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ScienceDirect

Energy Procedia 62 (2014) 236 – 245

Energy Procedia

6th International Conference on Sustainability in Energy and Buildings, SEB-14

A European impact assessment of the Eco-Design requirements for heating systems – What kind of savings can we expect?

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Abstract

Improving energy efficiency is seen as a key pillar in transforming the energy system. Residential heating systems could make a substantial contribution to reducing energy demand since they rank among the largest European energy consumers, accounting for about 21.5 % (10,327 PJ) of the total final energy demand in 2010. To exploit heating system-related saving potentials, the EU implemented the Eco-Design Directive, which sets minimum efficiency standards at the design phase. In terms of heating systems, Lots 1 and 2 were published in 2013 and Lots 15 and 20 are in the process of being developed. To evaluate the impact of these measures, a scenario analysis is being conducted as part of the Eco-Design preparation studies. The Eco-Design impact assessment is for time horizons to 2025 and 2035, which are rather short compared to the lifetime of heating systems of 20 years or more. The technology-specific assessments also neglect the interdependency between heating systems. This study aims to close this research gap by applying an impact assessment to a combination of all four Lots addressing heating systems. The bottom-up model FORECAST-Residential is used to analyse the EU27 building and heating stock on a country by country basis up to 2050. The analysis reveals that the Eco-Design Directives could reduce final energy demand by 1,376 PJ by 2050. The largest potential for savings are attributed to Lot 1, which is mainly related to replacing constant temperature and low temperature boilers by more efficient condensing boilers together with a strong diffusion of heat pumps.

Selection and peer-review under responsibility of KES International

Keywords: Bottom-up modelling; residential sector; heating energy demand; energy policy; impact assessment

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Selection and peer-review under responsibility of KES International
doi:10.1016/j.egypro.2014.12.385

1. Introduction

Given the challenge of climate change, there is a narrow timeframe in which to find sustainable and efficient solutions to transform the energy system [1]. The European Union addresses this issue with their ‘20-20-20’ energy and climate policy which defines targets for 2020. These targets impose a 20 % improvement of energy efficiency compared to a business-as-usual projection, a reduction of greenhouse gas emissions of 20 % compared to 1990 and an increase in the share of renewable energies of up to 20 % in the primary energy mix [2]. Within this context, energy efficiency is regarded as the most important driver for the transformation of the energy system [3]. Heating systems in the residential sector can substantially contribute to the achievement of the efficiency target. The European residential sector ranks amongst the largest consumers in 2010 with a share of 26.7 % (12,814 PJ) of the total final energy demand in Europe (48,078 PJ). 10,327 PJ of this usage are attributed to residential heating demand, which is equivalent to about 21.5 % of the overall European final energy demand [4,5].

A variety of policy measures have been implemented during recent decades to address the high potential of energy efficiency [6-8]. The EU published the Eco-Design Directive in 2005 and revised it in 2009 to set minimum efficiency standards at the design phase in order to improve the energy efficiency of products [9,10]. This has resulted in the requirements for certain products being formulated in different implementing measures called Lots. The recently published Lots 1 and 2, as well as Lots 15 and 20 that are still in the process of being developed, focus on heating systems (see the scope of the corresponding implementation measures in Figure 1). An impact assessment of future energy demand has been developed with different scenarios for the EU27 [11-14]. This is part of the Eco-Design preparation studies that analyse the technological and economic aspects of these heating technologies. The period of analysis depends on the Lot: 1990 to 2025 (Lots 1 and 2), 2010 to 2025 (Lot 15) and 2011 to 2035 (Lot 20).

However, as heating systems have a lifetime of 20 years or more, and due to the fact that the point in time of reinvestment depends on the age distribution of a country’s heating system stock, the period of analysis of the Eco-Design preparation studies up until 2025 and 2035 seems to be rather short. Furthermore, the evaluation of the Eco-Design impact assessment has to be conducted for all heating systems simultaneously, as there is an interdependency between the systems which has a direct influence on the investment decision process.

This study aims to address these issues by applying an impact assessment on a combination of all four Lots addressing heating systems. The analysis of Lot 15 and Lot 20 is based solely on the current status of the preparatory studies. The bottom-up model FORECAST-Residential is used to analyse the EU27 building and heating stock on a country by country basis up to 2050. In this way the timeframe of the impact assessment in the preparatory studies is expanded and the analysis horizon is harmonised throughout the Lots. Furthermore, the heat demand is derived from the building typology by country and a direct allocation of heating technologies to the modelled buildings.

The study is structured as follows: firstly the methodology for the impact assessment is discussed (section 2); thereafter a case study of three explorative scenarios is conducted (section 3); and the study closes with conclusions (section 4).

2. Methodological approach

2.1. Structural framework

The simulation based bottom-up model FORECAST-Residential is used for the analysis. This models the final energy demand for heating purposes of the EU27[†] by country up to 2050 [15,16]. FORECAST-Residential is designed as a vintage stock model, which allows stock turnover to be modelled in detail, taking into account regulatory requirements. The framework for this heating system analysis is provided by the useful energy demand

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[†] *FORECAST is a modelling platform that captures the final energy demand of the industry, households, tertiary, transport and agriculture sector for the EU 27+3 (3: Norway, Switzerland, Turkey) by country up to 2050 [15,16].*

for heating purposes derived from the country-specific building typology differentiated by construction period (<1960, 1961-1990, 1991-2008, 2009-2020, 2021-2050). These are in turn divided into building types (single-family-houses (SFH), and multi-family-houses (MFH)) and five energy efficiency standards. Splitting the new building stock into those constructed before and after 2020 is related to the fact that major policy regulations regarding the energy performance of buildings are defined for the year 2020 (e.g. EPBD recast) [17]. Considering the building typology in this way, results in a total of 50 reference building segments per country and thus 1350 building segments for the EU27.

Scope of implementation measures

	Technological coverage	Performance level	Requirements on efficiency
Lot 1: Space heaters and combination heaters Implemented in: Sept. 2013	• Water-based heating systems for space heating and sanitary hot water purposes (incl. combinations with solarthermics) • Combustion of gaseous and liquid fuels*	• All technologies < 400 kW • CHP < 50 kW	Integrated heating systems: • Space heating efficiency > 86 % (depending on performance) • Water heating efficiency > 22-32 % (depending on performance)
Lot 2: Water heaters and hot water storage tanks Implemented in: Sept. 2013	• Heating systems for sanitary hot water purposes (incl. combinations with solarthermics) • Combustion of fuels **	• All technologies < 400 kW	Efficiency > 22-32 % (depending on performance)
Lot 20: Local space heaters Still in process	• Heating systems for space heating purposes which provide heat directly to the environment • Combustion of gaseous, liquid or solid fuels***	• All technologies < 50 kW	Efficiency > 38,5 % (depending on performance)
Lot 15: Solid fuel boilers Still in process	• Water-based heating systems for space heating and sanitary hot water purposes (incl. combinations with solarthermics) • Combustion of solid fuels	• All technologies < 1000 kW • CHP < 50 kW	Efficiency > 75-77 % (depending on performance)

* Heaters using gaseous/liquid fuels predominantly produced from biomass are not captured by the regulation.
** Heaters using solid fuels or gaseous/liquid fuels predominantly produced from biomass are not captured by the regulation.
*** Heaters using non-woody biomass are not captured by the regulation.

Fig 1: Relevant technologies, general and performance-based exceptions and Eco-Design requirements of Lot 1, 2, 15 and 20

The stock of heating technologies is represented by 11 reference technologies per country that capture the overall final energy demand for space heating and sanitary hot water purposes of the EU27. In terms of boilers, these include the energy carriers of oil, gas, coal and biomass, where biomass comprises pellets, firewood and wood chips. Further reference technologies are district heating, electric heat pumps, direct electric heating (including night storage heaters), solarthermics and decentralised technologies used to provide sanitary hot water, e.g. instantaneous water heater. Solarthermics can be considered either as a technological option in the context of a bivalent system, or solely for the provision of sanitary hot water.

On a second level the heating systems are differentiated by five efficiency classes. These range from inefficient technologies such as constant temperature boilers to highly efficient technologies such as condensing boilers. Hence, there are 55 technological options per country that are further distinguished by performance level which is dependent on the useful energy demand of the building.

Each of these 55 technologies is represented by an utilisation factor. CHP is not explicitly modelled by FORECAST-Residential as decentralised combined heat and power generation (CHP) captures less than 1 % of the total final energy demand for heating purposes in each country and as its future market potential is seen as limited [18]. The final energy demand of CHP is allocated to the boiler type of the corresponding primary energy source.

The structural design of the heating module of FORECAST-Residential is illustrated in Figure 2. The initial modelling process is that of calibration; the challenge is to generate a consistent dataset between the useful energy demand defined by the building typology and the final energy demand represented by the heating systems. The transformation of the building and heating stock is calculated based on a multinomial Logit-approach, where the decision making parameters of the utility function are derived from the Total Cost of Ownership (TCO) of an investment (see section 2.2) [19]. Besides TCO the investment alternatives are restricted due to energy policy regulations, e.g. the Eco-Design Directive, and other modelled system boundaries. These include the refurbishment of buildings which is allowed 20 years after construction at the earliest and demolition which can take place after 30 years [20]. In a final step the model output is calculated followed by a subsequent result validation.

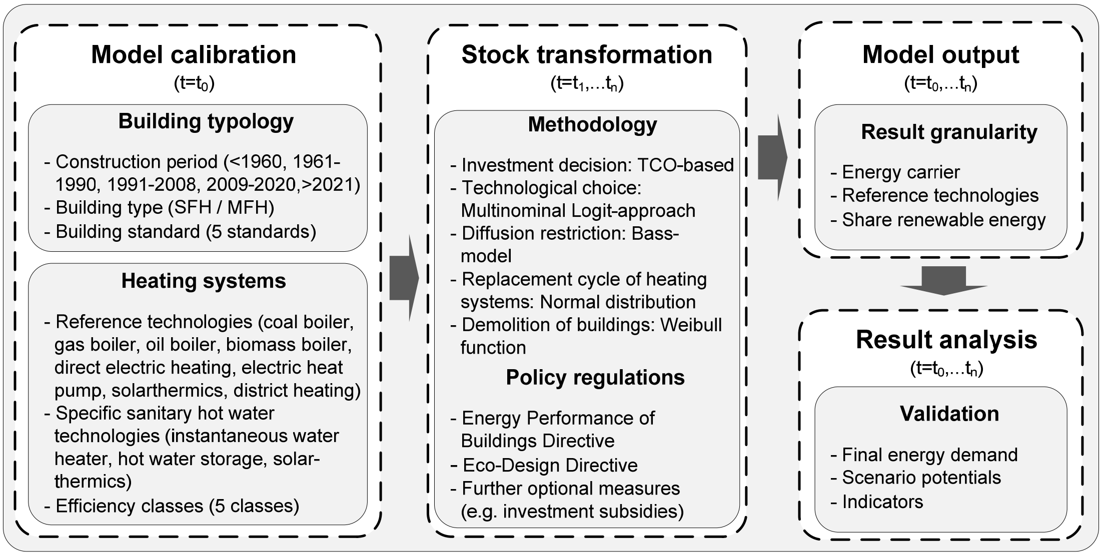

Fig 2: Structural framework of the heating model of FORECAST-Residential

2.2. Modelling final energy demand

The basis of final energy demand calculation is given by the useful energy demand related to space heating and sanitary hot water per building segment *k*, calculated by equation (1):

$$\mathrm{UED}_{\mathrm{total},t} = \mathrm{UED}_{\mathrm{SH},t} + \mathrm{UED}_{\mathrm{SHW},t} = \sum_{k=1}^{l} s_{k,t} \cdot f_{k,t} \cdot \left(ued_{k,t} + w_k \cdot c_w \cdot \Delta T_k\right) \quad (1)$$

where $UED_{total,t}$ is the useful energy demand of the residential sector for space heating $UED_{SH,t}$ and water heating $UED_{SHW,t}$ purposes, $s_{k,t}$ is the building stock, $f_{k,t}$ is the conditioned floor area per building segment, $ued_{k,t}$ is the specific useful energy demand of space heating, w_k the hot water demand per square meter, c_w is the specific heat capacity of water and ΔT_k is the temperature difference between the inlet and outlet temperature. When it comes to the investment decision, residents decide to select the heating system *i* with the highest utility. The utility function is described as follows:

$$U_{i,t} = \beta_{i,0} + \beta_{i,1} \cdot A_{i,t}(I_{i,t}, r_i, n_i) + \beta_{i,2} \cdot FS_{i,j,k,t}(I_{i,t}, r_i, n_i) + \beta_{i,3} \cdot S_{i,t} + \beta_{i,4} \cdot MC_{i,t} + \beta_{i,5} \cdot EC_{i,t} \tag{2}$$

where $U_{i,t}$ is the utility of an average residential decision maker, $A_{i,t}$ is the annuity which is derived from the investment sum $I_{i,t}$ in cases no heating system was installed beforehand, the discount rate r_i, and the amortisation period n_i, $FS_{i,j,k,t}$ is the fuel switching costs in case of a heating system replacement, $S_{i,t}$ is the investment subsidy, $MC_{i,t}$ is the maintenance costs and $EC_{i,t}$ is the energy costs. The fuel switching costs extend the investment decision by one dimension, as the associated costs depend both on the system to be replaced *j* and the target system *i*, e.g. additional investment due to infrastructure extension. The fuel switching costs are calculated by equation (3):

$$FS_{i,j,k,t} = \begin{pmatrix} I_{i,t} \cdot fs_{1,1,k,t} & I_{i,t} \cdot fs_{2,1,k,t} & \cdots & I_{i,t} \cdot fs_{n-1,1,k,t} & I_{i,t} \cdot fs_{n,1,k,t} \\ I_{i,t} \cdot fs_{1,2,k,t} & I_{i,t} \cdot fs_{2,2,k,t} & & I_{i,t} \cdot fs_{n-1,2,k,t} & I_{i,t} \cdot fs_{n,2,k,t} \\ \vdots & & \ddots & & \vdots \\ I_{i,t} \cdot fs_{1,m-1,k,t} & I_{i,t} \cdot fs_{2,m-1,k,t} & \cdots & I_{i,t} \cdot fs_{n-1,m-1,k,t} & I_{i,t} \cdot fs_{n-1,m,k,t} \\ I_{i,t} \cdot fs_{1,m,k,t} & I_{i,t} \cdot fs_{2,m,k,t} & & I_{i,t} \cdot fs_{n-1,m,k,t} & I_{i,t} \cdot fs_{n,m,k,t} \end{pmatrix} \tag{3}$$

where $FS_{i,j,k,t}$ is the fuel switching costs, $I_{i,t}$ is the investment for the retrofitting of the currently installed system and $fs_{i,j,k,t}$ is a percentage markup on this investment depending on the current and target heating system. The energy-related costs are based on the energy demand and energy carrier price. Sectoral competition for certain energy carriers, especially that of biomass requires sectoral allocation to be defined ex ante to ensure that the national biomass potentials are not exceeded. From a modelling perspective this is addressed by cost potential curves, which are used as a synthetic cost markup on the energy carrier price of biomass. Thus, the markup increases as the saturation level of the residential biomass potential is reached (see equation (4)):

$$EC_{i,t} = ED_{i,1} \cdot e_{i,t} \cdot \left[1 + \left(\exp^{\Delta sl_t} - 1\right)\right] \tag{4}$$

where $EC_{i,t}$ are the energy costs, $ED_{i,t}$ is the final energy demand, $e_{i,t}$ is the energy carrier price and Δsl_t is the synthetic markup on the energy carrier price. However, as the Eco-Design Directive is a regulatory measure that narrows the overall number of rival alternatives that could be selected from a resident in a time-dependent manner, restrictions for the technological choice are determined as in equation (5):

$$UR_{i,k,t} = \begin{pmatrix} U_{1,t} \cdot R_{1,1,t} & U_{2,t} \cdot R_{2,1,t} & \cdots & U_{n-1,t} \cdot R_{n-1,1,t} & U_{n,t} \cdot R_{n,1,t} \\ U_{1,t} \cdot R_{1,2,t} & U_{2,t} \cdot R_{2,2,t} & & U_{n-1,t} \cdot R_{n-1,2,t} & U_{n,t} \cdot R_{n,2,t} \\ \vdots & & \ddots & & \vdots \\ U_{1,t} \cdot R_{1,l-1,t} & U_{2,t} \cdot R_{2,l-1,t} & \cdots & U_{n-1,t} \cdot R_{n-1,l-1,t} & U_{n,t} \cdot R_{n,l-1,t} \\ U_{1,t} \cdot R_{1,l,t} & U_{2,t} \cdot R_{2,l,t} & & U_{n-1,t} \cdot R_{n-1,l,t} & U_{n,t} \cdot R_{n,l,t} \end{pmatrix} \tag{5}$$

where $UR_{i\,k,t}$ is the utility of an average residential decision maker given regulatory restrictions, $U_{i,t}$ is the utility of an average residential decision maker without restrictions (see equation (2)) and $R_{i,k,t}$ represents regulatory parameters. The latter is a binary variable that determines the efficiency levels of heating technologies that are allowed to be installed at a certain point in time. The transformation of the restricted utility functions into market shares of heating systems is represented by a multinomial Logit-approach described as follows:

$$ms_{i,k,t} = \frac{\exp^{-\lambda \cdot \frac{UR_{i,k,t}}{UR_{mean,k,t}}}}{\sum_{i=0}^{n} \exp^{-\lambda \cdot \frac{UR_{i,k,t}}{UR_{mean,k,t}}}} \quad (6)$$

where $ms_{i,k,t}$ is the market share, λ is the distribution parameter representing the heterogeneity of the market, $UR_{i,k,t}$ is the utility of a resident under legal restrictions and $UR_{mean,k,t}$ is the utility of a reference heating system. To ensure that the modelling of diffusion captures the inertia of market dynamics the results of the Logit-approach are bounded by exogenous growth curves predefining the upper and lower level of heating stock change, which depend on empirical findings [21]. In a last step the final energy demand is calculated based on the useful energy demand for heating purposes (equation (1)), the heating system stock and the utilisation factor of the heating system (see equation (7)):

$$ED_{total,i,t} = \frac{UED_{total,t}}{MS_{i,k,t} \cdot \eta_{i,t}} \quad (7)$$

where $ED_{total,i,t}$ is the final energy demand for heating purposes, $UED_{total,t}$ is the total useful energy demand for space and water heating, $MS_{i,k,t}$ is the heating system stock and $\eta i,t$ is the utilization factor of the heating system. If the system is bivalent the overall utilisation factor is derived from the utilisation factor of each system weighted with their full load hour equivalents.

3. Case Study

3.1. Scenario definition and framework

The explorative scenario analysis examines the final energy demand of heating systems in the EU27 residential sector in the period 2008-2050. The reference scenario (REF-S) analyses the final energy demand without considering any Eco-Design requirements. In the first Eco-Design scenario (ECO_I-S), Lots 1 and 2 are implemented as scheduled in September 2013 (considered in the modelling from 2014) and Lots 15 and 20 are assumed to be implemented from the beginning of 2015, without considering any amendments to these four regulations. The second Eco-Design scenario (ECO_II-S) builds upon ECO_I-S but assumes more ambitious efficiency requirements addressing the technologies currently covered by the Lots up to 2050 without expanding these to include other further technologies.

As the Eco-Design Directive is a regulatory measure, it is transformed into modelling parameters by restricting the technological choice of residents in terms of lower efficiency classes (Figure 3). Thus, in the two Eco-Design scenarios, lower efficiency classes become unavailable to residents after a certain point in time. This is not the case in the REF-S. The upper limit to the efficiency classes available to residents in the short- to medium-term is derived from the Labelling Directive [22]. However, as technological change progresses, heating systems become more efficient, approaching the maximum possible efficiency in the long run which is derived from [23-25]. The socio-economic framework parameters by country (e.g. number of dwellings) are taken from a study conducted by the Energy System Analysis Agency for the EU27 [15,26] and the techno-economic parameters for heating systems are mainly based on [11-14,27,28].

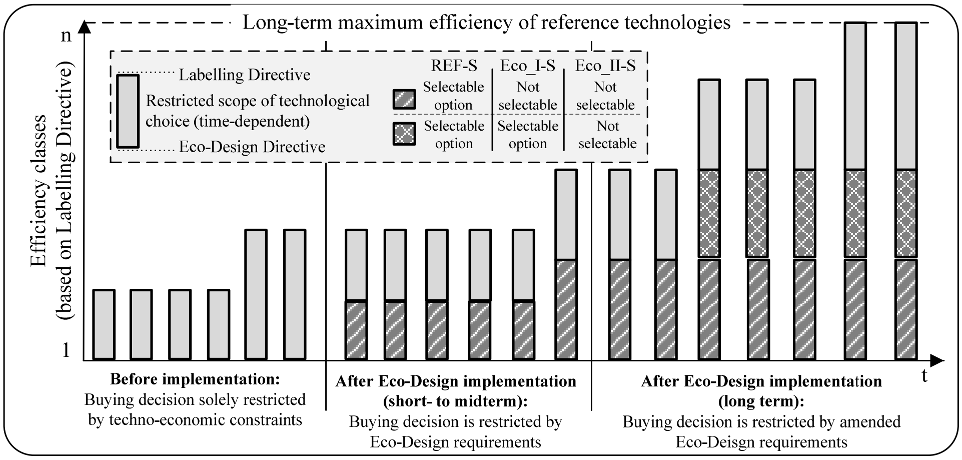

Fig 3: Schematic illustration on the transformation of Eco-Design requirements into modelling parameters

3.2. Results

To isolate the saving potentials related to the implementation of Eco-Design, first the development of useful energy demand for space heating (SH) and sanitary hot water (SHW) purposes needs to be analysed. Figure 4 depicts the useful energy demand by SFH and MFH which is further distinguished by climate zone. Zones are defined by heating degree days (HDD) and divided into cold climate zones (>4200 HDD), moderate climate zones (2200-4200 HDD) and warm climate zones (<2200 HDD). The results show that the total useful energy demand for SH decreases by 1,985 PJ (-27.2 %) by 2050 compared to 2008. The main driver here is the demolition of old buildings with low thermal efficiency and their replacement by new buildings that are twice as efficient. The second key driver is the refurbishment of existing buildings. Comparing the useful energy demand for SHW in 2008 and 2050 indicates an increase of 322 PJ (+25.1 %), which is mainly related to changes in the building stock. The relative share of SHW in terms of total useful energy demand increases from 15.0 % (1,284 PJ) in 2008 to 23.3 % (1,607 PJ) in 2050.

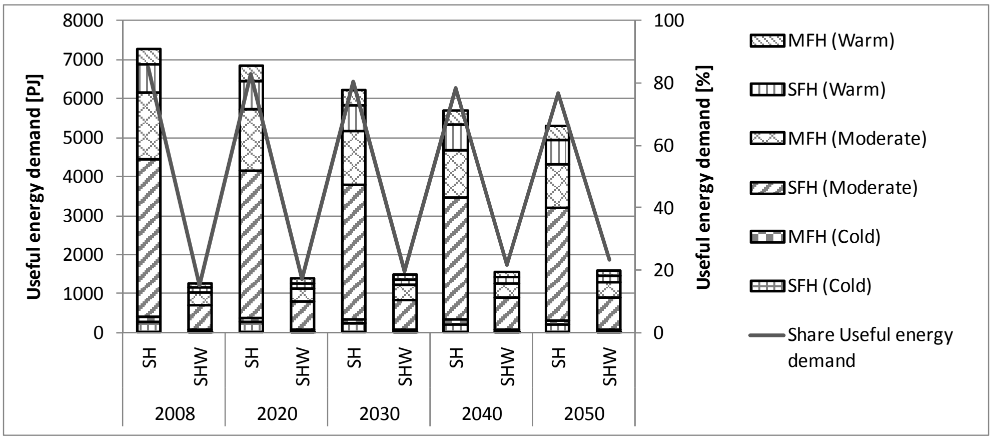

Fig 4: Useful energy demand for space heating and sanitary hot water by SFH and MFH as well as climate zone

The results in Figure 5 show that the total demand in the REF-S decreases by 1,719 PJ (-17.8 %) between 2008 and 2050. The implementation of the Lots in 2014 and 2015 in ECO I-S leads to final energy demand decreasing by another 879 PJ (-9.1 %) in the same period. Comparing REF-S with ECO_I-S in the year 2030 shows that additional savings are mainly due to gas boilers with 267 PJ. Comparing these two scenarios between 2030 and 2050 shows that, without the Eco-Design amendments, the dynamic potential improvement stagnates immediately prior to 2030. But continuing to adapt the Eco-Design requirements beyond the current schedule, as is the case in the ECO_II-S, leads to additional savings of 497 PJ by 2050 when compared to ECO_I-S. Again, these are mainly attributed to gas boilers saving 257 PJ by 2050. At the same time, the proportion of heating systems based on renewable energies increases to 25.4 % in 2050 in the ECO_II-S.

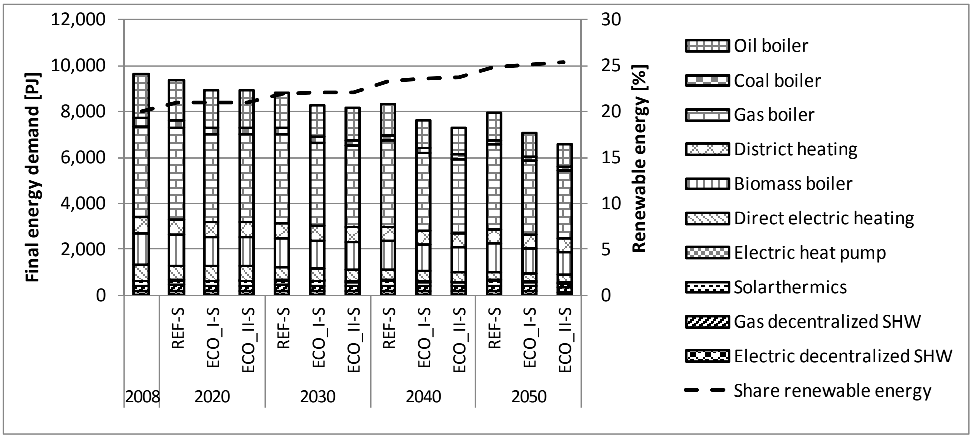

Fig 5: Final energy demand for heating purposes by reference technology and scenario

A decomposition analysis breaks the savings down into the Lots. The results in Figure 6 show that by far the largest saving potential is attributed to Lot 1 for both the currently scheduled period to 2025 and for the extension of the regulation until 2050 (653 PJ, ECO_I-S; 1,011 PJ, ECO_II-S until 2050). These savings are mainly related to the replacement of constant temperature and low temperature boilers with more efficient condensing boilers as well as strong heat pump diffusion. The second largest potential is attributed to Lot 20 with the phasing out in some countries of electricity-based heaters, such as radiant heaters and night storage heaters (118 PJ, ECO_I-S; 167 PJ, ECO_II-S until 2050). This is also driven by targets given for primary energy usage in buildings. The third largest potential is related to Lot 15 (71 PJ, ECO_I-S; 120 PJ, ECO_II-S until 2050), closely followed by Lot 2 (37 PJ, ECO_I-S; 78 PJ, ECO_II-S until 2050). This is due to the strong diffusion of solar thermal, especially in countries in the warm climate zone, and, due to replacing instantaneous water heaters by hot water storage systems, especially in Eastern European countries.

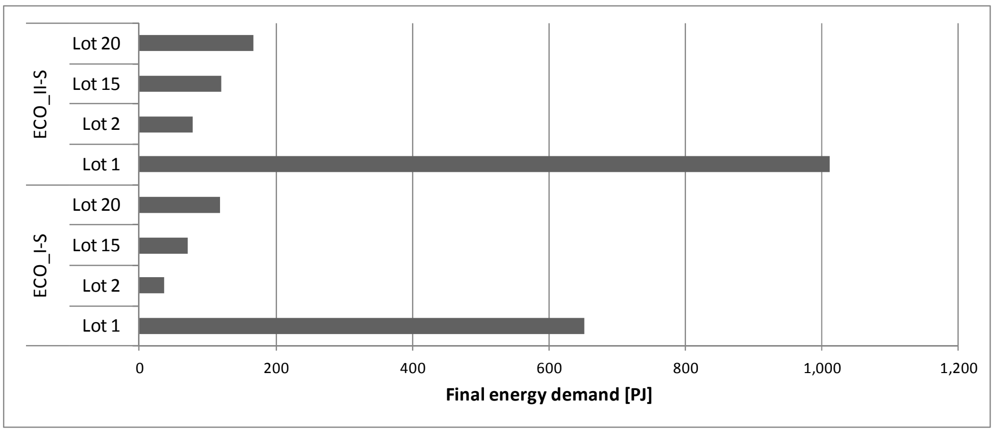

Fig 6: Final energy demand by saving potential of the Lots in the period 2008 to 2050

4. Conclusions

The analysis reveals that the Eco-Design Directives already implemented (Lots 1 and 2) and those still in the process of being implemented (Lots 15 and 20) that address space heating and sanitary hot water could reduce final energy demand by an additional 1,376 PJ by 2050 (-17.4 %). This was shown by the comparison with a reference scenario excluding Eco-Design Directive requirements. The largest potential for savings is attributed to Lot 1, which is mainly related to the replacement of constant temperature and low temperature boilers by more efficient condensing boilers together with a strong diffusion of heat pumps. As the methodological approach is designed as a bottom-up vintage stock model, the regulatory requirements of the Eco-Design Directive can be explicitly considered using the investment decisions of residential decision-makers. Another added value of the study is the combination of heating system and building stock modelling, with the latter based on the European building stock typology. Furthermore, evaluating the impact of regulatory measures up to 2050 avoids neglecting changes to long-lived heating systems as was the case in the impact assessment of the Eco-Design preparatory studies. Given that some reinvestment cycles take up to 30 years, some heating systems are not even replaced or retrofitted within the scenario horizon until 2025 or 2035.

However, the results have to be interpreted with caution. Within this analysis, strong enforcement of the Eco-Design Directive is assumed in the EU Member States. This might not be the case in reality, as non-compliance is already about 20-30 % in some countries. Despite the fact that recently published studies show small market shares in terms of the market potentials for combined heat and power generation in the residential sector, a longer-term impact assessment of their final energy demand could provide valuable information.

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