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Final and primary energy consumption of the residential sector in Spain and La Rioja (1991–2013), verifying the degree of compliance with the European 2020 goals by means of energy indicators

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ABSTRACT

Among other things, the European Union climate and energy legislation package seeks to achieve a renewable energy contribution of 20% to total energy consumption by the year 2020. In addition, it also seeks to improve energy efficiency and to reduce the 2005 total primary energy consumption by 20% in that same year. In 2013, the residential sector of Spain consumed 15.0 Mtoe of final energy, representing 19% of total energy consumption. This sector has great potential for savings and energetic improvement due to the multitude of possible actions that can be taken to improve it. This paper presents a methodology for evaluating the final energy consumption, primary energy consumption, and contribution by renewable energy of the residential sector decomposed by energy source in any Autonomous Community and in Spain as a whole. The method is applied to the Autonomous Community of La Rioja and to Spain between 1991 and 2013. The results show a complete energy analysis of the Riojan and Spanish residential sectors, ultimately obtaining the key energy indicators to demonstrate the advances toward compliance with European goals for 2020, adapted to the residential sector. The results themselves serve as a control tool for energy planning.

1. Introduction

The Europe 2020 strategy [1] establishes ambitious growth objectives in employment, innovation, education, social integration, and climate and energy. Concretely, for climate and energy, there is a legislation package that involves meeting the following objectives: i) reducing the emission of greenhouse gases by 20% compared to their 1990 levels [2]; ii) achieving a 20% contribution of renewable energy to total energy consumption [3]; and iii) improving energy efficiency to reduce primary energy consumption by 20% compared to 2005 consumption [4]. Currently, these goals are being reviewed and increased by a new 2020–2030 implementation calendar, pending growth in the global economy and especially that of the EU-28 [5,6].

Goals i, ii, and iii have been individually adapted and established for each of the Member States [7]. In the case of Spain, greenhouse gas emissions should not exceed 232.6 Mt CO_2 by 2020; the contribution of renewable energy must be at least 20%, and the consumption of primary energy must not exceed 108.72 Mtoe. All of these values have been calculated from Eurostat data [8]. Previously, Klessmann et al. [9] studied what was needed to reach the 2020 Europe's renewable energy target and Tolón-Becerra et al. [10] proposed a multi-criteria model for the distribution of this objective by countries after analyzing the indicators related to renewable energy. On the other hand, Harmsen et al. [11] studied possible scenarios for the achievement of these objectives by adapting the Physical Energy Content Method of IEA and Eurostat [12] and the Primary Energy Method of Segers [13].

One of the sectors with the greatest potential for energy savings and improvement, in which more measures can be implemented, is the residential sector. In 2013, this sector consumed 27% of the total final energy in the EU-28 (295.9 Mtoe) and 19% of the total final energy in Spain (15.0 Mtoe) [14]. There are studies at the international level such as that of Nejat et al. [15] which showed a global review of energy consumption in the residential sector in China, USA, India, Russia, Japan, Germany, South Korea, Canada, Iran and UK; and that of Zhang [16], in which the annual residential energy consumption in China by climatic zone and residence was studied and the results were compared with Japan, Canada and USA. At the national level, in the research carried out by Chen et al. [17] a statistical method to investigate national energy consumption in the residential building sector of China was presented. On the other hand, Ang [18] published a practical guide on the LMDI approach to decomposition analysis. This LMDI approach has been developed and expanded to study residential energy con-

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sumption, both nationally and in different regions and cities in China: Nie and Kemp [19] applied it at the national level, Zhao et al. [20] at the national urban level, Zhang et al. [21] for the urban and rural Jiangsu region, and Chung et al. [22] for Hong Kong. At the European level, the work done by Pablo-Romero and Sánchez-Braza [23] stands out, in which they analyzed the relationships between residential energy consumption and income in EU-28 countries. In this study, energy consumption in the residential sector was estimated for each year and country by adapting environmental Kuznets curves, using a multimixed-effects model and residential energy consumption elasticities with respect to gross domestic product per capita. Approaching a renewable-energy-only scenario, Gaigalis et al. [24] analyzed the possibilities of the energy transition after the decommissioning of a nuclear power plant in the Ignalina region in Lithuania, whereas Gaigalis and Skema [25] analyzed fuel and energy transition possibilities in the Lithuanian household sector and its sustainable development in compliance with EU policy. The European Union needs its Member States to meet EU goals individually. Similarly, Spain needs its various Autonomous Communities (ACs) to meet these goals, given that many powers related to energy matters have been transferred to the ACs.

The goal of this paper is to create a methodology for evaluating the final energy consumption, primary energy consumption, and contribution by renewable energy in the residential sectors of the various ACs. For the purpose of extrapolating this new method to evaluate the primary energy consumption and the contribution of renewable energy of the Spanish residential sector, the Autonomous Community of La Rioja has been chosen as a case study. In La Rioja, work on proposals for the use of renewable energy has been conducted by López González et al. [26]. The contribution of renewable energy to electrical production has been studied by López González et al. [27], and a 2015–2020 Energy Plan is being prepared [28]. Studies similar to [27] have been conducted in the Autonomous Community of Navarre by López González et al. [29] and in the Autonomous Community of Galicia by Míguez et al. [30]. Another objective is to analyze and verify the residential sector's contribution to the achievement of European energy targets for 2020 through the proposed energy indicators.

This paper is organized as follows: The methodology developed for the evaluation of energy consumption, the proposed indicators, and the data and sources employed are presented in Section 2. The detailed final energy consumption and primary energy consumption for the La Rioja residential sector are presented in Section 3 and for Spain in Section 4. The energy indicators and the comparison between the residential sector of La Rioja and Spain can be found in Section 5. This study closes with conclusions and discussion in Section 6.

2. Methodology, energy indicators and data

The method developed consists of adapting the IEA methodology [12] to the residential sector at the regional level, improving the methodology developed as a basis of the future La Rioja Energy Plan [28]. Initially, the method for evaluating the final energy consumption and the primary energy consumption of the sector is developed. Subsequently, energy indicators are defined for consumption and renewable energy. Finally, the data necessary to carry out this work are shown.

2.1. Evaluation of final energy consumption

The total final energy consumption of the residential sector for year y in a given AC can be expressed as the following equation:

$$FEC_{total,y} = \sum_{j} FEC_{j,y}^{fuel} + FEC_{total,y}^{elect} \quad (1)$$

where the index j represents the fuel type (natural gas, gas-oil C, LPG, coal, and biomass); the index y represents the year; $FEC_{total,y}$ is the final total energy consumption of year y; $FEC_{j,y}^{fuel}$ is the final energy consumption of fuel j in year y; and $FEC_{total,y}^{elect}$ is the final electric energy consumption of year y. Note that petroleum products encompass gas-oil C and LPG.

All energy consumption noted above is expressed in toe. Therefore, it is necessary to convert the consumption of each energy source by means of its corresponding energy density (Table 1).

Table 1
Conversion factors from final energy to primary energy for fuels [73,74].

Fuels	Final energy			Primary energy
	toe	Energy density		toe
Hard coal	1	2.01	t/toe	1.14
Black lignite	1	3.14	t/toe	1.14
Coke	1	1.45	t/toe	1.14
Agricultural biomass	1	3.34	t/toe	1.25
Forest biomass	1	2.87	t/toe	1.25
Gas-oil C	1	1092	l/toe	1.12
Fuel oil	1	1126	l/toe	1.11
Natural Gas (NG)	1	910	Nm^3/toe	1.07
Liquefied Petroleum Gases (LPG)	1	1763	l/toe	1.05
Butane	1	1670	l/toe	1.05
Propane	1	1748	l/toe	1.05

2.2. Evaluation of primary energy consumption

The total primary energy consumption of the residential sector for year y in a given AC can be expressed as the following equation:

$$PEC_{total,y} = \sum_{k} PEC_{k,y} \quad (2)$$

where the index k represents the type of primary energy source (natural gas, petroleum, coal, nuclear, hydropower, biomass, wind, solar, and others); index y represents the year; $PEC_{total,y}$ is the total primary energy consumption for year y; and $PEC_{k,y}$ is the primary energy consumption from the primary source k for year y.

$PEC_{k,y}$ is the sum of the primary energy consumption of primary source k during year y, used either as a fuel or for electric production, according to the following equation:

$$PEC_{k,y} = PEC_{k,y}^{fuel} + PEC_{k,y}^{elect} \quad (3)$$

where $PEC_{k,y}^{fuel}$ is the primary energy consumption of the primary source k in year y, used as a fuel. It is calculated by multiplying the final energy consumption of fuel j during year y ($FEC_{j,y}^{fuel}$) and the final to primary energy conversion factor for the corresponding fuel j (p_j^{fuel}), extracted from Table 1:

$$PEC_{k,y}^{fuel} = FEC_{j,y}^{fuel} \cdot p_j^{fuel} \quad (4)$$

Every primary energy source k coincides with its corresponding fuel j, with the exceptions of gas-oil C and LPG, which are grouped in the primary source “petroleum.”

$PEC_{k,y}^{elect}$ is the primary energy consumption of primary source k during year y used for electricity generation. It is the sum of the primary energy consumption used for electricity generation by the primary source k during year y in the given AC ($PEC_{k,y}^{elect,AC}$) and in Spain ($PEC_{k,y}^{elect,ES}$):

$$PEC_{k,y}^{elect} = PEC_{k,y}^{elect,AC} + PEC_{k,y}^{elect,ES} \quad (5)$$

For the calculation of the primary energy consumption for electricity generation, whether the AC supplies itself for all of its final electric energy consumption (all sectors) must be taken into account. If the AC is not able to fulfill this consumption with its own production, then the rest of Spain supplies the remaining final energy consumption.