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Modelling opportunities and costs associated with energy conservation in the Spanish building stock

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ABSTRACT

The aim of this paper is twofold: to investigate the applicability of a building-stock modelling methodology to assess the potential of Energy Conservation Measures (ECMs) and their associated effects on carbon dioxide (CO_2) emissions for a building stock in a South European climate, with Spain being used as an example; and to analyse the technical potentials and costs of the ECMs when applied both individually and as packages of multiple ECMs for the entire Spanish building stock, including residential and non-residential buildings. The modelling methodology, which has been designed to be applicable to any European country, is fully dynamic and based on an aggregated description of the building stock. This paper updates and validates the methodology to account for the climate and technical characteristics of the region under study. Applying all ECMs as a package gives a potential technical reduction in final energy demand of 55% and a 65% reduction in CO_2 emissions, while the corresponding techno-economical potentials are 33% and 37%. Nevertheless, the market potentials estimated are substantially lower (5–10%), which indicate that policy shifts are needed if the techno-economic potentials identified in this work are to be realized.

1. Introduction

In response to international concern regarding climate change, the security of supply, and competitiveness, the European Union (EU) is working to improve the energy efficiency of all end-use sectors. To promote energy efficiency in the building sector of the EU Member States (MS), the European Commission (EC) has introduced the Energy Efficiency Directive 2012/27/EU (EED), the Buildings Directive 2010/31/EU (EPBD) and the Ecodesign & Labelling Directive 2009/125/EC (EL). First, the EED establishes a common framework of measures for the promotion of energy efficiency within the EU (so as to ensure a 20% improvement in energy efficiency) and therefore targets *primary energy demand*, although the directive also includes measures related to building renovation and the use of Energy Efficiency Obligation Schemes[1], which target reduction of *final energy demand* while monitoring the different fuels used in the energy system. Second, the recently recast EPBD [1] establishes an EU framework for a new methodology that requires the MS to: (a) define residential (R) and non-residential (NR) reference buildings that are representative in terms of functionality and climatic conditions, both for new and existing buildings; (b) define Energy Conservation Measures (ECMs)[2] for the reference buildings; (c) assess the final and primary energy demands; and d) calculate the costs of the ECMs over the expected economic lifecycles of the reference buildings. Third, the EL Directive targets exclusively the use of electricity. In addition to the directives, MS can formulate national targets that address reductions in *energy use* (see for instance the Swedish targets listed in [2]). Finally, there are subsidies (e.g., to increase the use of renewables), as well as regular renovation cycles. In summary, renovation and retrofitting dynamics target the different end-uses from primary energy to net energy. Consequently, modelling tools used to investigate the implementation of ECMs should allow monitoring of these targets. Furthermore, a recent report by the Buildings Performance Institute Europe [3] concluded that "*without further guidance, EU countries may mismanage their energy efficiency commitments and risk missing their energy*

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[1] The EED states that each MS has to establish an Energy Efficiency Obligation Scheme (EEOS). The aim of this scheme is to ensure that either all energy distributors or all retail energy sales companies operating in the territory of the MS achieve annual energy savings equal to 1.5% of their energy sales, by volume, in that MS, excluding energy used in transportation.

[2] In this paper, we use the term 'ECMs' to describe what the directive calls "*energy-efficiency measures, measures based on renewable energy sources and/or packages and variants of such measures for each reference building*".

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savings' target". Thus, there is a need to develop methods that can be used to investigate the effects and costs of various ECMs and to provide a unified and extensive assessment, which would include the effects of ECMs in all end-uses from primary energy to net energy, among the different building categories of the building stock in any region of the EU.

The literature contains many assessments of the potential for energy and CO_2 reductions in the EU building sector. However, such assessments have different focuses and scopes, which do not fully meet the above-stated requirements. To start with, the types of ECMs applied vary significantly across the reported studies, with the ECMs addressing: only reductions in energy use with [4,5] or without [6–9] on-site generation using renewable energy sources (RES); or increased efficiency of the energy supply, thus referring to reductions in final energy demand [4,5,10–12]. In some studies, ECMs have been investigated individually [4,7–13], while other studies [5,6,11,14–16] have assessed different packages comprising groups of measures. In addition, some studies have assessed only R buildings, while other studies have addressed only NR buildings or, in cases where the building sector as a whole was studied the results have been presented in aggregated form for the entire sector [6,11,16]. Finally, the studies may investigate only one end-use [4,8,10,12], such as space heating, hot water or electricity, or they may include all end-uses combined [5–7,9,11]. Although the above studies provide valuable contributions to estimate the energy efficiencies of buildings and building stocks applying different types of modelling tools, none of these studies have attempted to formulate a unified modelling methodology that is applicable to all the EU countries but that takes into account the differences between building structures.

The present work is part of an on-going project to develop a methodology that can be used to assess the potential of ECMs in all end-uses, from primary energy to energy use, among the different building categories of any specified EU region [17]. Such methodology rests on an aggregated description of the building stock of a certain region [18] which is used as input to a modelling framework to assess the effects of different ECMs. For this purpose, a model entitled Energy, Carbon and Cost Assessment of Building Stocks (ECCABS) has been developed previously by the authors [19] and validated for the Swedish residential building stock [2], i.e. for a Northern European climate. Before further implementing the methodology to other EU countries, it should be validated and discussed for other European regions with different climate, energy system and building characteristics—including non-residential buildings. Therefore, the aim of this paper is to investigate the applicability of the modelling methodology to a south European climate as well as to assess the effects of different ECMs – in the form of technical, techno-economic and market potentials – for such conditions using Spain as an example.

2. Methodology

The following issues can be foreseen as requiring further attention when applying the modelling methodology to other EU regions: the simplified one-zone model used for each representative building may not be sufficient for South European regions. This, since the climate may require more active operation of buildings to maintain a steady comfort temperature, especially if applying passive systems (e.g., natural ventilation), or it might require the maintenance of different thermal zones within the same building. Additionally, in the ECCABS model, solar gains through windows are found from solar radiation through one horizontal window, where the area represents the total glazing area on the building. The main reason for this simplification is the lack of data about the distribution and orientation of the windows. The difference between

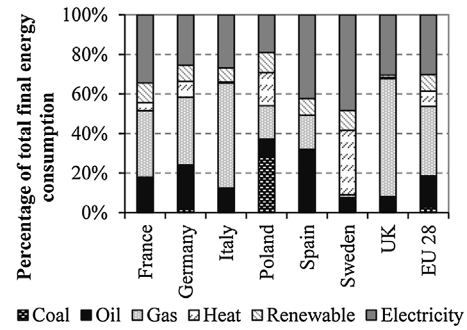

Fig. 1. Final energy consumption levels for the building sector (residential and non-residential buildings) in relation to different fuels, for the EU-28 and selected MS. Source: year 2011 data from the Eurostat database.

horizontal and vertical sun radiation is handled by a certain coefficient, which is specific for a geographic region. Furthermore, both the one zone and one window simplifications need to be tested for NR buildings that typically (a) have a more variable ratio of surfaces window/façade for the different building uses; and (b) have higher cooling demand than R buildings, which might result in the heating and cooling loads being compensated in one zone modelling but occurring actually in different facades of the building (e.g. an office building). With higher levels of solar radiation than those in northern Europe, supply from solar-based renewable technologies should be considered. Finally, individual heating systems are predominant in South European countries while in Sweden, the focus of the previous work, district heating is the dominating heating technology.

With respect to the energy system, Fig. 1 shows how the final energy consumption by fuel for the building sectors (including R and NR buildings) of selected MS varies. While the already studied Swedish R buildings [2] mostly use electricity and district heating (labelled as "Heat" in the figure), Spanish buildings use, in addition to electricity, a substantial amount of oil and gas. Additionally, the electricity in Sweden is generated from hydro and nuclear sources and the heat from biomass fuels, with the consequence that the CO_2 emissions are low[3]. This is not the case in Spain, where electricity is the most CO_2-intensive energy carrier [0.649 $kgCO_2/kWh$ for the Spanish mix [20][4]. The characteristics of the Spanish energy system and the energy use of buildings in Spain have been recently described [5,21,22], and therefore will not be presented here. Cooling demand is not included in the present analysis, since there is a lack of statistics on cooling demand in open sources (and some is hidden in the electricity use) and since within the EU the energy demand from space heating is still a parameter of the highest significance.

2.1. Building-stock modelling

The ECCABS model is a bottom-up engineering model which is described in [19]. Swan and Ugursal [23] have reviewed techniques for modelling end-use energy consumption in the residential sector, including their strengths and weaknesses, and conclude that if the objective is to evaluate the impact of new technologies such as ECMs, the only option is to use bottom-up engineering modelling.

[3] Although there is a common electricity market with connections to neighbouring countries and continental Europe, it is not obvious what are the marginal effects on CO_2 emissions derived from a change in electricity.

[4] Literature gives estimates of 0.457 $kgCO_2/kWh$ [21] and 0.501 $kgCO_2/kWh$ [28] for year 2005 as well as 0.297 $kgCO_2/kWh$ for year 2009 [21], which are lower than the emissions factors used in this work, but in any case substantially higher than the 0.015 $kgCO_2/kWh$ emitted by the average electricity production mix in the Nordic market [2].