Modelling the effect of the Ecodesign and Labelling directives – Bottom-up analysis of EU-27 residential electricity use

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Abstract

The Ecodesign and Labelling directives are key policy measures to increase energy efficiency in Europe. In view of the extension of Ecodesign and Labelling to further products as well as the revision of the current implementing directives, it is essential to evaluate the potential energy savings, taking into account different paths of technological development and diffusion. Our study uses bottom-up modelling to evaluate the long-term saving potentials of Ecodesign and Labelling for residential appliances (including large appliances, cooking and ICT), lighting and air conditioning. The household end-uses that are affected by the legislation are implemented in the model in a disaggregated way. The model is designed as a vintage stock approach and based on the simulation of consumer activities as well as technological trajectories.

We model the electricity demand of household end-uses in the EU-27 by country and compare various scenarios. Our Reference Scenario reflects the electricity demand of household end-uses without any policy measures implemented after 2008. Our current Policy Scenario includes all implementing directives that are currently in force and assumes that the sensitivity of consumers to the total cost of ownership remains at the currently witnessed level. Finally, our LLCC Scenario explores the potential energy savings assuming that consumers choose the economically favourable options considering the total cost of ownership.

Introduction

Energy efficiency is of key importance to reduce greenhouse gas emissions and to reach the European and national energy and climate policy targets. Furthermore, energy efficiency plays a critical role in addressing energy security, environmental and economic challenges (IEA, 2012). The EU is aiming for a 20% cut in Europe's annual primary energy consumption by 2020 and has recently proposed a EU energy efficiency target of 30% for 2030. For residential electricity use, the Ecodesign and Labelling directives are the most relevant European policy measures to increase energy efficiency. The Ecodesign directive provides a framework to set minimum efficiency requirements, where products that do not comply are banned from the European market. The Labelling directive requires manufacturers to provide information about the products' energy efficiency through a European-wide harmonised Energy Label on products, displaying the energy efficiency class on a predefined scale. In total, implementing measures for more than 40 products have been adopted so far.

The Ecodesign and Labelling directives address several barriers that lead to the observed energy efficiency gap between actual and economically optimal energy use (Jaffe & Stavins, 1994). For residential electricity use, market barriers include imperfect information, principal-agent issues and access to credit constraints. Even though the size of the energy efficiency gap is controversially debated (for a review see e.g. Gillingham & Palmer, 2013), energy efficiency policies addressing market failures may increase energy efficiency as well as economic efficiency.

It is essential that the policy measures are implemented effectively to exploit their entire saving potential. For instance, in case of Labelling, it has been observed that the current Label is inefficient in communicating the benefits of life-cycle costs (LLCC) (Bull, 2012). In order to ensure an effective and cost-efficient policy design and implementation, evaluation plays an important role. Energy demand modelling is frequently used in ex-ante policy evaluation, typically comparing various scenarios with different policy options and intensities (for a review see e.g. (Mundaca & Neij, 2010)). Whereas regulatory requirements such as the ones set by the Ecodesign directive are integrated straight forward in energy demand modelling by boundary conditions defining market entrance and exit, Labelling involves behavioural aspects in the decision making process which are more challenging to capture in a bottom-up modelling approach

In this article, we evaluate the saving potentials of the Ecodesign and Labelling directives for residential appliances, lighting and air conditioning in the EU-27 until 2030 and highlight the importance to investigate the factors that influence decision-making both at firm-level and of the end-users.

Description of the Model

We use the model FORECAST-Residential[1,2], a bottom up energy demand model covering the EU-27 as well as Norway, Switzerland and Turkey, in which the energy demand is simulated by country, distinguishing a variety of energy demand end-uses. For residential electricity use, the model covers large appliances (refrigerator, freezer, dishwasher, washing machine, dryer), cooking, lighting, ICT appliances (television, set top boxes, laptop and desktop computers, monitors, modems) and air conditioning.

The model FORECAST-Residential is a vintage stock model allowing a detailed modelling of the stock turnover, taking into account autonomous and policy-driven improvements of the 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 energy efficiency of the different alternatives is typically specified either by the Energy Efficiency Index (EEI), which is then multiplied with a reference power to yield the power of the respective appliance, or in absolute terms (e.g. kWh/year).

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 markers choose among alternative technologies competing with each other (see e.g. (Revelt & Train, 1997)).

Figure 1 provides a schematic overview over 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 development is projected using a Bass model (Bass, 1969). The EU Energy Label influences investment decisions (see upper left), which in turn influence the diffusion of technologies and thus electricity demand. The annual electricity demand is calculated as the product of the specific consumption per end-use and efficiency category and the corresponding stock.

1 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).
2 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).

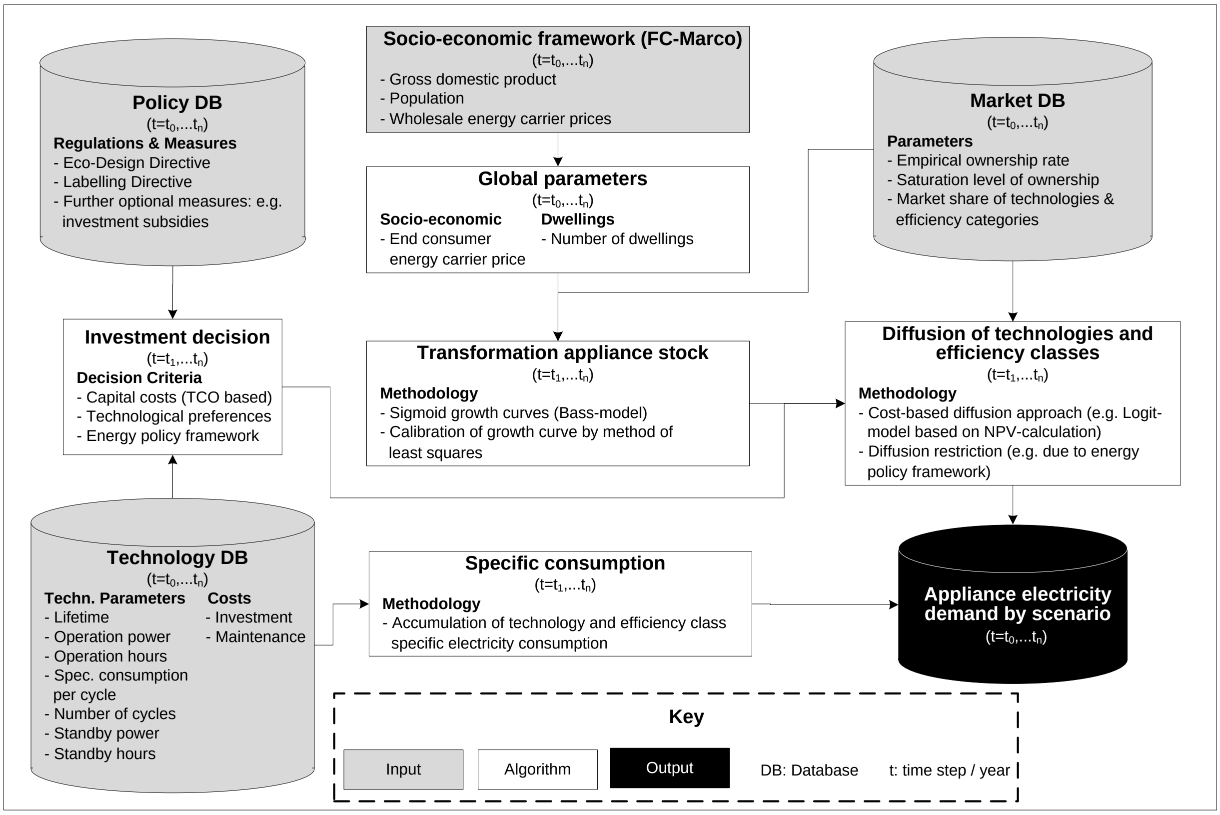

Figure 1: Overview over the modelling approach (Elsland, Schlomann, & Eichhammer, 2013)

The implementation of the investment decision process in FORECAST-Residential follows a multinomial logit-approach, where the market share S_k for a given technology option k is calculated using equation (1), with U denoting the utility function and the sum over U_k running over the N available alternatives. The logit model also includes a parameter ν 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 I_k and the lifetime T.

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

Modelling the EU Energy Label and Ecodesign directive

This section outlines how the Ecodesign and Energy Labelling directives are implemented in our modelling framework. After describing the methodology for modelling each of the two policy measures individually, we outline our strategy to describe the combined effect.

Modelling the impact of Energy Labelling

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 commercialise 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.

Modelling the impact of Labelling on a firm level: The impact of Energy Labelling on the development of new technologies has been subject to an increasing number of studies in recent years (Braungardt, Smith, Williams, McAlister, & Attali, 2014), (Edler, 2013) (Schiellerup & Atanasiu, 2011). Labelling policies have an effect on appliance manufacturers, who 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. 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.

Modelling the impact of Labelling on purchase decisions: 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).

In energy demand modelling, information- or preference-based barriers are typically taken into account by assuming high implicit discount rates. This approach is based on the observation that consumers tend to overestimate the importance of investment costs as opposed to life-cycle costs. However, when using discount rates to account for non-monetary barriers, it is essential to use a dynamic approach which allows for lowering these implicit discount rates as Labelling policies (or possible new financing mechanisms) are introduced. Furthermore, it is essential to keep in mind that any economic analysis of the costs related to energy efficiency policy have to be based on real discount rates and not on the ones that include non-monetary barriers. In our approach, information- and preference-related effects are modelled by adjusting both the discount rates and the logit parameter. This approach reflects that fact that Labelling leads to a higher share of consumers choosing appliances with the lowest total cost of ownership.

Modelling the impact of Ecodesign

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 (see eq. 1) to account for the models that are removed from the market.

Modelling the combined effect of Ecodesign and Energy Labelling

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 therefore display the combined savings of Ecodesign and Labelling, taking into account their interactions.

Scenarios and Scope

In the scope of this study, we analyse the impact of the Ecodesign and Energy Labelling legislations on the electricity demand for appliances, lighting and air conditioning in the EU-27 between 2010 and 2030. The energy demand modelling is performed on a country by country level, taking into account the differences in stock, energy prices, preferences and socio-economic development.

In our analysis, we compare three different Scenarios (see **Table 1**): 1) A Reference Scenario that estimates the evolution of the electricity demand without the Ecodesign and Labelling policy measures. In this Scenario, consumer's purchase decisions show a low sensitivity to the total cost of ownership. Likewise, firms have limited incentives to develop appliances with higher energy efficiency. 2) A Policy Scenario, in which the current Ecodesign and Labelling measures are implemented, and where it is assumed that consumers as well as manufacturers react to the legislations. The level of impact that is achieved is based on estimates taking into account the empirical evidence. 3) A least life-cycle-cost Scenario, in which it is assumed that consumers base their decision strictly on the total cost of ownership.

Table 1: Description of the Scenarios

Reference Scenario	The Reference Scenario is a fictive Scenario that projects the evolution of the electricity demand for appliances, lighting and air conditioning assuming that no additional policy measures are implemented after 2008. The scenario assumes only minor improvements of the technologies that are available on the market.
Policy Scenario	The Policy Scenario includes the Ecodesign and Labelling implementing measures displayed in **Error! Reference source not found.** and assumes an effective rescaling of the Labelling scheme in 2015. In this Scenario, Energy Labelling is assumed to have an effect on the development and market uptake of new technologies, as well as on the reduction of information-related barriers.
LLCC Scenario	The LLCC Scenario assumes consumers' investment decisions are based strictly on the total cost of ownership. This means that information-related barriers are fully removed, and that effective financing models are implemented in order to address the barriers due to lack of capital. The technology options and their investment prices are estimated based on current best available technologies using learning curves.

The socio-economic framework and the global parameters (see **Error! Reference source not found.**) remain the same for all scenarios. The main economic input like energy balances and energy prices are calibrated to most recent EUROSTAT3 statistics whenever possible. The projections of the ownership rates differ between the various member states, however, the following main trends are observed:

- White goods: Washing machines and refrigerators have already reached a saturation level of around 100% in most countries. For freezers, dish washers and dryers an

3 epp.eurostat.ec.europa.eu/

increase between 10-40% is expected depending on the countries.

- Cooking: It is assumed that each household owns one cooking device, however, there are strong differences between the share of electrical cooking in the different EU member states.
- ICT: The most significant increase of the ownership rates is expected for ICT devices, ranging between 40-60%.
- Lighting: A moderate increase in light consumption is assumed for countries with a high market share of LED technologies.
- Air conditioning is assumed to increase by 20-50% depending on geographical and cultural conditions.

The Ecodesign and Labelling legislations that are in place for the appliances that are modelled in a disaggregated way in Scenario 2 and 3 are displayed in the appendix.

Results

The projected residential electricity use (excluding heating) for the EU-27 is displayed in Figure 2 for the three scenarios. While significant savings are achieved in the Policy Scenario as compared to the Reference Scenario, a comparison with the LLCC Scenario shows that especially in view of the 2030 potentials significant further savings could be achieved.

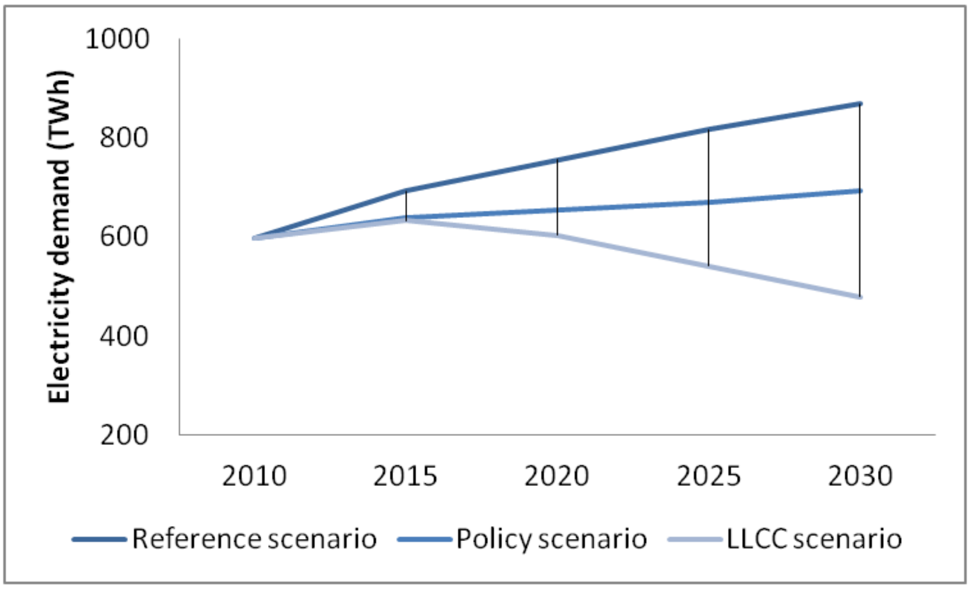

Figure 2: Projected residential electricity demand by scenario (excluding heating) in the EU-27.

Figure 3 compares the share of different end-uses in the total electricity demand in 2010 and 2030 for the Policy Scenario. To illustrate the variations between the different EU member states, the exemplary cases of Germany, Italy and UK are depicted. In general, for some end uses (white appliances, lighting and cooking) the share is reduced, the share of air conditioning, ICT and New &Others (N&O) increases. N&O includes small appliances that are not modelled individually and furthermore account for the fact that it is likely that new appliances will enter the market until 2030. For air conditioning, ICT and N&O, the ownership rates are expected to increase significantly, whereas for large appliances, lighting and cooking the ownership rate is largely saturated in Europe.

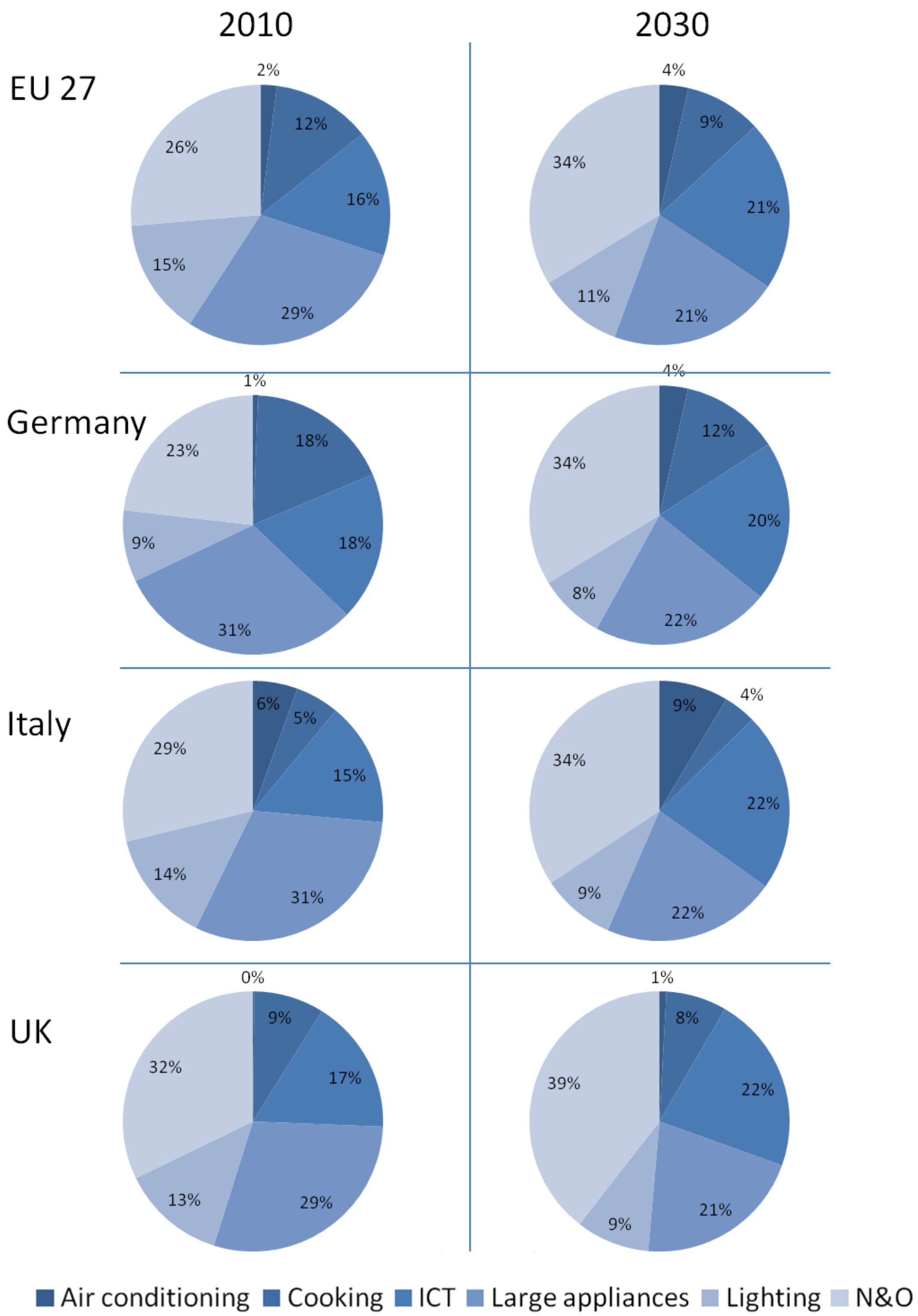

Figure 3: Share of end-use groups in percentage in 2010 vs. 2030 (Policy Scenario).

Figure 4Figure 6 take a detailed look at the electricity demand by end-use group for the different scenarios. The results show that for all end-uses, significant savings are achieved in the Policy Scenario. From Figure 4 it becomes clear that without policy measures, electricity demand is expected to increase significantly.

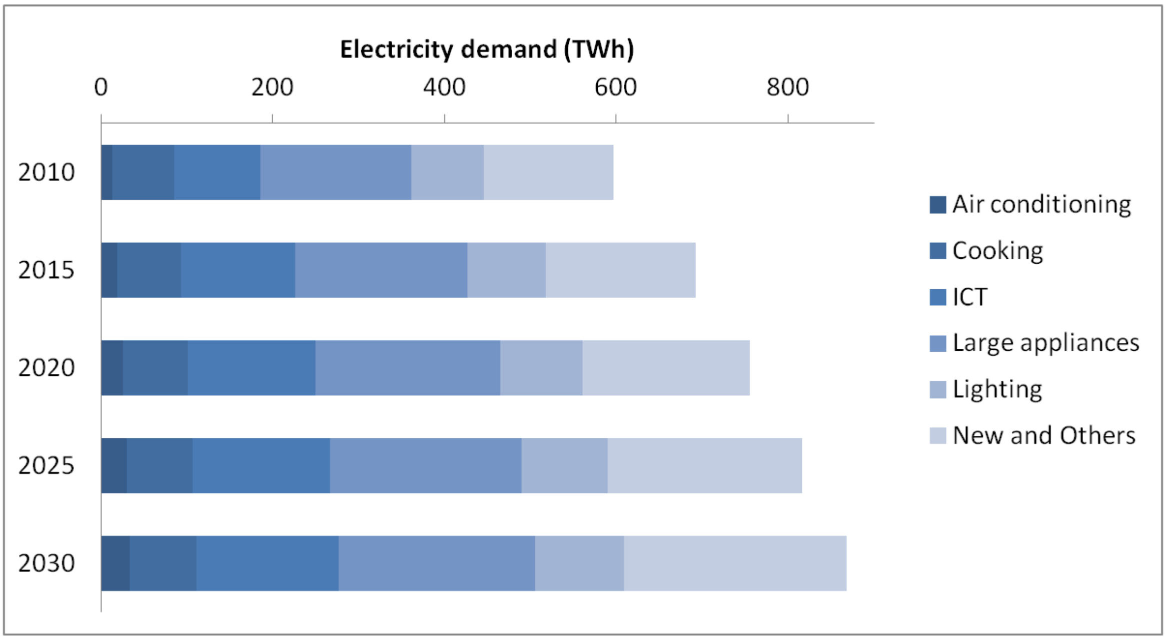

Figure 4: Projected residential electricity demand (excl. heating) in the EU-27 by end-use group (Reference Scenario)

Figure 5 shows that the Ecodesign and Labelling legislations have a potential to significantly reduce electricity consumption with respect to the Reference Scenario. It is important to note that such a continuous effect can only be achieved with an ambitious rescaling, as a number of products have reached a situation where most models are in the highest class, even with the extension to A+, A++ and A+++. Furthermore, it is essential that a high level of compliance is ensured.

For ICT appliances and air conditioning, the increase in efficiency is outweighed by the increase in ownership, leading to a total increase in electricity demand. This is partly due to the fact that the current implementations for ICT have typically lacked ambition, which in part may be explained by the fact that the legislative processes are rather long compared to the fast innovation dynamics.

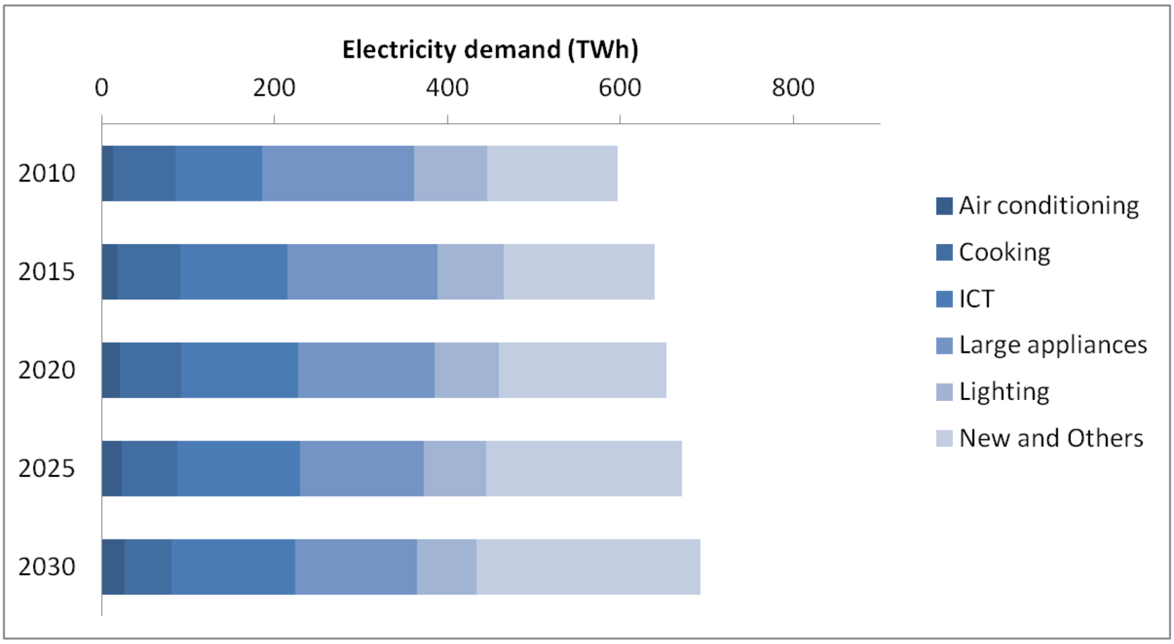

Figure 5: Projected residential electricity demand (excl. heating) in the EU-27 by end-use groups (Policy Scenario)

In the LLCC Scenario (Figure 6), additional savings are achieved for all end-uses, leading to an absolute decrease of electricity demand. While all end-uses show potentials for additional savings, the strongest increase is observed for N&O and ICT.

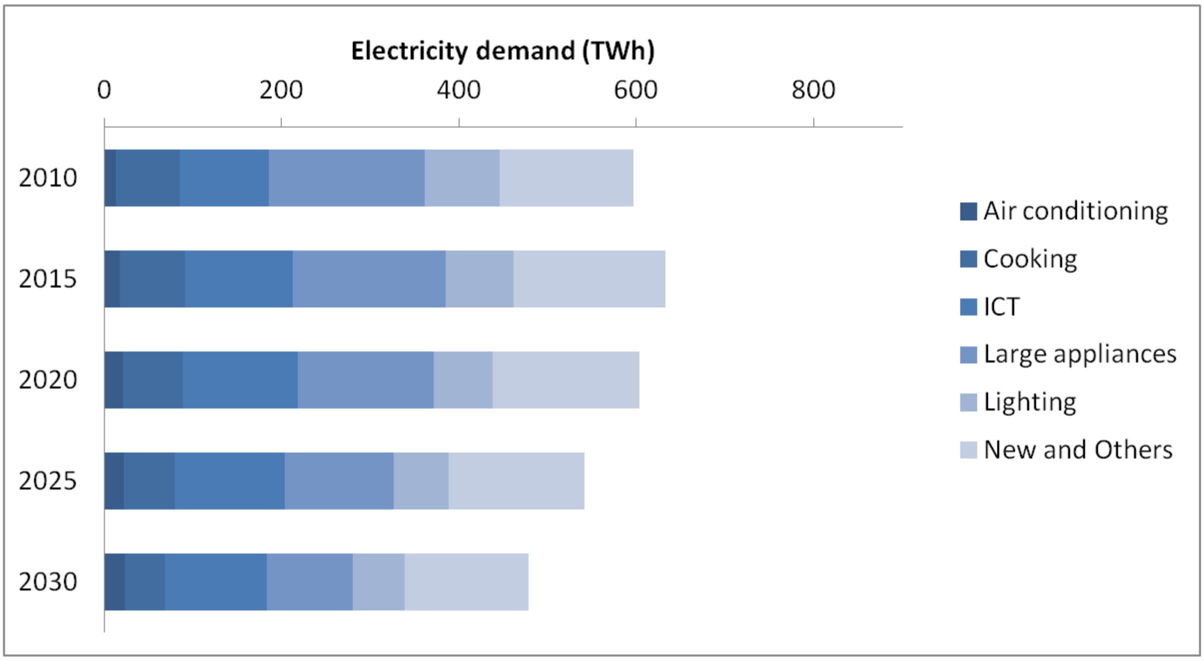

Figure 6: Projected residential electricity demand (excl. heating) in the EU-27 by end-use groups (LLCC Scenario)

Summary and Conclusions

The impact of the Ecodesign and Labelling regulations on the electricity demand of residential appliances, lighting and air conditioning in Europe was evaluated by considering different diffusion paths determined by the impact and intension of product policy measures. The impact of the Ecodesign directive is implemented rather straight forwardly by restricting the diffusion of appliances that do not fulfil the requirements. By contrast, evaluating Labelling policy is more challenging and faces a higher level of uncertainty due to the heterogeneity of preferences. From a methodological point of view, it is essential to further investigate the influence of policy measures on the decision-making processes at micro level in order to increase the impact of policy measures and to increase the validity of policy evaluation. Furthermore, it is essential to gain further understanding of the impact of Labelling on the development and commercialization of energy efficient appliances, as well as on its effect on the purchase prices.

Our Policy Scenario shows that the Ecodesign and Labelling directive have strong potentials to reduce residential electricity demand when implemented effectively. For Ecodesign, the scenario reflects the currently implemented minimum requirements. For Labelling, the scenario assumes a continuous effect on consumers as well as manufacturers. The LLCC Scenario highlights the significant saving potentials beyond Ecodesign and Labelling, assuming that consumers always choose the option with minimal total cost of ownership. This aim of the scenario is to explore the potential of implementing policy measures that address barriers related to the lack of capital as well as the lack of information, which are not fully addressed by Ecodesign and Labelling.

From a methodological point of view, one of the main challenges consists in capturing the effect of Energy Labelling on consumers' decision making. In order to improve the validity of energy demand modelling in the residential sector, it would be of great value to enhance the empirical understanding of consumers' response to Energy Labelling. Furthermore, projecting the future electricity demand of rapidly developing ICT appliances as well as end uses that are new to the market necessarily lead to rather significant uncertainties for these technologies.

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Appendix: Labelling and Ecodesign implementing measures for the appliances that are modelled

End-use	Ecodesign	Labelling
Refrigerators	Since 2009	Since 2003, recast in 2010
Freezers	Since 2009	Since 2003, recast in 2010
Dishwashers	Since 2010	Since 1999, recast in 2010
Washing machines	Since 2010	Since 1995, recast in 2010
Dryers	Since 2012	Since 1995, revision in 2012
Stoves	Since 2014	Since 2002, revision in 2014
Lighting	Non-directional household lamps 2009, amended 2012	Since 1998, updated in 2012
Televisions	Since 2009	Since 2010
Laptop computers	Since 2013	-
Desktop computers	Since 2013	-
Computer monitors	Since 2013	-
Set top boxes (STB)	Simple STB: Since 2009, Complex STB: Voluntary agreement	-
Air conditioning	Ventilation fans since 2011; Room A/C 2013/14	Room A/C 2011 (additional classes from 2013)