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Unraveling electricity consumption profiles in households through clusters: Combining smart meters and door-to-door surveys

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ABSTRACT

Improvements of energy efficiency and reduction of Electricity Consumption (EC) could be pushed by increased knowledge on consumption profiles. This paper contributes to a comprehensive understanding of the EC profiles in a Southwest European city through the combination of high-resolution data from smart meters (daily electricity consumption) with door-to-door 110-question surveys for a sample of 265 households in the city of Évora, in Portugal. This analysis allowed to define ten power consumption clusters using Ward's method hierarchical clustering, corresponding to four distinct types of annual consumption profiles: U shape (sharp and soft), W shape and Flat. U shape pattern is the most common one, covering 77% of the sampled households.

The results show that three major groups of determinants characterize the electricity consumption segmentation: physical characteristics of a dwelling, especially year of construction and floor area; HVAC equipment and fireplaces ownership and use; and occupants' profiles (mainly number and monthly income).

The combination of the daily EC data with qualitative door-to-door survey-based data proved to be a powerful data nutshell to distinguish groups of power consumers, allowing to derive insights to support DSOs, ESCOs, and retailers to design measures and instruments targeted to effective energy reduction (e.g. peak shaving, energy efficiency).

1. Introduction

Greenhouse gases (GHG) emissions will hold steady or might even increase in developed countries if effective reduction of energy consumption will not be taken [1], contrary to policy goals aiming a transition toward low carbon economies. The need for energy consumption reduction is also linked to energy supply security and affordability, and climate change strategies. Therefore, increased search for energy efficiency, GHG emissions reduction and increased share of renewable energy sources, as established in the European Union (EU) goals by 2030 [2] requires more successful and directed actions.

Energy consumption in residential buildings deserves special attention since they represent a significant share of final energy consumption in OECD (Organization for Economic Co-operation and Development) countries, 27% in EU28 in 2013 [3]. In Portugal, residential buildings consume approximately one third of total electricity, with a growth of 70% from 1995 to 2012 [4]. This consumption is a complex issue that can be explained by a combination of physical, technological, demographic, climatic and behavioral characteristics of a dwelling and its occupants.

Understanding the determinants that govern energy consumption has thus been the subject of abundant international literature for more than 30 years (e.g. [5,6–8]). More recently, Jones et al. [9] presented a literature review of the existing research investigating the socio economic, dwelling and appliance related factors that affect electricity consumption in the residential sector.

In this area of study, smart meters have been gaining higher interest in demand side management initiatives and for utilities, and are seen as an important instrument for giving energy consumption feedback to households and for consumers' profiles analysis [10]. With growing deployment of smart meters and

Abbreviations: DHW, domestic hot water; DSO's, Distribution System Operators; DWM, dishwasher machines; ESCO's, energy services companies; EU, European Union; FSK, frequency-shift keying; GHG, greenhouse gas; HVAC, heating ventilating and air conditioning; OECD, Organization for Economic Co-operation and Development; PLC, power lie communication.

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real-time home energy-monitoring services, adequate data allowing the study of electricity consumers' profiles in households and its the determinants are becoming available.

Hayn et al. [11] worked on daily electricity household profiles through segmentation based on lifestyles, socio demographic factors, and electric appliances and on new technologies for heat and electricity generation. Crossing the information delivered by the smart meters with the main determinants of energy consumption in each household, allows for market segmentation identifying consumers with similar needs and behaviors [12]. This valuable knowledge promotes individually and personalized feedback evaluation to households or groups of similar consumers being important for energy savings. Furthermore, tailoring of energy efficiency measures based on specific household profiles enables the change of behavior and equipment with the ultimate goal of an effective energy consumption reduction and load curve consumption peaks minimization.

There are studies on the residential electricity consumption profiles using smart metering data. Seo and Hong [13] with a 30 households sample for Daegu in South Korea characterized power consumption patterns and presented summer load profiles. Rhodes et al. [51] using 103 homes for Austin in Texas determined representative residential electricity use profiles within each season drawing correlations to the different profiles based on survey data. Lee et al. [14] demonstrated profiles of electricity consumption for 60 low energy-housing houses in South Australia. Ramos et al. [15] identified daily load profiles of medium voltage customers applying several clustering algorithms; McLoughlin et al. [16] presented a methodology for electricity load profile characterization through clusters for Ireland using 3941 customers.

The Southwest European region have not yet be analyzed in terms of electricity consumer profiles, which has been seen as a bottleneck for the identification of opportunities for energy reduction and further energy efficiency achievements. Usually, there are statistics and knowledge regarding the national level, although, for effective opportunities of policy instruments or services toward energy efficiency and reduction there is the need for data and knowledge at a more local level.

An analysis of the data available for Évora indicates that, 82% of the residential buildings are associated with single-family houses (mainly terraced houses) and only 8% with apartments [17]. This presents a relevant difference from the EU average countries with 64% of residential buildings being single-family houses and the remaining 36% being apartments [18].

A substantial share of the buildings stock in Évora, as in other European cities, is older than 50 years. More than 20% of the residential buildings have been constructed before the 1940s when energy-building regulations were very limited. A large increase in construction in 1946–1990 is also evident, with the buildings constructed in this period representing around 56% of the current city stock [17].

This paper aims to identify, understand and explain representative yearly electricity consumption profiles of households, for the case study of Évora municipality. We applied a clustering approach to electricity consumption data, gathered from smart meters, and linked it with a dedicated survey for the same households to identify and characterize target groups of consumers.

We argue that the proposed methodology and the achieved results are useful to derive insights to support utilities, retailers and ESCO's for marketing segmentation and innovative policies for effective energy reduction, as it is the case of tariff design, demand side management strategies, energy efficiency improvements, among others.

The paper is organized in four sections. Section 2 describes the methods and discloses the data used. Section 3 presents selected results regarding electricity profiles by consumption clusters and related explaining variables. Section 4 concludes.

2. Methods and data

This section describes the methodology used. Through the combination of the smart metering dataset provided by an electricity distribution company as in Wyatt [19] and Bartusch et al. [20]; and a door-to-door survey as in Kavousian et al. [21] and Gram-Hanssen et al. [22]; we have made an in-depth analysis through segmentation of consumers based on clustering electricity consumption, aiming to identify distinct yearly electricity consumption profiles and to characterize their determinants. Fig. 1 explains how the work was developed and how the different steps were addressed. Each step will be described next.

2.1. Door-to-door household surveys

The door-to-door survey consisted in 110 questions and encompassed information on location, socio economic data (e.g. average monthly income, family size), equipment's ownership and use (e.g. number of hours of use in a day) and physical characteristics of the dwellings (e.g. bearing structure).

The fieldwork of the survey was carried out through the municipality of Évora during July and August 2014, including urban and rural areas. The identification and selection of the locations to make interviews was supported on the existing internal districts of the municipality i.e. parishes, which are the lowest spatial unit with available statistical data. Évora municipality has twelve parishes, three in the urban area comprising around 80% of the population and nine in the rural areas. Therefore, for our purpose, four districts were identified: we combined all the rural parishes in one sector and the three urban parishes were individually kept as districts.

Due to budget limitations we set a maximum of 400 interviews to be done. Because of onsite difficulties, time and transport logistics and interviewers availability constraints, we were able to collect 389 valid surveys, representing 97% of the total expected surveys, being 37% of the surveys answers collected in rural areas, and the remaining in the urban area. This way we were able to capture different households characteristics and consumer types.

2.2. Smart meters dataset

This study also relies on data from a massive smart metering system conducted for the first time in Portugal in the municipality of Évora, within the InovCity project (EDP Distribuição S.A. [23]). It contains measurements of electricity consumption registries gathered from 31,000 household every 15 min since April 2010. The installed equipment's in Évora are concentrators from EFACEC and Janz meters with PLC communication (FSK modulation) in the CENELEC-A frequency band (35–91 kHz). Data collection of load diagrams from the meters to the distribution transformer controller is done on a daily basis starting at 00:00 and for every 6 h. The InovCity project is being carried out by the main Portuguese electricity distribution company, hence the smart meters component is integrated within a full smart city philosophy, which comprises better network management, remote and centralized control stations; electric mobility and distributed generation systems (EDP Distribuição S.A. [23]).

Residential electricity consumption has strong temporal variation, which is not captured with low-resolution consumption data such as monthly bills, thus high-resolution electricity consumption data from smart meters is vital. Therefore, making use of this data, a sample was collected; the household surveys were linked to the smart meters database through the household meter number, while preserving the confidentiality of the house owners. As