyles, which makes this important driver one of the largest contributors to uncertainty. As mentioned above, the number of household was used as estimated in EU Reference Scenario 2016.

A further element of uncertainty are appliance purchase prices. Based on previous empirical studies (Weiss et al. 2010), the FORECAST model assumes prices for all efficiency levels to fall steadily each year. If purchase prices for the currently most efficient appliances were to fall faster than for other appliances, more efficient appliances would become more attractive. However, Weiss et al. 2008 found indications that more efficient appliances do not become cheaper with higher speed. This may be since more efficient appliances usually mean incremental improvements of existing technologies and do not include a technology shift.

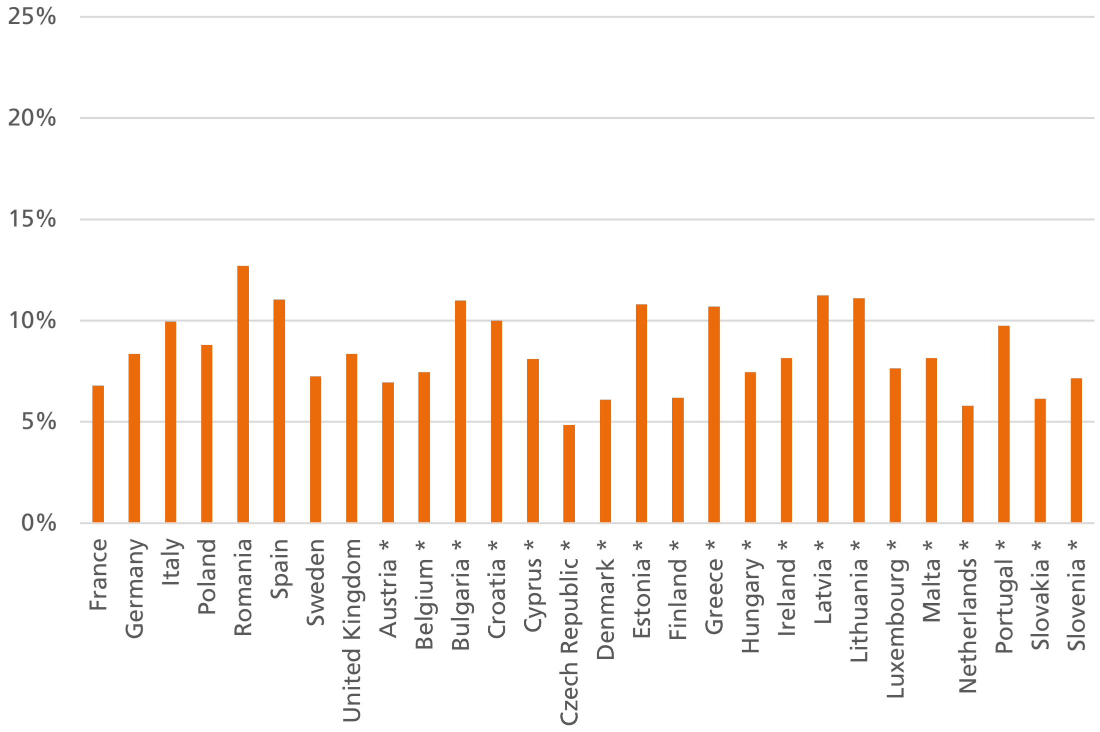


Figure 29: Share of low-income households informed about the possible subsidy in the scenario, original definition and data according to (Eurostat (EU-SILC survey [ilc_li02]), year 2015, extracted on 2017-05-23). Countries not included in the survey with *.

4 Results for current policy scenario

Before analyzing the impact of policies and discount rates in chapter 5 we give an overview of the modelling results for energy demand and cost developments until the year 2030 in the EU 28 member states in a current policy scenario in this chapter. Those quantitative results provide a baseline for the evaluation of policy effects in other scenarios. The main indicators are presented separately for heating and cooling in residential buildings and electric appliances in the residential sector.

4.1 Heating and Cooling in Residential buildings

In this section we illustrate the main indicators derived from the INVERT/EE-Lab model for a current policy scenario (see section 3.1) and the assumptions on discount rates derived from WP2 survey results. First, we illustrate the most likely estimation of energy demand developments for heating and cooling in the residential sector including the evolution of deployed energy carriers based on modelling consumer decisions within the building stock. Second, we show the related costs until the year 2030 with a focus on investments in thermal renovation and heating systems. All figures in this section are aggregated to EU 28 member states. However, model runs have been performed for each member state and selected country level results will be shown in chapter 5.

4.1.1 Development of energy demand for heating and cooling in the residential sector until 2030

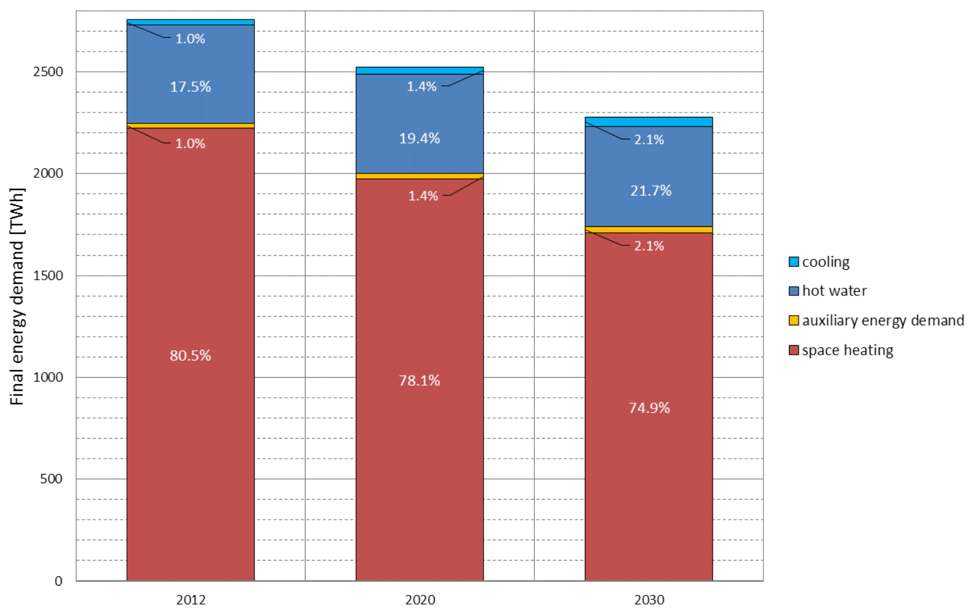


Figure 30 and Table 11 show the final energy demand results of the current policy scenario simulation for the main end use categories:

- space heating
- domestic hot water heating
- auxiliary devices
- cooling

Table 11: Final energy demand by usage types for EU28 in TWh

Final energy demand [TWh]	**2012**	**2020**	**2030**
space heating	2222	1973	1710
auxiliary energy demand	26	28	30
hot water	481	489	492
cooling	28	35	47
TOTAL	2757	2524	2279

It can be seen that the total final energy demand of the EU28 in 2012 amounts to 2757 TWh. 80% is caused by space heating, 17,5% by water heating and 1% by cooling as well as auxiliary devices. Within the current policy scenario the total final energy demand decreases by about 17% to 2279 TWh in 2030, due to energy efficiency gains and higher average temperatures. A slight shift in the share from space heating to water heating can be observed. Although space cooling demand is expected to increase by 70%, it still accounts for only a minor share of the final energy demand compared to space heating and domestic hot water supply.

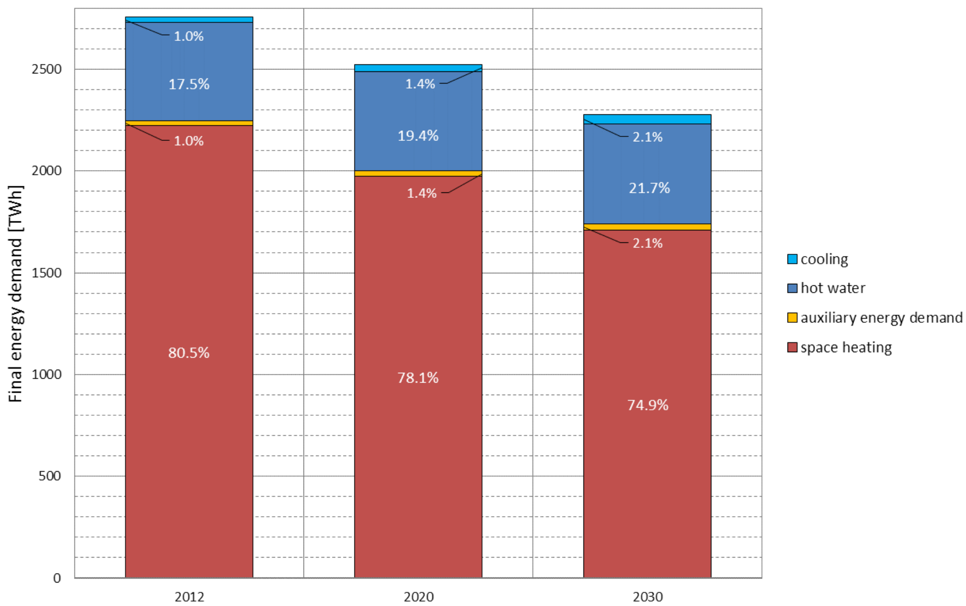


Figure 30: Final energy demand by usage types for the current policy scenario in EU28 in TWh

Figure 31 and Table 12 show the development of total final energy demand for heating and cooling per energy carrier from 2012 to 2030 in the current policy scenario. In addition, Figure 32 shows the shares of fossil fuels, renewable energy carriers (ambient heat, solar thermal and biomass), electricity and district heating.

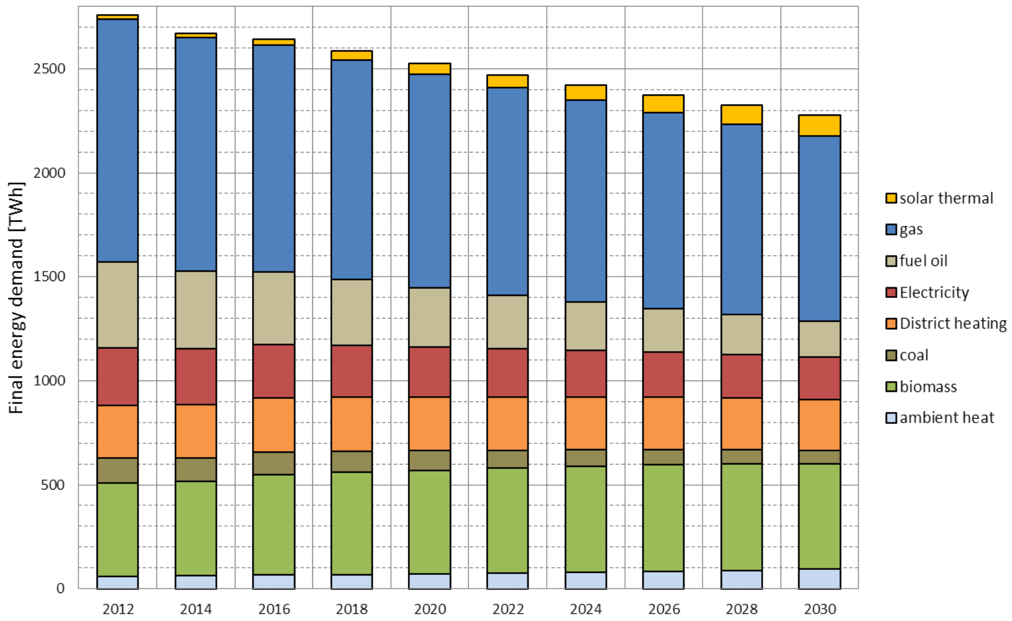


Figure 31: Final energy demand by energy carriers for EU28 in TWh

An increasing demand of renewable energy sources from 19% to 31% of the total demand can be seen, while demand for fossil fuels decreases from 62% to 49%. The decrease in fossils is mostly due to oil and coal demand reductions while demand for natural gas is less affected and is expected to still be the main final energy carrier used for heating in 2030 with around 39% of total final energy demand. Heat production from solar thermal, ambient heat (heat pumps) and biomass increases in absolute as well as relative terms and is expected to account for 31% of final energy demand for heating and cooling in 2030 compared to 19% in 2012.

Biomass is expected to be the most important renewable final energy carrier and is expected to account for around 22 % of heat supply in 2030. Model results suggest that final energy demand for electricity and district heating for heating and cooling purposes is slightly decreasing while their share in final energy supply is relatively constant. The decline in final energy demand for electricity is mainly due to the substitution of direct electric heating with more efficient heat pumps that allow to exploit ambient heat for space heating and hot water supply.

It should be noted that also heat from district heating and electricity is partly supplied by renewable energy carriers. The total share of renewables in primary energy supply depends on developments in the energy carrier mix for electricity and district heating which is not modelled in INVERT/EE-Lab.

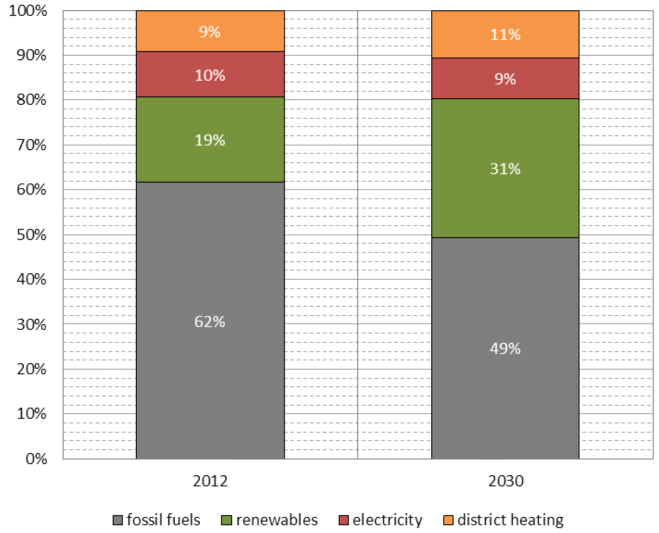


Figure 32: Share of energy carriers on final energy demand for the current policy scenario for EU28 in %

Table 12: Final energy demand for by energy carriers for the current policy scenario for EU28 in TWh

Final energy demand [TWh]	**2012**	**%**	**2030**	**%**
ambient heat	58	2.1%	94	4.1%
biomass	450	16.3%	507	22.2%
coal	120	4.3%	65	2.9%
District heating	254	9.2%	242	10.6%
Electricity	279	10.1%	208	9.1%
fuel oil	410	14.9%	172	7.5%
gas	1170	42.4%	888	39.0%
solar thermal	17	0.6%	104	4.6%
TOTAL	2757		2279	

4.1.2 Development of investments and expenditures in energy efficiency and renewable heat generation until 2030

This section briefly shows the investments and energy expenditures for heating and cooling and related investments in the thermal quality of existing buildings until 2030. Under the conditions of the current policy scenario the results for investments thermal renovation measures show an increase of the investments of about 29% from approximately 39 billion Euro in 2016 to slightly below 50 billion from 2026 to 2030 (see Figure 33). The subsidies granted for renovation actions according to the assumed subsidy regimes in each member state account for about six billion Euro in 2016 and slightly decrease to 5,4 billion in 2030. Although the amount of annual subsidies remain constant or even decreases in some countries, investments in thermal renovation still increases due to stricter building performance standards expected to be in place after 2020 on the one hand and higher prices for energy carriers which have been assumed in accordance with the EU reference scenario 2016.

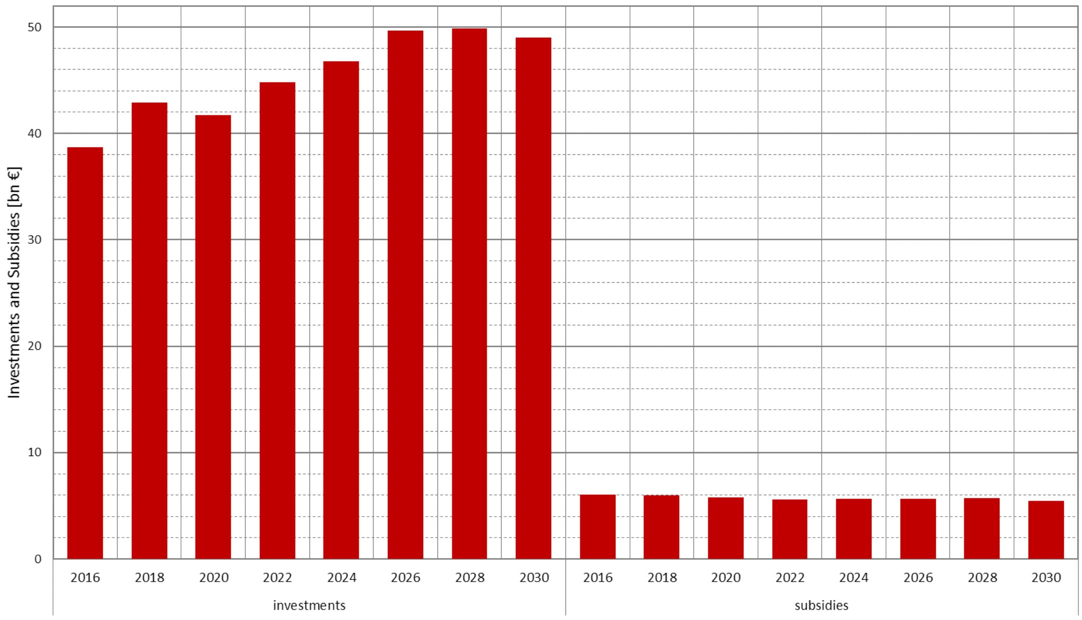


Figure 33: Investments and Subsidies in building renovation actions for EU28 in Bn €

Figure 34 shows results for annual investments in heating and hot water systems. In total, annual investments of about 45 billion Euro and public subsidies of about 3 billion Euro are calculated throughout the period between 2016 and 2030. While total investments are relatively constant, a shift towards investments in renewable heat supply technologies is expected. Figure 35 shows the investments for aggregated heating system classes. A clear shift from investments in fossil fuel system towards renewable energy technologies like solar thermal collectors and heat pumps can be observed.

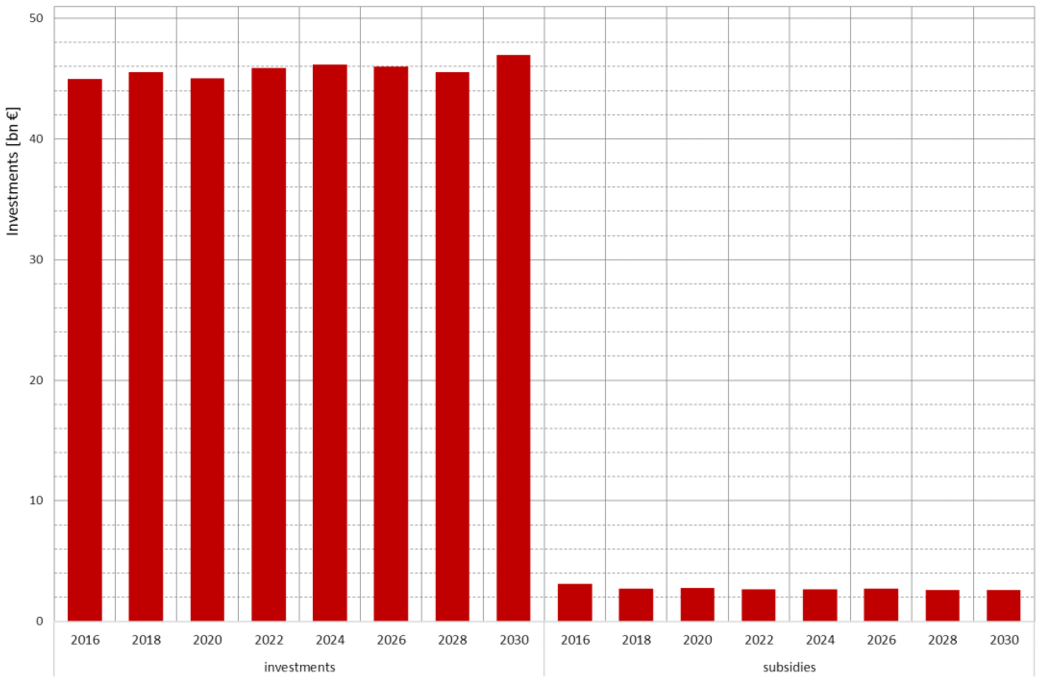


Figure 34: Investments and Subsidies in heating technologies for EU28 in Bn €

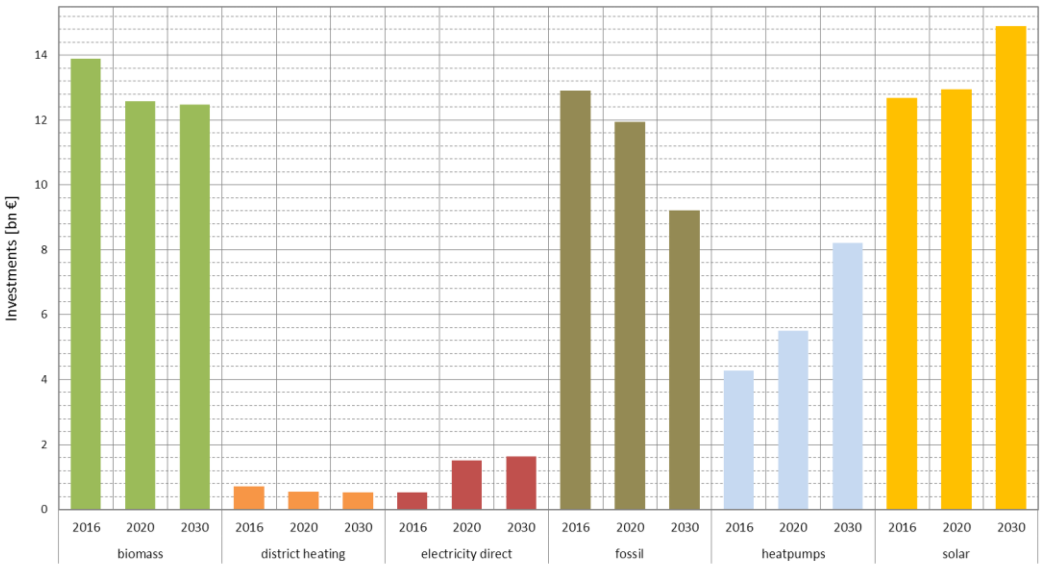


Figure 35: Investments in heating systems by technology in Bn €

Figure 36 shows the aggregated investments in renewable heating systems and Figure 37 shows annual energy expenditures for heating and cooling in EU28. Due to investments in renewable technologies in combination with thermal renovation, energy expenditures for heating and cooling slightly decrease in the current scenario projections from 255 to 244 billion Euro. Figure 38 and

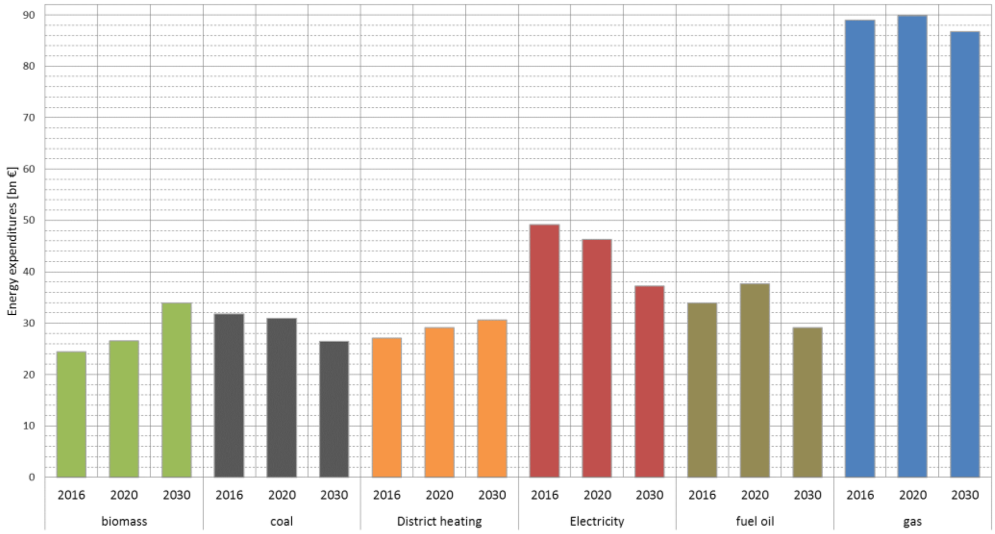


Figure 39 show the energy expenditures in more detail regarding usage type and energy carriers. Space heating costs decrease whereas costs for cooling and auxiliary energy increase, costs for water heating nearly remain constant. It can be seen that the expenditures of all energy carriers except biomass and district heating are decreasing. In total the expenditures on fossil fuel energy carriers in the residential sector are expected to decrease significantly despite increasing prices assumed in this scenario. Energy expenditures for natural gas however are expected to remain approximately at levels of 2016 and amount to the almost 50% of energy expenditures for heating and cooling. This is partly also due to the fact that condensing gas boilers are assumed to be an efficient conversion technology and condensing boilers are subsidies in some EU28 member states.

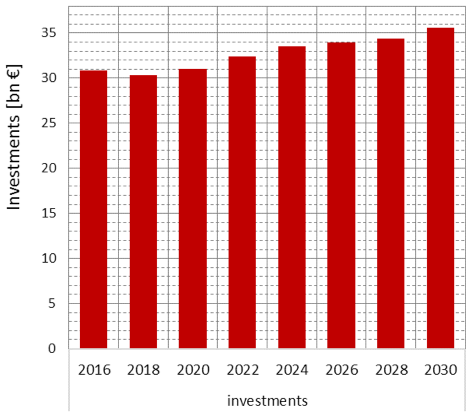


Figure 36:
Investments in renewable heat generation for EU28 in Bn €

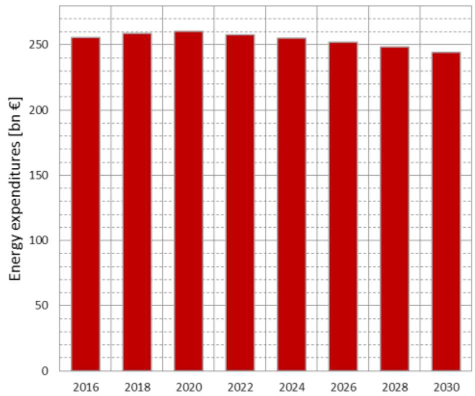


Figure 37:
Energy expenditures for space heating and hot water EU28 in Bn €

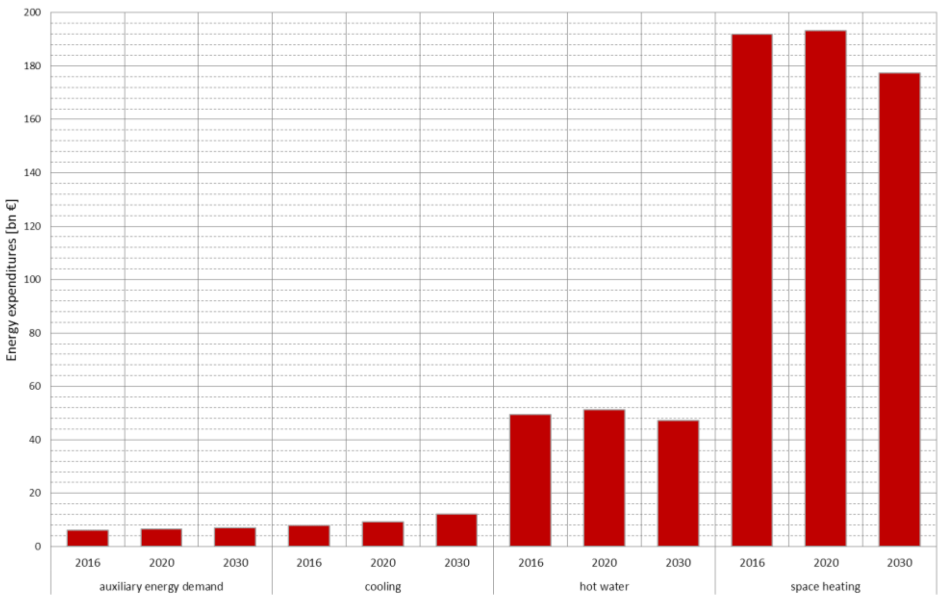


Figure 38: Energy expenditures for heating technologies by usage type for EU28 in Bn €

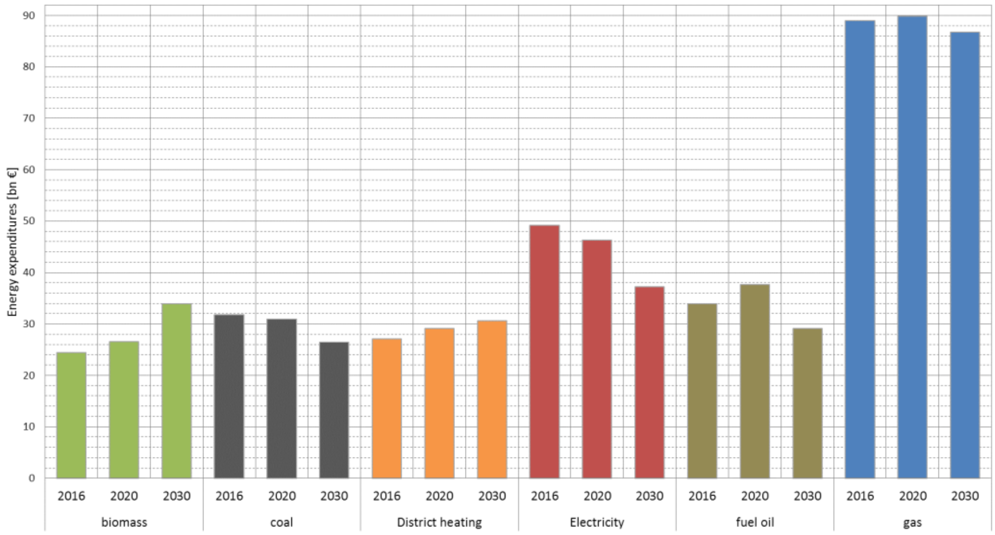


Figure 39: Energy expenditures for heating systems by energy carrier for EU28 in Bn €

4.2 Residential appliances and lighting

4.2.1 Development of energy demand until 2030

The projected total energy demand for appliances in the EU-28 countries is shown in Figure 40.

In the current policies scenario, the final energy demand increases by 2.3 % from 2012 to 2030 from 572 TWh in 2012 to 586 TWh in 2030.

The energy demand for lighting decreases strongly from 77 TWh in 2012 to 24 TWh in 2030 due to the short lifetime of current lighting technologies and replacement by very efficient LED lighting technologies.

Energy demand for ICT in the EU-28 increases by 31 % between 2012 and 2030 from 87 TWh to 114 TWh. New & Others energy demand rises from 153 TWh in 2012 to 200 TWh in 2030. In the current policies scenario, New & Others are assumed to grow by 1.5 % per year over the entire period.

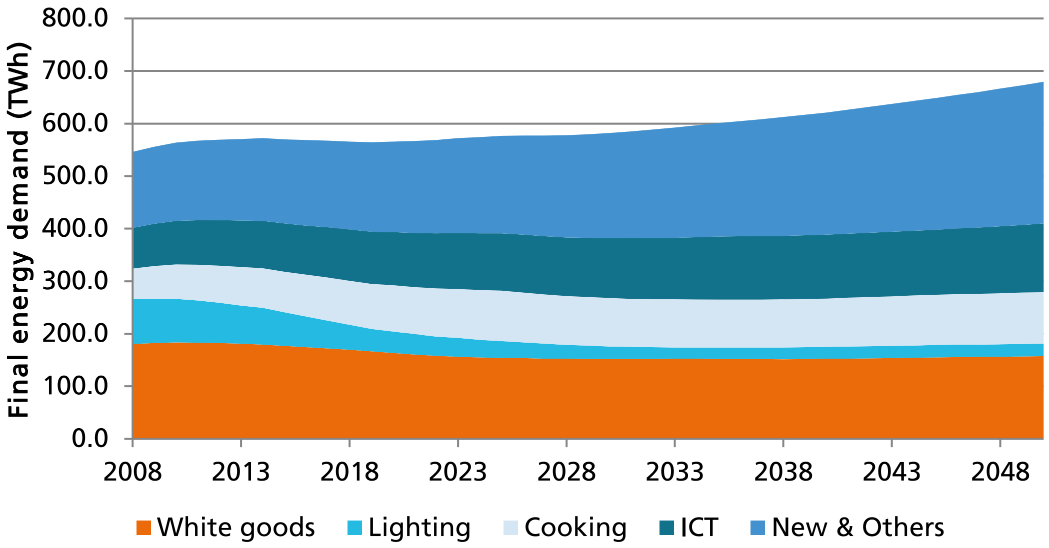


Figure 40: Final energy demand for appliances in the current policies scenario by end-use groups in EU-28

4.2.2 Development of investments in energy efficient appliances until 2030

Annual investments in appliances and lighting in the EU-28 are projected to increase from 98 billion EUR in 2012 to 183 billion EUR in 2030, as shown in Figure 41Figure 47.

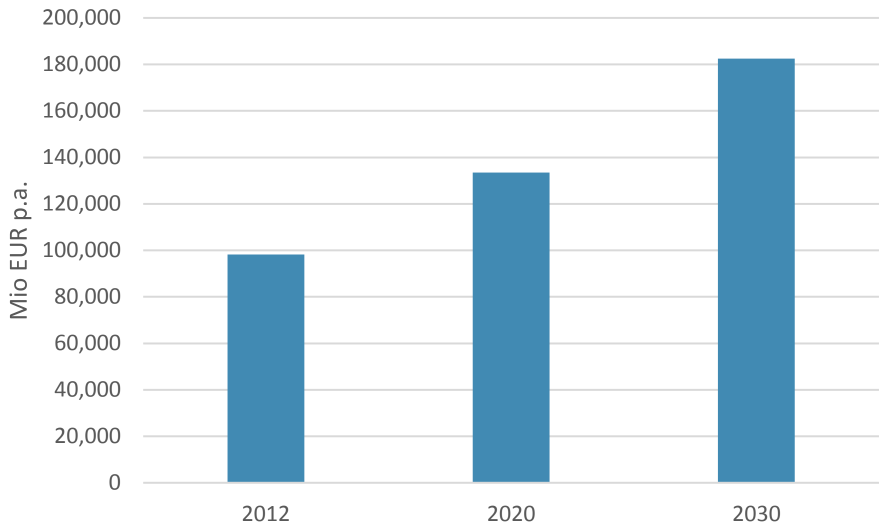


Figure 41: Investment to appliances and lighting in the current policies scenario

Energy costs in the current policies scenario increase by 17 % from 114 bilion EUR in 2012 to 133 billion EUR in 2030 (Figure 42). This is partly due to increasing prices and partly due to increasind demand.

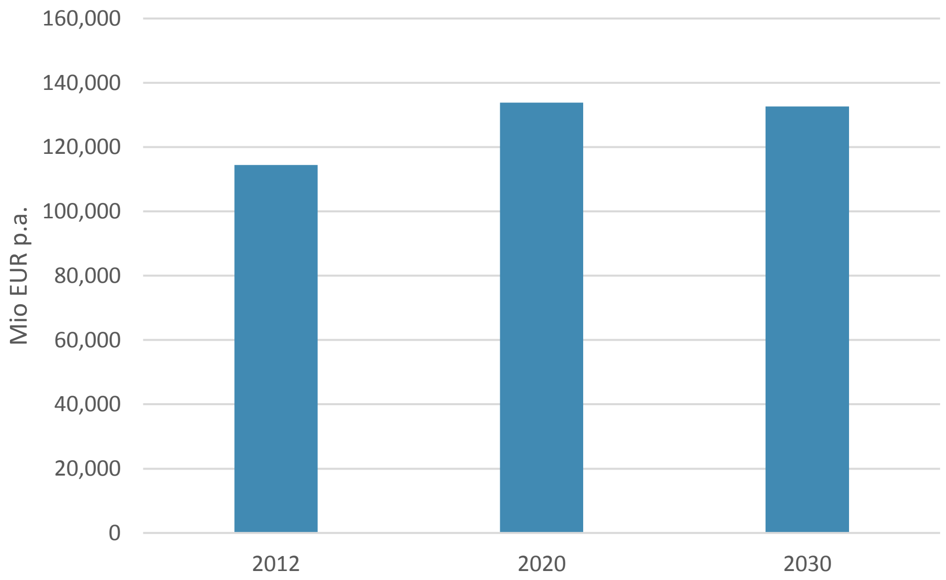


Figure 42: Energy costs for appliances in the current policies scenario

4.3 Final energy demand for the residential sector

Figure 43 shows the final energy demand for the residential sector in the BRISKEE current policies scenario as the sum of energy demand for buildings and appliances and lighting. There is a decrease in energy demand from 3330 TWh in 2012 to 2864 TWh in 2030, equal to savings of 456 TWh annually (14 % annually). The BRISKEE modelling used the same framework conditions as the EU Reference Scenario 2016 where possible. In this scenario, final energy demand for the residential sector decreases from 3650 TWh in 2010 to 3350 TWh in 2030, equal to savings of 300 TWh annually or 8 %. Thus, the improvements in energy efficiency with no additional measures are higher in the BRISKEE scenarios.

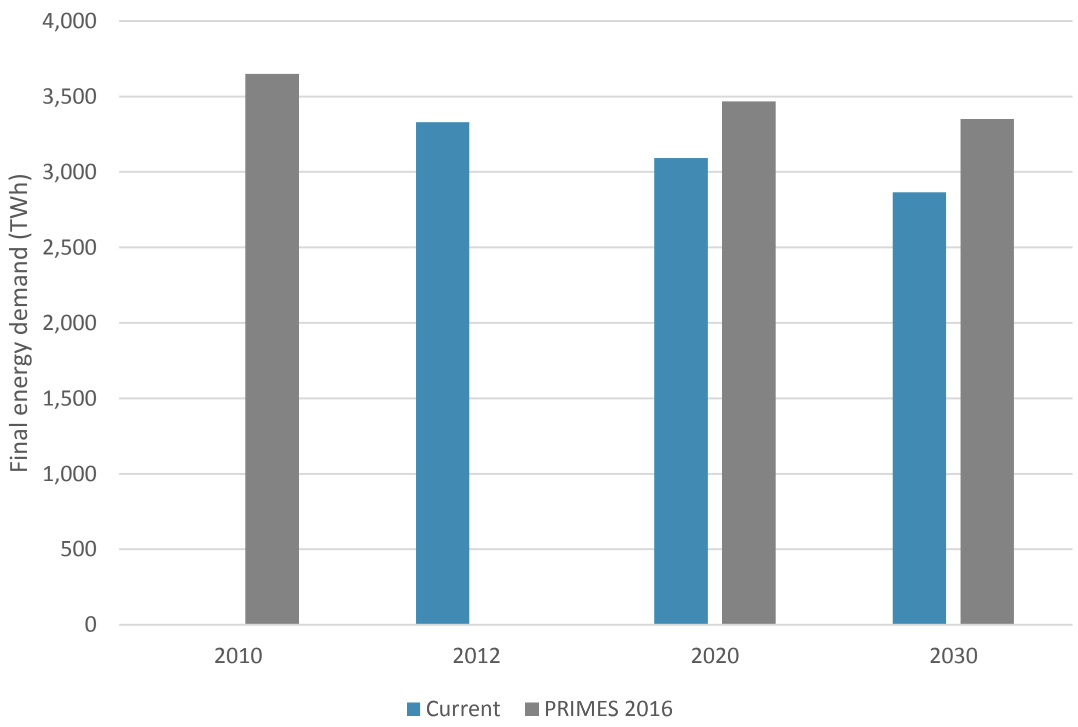


Figure 43: Comparison of final energy for the residential sector (sum of buildings and appliances) in the BRISKEE current policy scenario and in the EU Reference Scenario 2016 (PRIMES 2016). First value for PRIMES 2016 is for 2010, not 2012, due to data availability

5 Comparison of results for intensified-measures scenario and new actor-related measures scenario

This chapter is dedicated to the quantitative comparison of potential impacts of the policy measures described in chapter 3. The results for final energy demand, investments and energy expenditures from the current policy scenario are compared to an intensified-measures scenario aiming at increasing energy efficiency and reducing emissions from fossil fuels, and an additional policy scenario in which supplementary measures to reduce the discount rates of low income agents and increased awareness of environmental effects of appliances are assumed to affect the investment behavior of agents in the residential sector.

5.1 Heating and Cooling in Residential buildings – scenario comparison

In this section we focus on potential effects of monetary measures (mainly increased subsidies for renovation and renewable heating systems) to reduce energy demand for fossil fuels and the potential role of additional non-monetary measures addressing the discount rate and investment behavior of low income agents. The terms actor-related or agent specific are used as synonyms for this additional scenario. The default discount rates of investing agents are based on the survey results of WP2 and results from the project ENTRANZE[8] funded by the European Union in the Intelligent Energy Europe Program. The country and agent specific discount rates in the model INVERT/EE-Lab range from 2% to 9%. Discount rates for the current policy and intensified-measures scenario are kept constant. In the actor-related scenario discount rates of low income agents are assumed to decrease by 2% to 5% on average following the underlying assumption that additional measures are taken that affect the risk aversion of low income agents. The difference between the intensified-measures and the agent specific scenario is only due to assumed changes in the investment behavior of low income agents. Please also see chapter 2.2 for a more general discussion on the effect of assumed discount rates on developments in the residential building stock.

5.1.1 Development of energy demand for heating and cooling in the residential sector until 2030

The results for final energy demand developments in the current policy scenario, intensified-measures scenario as well as in the actor-related measures scenario can be seen in Figure 44. The results for both additional scenarios show a significantly more ambitious development in terms of energy demand reductions than the current policy scenario. The approach of actor-

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related measures, especially focusing on low income agents, leads to only slightly lower final energy demand compared to the original intensified-measures scenario. Within the simulation period, application of intensified measures leads to a final energy demand reduction of about 22%. Actor related measures lead to a reduction of about 23%. Note that a more detailed analysis suggests that the effect becomes more significant for longer time horizons because of relatively slow adaptation effects resulting from the long renovation investment cycles in buildings. A slight shift in the usage type shares from space heating to water heating can be seen, similar to the current policy results.

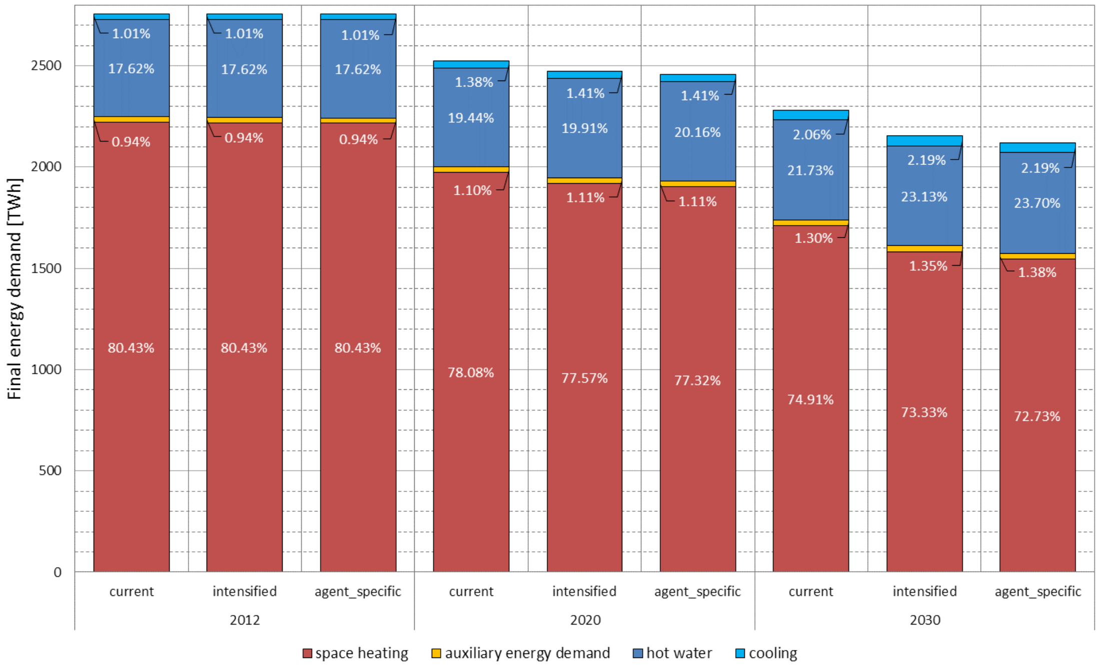

Figure 44: Final energy demand for current, intensified and agent specific scenario by usage type for EU28 in TWh

Table 12 contains the results for the final energy demand of the described scenarios by usage types for the EU28. Results on country level for all EU28 countries within the scope of BRISKEE are presented in Annex 7A.5. All countries show reductions of final energy demand for space heating but the size of the policy impact is different among the member states. Further analysis for a sample country (France) is shown later in this chapter.The final energy demand development exhibits a significant change in the shares of fossil and renewable demand, displayed in Figure 45 and Figure 46. Renewables account for 34% of the final energy demand in 2030 compered to 19% in 2012, while the share of fossil fuels drops from 62% in 2012 to 46% in 2030. Figure 46 illustrates the shift of the energy carriers in greater detail. Higher shares of biomass and the increasing usage of ambient and solar thermal energy lead to a higher share of renewables for both intesified and agent specific scenarios compared to the current policy scenario. Oil and coal demand is expected to nearly drop by 50% until 2030. The share of natural gas is also expected to decrease significantly compared to the current policy scenario, but still accounts for the largest share. Final energy demand per energy carrier, is presented in Figure 47, for all 3 scenarios.

The shares of renewables is 34% in the agent specific scenario compared to 32% in the intensified-measures policy scenario for the year 2030. The results show that reductions in discount rates of lower income agents can significantly increase the uptake of renewable heating systems across Europe. Compared to the case of thermal renovation described above, the assumed chances in the investment behaviour of low income agents have more impact on the model results.

Table 13: Final energy demand per usage type for current, intensified and agent specific scenario for EU28 in TWh (rounded values)

Final energy demand [TWh]	**2012**		
scenario	current	intensified	agent_specific
space heating	2219	2219	2219
auxiliary energy demand	26	26	26
hot water	485	485	485
cooling	28	28	28
	2757	2757	2757
Final energy demand [TWh]	**2020**		
scenario	current	intensified	agent_specific
space heating	1973	1921	1902
auxiliary energy demand	28	27	27
hot water	489	491	493
cooling	35	35	35
	2524	2474	2458
Final energy demand [TWh]	**2030**		
scenario	current	intensified	agent_specific
space heating	1710	1582	1545
auxiliary energy demand	30	29	29
hot water	492	495	498
cooling	47	47	47
	2279	2153	2119

We observe significantly higher shares of heat pumps and solar thermal systems in the agent specific scenario compared to the intensified scenario which focuses on providing more monetary incentives and measures to lower the discount rates of agents with high discount rates. One explanation for this larger impact on heating system stock can be found in the shorter lifetime of heating systems compared to renovation cycles in the building stock.

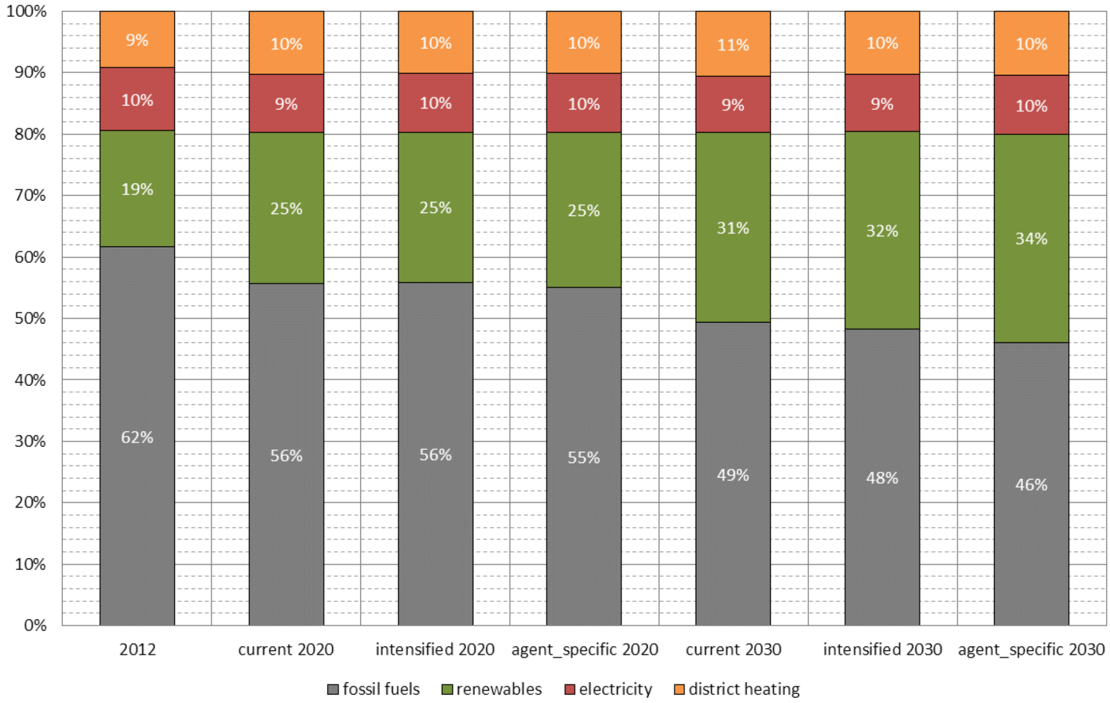

Figure 45: Share of energy carrers on final energy demand (1) for current, intensified and agent specific policy scenario for EU28 in %

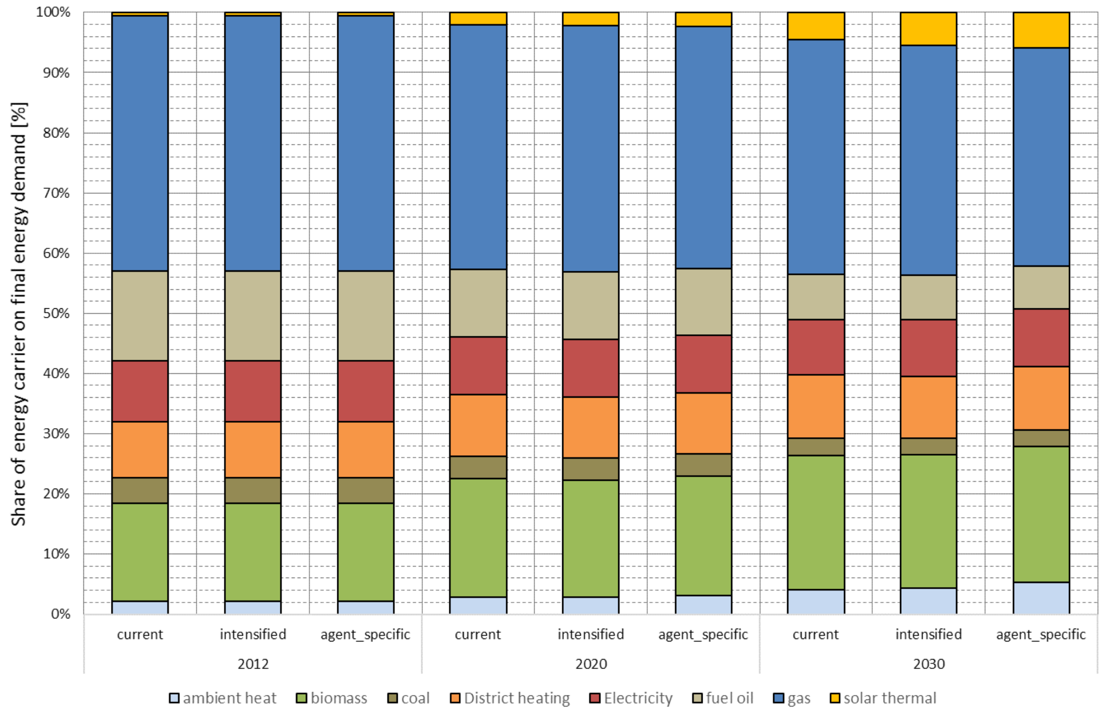

Figure 46: Share of energy carriers on final energy demand (2) for current, intensified and agent specific policy scenario for EU28 in %

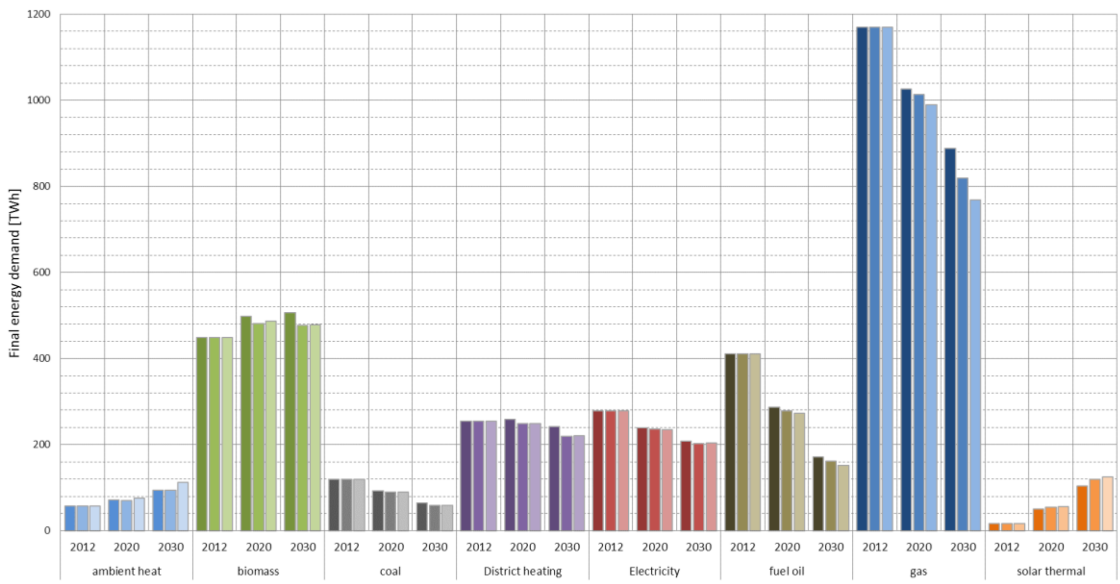

Figure 47: Final energy demand for current, intensified and agent specific scenario by energy carrier for EU28 in TWh (dark colour – current, standard colour - intensified ,bright colour – agent-specific)

5.1.2 Development of investments and expenditures in energy efficiency and renewable heat generation until 2030

This section illustrates modelling results for the investments in thermal renovation (excluding maintenance measures), investments in heating systems and energy expenditures per energy carrier until 2030 in all three scenarios. All values including the public subsidies represent annual values.

Figure 48 displays investments and subsidies for thermal building renovation in EU28 from 2016 to 2030. In comparison to current policy results, intensified financial incentives lead to significantly higher investments for renovation actions. Investments increase from below 50 to above 60 billion Euro annually. Figure 48 also shows that additional measures addressing the investment behavior of low income agents can trigger significant additional measures. Investments in the agent specific scenario run are around 15% higher compared to the intensified-measures scenario. Note that the subsidies remain on a similar level as it was assumed that the total budget for subsidies is capped by the same limit in both scenarios. Low income agents simply opt for more and deeper renovation options as more weight is put future energy savings in the decision making process.

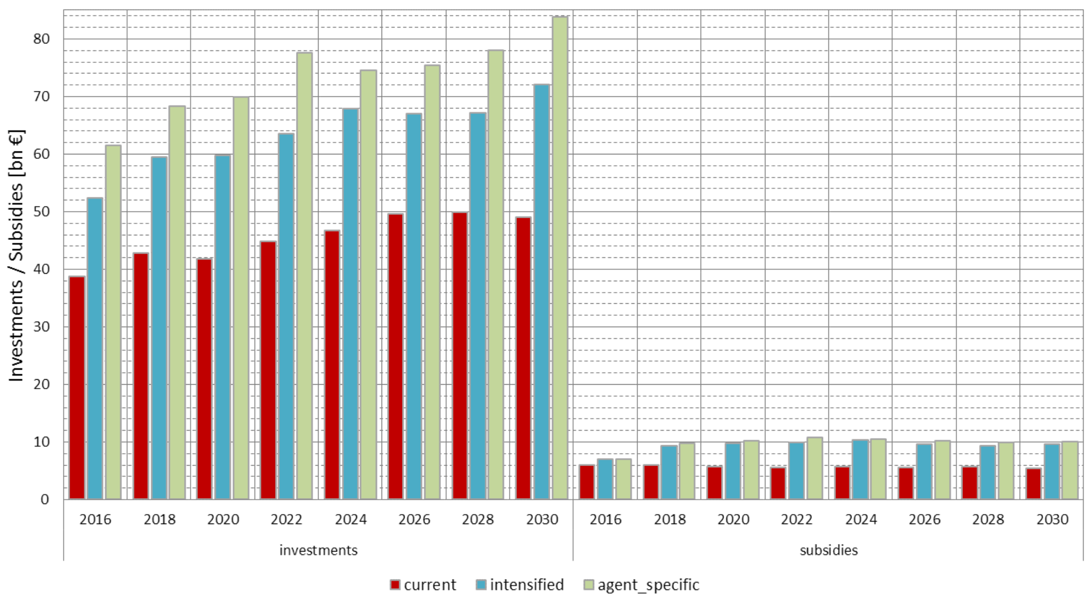

Figure 48: Investments and subsidies for building renovation actions for current, intensified and agent specific scenarios for EU28 in Bn €

Figure 49 shows investments and subsidies for space heating and domestic hot water systems. The same trend can be observed but differences among scenario results are smaller than for investments in thermal renovation. This is mainly because heating systems will have to be purchased anyway and differences in investments only result from differences in investment costs between heating technologies which are much smaller than differences in investment costs for renovation or maintenance options.

Apart from effects on total investments for heating systems the intensified-measures and agent specific scenario shifts investments from fossil heating systems to renewables. In particular heat pumps and solar thermal systems profit from those policy measures. Figure 50 shows annual investments for heating system grouped by technology. The figure shows that measures leading to lower discount rates of low income agents could significantly support the transition towards more efficient and renewable heating systems. In 2030 agent specific scenario results suggest that biomass powered systems, heat pumps and solar thermal systems could account for about 80% of investments in heating systems. It can also be seen that the agent specific scenario leads to a lower share of direct electric heating systems in favour of heat pumps which has been discussed as an example in chapter 2.2.2.

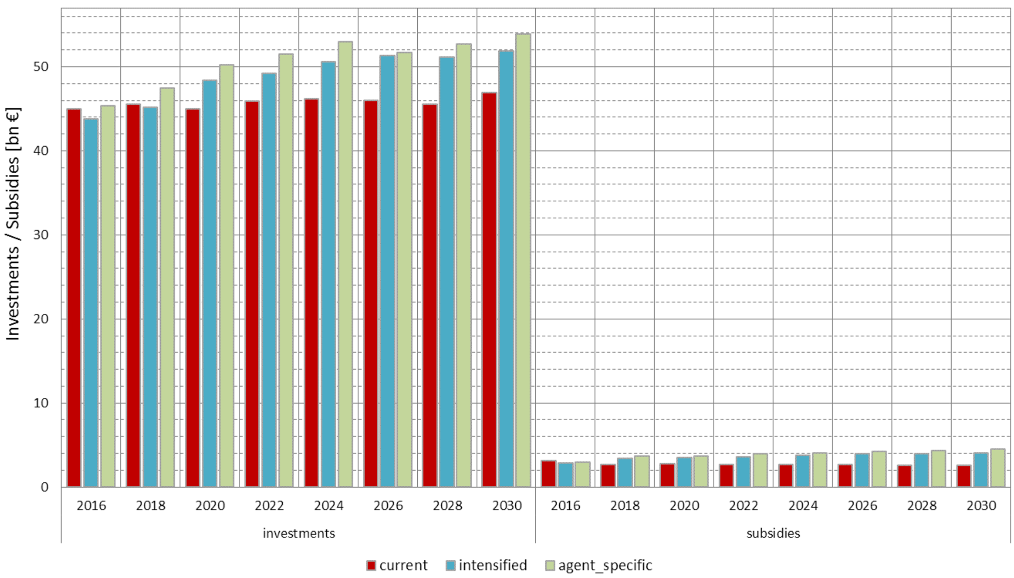

Figure 49: Investments and Subsidies in heating systems for current, intensified and agent specific scenario for EU28 in Bn €

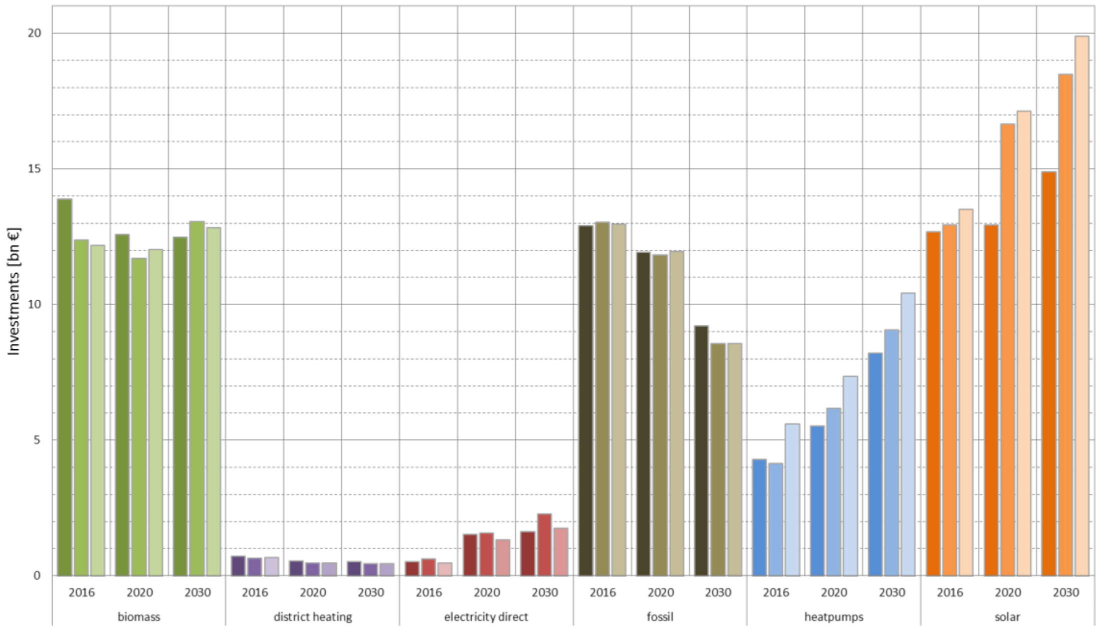

Figure 50: Investments in heating systems for current, intensified and agent specific scenario by technology/energy carrier for EU28 in Bn € (dark colour – current, standard colour – intensified, bright colour – agent specific)

Figure 51 and Figure 52 show running expenditures for energy in the residential sector. Compared to the current policy scenario expenditures for energy carriers are lower due to higher investments in heat demand reductions and more efficient heating systems. Note that annual expenditures are expected to decrease despite rising energy prices according to the EU reference scenario 2016. The main reductions in energy expenditures stem from reductions in space heating demand while expenditures for auxiliary energy and cooling increase slightly in absolute terms.

Finally, Figure 53 provides a more detailed view on model results for energy expenditures per energy carriers which follow the trends of final energy demand developments.

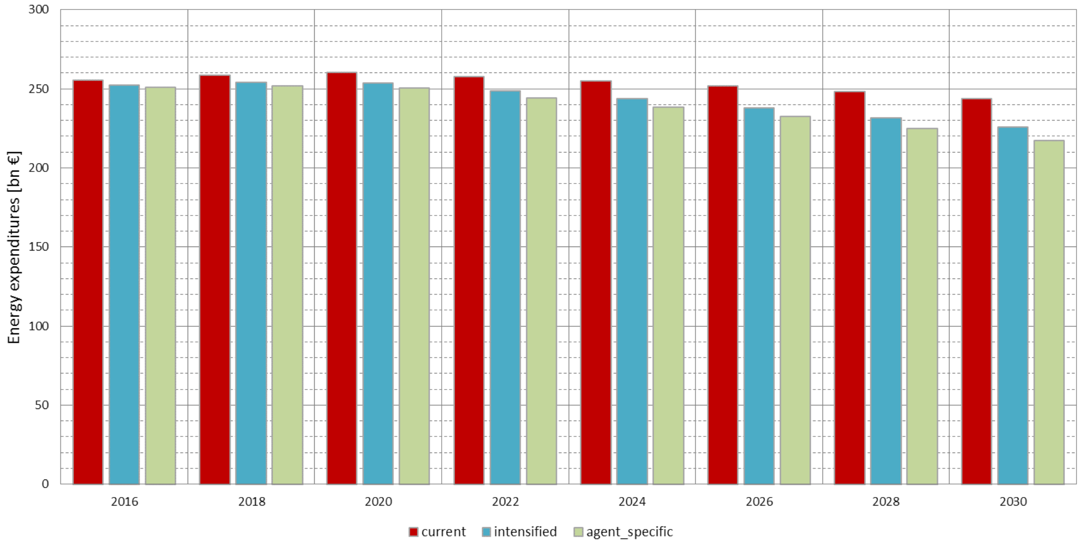

Figure 51: Energy expenditures for heating systems for current, intensified and agent specific scenario for EU28 in Bn €

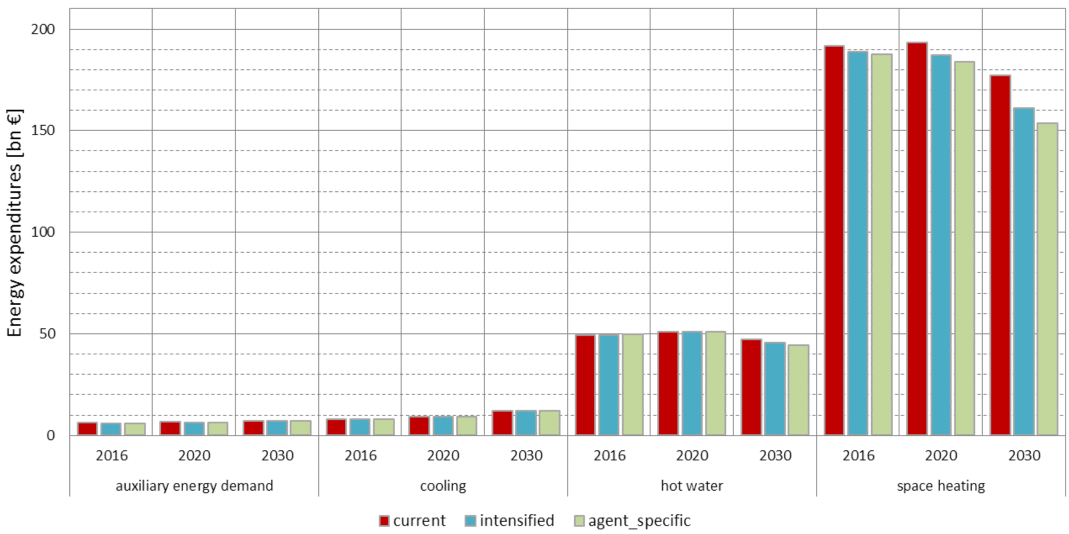

Figure 52: Energy expenditures for heating systems for current, intensified and agent specific scenario by usage type for EU28 in Bn €

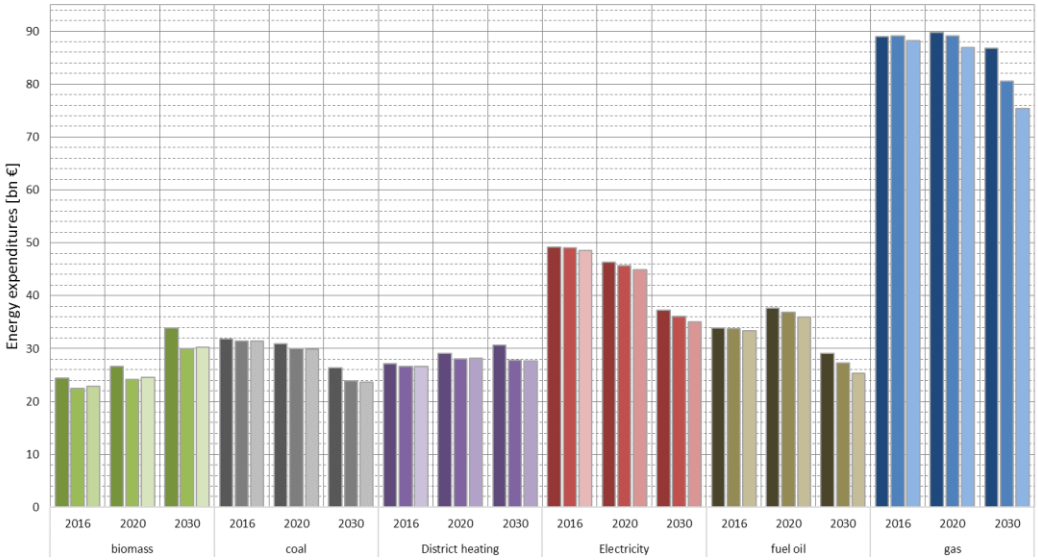

Figure 53: Energy expenditures for heating systems by energy carrier for current, intensified and agent specific scenario for EU28 in Bn € (dark colour – current, standard colour – intensified, bright colour – agent specific)

5.1.3 Modelling details for sample country France

In this section we provide details on the efficiency developments in the building stock of France as a sample country to show the level of details on which the results shown above are based. The same results are available for all EU 28 member state countries but not shown in this report.

Error! Reference source not found. illustrates the renovation activities of the whole building stock of France including residential buildings and the service sector from 2015 to 2030 in each scenario. The figure shows the annual specific heat demand per area in kWh/m^2 over the area of each building class implemented in INVERT/EE-Lab of the floor area of each building class of France. The areas shown in the figure therefore represent the annual energy demand of the total building stock.

The blue areas indicate the buildings that have been thermally renovated within this period, while the grey area indicates buildings where only maintenance measures have been performed. The red area illustrates the specific heat demand of new buildings. The black area represents existing building classes where no renovation options take place within the simulation period. The green bars on top of renovated building classes (blue area) indicate the energy savings achieved through thermal renovation for each building class.

It can be seen that the intensified policy measures (figure in the middle) lead to significantly more renovation activities than in the current policy scenario (top figure). In total the energy savings stem from several effects. In total more agents decide to invest in maintenance or renovation (black area decreases). The share of buildings that opt to invest in thermal renovation on top of maintenance measures increases significantly. Within the agents that opt for thermal renovation options more agents decide for deeper renovation leading to lower average specific heat demands. Finally also average of specific heat demand of new buildings is lower in the intensified-measures scenario compared to the current policy scenario.

Comparing the results of the intensified-measures scenario with the agent-specific scenario (bottom figure) it can be seen that the assumptions on the discount rate of low income agents significantly influences modelling results. The agent specific scenario assumes that non-monetary policy measures applied in France succeed in lowering the discount rate of low income agents in France from 7% to 3.5% and reduce the agents weight on investment costs in favor of an overall economic assessment in their investment appraisal.

The comparison reveals that support low income agents can significantly increase renovation activities in France indicated by the larger blue are in the agent-specific scenario. Annual energy savings through renovation are estimated to be 81 TWh in the agent-specific scenario compared 60.9 TWh in the intensified-measures scenario. Reductions in overall energy demand for space heating between the scenarios is around -2.5% which could be seen as an upper limit for potential annual energy savings through non-monetary policy measures addressing the investment behavior of low income agents until the year 2030 in the residential sector of France.

The case of France also provides an illustrative example for substitution effects of energy carriers through the choice of agents for heating systems.

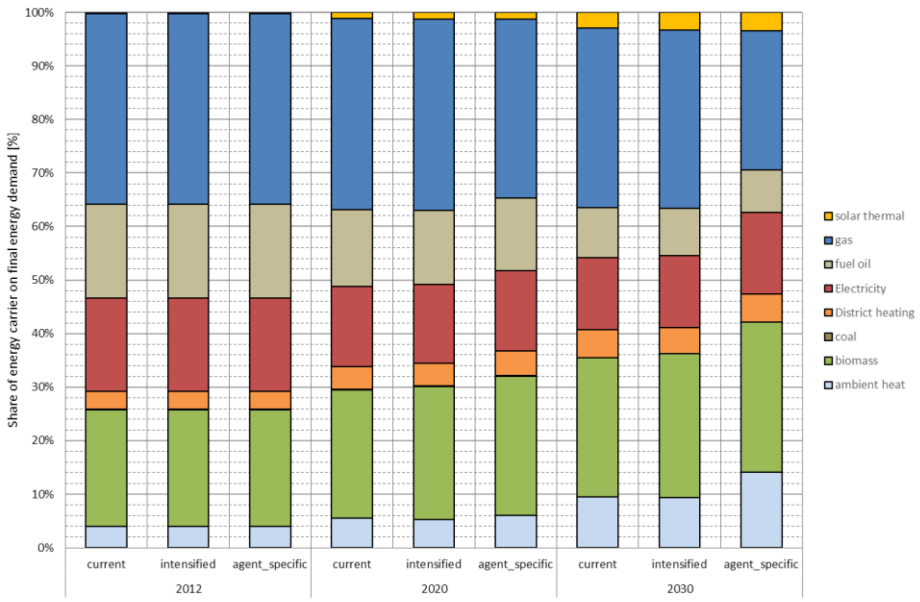

Figure 55 shows the shares of final energy carriers for heating and cooling in the residential sector in France for each scenario up to 2030 and **Error! Reference source not found.** illustrates investments in heating systems. The monetary policy measures lead to a shift towards more renewable heating systems. The transition from fossil fuels to renewables however is much stronger in the agent specific scenario which stimulates investments in solar thermal systems and heat pumps. It can also be seen that the assumption of lower discount rates for low income agents leads to a substitution of direct electric heating systems towards more efficient heat pumps. Note that the assumptions in the intensified policy scenario lead to an increase of direct electric heating systems and decrease of investments in heat pumps compared to the current policy scenario. This can be explained by the fact that heat pumps are less competitive for buildings with lower heat demand as investment costs account for a larger share of total costs for heating. As the intensified measures lead to more renovation activities and lower specific heat demand per building, agents would opt in favor of technologies with lower initial investment costs more often. The assumed measures that lead to lower discount rates of low income agents offset this effect because the expected energy cost savings exceed the difference in investment costs between heat pumps and direct electric heating systems. As a result investments in heat pumps are expected to be higher than in the current policy scenario despite lower average specific heat demand.

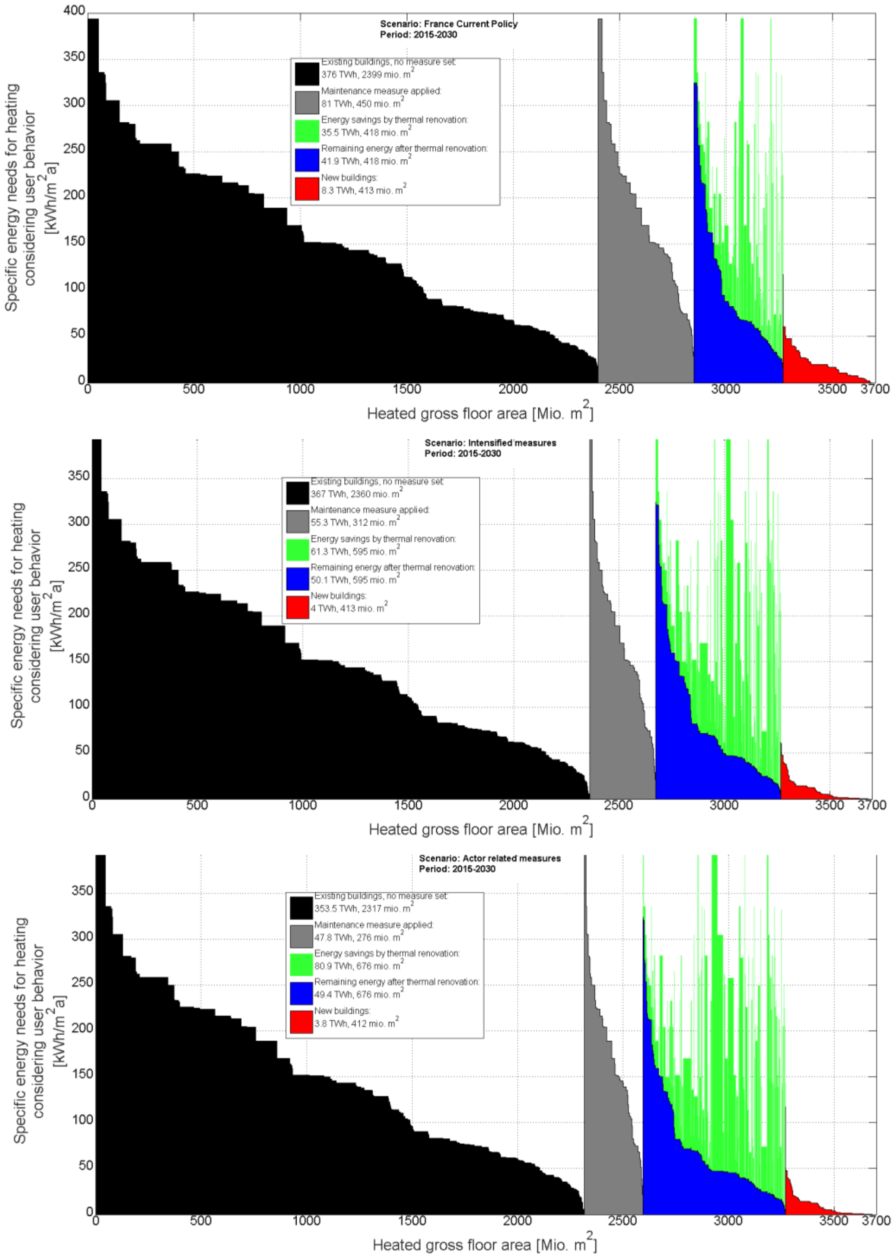

Figure 54: Development of the specific demand for space heating in the building stock of (residential buildings and service sectors) France for all 3 scenarios

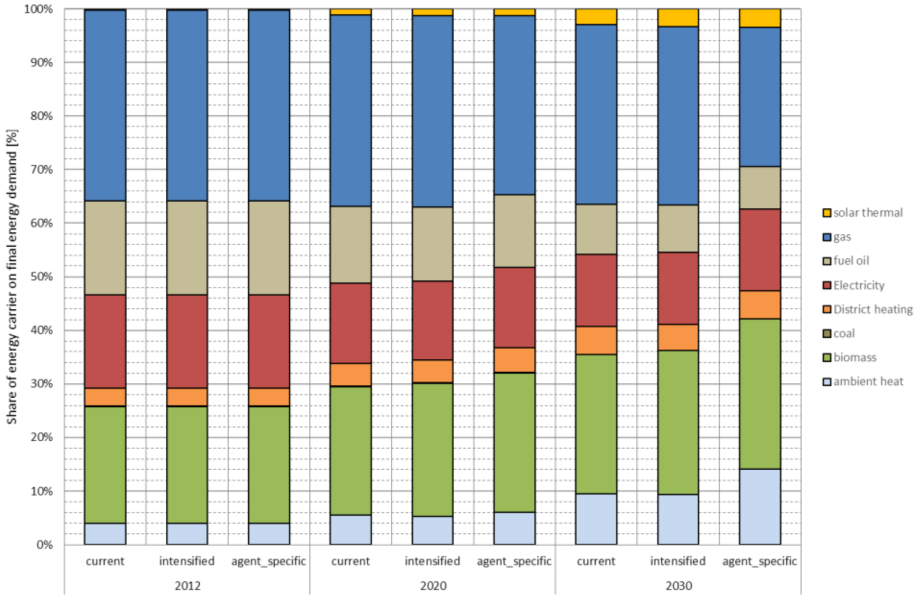

Figure 55: Share of energy carriers on final energy demand for current, intensified and agent specific policy scenario for France in %

The results also suggest that demand for natural gas would significantly decrease in the agent specific scenario compared to the current policy and intensified-measures scenario due to increased renovation of multi-family houses supplied by natural gas and increased substation of heating systems fueled by natural gas with other heating systems.

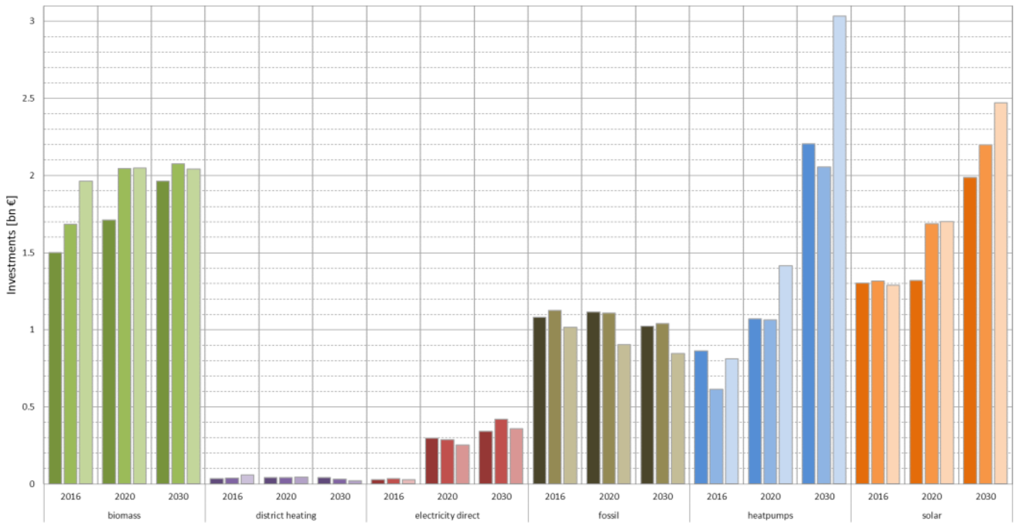

Figure 56: Investments in heating systems for current, intensified and agent specific scenario by technology/energy carrier for France in Billion € (dark colour – current, standard colour – intensified, bright colour – agent specific)

5.2 Appliances and lighting

5.2.1 Development energy demand in the residential sector until 2030

The projected total energy demand for appliances in the EU-28 countries is shown in Figure 57.

In the current policies scenario, the final energy demand increases by 2.3 % from 2012 to 2030 while it decreases by 6.3 % in the intensified policies scenario and by 8.7 % in the actor-related policies scenario. Compared to the current policies scenario, the intensified policies scenario and actor-related policies scenario include annual savings in 2030 of 49 TWh and 62 TWh, respectively.

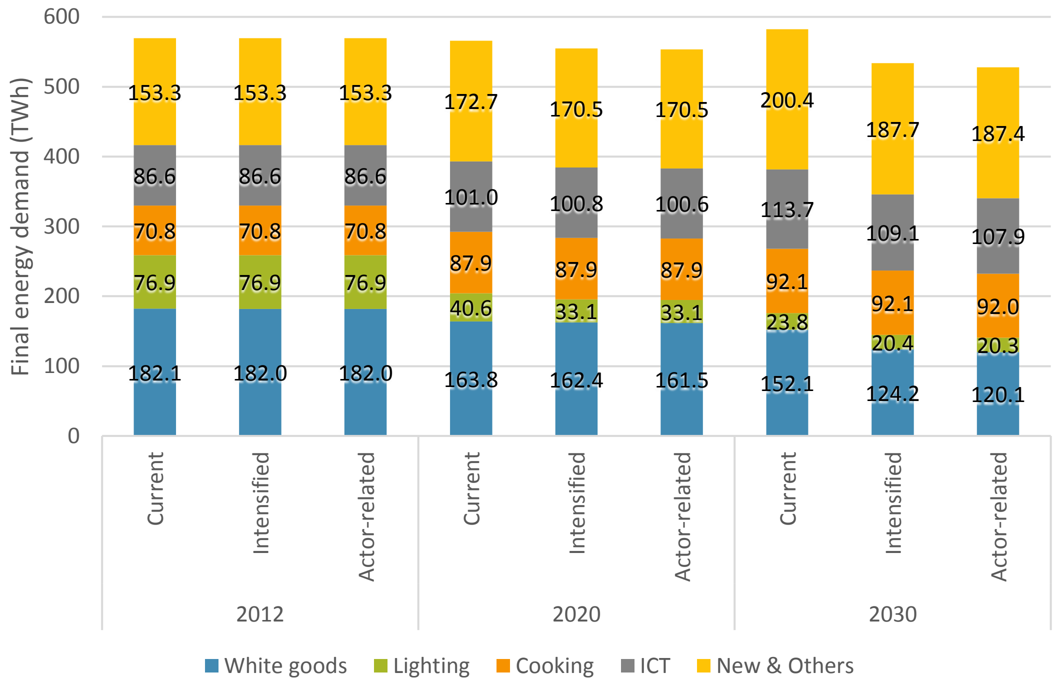

Figure 57: Final energy demand in the EU-28 for appliances by energy use type in the three scenarios

The energy demand for lighting decreases strongly in the current policies scenario already due to the spread of LED technologies. Increased ecodesign and information measures in the more ambitious scenarios merely lower the energy demand in the EU-28 in 2030 for lighting from 23 TWh to 20 TWh (both intensified and actor-related policies scenario).

Due to a slightly increasing population in the EU and households becoming smaller, the energy demand for cooking increases over the simulation period.

In the area of ICT, only televisions are directly addressed by measures in the two ambitious scenarios due to availability of information on potentials in the literature and on the current market. The effect is a decrease in 2030 from 114 TWh to 109 TWh in the intensified policies scenario and 108 TWh in the actor-related policies scenario.

The partial regulation of New & Others has the effect of lowering energy demand in 2030 from 200 TWh in the current policies scenario by about 6 % to 188 TWh and 187 TWh, respectively.

Since the ambition of MEPS for white good appliances is strongly increased in the two ambitious scenarios, energy demand for white goods appliances is significantly decreased by 18 % and 21 % in the intensified and actor-related policies scenario, respectively. This amounts to a change from 152 TWh in 2030 in the current policies scenario to 124 TWh and 120 TWh, respectively. This means savings up to 32 TWh annually.

The analysis shows that the largest share of savings results from increased ambitioun of MEPS, while purchase behaviour of environmentally conscious households contributes to a smaller extent. The 150 EUR subsidy for low-income households has only a minor effect. Based on the estimated prices, the price difference to highly efficient remains large despite the considerable subsidy. Prices for highly efficient appliances would need to fall much faster to reach higher market shares.

On top of the efficiency improvements in the current policies scenario, the intensified and actor-related policies scenarios include additional savings in 2030 of 28 % and 31 %, respectively.

5.2.2 Development of investments in energy efficient appliances until 2030

As input to the macroeconomic modelling in work package 4, investments and energy costs for residential appliances are calculated using the FORECAST model. These make the connection between micro-level insights used in the meso-modelling and the energy demand scenarios to macroeconomic modelling.

Investments to appliances are higher in the intensified and actor-related policies scenarios compared to the current policy scenario for the EU-28 countries. This is due to more efficient and more expensive appliances being purchased to a larger degree. The investments are shown in Figure 58.

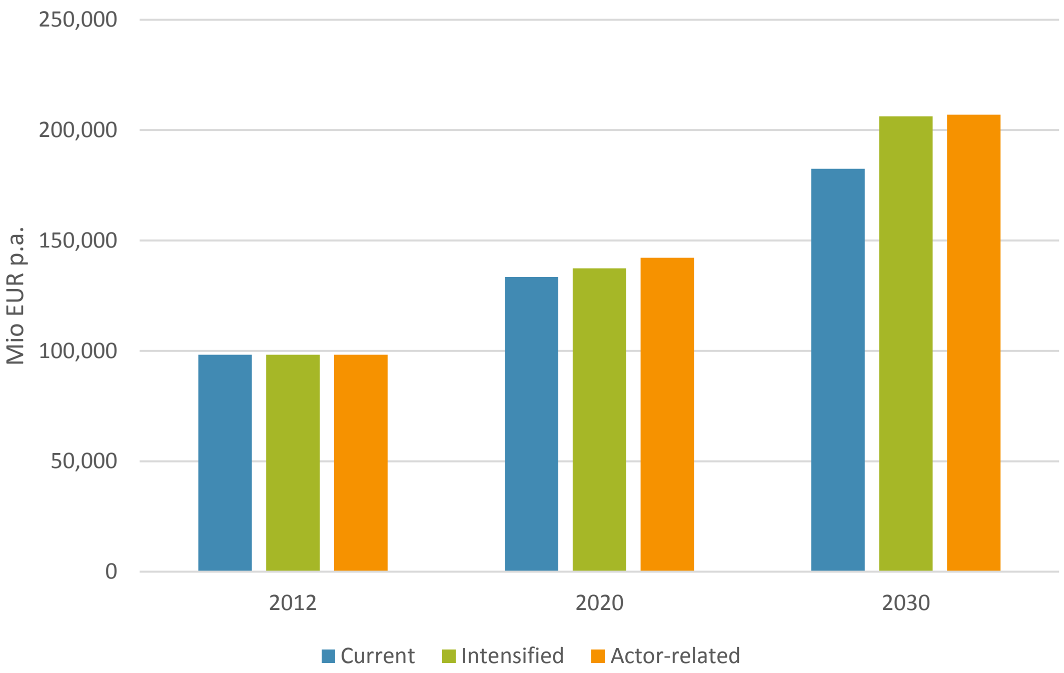

Figure 58: Investment to appliances in the three scenarios

Due to the improved efficiency of appliances, according to the energy demand presented in section 4.2.1, the energy costs in the EU-28 are lower in the in the intensified and actor-related policies scenarios compared to the current policy scenario for the EU-28 countries. The energy costs are shown in Figure 59.

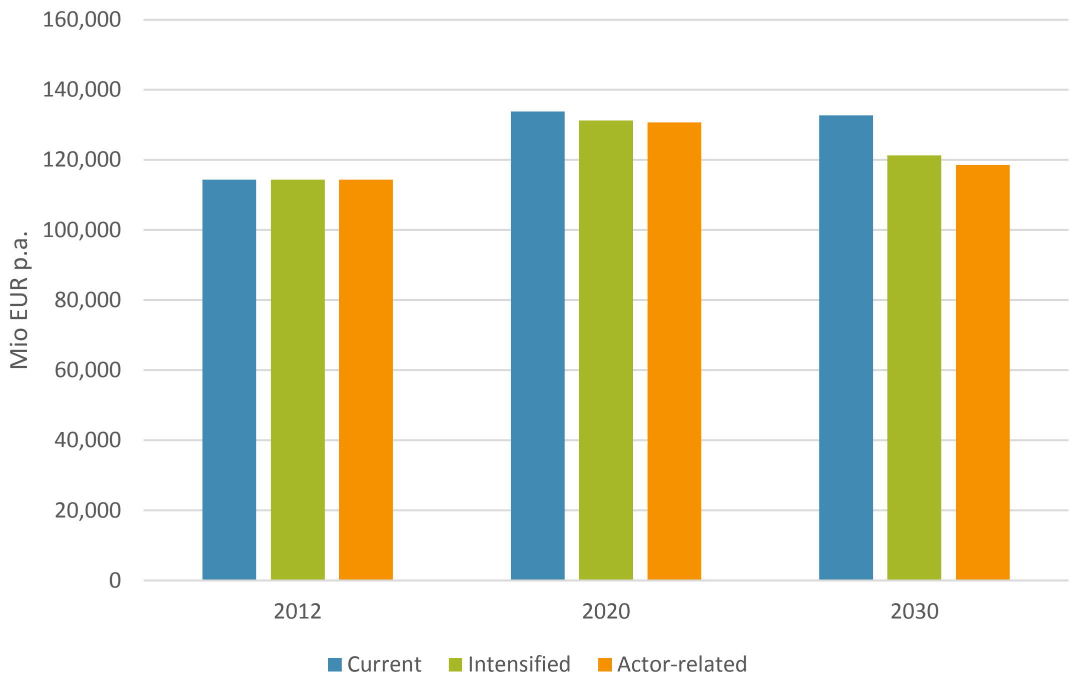

Figure 59: Energy costs for appliances in the three scenarios

6 Summary of key findings

Within WP3 of the BRISKEE project the results from surveys conducted in WP2 on the decision making behavior of agents in the residential sector have been implemented in the model INVERT/EE-Lab and FORECAST to quantify the impacts of policy measures on the development of energy demand and costs related to heating and cooling and appliances in the residential sector. The following key findings have been derived from modelling results of all EU28 member states until the year 2030:

- In total final energy demand of the building stock is expected to decrease until 2030 for all calculated scenarios. Additional monetary policy measures like subsidies can reduce final energy demand significantly. On top of monetary incentives, policy measures aiming at reducing the implicit discount rates of investment agents can lead to significant additional energy savings. Figure 62 shows the final energy demand for the residential sector in the BRISKEE scenarios as the sum of energy demand for buildings and appliances. Compared to the current policy scenario, energy demand in 2030 in the intensified and actor-related policies scenario decreases to 2690 TWh (-6 %) and 2642 TWh (-8 %), respectively.

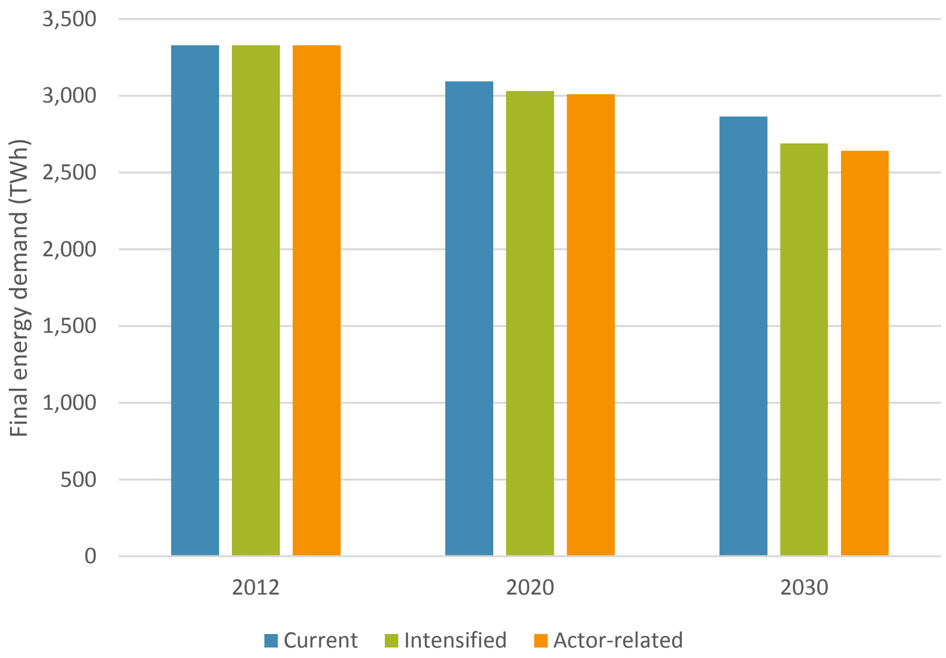

Figure 60: Comparison of final energy for the residential sector (sum of buildings and appliances) in the BRISKEE scenarios

On top of increased energy savings policy measures addressing the investment behavior of agents can significantly increase the share of renewable energy carriers in the building stock.

Renewable heating system like solar thermal systems and heat pumps typically cause less future energy expenditures for building occupants at the costs of higher initial investments. The numeric simulation indicate that lower discounts rates of low incoume agents supports the uptake of those technologies. Figure 61 shows that the share of renewables in heating and cooling in the scenario with agent specific measures is 34% compared to 32% for a scenario which mainly focuses on monetary incentives.

Figure 61: Share of energy carriers on final energy demand (1) for current, intensified and agent specific policy scenario for EU28 in %

In general the effect of actor related measures is higher for heating systems compared to thermal renovation measures. This is mainly due to the longer investment cycles for refurbishments compared to changes of heating systems. It should be noted that the full effect of policy measures can only be seen in longer simulation periods of more than 30-40 years in which most buildings have to be refurbished at least once.

The results also show that more investments can be triggered without additional monetary subsidies. Information and labelling campaigns can therefore be sensible supplementary policy measures. Their cost effectiveness depends on the program costs and expected additional energy or fossil fuel savings compared to monetary subsidies. This comparison has not been done within the BRISKEE project and is subject to further research in the field of policy measures related to energy efficiency.

In all scenarios calculated within this work package fossil fuels are expected to decrease significantly until 2030 and beyond. This mainly results from reductions in fuel oil and coal for heating purposes. Natural gas however is still expected to be the main energy carrier for heating and cooling in the residential sector and still shows relatively high market shares for new installations. In many areas of Europe with gas supply, heating systems fueled by natural gas are considered to be the most cost effective options by investors. The future development of renewable heating systems and in particular also district heating will strongly depend on natural gas prices. Low natural gas prices could lead to significantly less investments into renewable energy sources and thermal refurbishments. In the light of the Paris agreement the role of natural gas for heating and cooling in the residential sector needs to be discussed as high shares of natural gas might contradict with ambitious CO_2 emission reduction targets for the residential sector. Modelling results also show that actions need to be taken early due to the long life time of technologies and investment decision cycles in the building stock.

The final energy demand for appliances remains increases by 2.3 % from 2012 to 2030 in the current policies scenario . With intensified policies, in particular more ambitious MEPS for appliances through the ecodesign directive, the energy demand in 2030 reduces by 8.3 %. In the actor-related measures scenario, the savings in 2030 increase to 10.7 % or 62 TWh overall.

Due to the ongoing efficiency leap in lighting technologies due to LEDs, the energy demand for lighting strongly decreases in all scenarios. Intensified policies only contribute to additional savings of 3 TWh in the EU-28 in 2030.

As ecodesign achieves the highest savings in white goods appliances such as refrigerators and washing machines and successfully lowers the energy consumption for these energy services, other appliance groups become more relevant. The energy savings in 2030 compared to 2012 without additional measures are 16 %. The intensified and new policies in the two ambitious scenarios lead to much larger savings of 32 % and 34 %, respectively. This means savings up to 32 TWh annually from 2030 compared to the current policies scenario. Ecodesign is the most effective instrument in the model while improved labelling also contributes to more energy conscious purchase behaviour.

A programme subsidising the purchase of very efficient white goods appliances for low-income households in all EU member states only leads to minor savings in the model. This is due to the large price difference using current prices, which is not sufficiently compensated by the assumed of 150 euro per appliance. A similarly small effect was found an empirical study by Seifried and Albert-Seifried (2015). Highly efficient appliances need to become significantly cheaper to reach a major market uptake.

Figure 62 shows the energy demand in the EU-28 by appliance group. In all scenarios, energy demand for lighting decreases strongly due to the technology leap as LED lighting is established. Moreover, energy demand for white goods is reduced significantly due to increased policy measures in the intensified and actor-related policies scenario. Various ICT devices that are likely established in the coming years and may spread quickly are grouped as New & Others in Figure 62. The aggregated projection does not assume effective, major policy instruments addressing this appliance group. Even in the most ambitious scenario, energy demand for New & Others increases by 10 % between 2020 and 2030. In the three BRISKEE scenarios, this appliance group makes up 34 - 36 % of energy demand in 2030. Relevant policy measures should therefore be designed as early as possible.

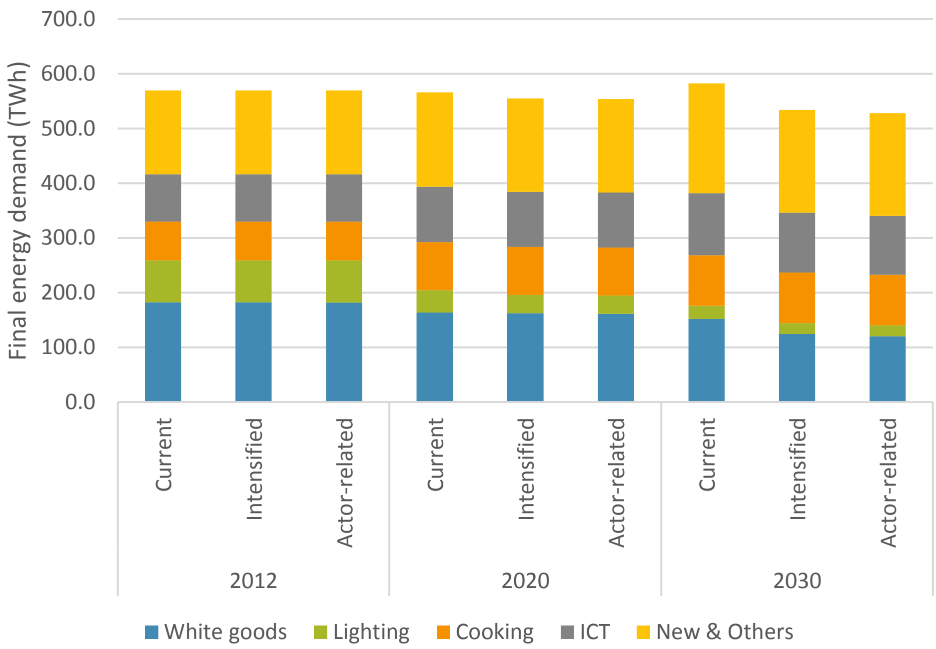

Figure 62: Final energy demand in the EU-28 for appliances by energy use type in the three scenarios

Since more efficient appliances tend to have a higher purchase price, the shift to more efficient appliances also causes an increase in investments in appliances, while annual energy costs decrease.

The results show that energy expenditures for heating and cooling in the residential sector are expected to decrease despite higher future energy prices assumed in the scenarios. This will however depend on the investment decision of buildings occupants and their weighting of investment costs versus expected energy expenditures which is directly linked to the implicit discount rates of investing agents.

7 Literature

Selected References for most recent applications of the INVERT/EE-Lab model can be found at the model homepage: www.invert.at. The most detailed description of the model algorithm and its implementation are given by:

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A.1 Annex

A.1.1 Model description INVERT/EE-Lab

The INVERT/EE-Lab model: Modelling the energy demand for space heating, cooling and hot water in buildings

Invert/EE-Lab is a dynamic bottom-up simulation tool that evaluates the effects of different promotion schemes (in particular different settings of economic and regulatory incentives) on the total energy demand, energy carrier mix, CO2 reductions and costs for space heating, cooling and hot water preparations in buildings. Furthermore, Invert/EE-Lab is designed to simulate different scenarios (price scenarios, insulation scenarios, different consumer behaviours, etc.) and their respective impact on future trends of energy demand and mix of renewable as well as conventional energy sources on a national and regional level. More information is available on www.invert.at or e.g. in Müller (2015) and Steinbach (2015).

The basic structure and concept is described in Figure 63.

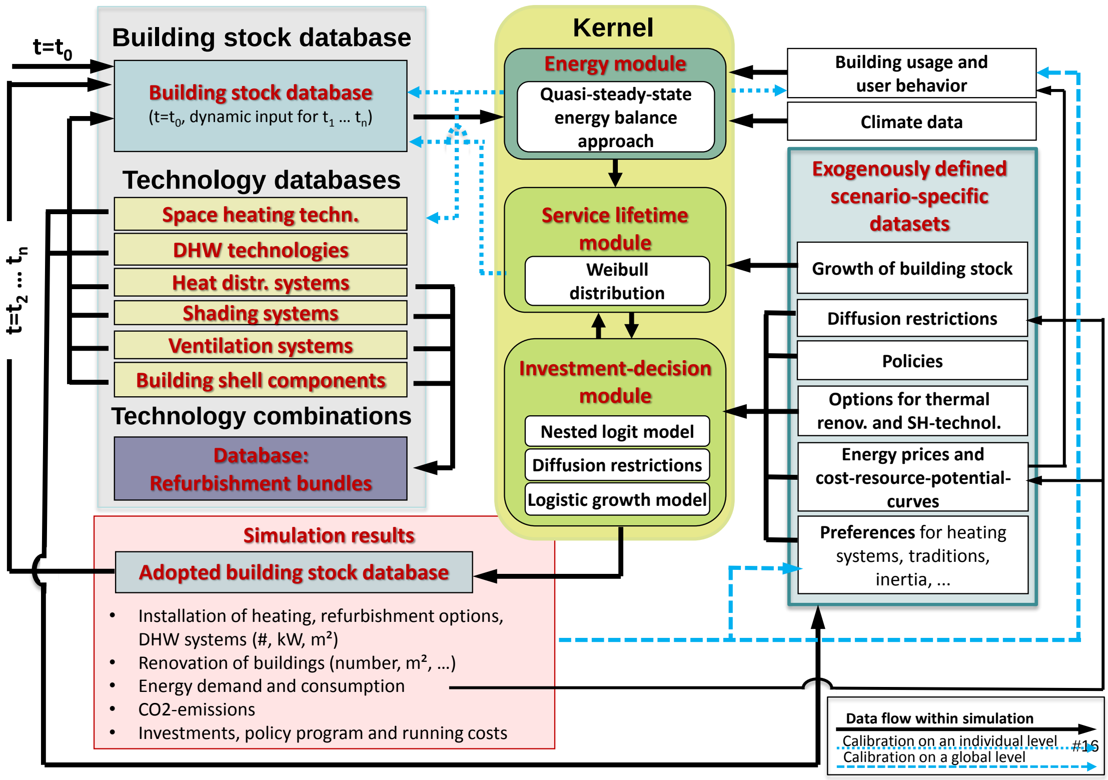

Figure 63: Overview structure of Simulation-Tool Invert/EE-Lab

Invert simulation tool originally has been developed by Vienna University of Technology/EEG in the frame of the Altener project Invert (Investing in RES&RUE technologies: models for saving public money). In more than 30 projects and studies for more than 15 countries, the model has been extended and applied to different regions within Europe, see e.g. (Kranzl et al., 2012), (Kranzl et al., 2013), (Biermayr et al., 2007), (Haas et al., 2009), (Kranzl et al., 2006), (Kranzl et al., 2007), (Nast et al., 2006), (Schriefl, 2007), (Stadler et al., 2007). By 2009, a major modification process of the model started, including a re-programming process and accommodation of the tool, in particular taking into account the inhomogeneous structure of decision makers in the building sector and corresponding distributions (Müller, 2010, Steinbach 2015) The current state of the model relies on this new calculation-core (called EE-Lab) leading to the current version of the model Invert/EE-Lab.

The basic idea of the model is to describe the building stock, heating, cooling and hot water systems on highly disaggregated 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. The core of the tool is a myopical, nested logit approach, which optimizes objectives of "agents" under imperfect information conditions and by that represents the decisions maker concerning building related decisions.

Coverage and data structure

The model Invert/EE-Lab up to now has been applied in all countries of **EU-28 (+ Serbia, Swiss, Norway and Iceland)**. A representation of the implemented data of the building stock is given at www.entranze.eu.

Invert/EE-Lab covers **residential and non-residential buildings**. Industrial buildings are excluded (as far as they are not included in the official statistics of office or other non-residential buildings).

The following figure shows the disaggregated modelling of the building stock within each country. The level of detail, the number of construction periods, etc. depend on the data availability and structure of national statistics. We take into account data from Eurostat, national building statistics, national statistics on various economic sectors for non-residential buildings, BPIE data hub, Odyssee, which are finally summarized in the ENTRANZE database (www.entranze.eu).

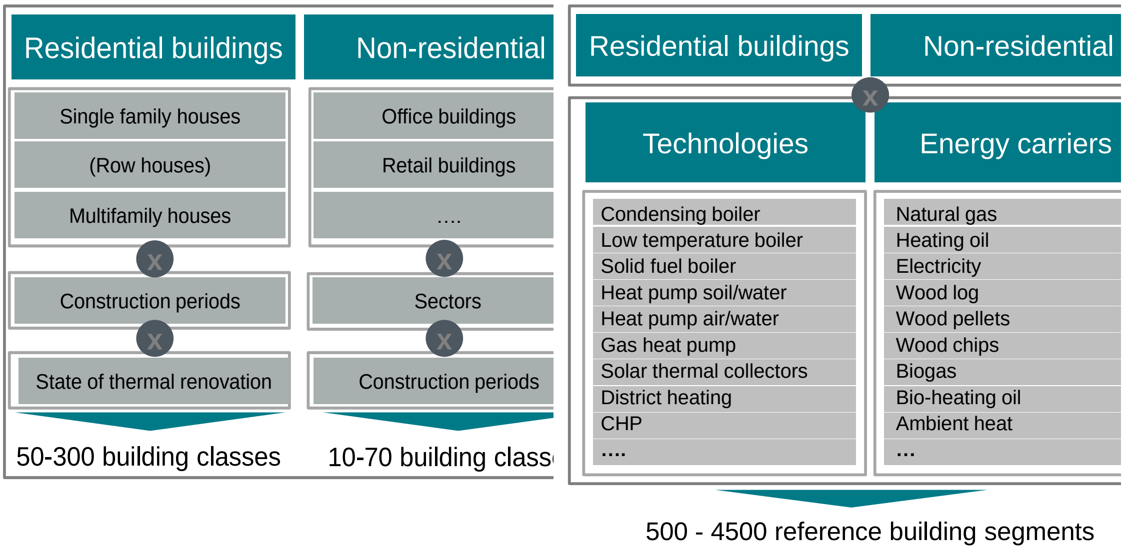

Figure 64: Disaggregated modelling of the building stock within each country. Where relevant, climatic zones are taken into account within a country.

As **efficiency technologies** Invert/EE-Lab models the uptake of different levels of renovation measures (country specific) and the diffusion of efficient heating and hot water systems.

Basic approach and methodology

The core of the simulation model is a myopical approach which optimizes objectives of agents under imperfect information conditions and by that represents the decisions concerning building related investments. It applies a nested logit approach in order to calculate market shares of heating systems and energy efficiency measures depending on building and investor type. The following equation depicts the market share calculation as logit-model – in order to reduce complexity in the representation:

$$ms_{n\,jb,t} = \frac{e^{-\lambda_b \cdot r_{njb}}}{\sum_{j=1}^{J} e^{-\lambda_b \cdot r_{njb}}}$$

$$r_{njb,t} = \frac{V_{njb,t}}{\sum_{j=1}^{J} ms_{njb,t-1} \times V_{njb,t}}$$

$$\mathrm{ms_{njb}} = \text{market share of alternative j in building b for investor type n at period t}$$

$$\mathrm{r_{njb}} = \text{relative utility of alternative j in building b for investor type n}$$

The model enables the definition of a various number of different owner types as instances of predefined investor classes: owner occupier, private landlords, community of owners (joint-ownership), and housing association. The structure is motivated by the different perspectives regarding building related investments. For instance, energy cost savings are only relevant for those owners which occupy the building. The corresponding variable relevant to landlords is a refinancing of energy savings measures through additional rental income (investor-tenant dilemma).

Owner types are differentiated by their investment decision behaviour and the perception of the environment, The former is captured by investor-specific weights of economic and non-economic attributes of alternatives. The perception relevant variables – information awareness, energy price calculation, risk aversion – influence the attribute values.

Outputs from Invert/EE-Lab

Standard outputs from the Invert/EE-Lab on an annual basis are:

- Installation of heating and hot water systems by energy carrier and technology (number of buildings, number of dwellings supplied)
- Refurbishment measures by level of refurbishment (number of buildings, number of dwellings)
- Total delivered energy by energy carriers and building categories (GWh)
- Total energy need by building categories (GWh)
- Policy programme costs, e.g. support volume for investment subsidies (M€)
- Total investment (M€)

Moreover, Invert/EE-Lab offers the possibility to derive more detailed and other type of result evaluations as well. Based on the needs of the policy processes we will have to discuss which other type of evaluations of the result data set might be required.

General approach of modelling policy instruments in Invert/EE-Lab

Invert/EE-Lab models the decision making of agents (i.e. building owner types) regarding building renovation and heating, hot water and cooling systems. Policy instruments may affect these decisions (in reality and in Invert/EE-Lab) in the following ways:

- Economic incentives change the economic effectiveness of different options and thus lead to other investment decisions. This change leads to higher market share of the supported technology in the Invert/EE-Lab (via the nested logit approach).
- Regulatory instruments (e.g. building codes or renewable heat obligations) restrict the technological options that decision makers have; limited compliance with these measures can be taken into account by limiting the information level of different agents regarding this measure (see next bullet point).

- Information, advice, etc: Agents have different levels of information. Lack of information may lead to neglecting of innovative technologies in the decision making process or to a lack of awareness regarding subsidies or other support policies. Information campaigns and advice can increase this level of information. Thus, the consideration of innovative technologies, knowledge about support programmes and compliance with regulatory standards increases.
- R&D can push technological progress. The progress in terms of efficiency increase or cost reduction of technologies can be implemented in Invert/EE-Lab.

A.2 Model description Forecast

The model system FORECAST/eLOAD (www.forecast-model.eu) has been developed by the Fraunhofer Institute for Systems- und Innovation Research, TEP Energy GmbH and IREES GmbH. It addresses various research questions related to the dynamics of energy demand.

FORECAST has been applied to a number of research projects analyzing different aspects of the future development of energy demand. This includes the impact of policy-measures, technology dynamics, prices and other socio-economic factors on energy demand and greenhouse gas emissions until 2030 or 2050.

Model approach

FORECAST uses a bottom-up approach, which distinguishes individual technologies, and allows for modeling the diffusion of technologies as the result of individual investment decisions taken over time. For all types of investment decisions, the model follows a simulation approach rather than optimization in order to better capture the real-life behavior of companies and households.

Whenever possible, the investment decision is modeled as a discrete choice process, where households or companies choose among alternative technologies to satisfy a certain energy service. It is implemented as a logit-approach considering the total cost of ownership (TCO) of an investment plus other intangible costs. This approach ensures that even if one technology choice is more cost-effective than the others, it will not gain a 100% market share. This effect reflects heterogeneity in the market, niche markets and non-rational behavior of companies and households, which is a central capability to model policies. Still, the resulting technology development (and energy demand) is price sensitive.

The replacement of equipment/buildings/technologies is based on a vintage stock approach allowing to realistically model the replacement of the capital stock considering its age distribution. Some parts of the industrial and the tertiary sector are not using a vintage stock approach, due to the huge heterogeneity of technologies on the one hand and data scarcity on the other. Technology diffusion, however, is modeled based on a similar simulation algorithm taking heterogeneity and non-rational behavior into account.

The energy saving potentials for household appliances depend on the market uptake of energy efficient technologies. For each appliance, the FORECAST model distinguishes between a variety of technologies, where the energy efficiency is typically indicated by the energy efficiency index (EEI) or the energy use per year in order to model the requirements specified in the European product policy documents. For appliances covered under the Labelling legislation, the energy efficiency classes are distinguished as defined in the legislative documents.

The diffusion of technologies is modeled as a result of individual investment decisions taken over time. The investment decisions are modeled as a discrete choice process, where households choose among alternative technologies and efficiency classes. The implementation of the investment decisions follows a logit approach considering the total cost of ownership of an investment as well as non-monetary barriers to the investment in energy efficient appliances. Monetary irrationality and lack of information are represented by means of varying discount rates in the NPV evaluation as well as logit fuzziness depending on technology and country. This approach ensures that even if one technology choice is more cost-effective than the others, it will not gain a 100% market share, reflecting the heterogeneity in the market, niche markets and non-rational behavior. The replacement of appliances is based on a vintage stock approach allowing to realistically model the replacement of the capital stock considering its age distribution.

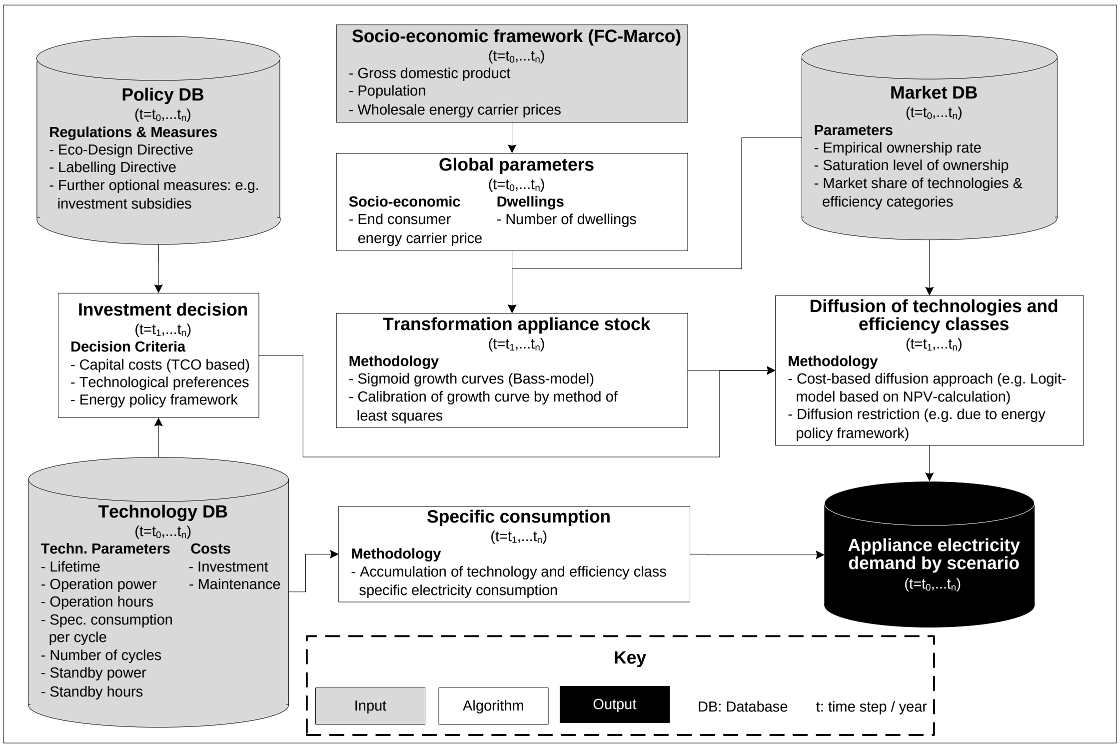

Figure 65: Overview over the modelling approach

Coverage

The FORECAST-Residential model covers the EU-28 (+Norway, Switzerland and Turkey). The model covers the most relevant energy using devices in the residential sector, in particular:

- ***Large appliances:*** The model distinguishes refrigerators, freezers, washing machines, dryers and dishwashers
- ***Information/Communication Technologies ICT:*** we distinguish televisions, laptop ***c***omputers, desktop computers, computer screens, modems, set top boxes but group them here in this category.
- ***Lighting***
- ***Air conditioning***
- ***(electric and non-electric) Cooking***

The model has been in recent years frequently applied to national as well as EU-wide studies. Some examples of recent EU-wide applications are as follows:

- Calculation of energy saving potentials in the industrial sector of the EU by member state until 2030 for DG ENER (Eichhammer et al. 2009)
- Contribution of energy efficiency to the EU 2050 climate protection scenarios for the German Environmental Ministry (Boßmann et al. 2012)
- Long-term electricity demand of the EU by member state until 2050 for all demand sectors (ESA² 2013; www.esa2.eu)
- Assessment of the impact of energy-efficiency policies on the electricity demand in the EU's tertiary sector by member state until 2035 (Jakob et al. 2012; Jakob et al. 2013)
- Ongoing: Evaluation of energy-efficiency policies for the EU by member state until 2020 and 2030 for DG ENER

Examples for national studies:

Long-term climate policy scenarios for Germany in all demand sectors (Schlomann et al. 2011)

Saving potentials and costs in German energy-intensive industries (Fleiter et al. 2011a; Fleiter et al. 2012; Fleiter et al. 2013)

Ex-Ante impact assessment of energy-efficiency policies in the Turkish residential sector (Elsland et al. 2013a)

Ex-Ante impact assessment of energy-efficiency policies in the German residential sector (Elsland et al. 2013b)

Publications relying on FORECAST

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Fleiter, T.; Hirzel, S.; Jakob, M.; Barth, J.; Quandt, L.; Reitze, F.; Toro, F. (2010): Electricity demand in the European service sector: a detailed bottom-up estimate by sector and by end-use, Konferenzband der IEECB 13-14.04.2010, Frankfurt.

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Schlomann, B.; Fleiter, T.; Hansen, P.; Horn, M.; Matthes, F.-C.; Gores, S. (2011): Impact of energy and climate policies until 2030 - a detailed bottom-up modelling approach: IEPEC 2010, 9-10 June, Paris.

A.3 Descriptive Statistics of Survey

Weight of decision criteria for participants when refurbishing their building or replace the heating system

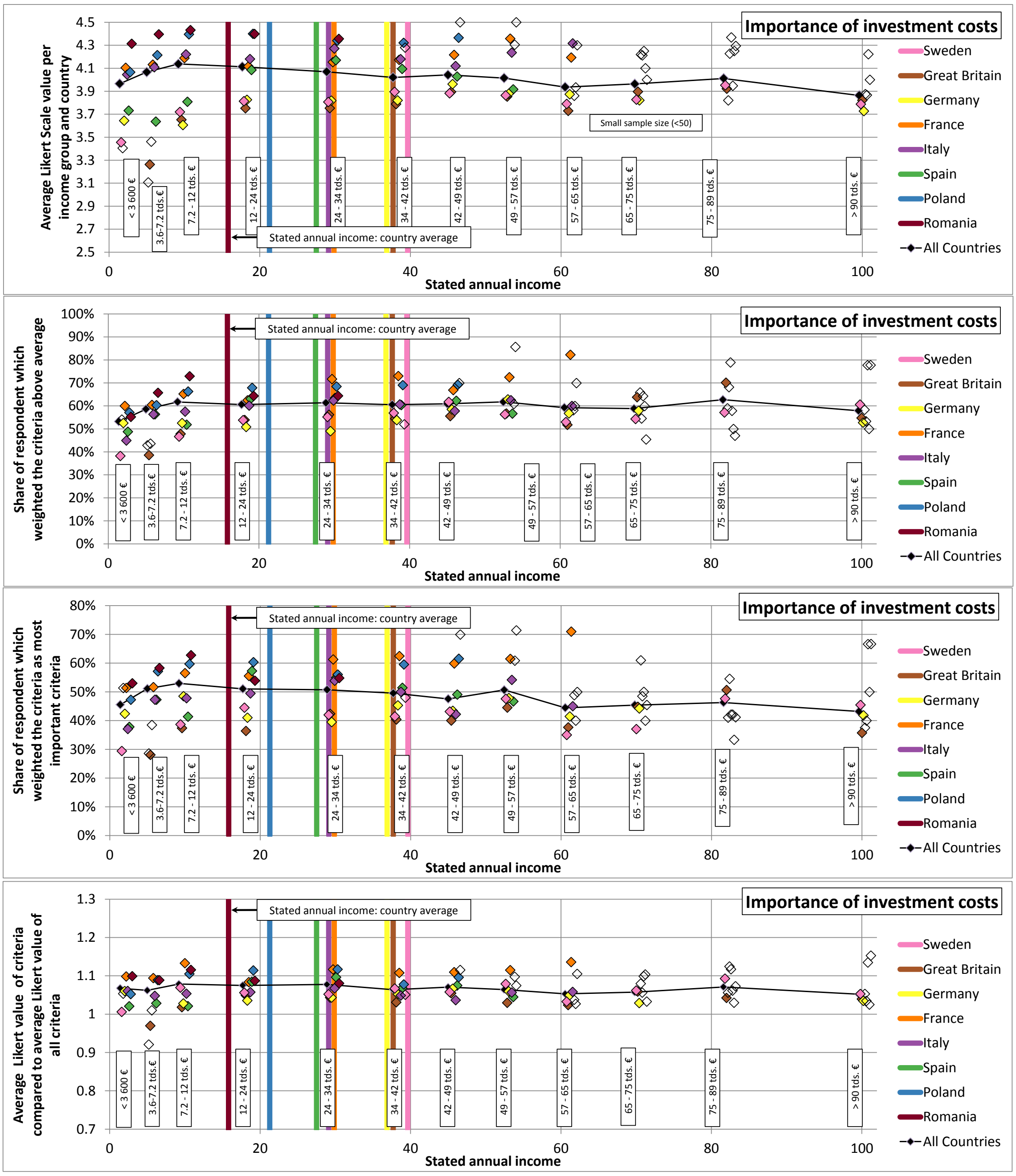

Figure 66: Average weight of the criteria: investment costs per country and income group.

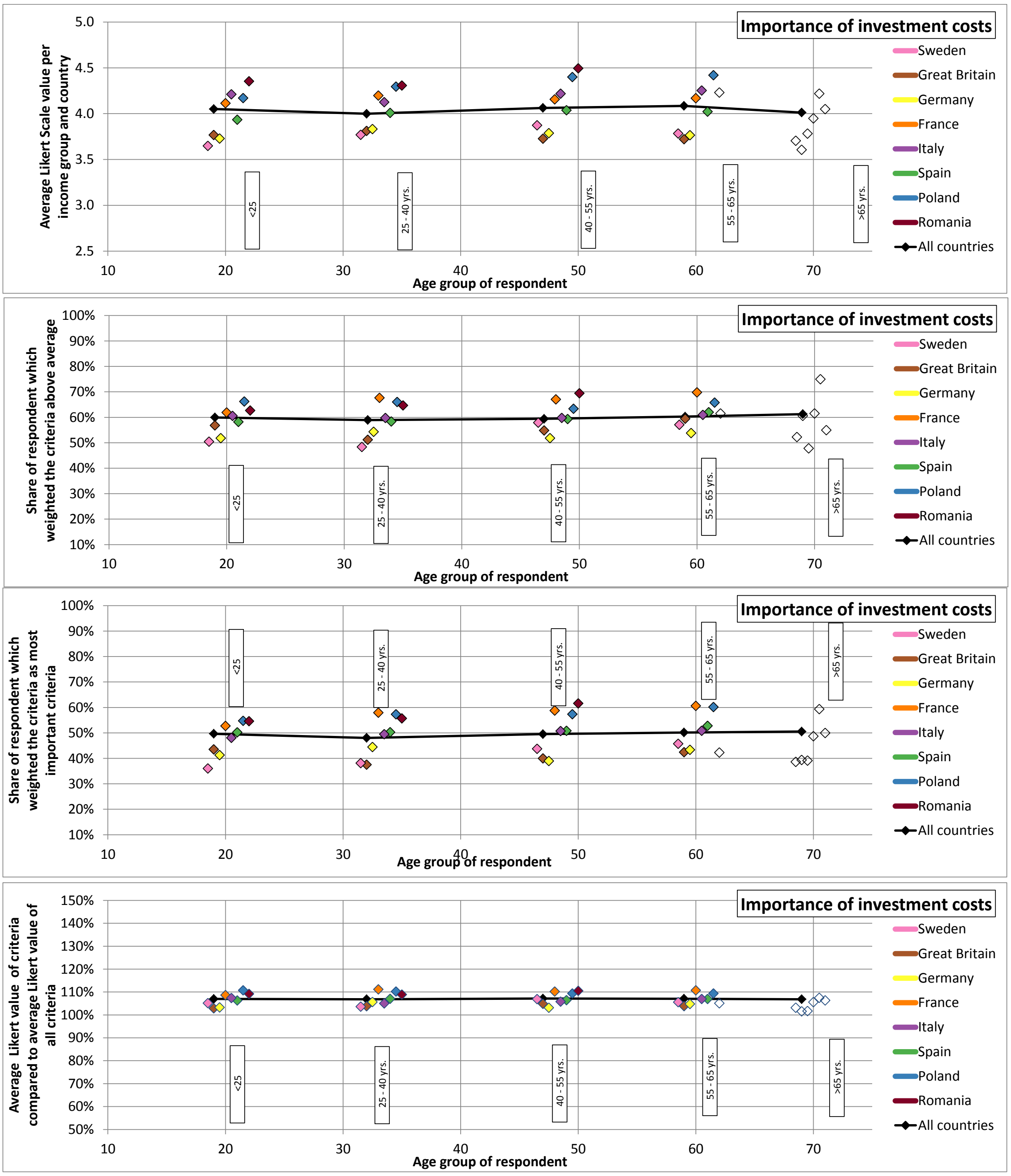

Figure 67: Average weight of the criteria: investment costs per country and age group.

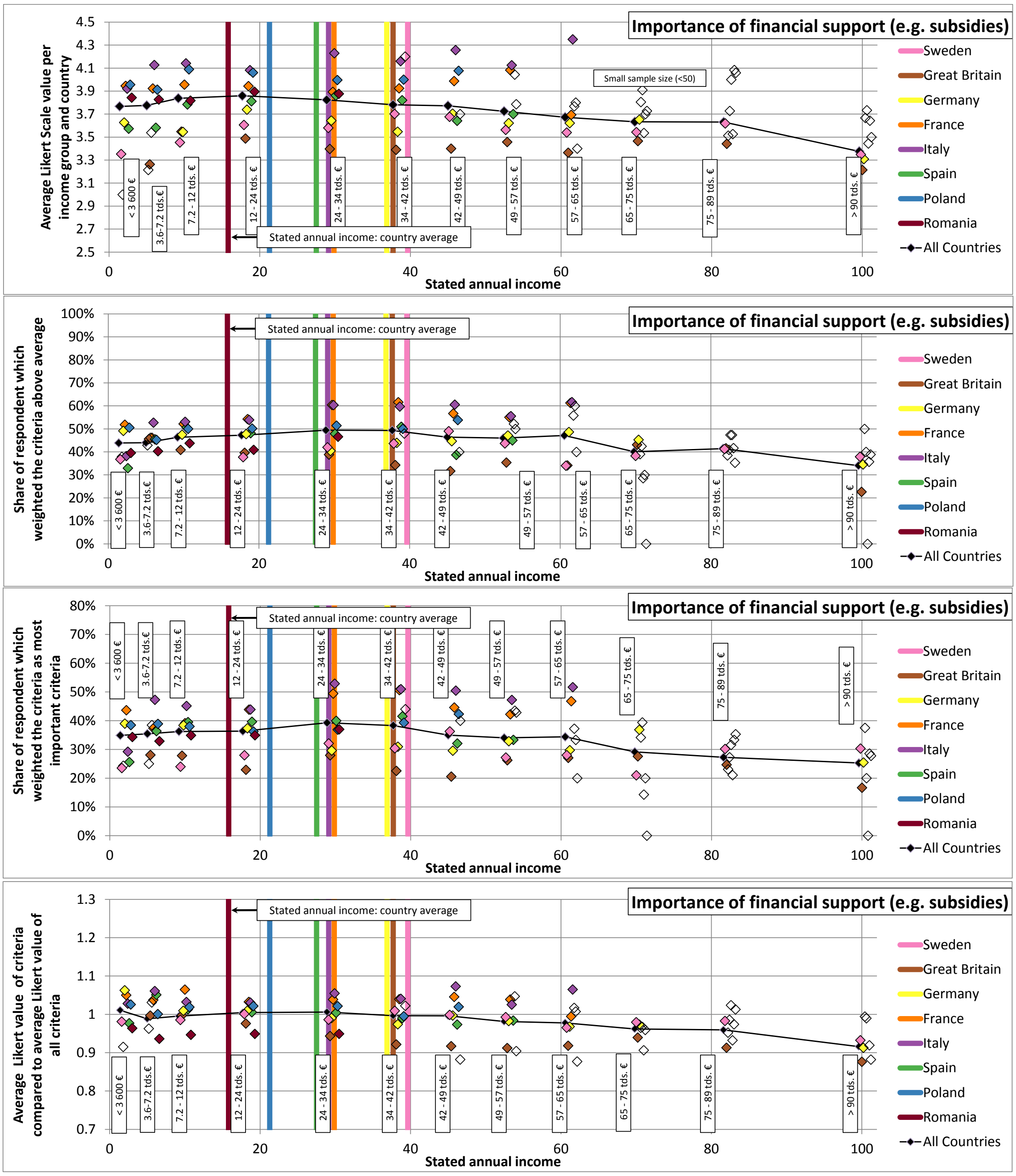

Figure 68: Average weight of the criteria: financial support per country and income group.

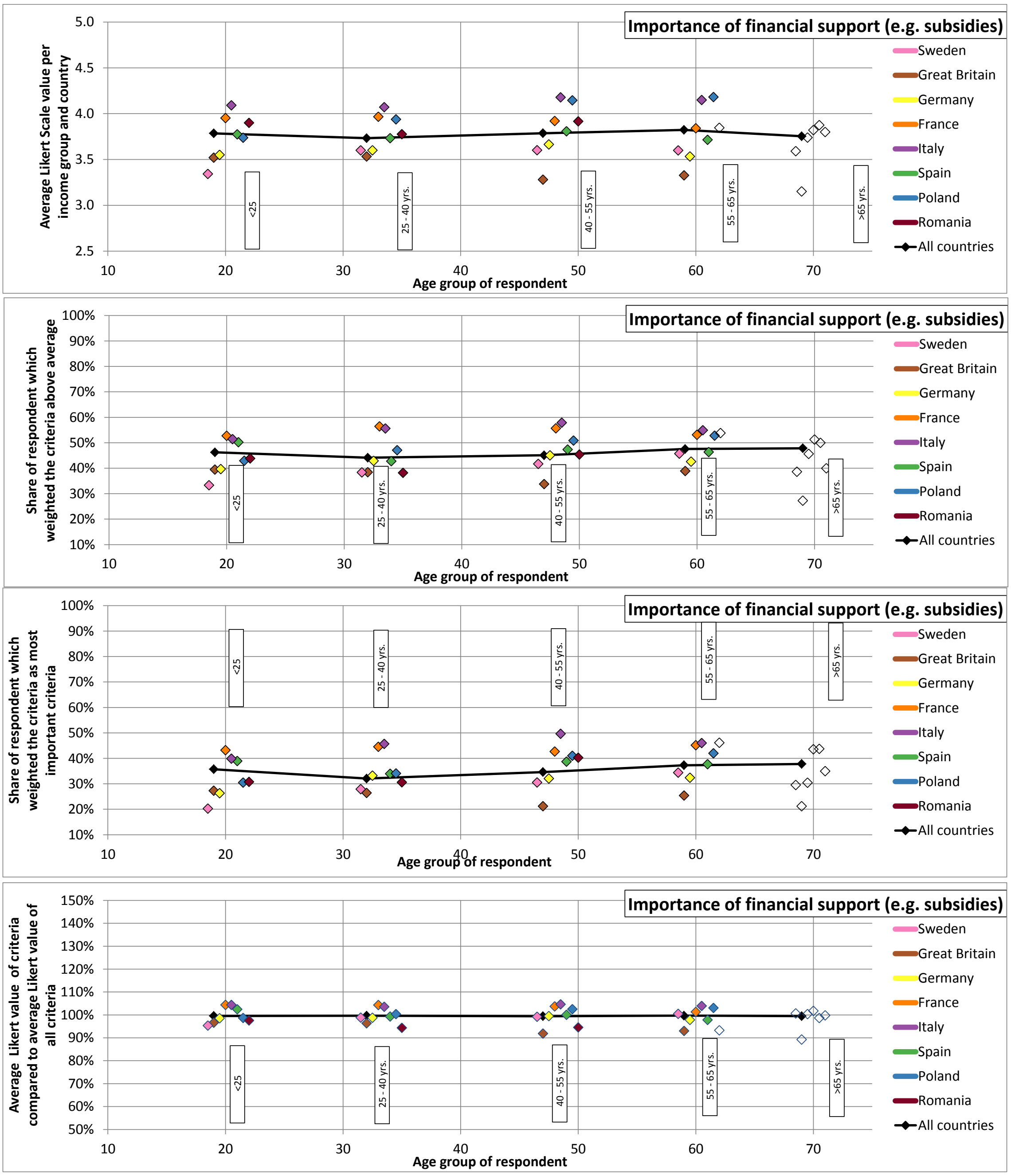

Figure 69: Average weight of the criteria: financial support per country and age group.

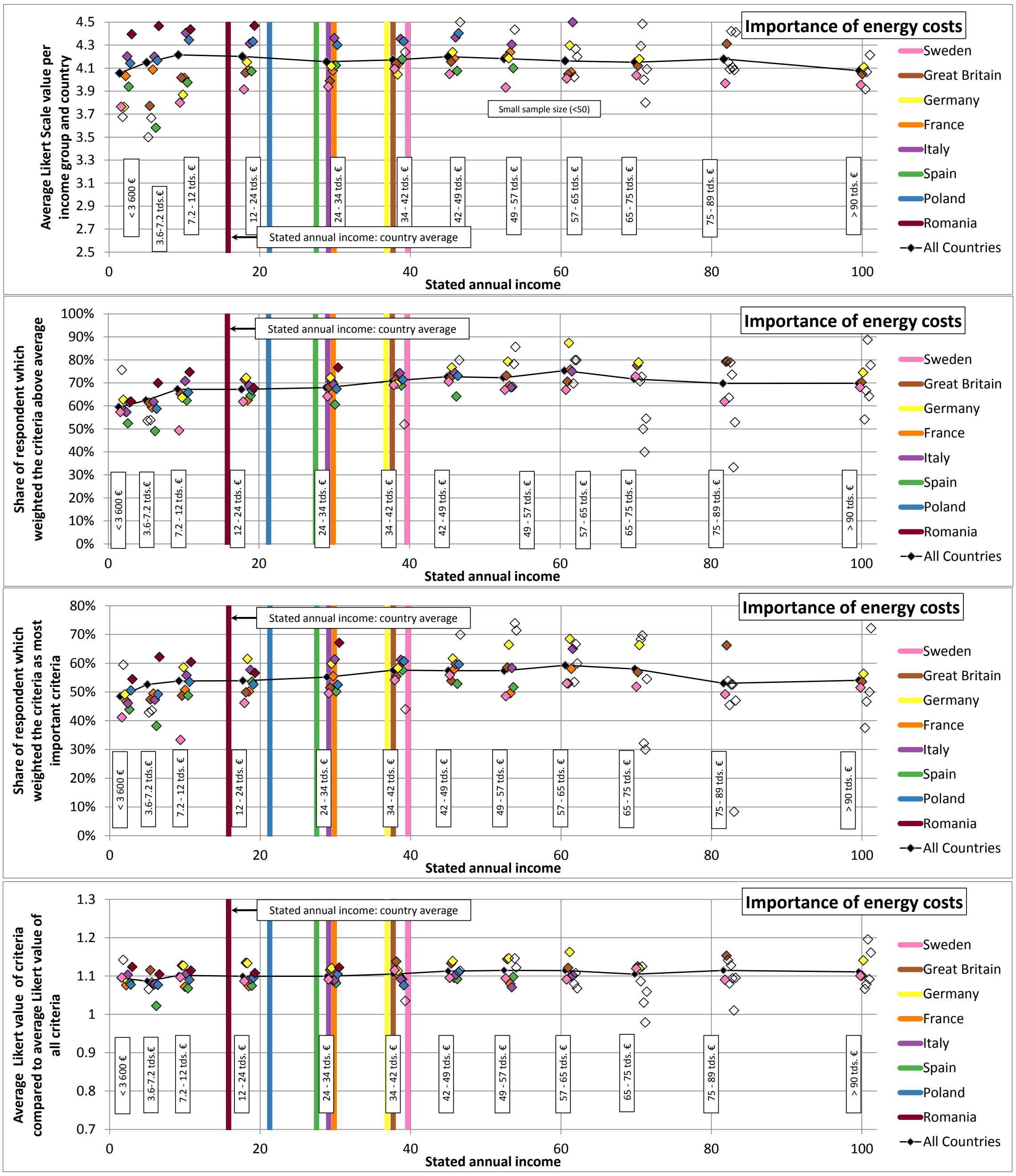

Figure 70: Average weight of the criteria: energy costs per country and income group.

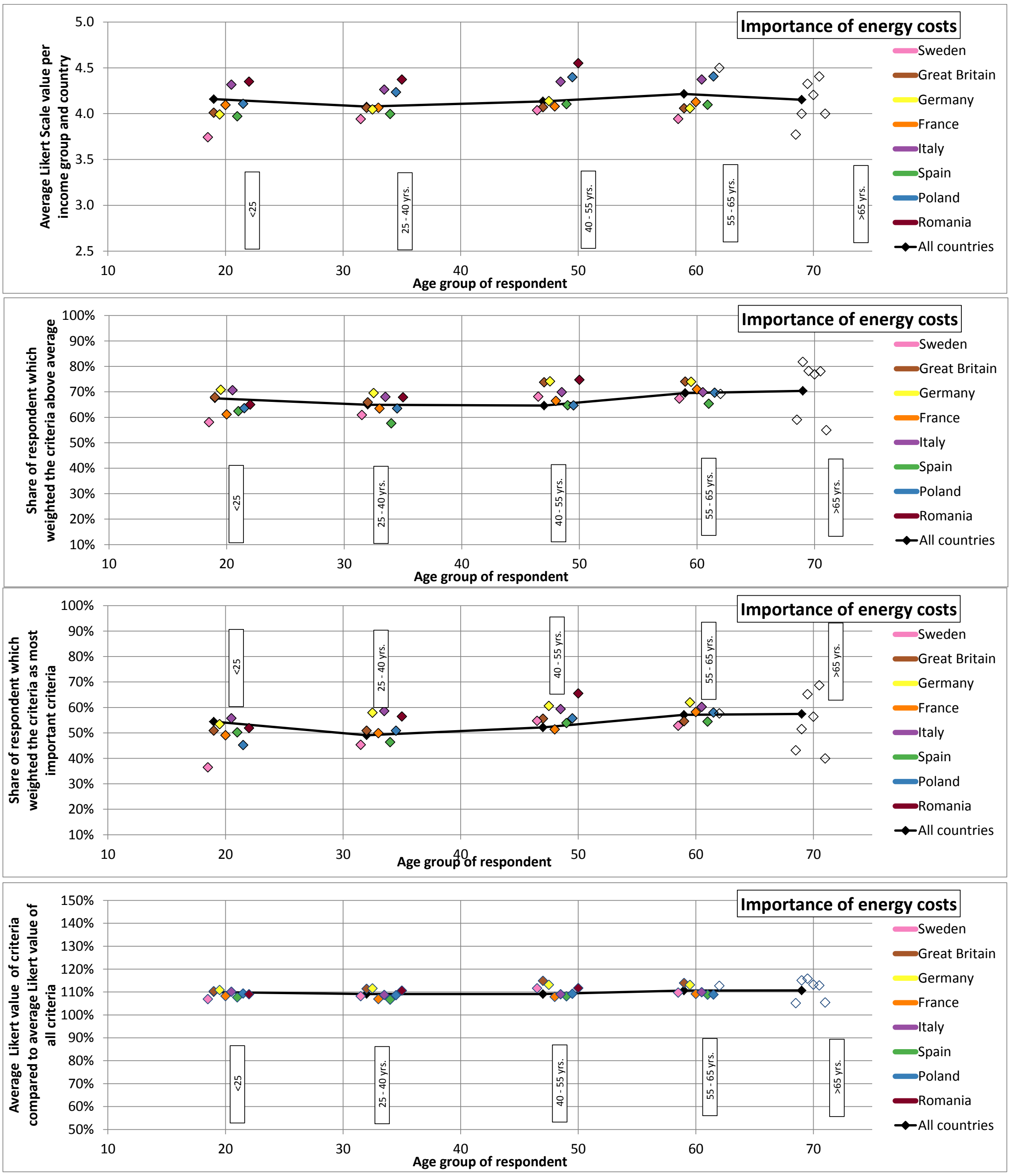

Figure 71: Average weight of the criteria: energy costs per country and age group.

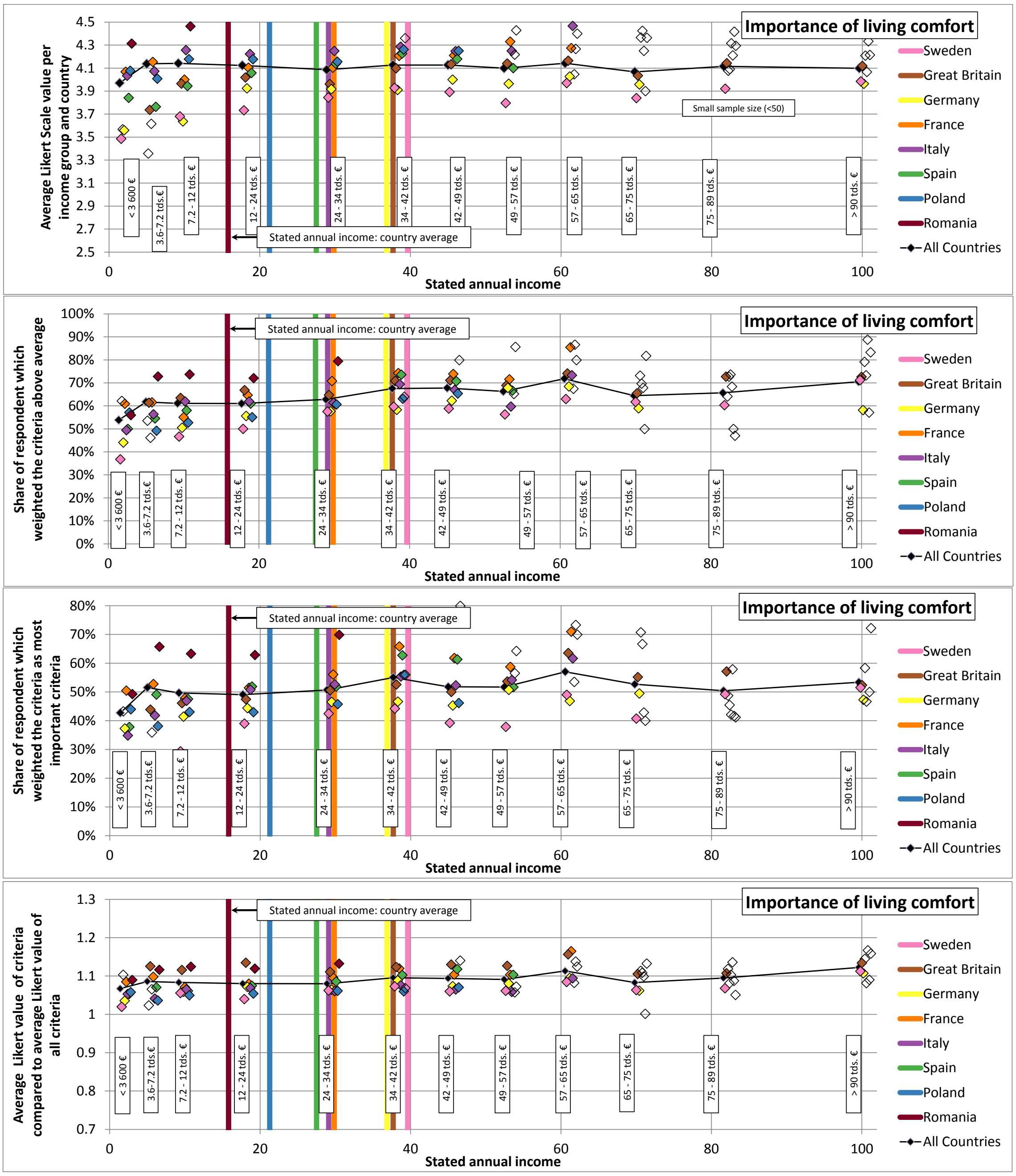

Figure 72: Average weight of the criteria: living comfort per country and income group.

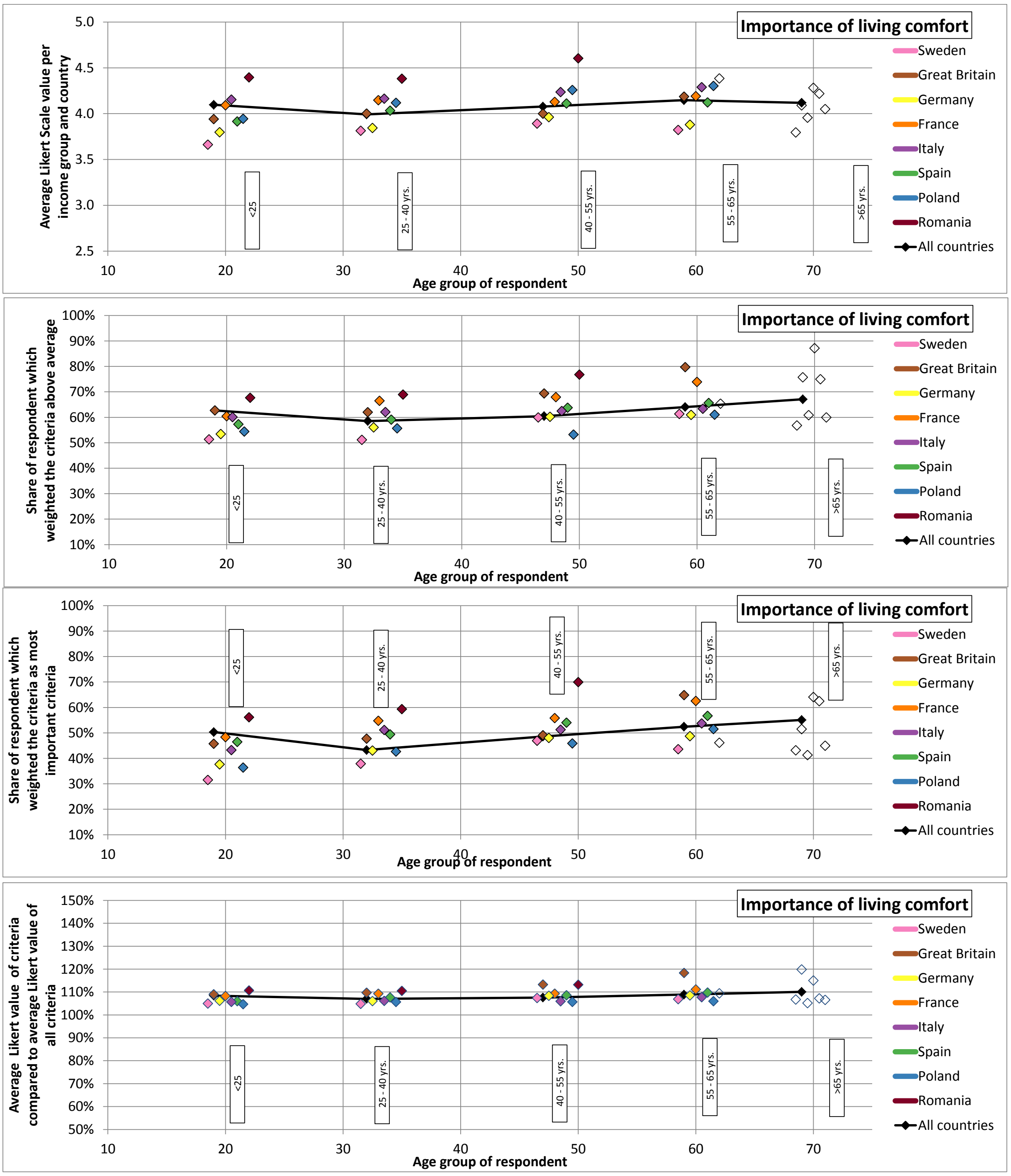

Figure 73: Average weight of the criteria: living comfort per country and age group.

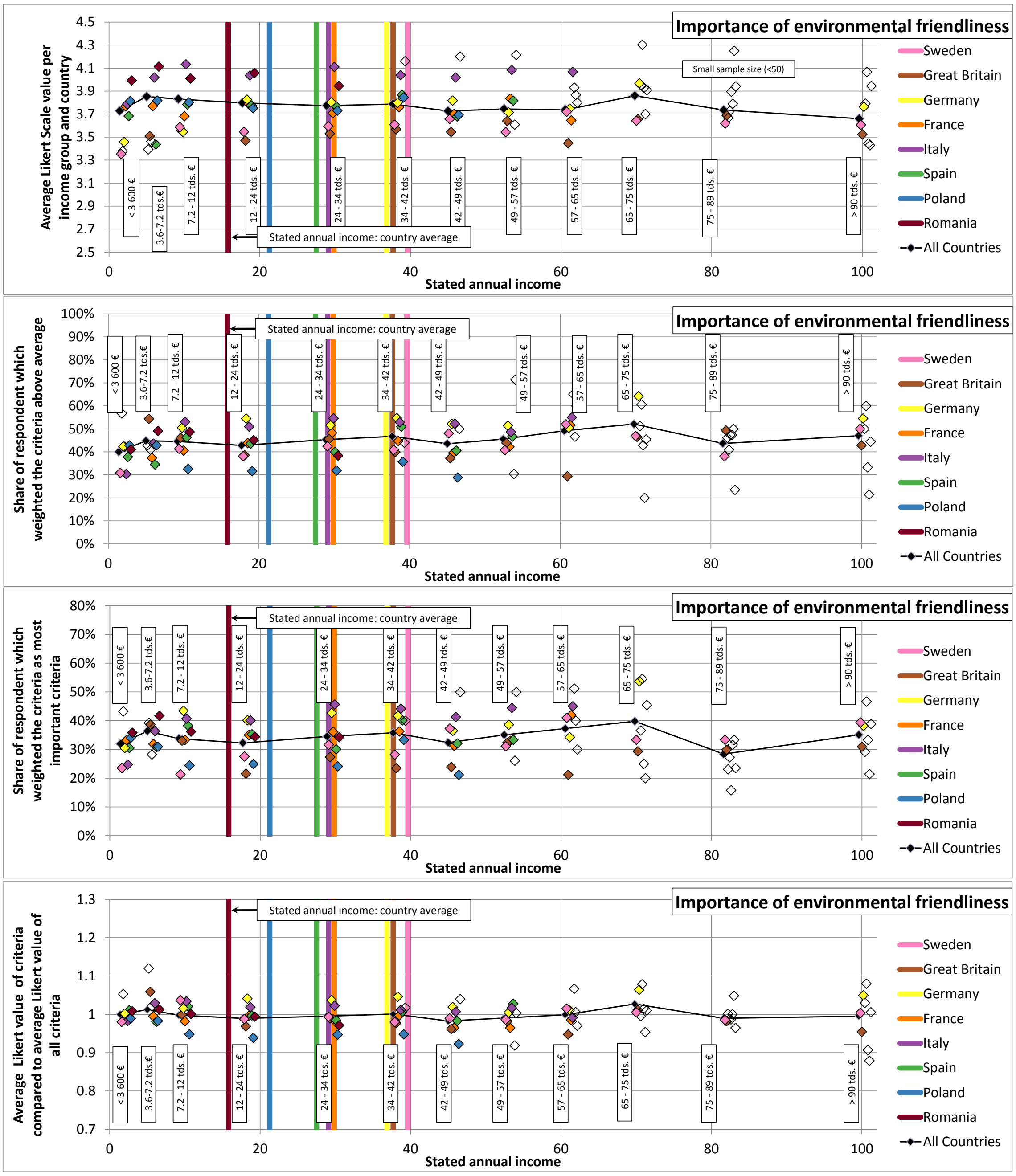

Figure 74: Average weight of the criteria: environmental friendliness per country and income group.

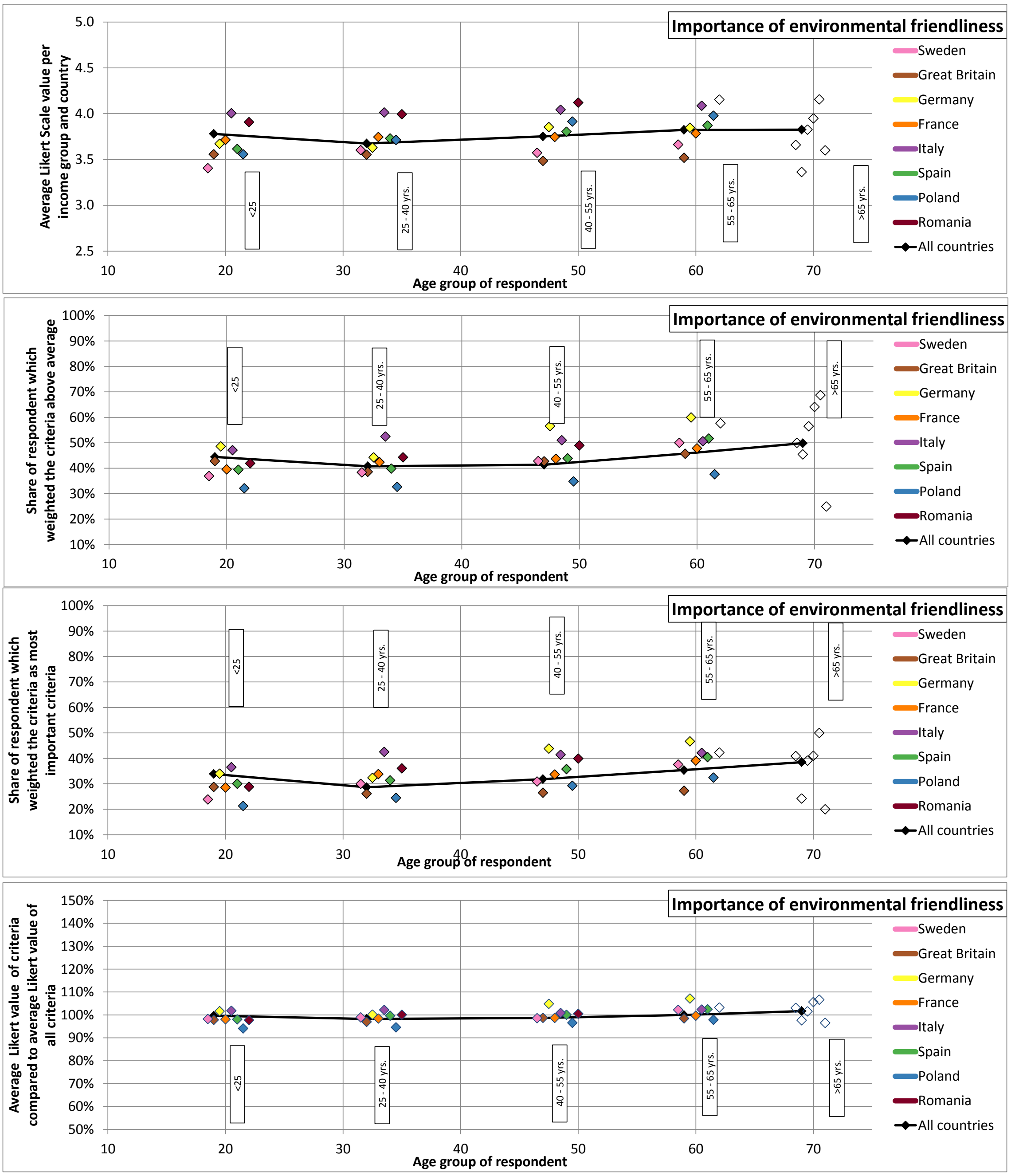

Figure 75: Average weight of the criteria: environmental friendliness per country and age group.

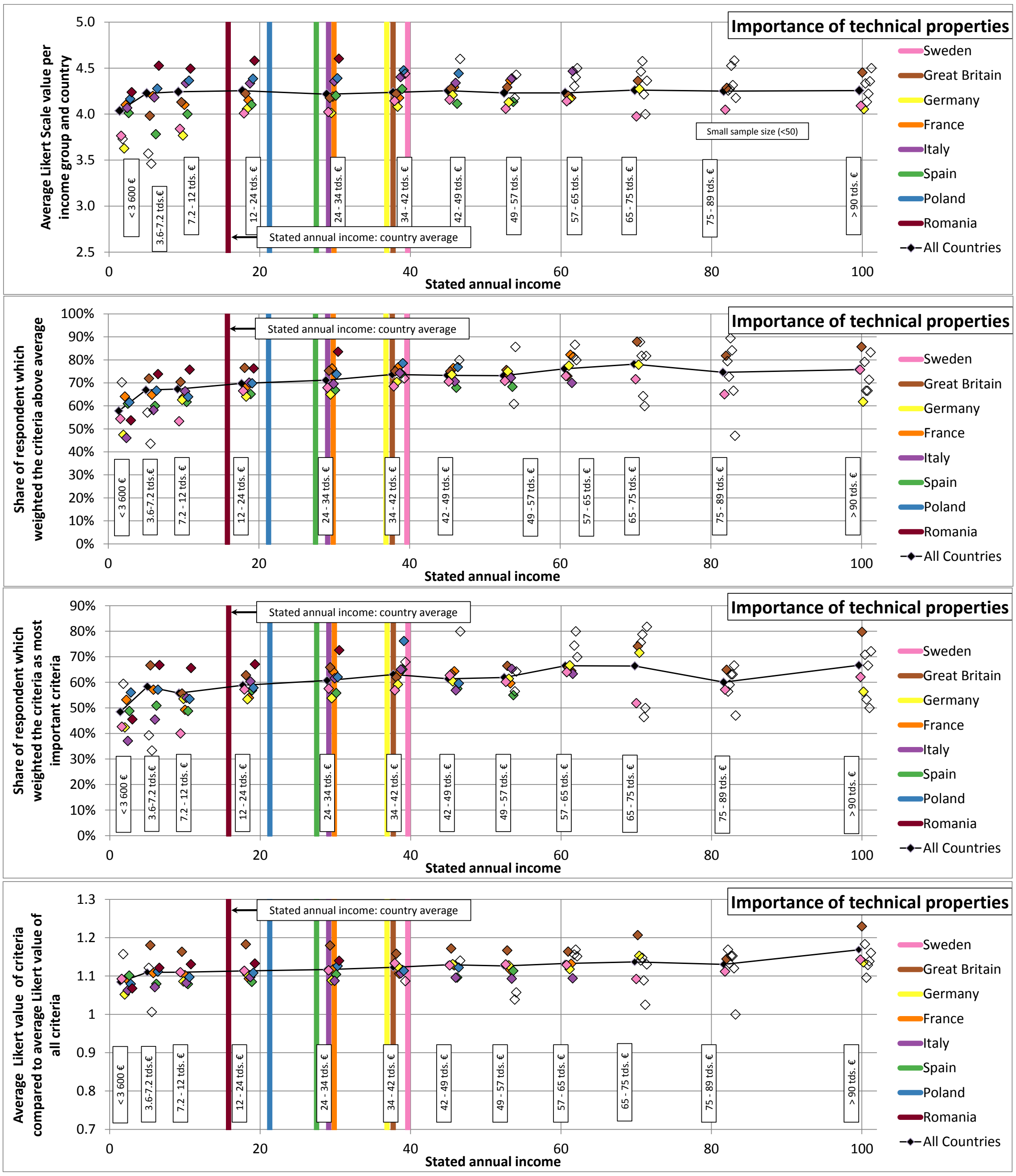

Figure 76: Average weight of the criteria: technical properties per country and income group.

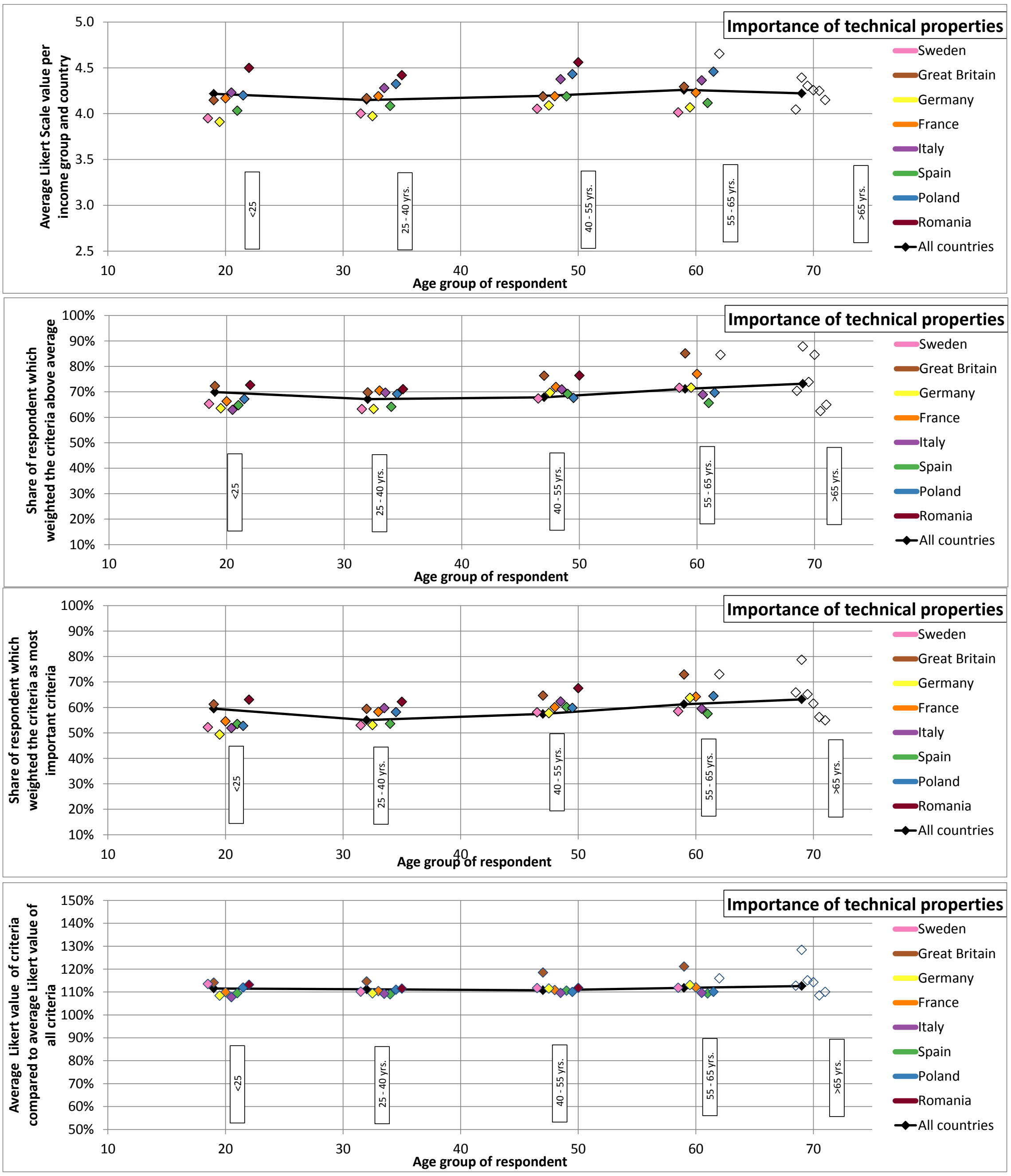

Figure 77: Average weight of the criteria: technical properties per country and age group.

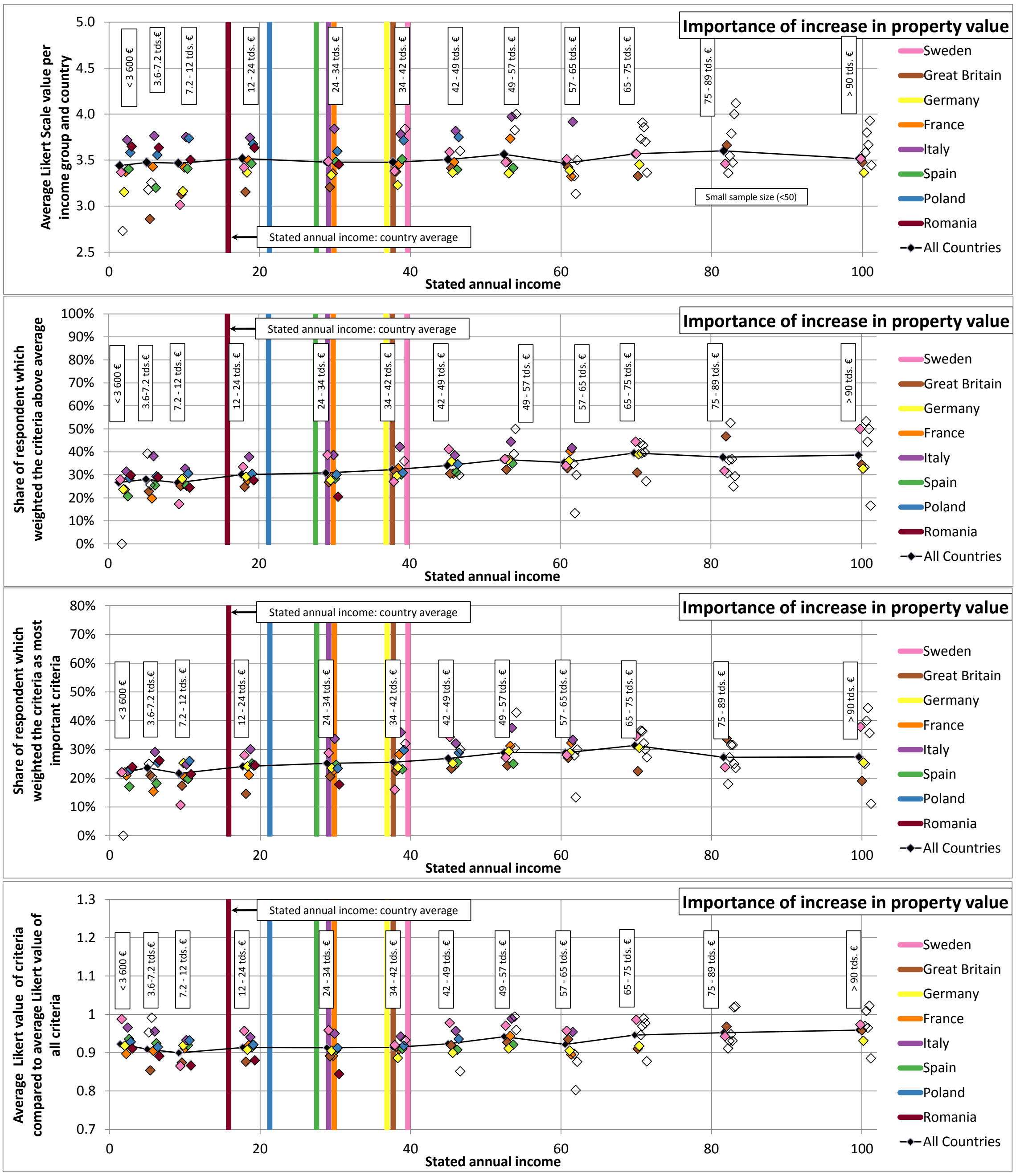

Figure 78: Average weight of the criteria: increase in property value per country and income group.

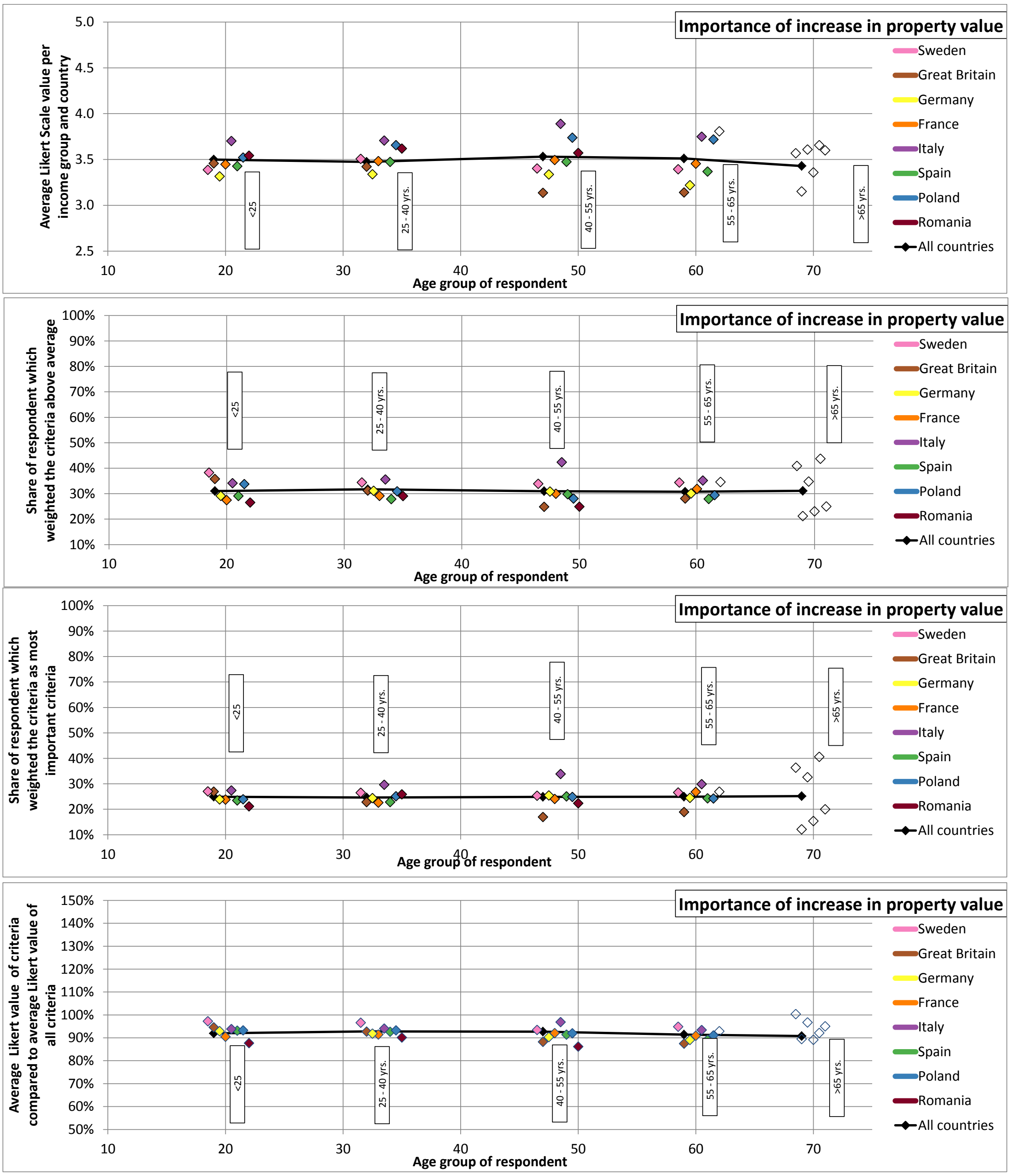

Figure 79: Average weight of the criteria: increase in property value per country and age group.

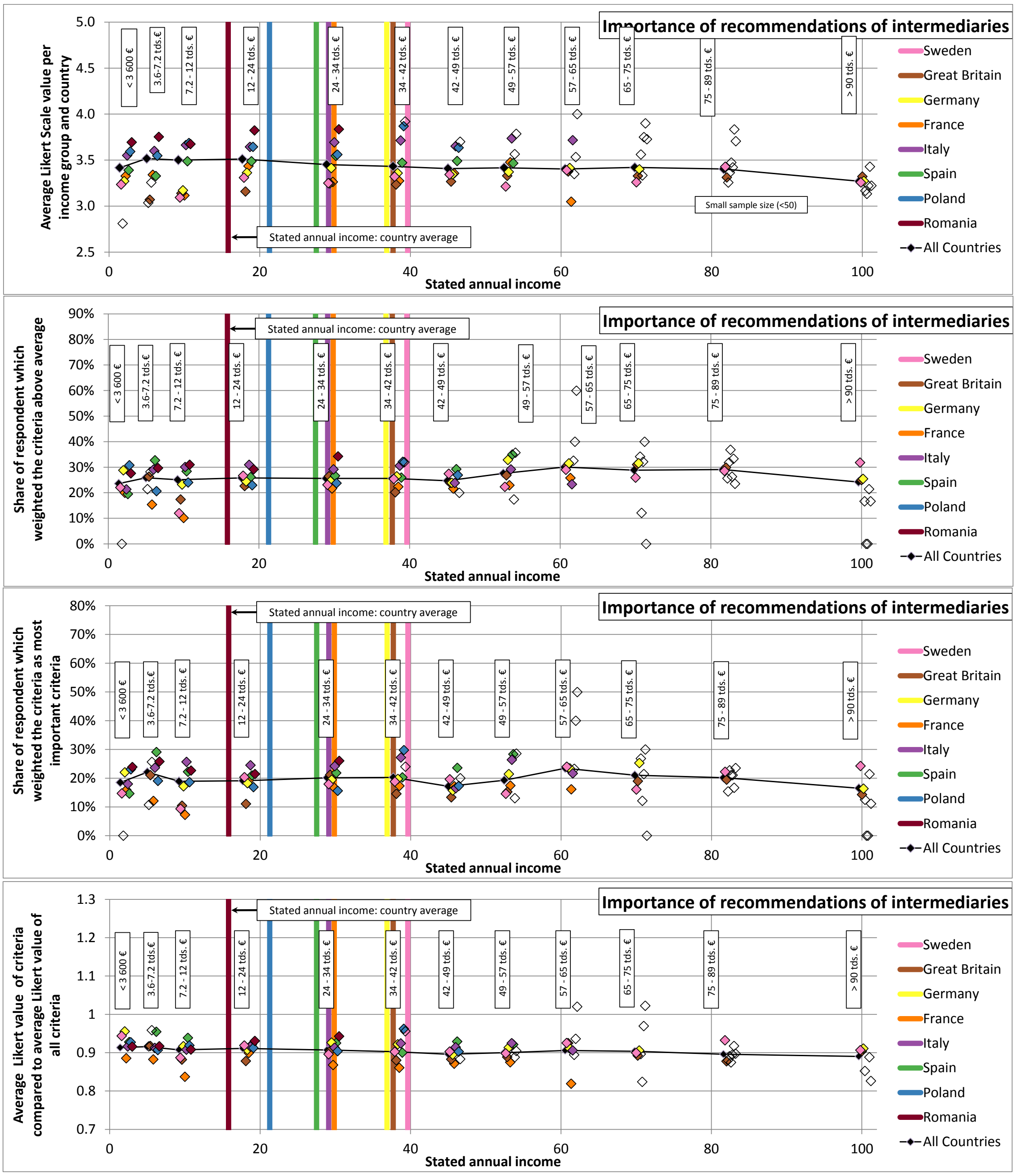

Figure 80: Average weight of the criteria: recommendations of intermediaries per country and income group.

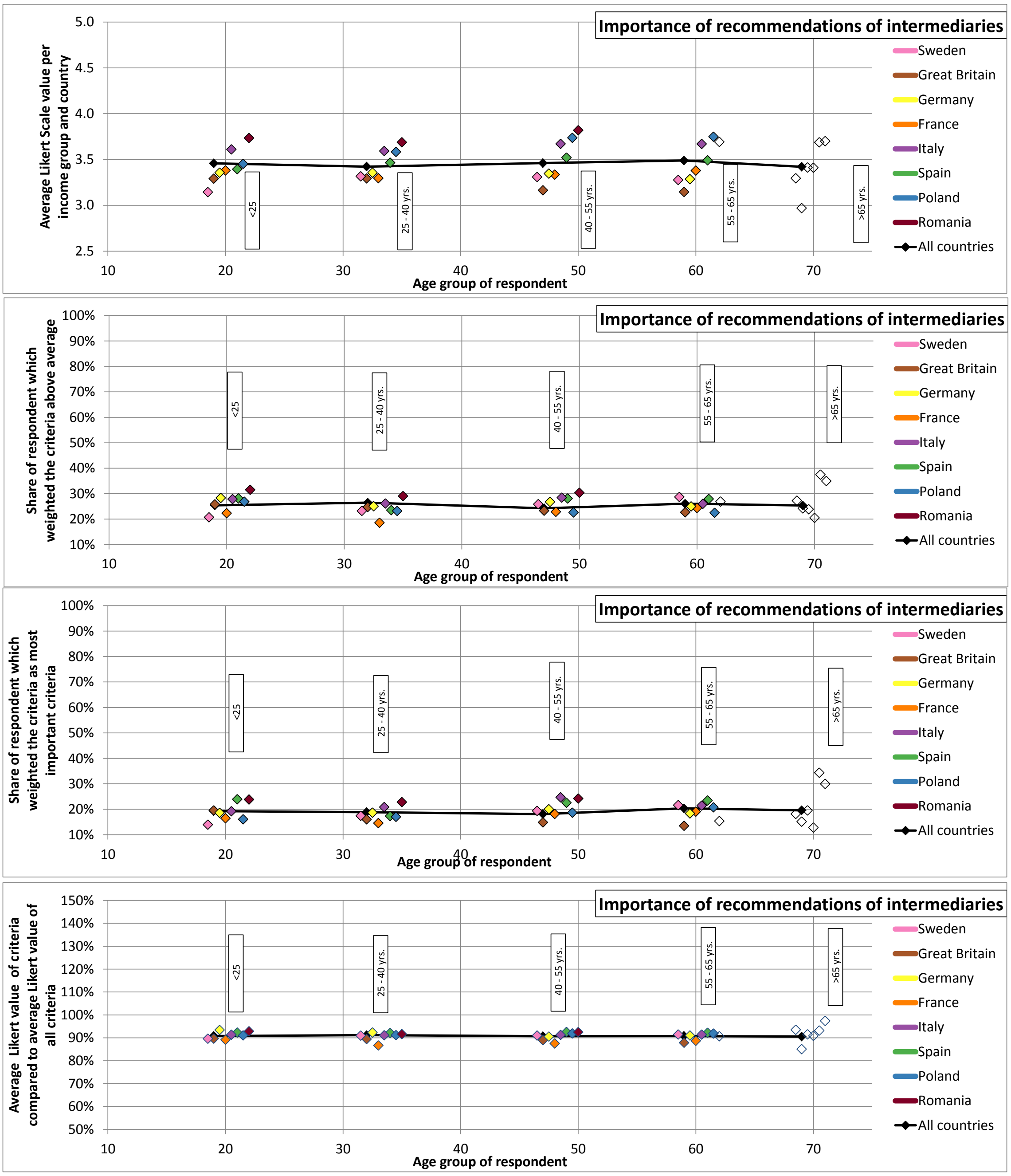

Figure 81: Average weight of the criteria: recommendations of intermediaries per country and age group.

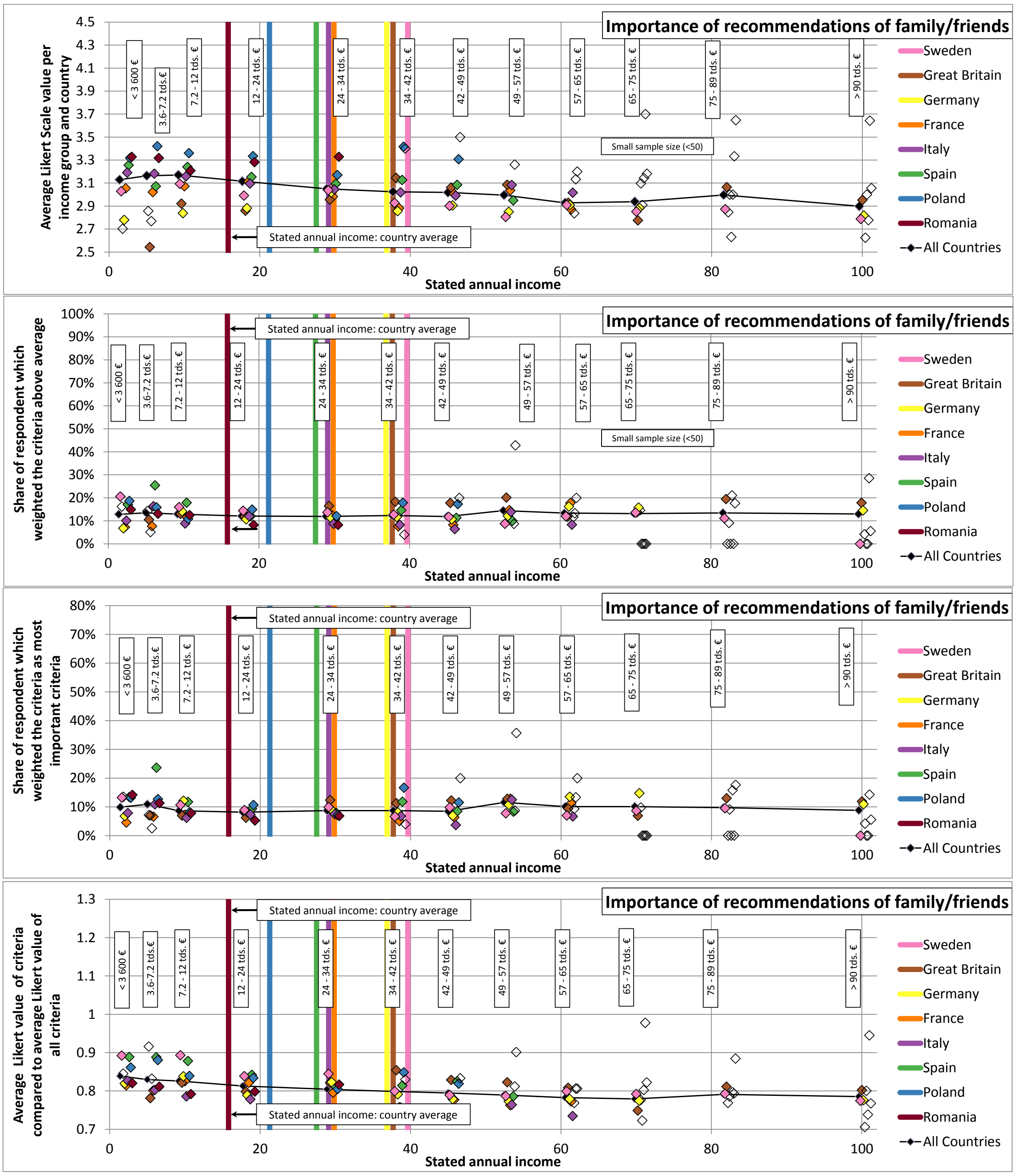

Figure 82: Average weight of the criteria: recommendations of family/friends per country and income group.

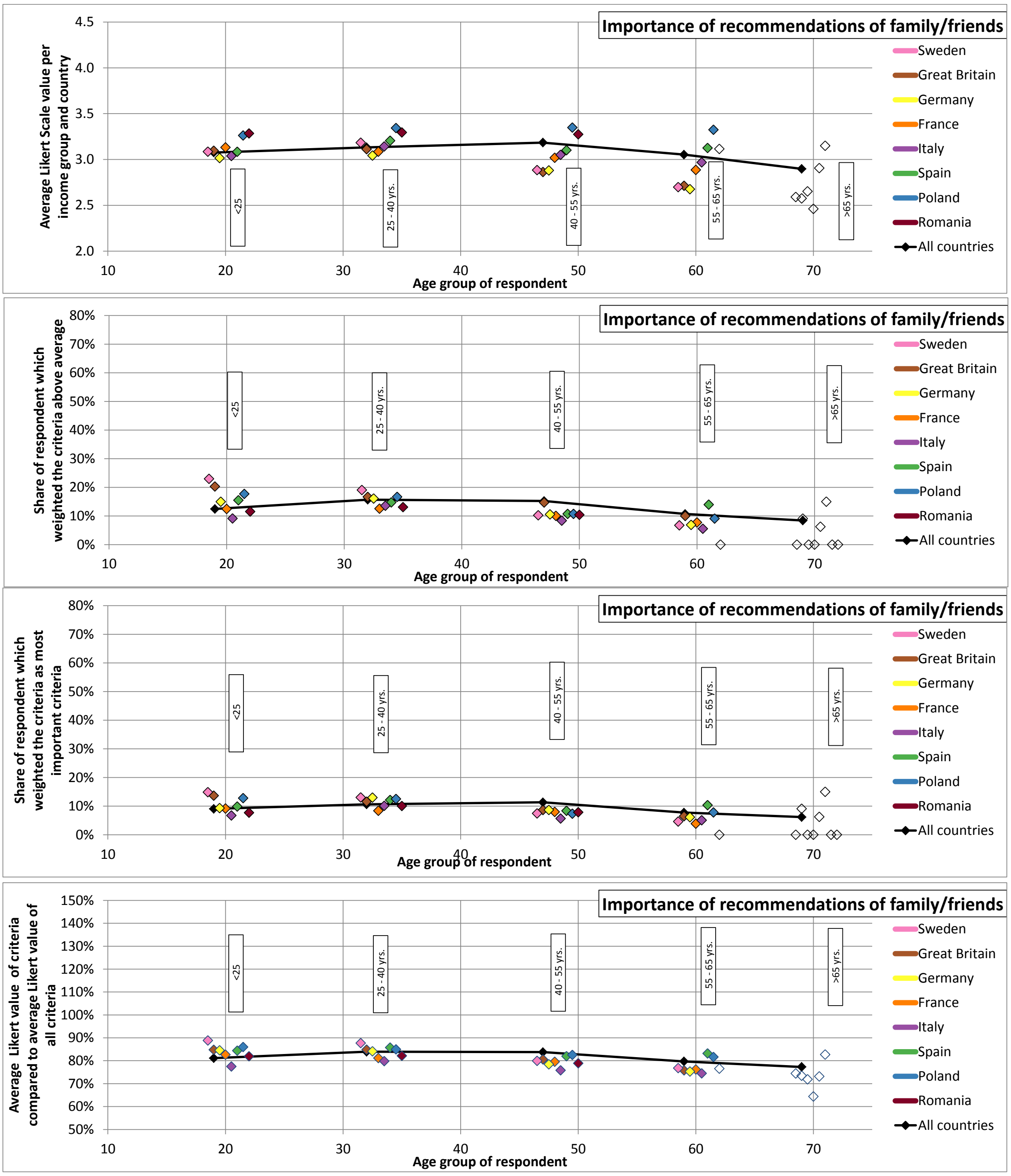

Figure 83: Average weight of the criteria: recommendations of family/friends per country and age group.

Time discounting per country and income class

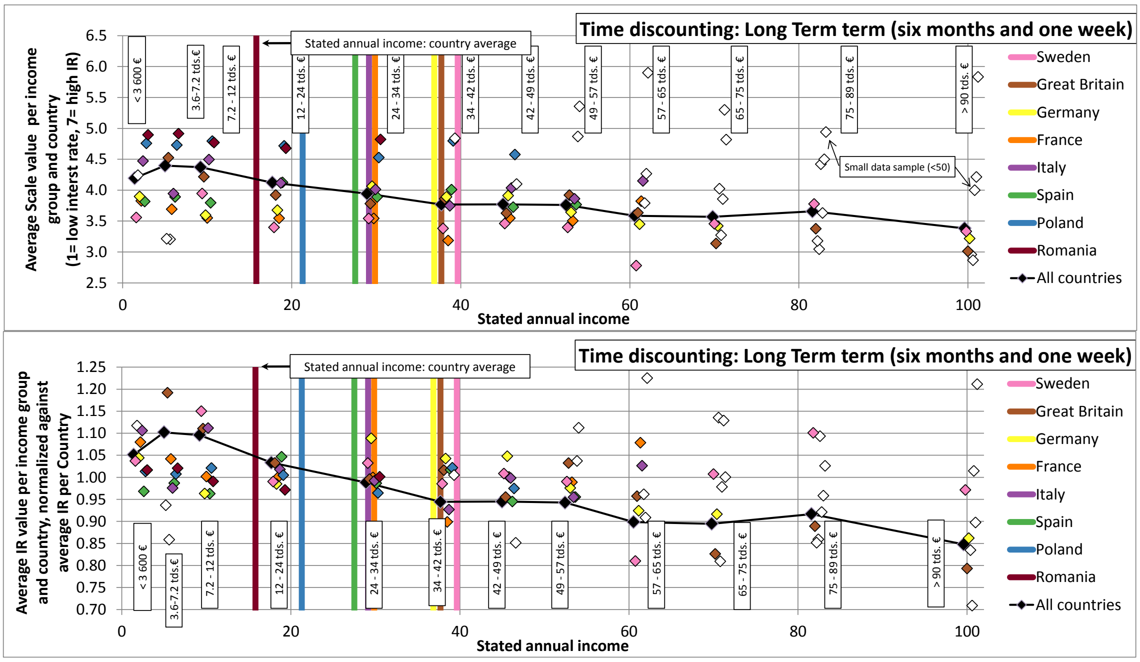

Figure 84: Average long term (six months versus six months plus one week) time discounting indicator per income group and country.

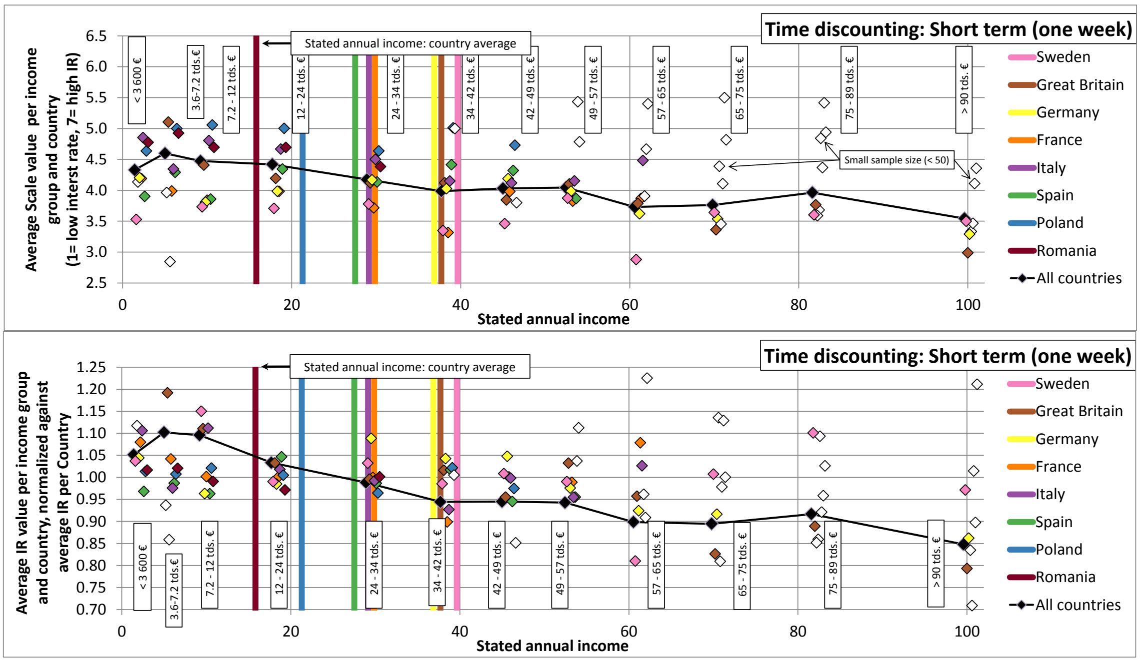

Figure 85: Average short term (now versus one week) time discounting indicator per income group and country.

A.4 Assumptions of discount rates for median and low income agents in INVERT/EE-Lab

Table 14: Discount rates and weight for investment decisions in renovation and heating systems for median income and low income agents in INVERT/EE-Lab for the current policy and intensified-measures scenario in BRISKEE

			Renovation weights			Heating systems weigths						
	Agent group	discount rates	investment	profitability	comfort	Economic weight	investment	payback time	profitability	non-economic weight	sustainability	comfort
Belgium	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Bulgaria	Median income	8%	0.30	0.30	0.39	0.51	0.50	0.30	0.20	0.49	0.32	0.68
	Low income	16%	0.30	0.30	0.39	0.51	0.50	0.30	0.20	0.49	0.32	0.68
CYPRUS	Median income	5%	0.26	0.52	0.22	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	10%	0.26	0.52	0.22	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Czech Republic	Median income	4%	0.29	0.24	0.47	0.41	0.56	0.22	0.22	0.59	0.38	0.62
	Low income	9%	0.29	0.24	0.47	0.41	0.56	0.22	0.22	0.59	0.38	0.62
Denmark	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Spain	Median income	5%	0.26	0.67	0.07	0.52	0.42	0.33	0.25	0.48	0.36	0.64
	Low income	9%	0.26	0.67	0.07	0.52	0.42	0.33	0.25	0.48	0.36	0.64
Estonia	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Finland	Median income	4%	0.29	0.35	0.35	0.55	0.45	0.45	0.09	0.45	0.33	0.67
	Low income	7%	0.29	0.35	0.35	0.55	0.45	0.45	0.09	0.45	0.33	0.67
France	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
United Kingdom	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Greece	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Croatia	Median income	8%	0.30	0.30	0.39	0.51	0.50	0.30	0.20	0.49	0.32	0.68
	Low income	16%	0.30	0.30	0.39	0.51	0.50	0.30	0.20	0.49	0.32	0.68
Hungary	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Ireland	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55

			Renovation weights			Heating systems weigths						
	Agent group	discount rates	investment	profitability	comfort	Economic weight	investment	payback time	profitability	non-economic weight	sustainability	comfort
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Italy	Median income	5%	0.26	0.62	0.12	0.48	0.45	0.27	0.27	0.52	0.33	0.67
	Low income	9%	0.26	0.62	0.12	0.48	0.45	0.27	0.27	0.52	0.33	0.67
Lithuania	Median income	4%	0.29	0.24	0.47	0.41	0.56	0.22	0.22	0.59	0.38	0.62
	Low income	9%	0.29	0.24	0.47	0.41	0.56	0.22	0.22	0.59	0.38	0.62
Luxembourg	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Latvia	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Malta	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Netherlands	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Poland	Median income	4%	0.29	0.54	0.17	0.41	0.56	0.22	0.22	0.59	0.38	0.62
	Low income	9%	0.29	0.54	0.17	0.41	0.56	0.22	0.22	0.59	0.38	0.62
Portugal	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Romania	Median income	8%	0.26	0.67	0.07	0.52	0.42	0.42	0.17	0.48	0.36	0.64
	Low income	16%	0.26	0.67	0.07	0.52	0.42	0.42	0.17	0.48	0.36	0.64
Slovakia	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
Slovenia	Median income	4%	0.29	0.24	0.47	0.41	0.56	0.22	0.22	0.59	0.38	0.62
	Low income	9%	0.29	0.24	0.47	0.41	0.56	0.22	0.22	0.59	0.38	0.62
Sweden	Median income	4%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55
	Low income	7%	0.26	0.32	0.42	0.43	0.45	0.27	0.27	0.57	0.45	0.55

A.5 Final energy demand by usage types per country

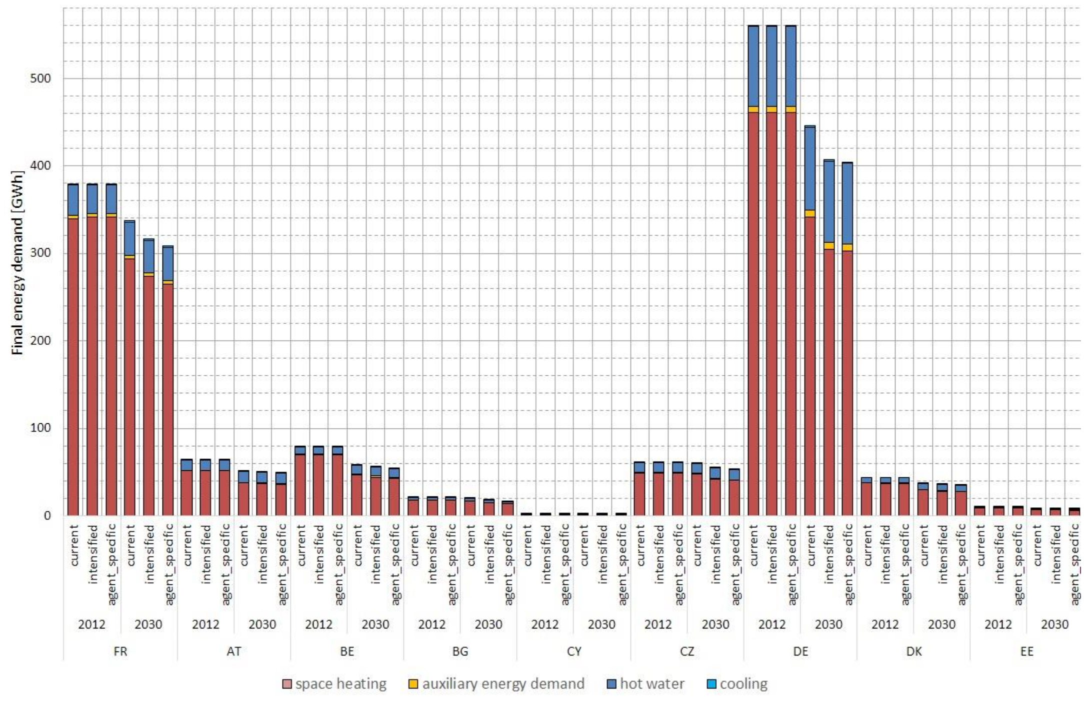

Figure 86: Final energy demand by usage types per country for EU28 (1)

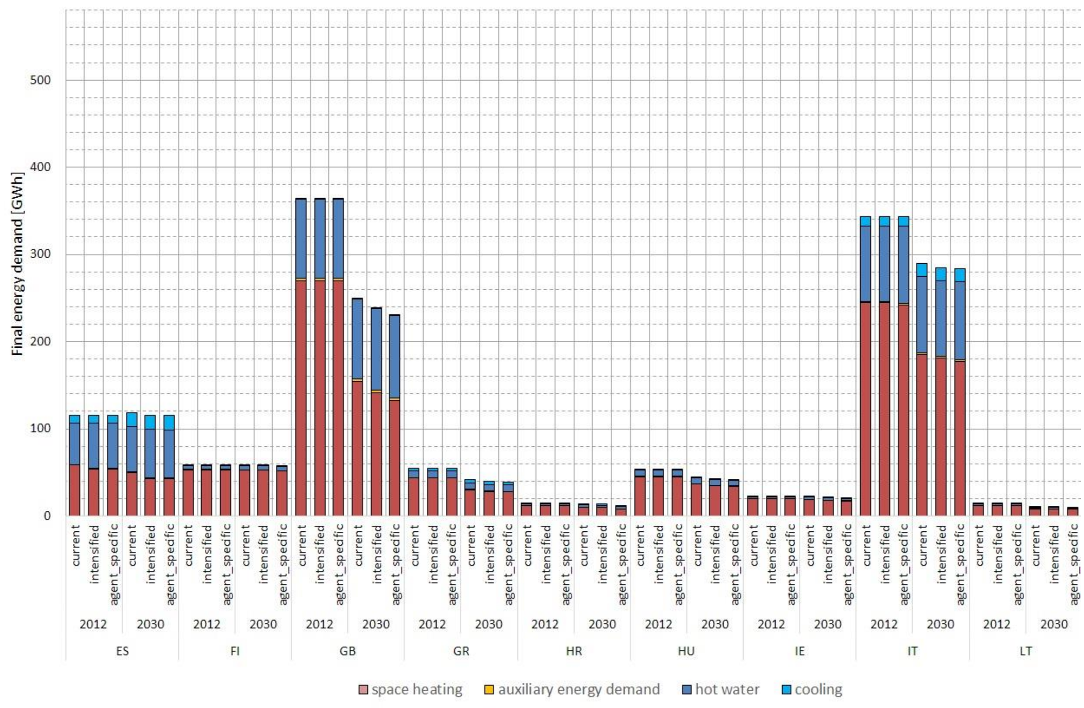

Figure 87: Final energy demand by usage types per country for EU28 (2)

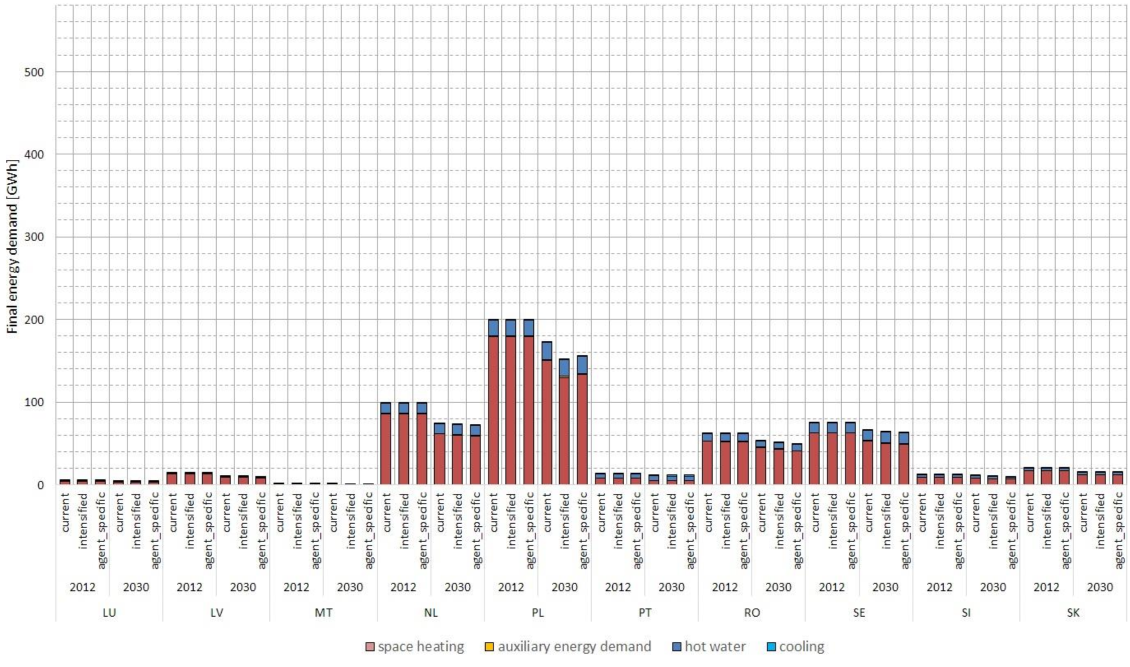

Figure 88: Final energy demand by usage types per country for EU28 (3)