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Technology assessment of the two most relevant aspects for improving urban energy efficiency identified in six mid-sized European cities from case studies in Sweden

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HIGHLIGHTS

- An assessment tool was built to identify city energy efficiency improvement potential.
- Consumers' perspective on the use of smart meters and electric vehicles was analyzed.
- Higher overall efficiency for biogas derived electricity use in electric buses.
- Information is needed to engage consumers in using energy efficient technologies.

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ABSTRACT

The increasing population living in cities is leading to higher resource utilization, which strains the cities' ability to focus on sustainability. Adoption of different technologies can transform cities into "smart cities" that utilize energy in a more efficiently.

This paper presents results from a technology assessment tool developed together with six mid-sized European cities. The main areas of focus have been evaluated based on the cities' priorities: transportation (both public and private) and consumers' perspectives on the use of smart electricity meters. The use of electric vehicles in Sweden, and a techno-economic evaluation of biogas-derived biomethane and electricity use in public transportation have been analyzed. The main conclusions show an overall higher efficiency for biogas-derived electricity use in electric buses; a need for higher consumer engagement through more detailed information provision for both increasing EV market penetration and electricity savings; and a need to establish detailed technology assessments for successful technology adoption in cities.

1. Introduction

The world population continues to grow, while cities are responsible for approximately two thirds of global primary energy consumption of which 86% is being supplied by fossil fuels [1]. Thus there is a huge effort focused on increasing urban sustainability and efficiency.

The effective use of technology in our city services (e.g. transportation, energy production and distribution, waste management, etc.) has led to the development of "smart cities". Although heterogeneous and lacking a unique definition, the "smart city" concept was first introduced in 1994 [2]. Based on a literature review carried out by Caragliu et al. (2009) the "smart city" was defined as an "urban strategy that uses information and communication technologies (ICT), knowledge and environmental safeguard to improve the quality of life in the urban space and to promote innovation and community building" [3]. Other similar terms placing cities within the framework of sustainability have been described in [4], where special emphasis was put on low-carbon cities (LCC) by developing a comprehensive indicator system for evaluation, implementation and standardization of LCC. Based on the definitions presented by [4], one of the most noticeable differences between "smart cities" and the rest is the presence of ICT.

One of the main challenges of applying ICT in cities is that there are no one-size-fits-all solutions that can be directly applied to all types of cities. Additionally, there is an overall lack of holistic knowledge about energy efficiency potentials in cities; the current approach means individual strategies, stakeholders and solutions focusing on tackling separate key issues. Finding an integrated

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approach to achieving sustainable, energy efficient and smart cities is the aim of the "Planning for Energy Efficient Cities" (PLEEC) project, supported by the EU Seventh Framework Program. The project was carried out between 2013 and 2016 together with 17 partners from 13 European countries (Sweden, Estonia, Finland, Spain, Bulgaria, France and Germany among others). From the 13 countries, 6 medium-sized cities (Eskilstuna, Turku, Jyväskylä, Tartu, Stoke-on-Trent, Santiago de Compostela) were selected as the project's partner cities for whom experts in the different fields provided support to create long-term energy efficiency plans, integrating well-defined key fields. Research focusing on small and medium-sized cities is of significant importance considering that in 2015, 48% of the urban population lived in small- and medium-sized cities; followed with 14.6% of the population living in "megacities", with 10,000,000 inhabitants [5]. In Europe, 40% of all urban citizens live in cities with populations between 100,000 and 500,000 inhabitants (distributed between 586 cities). Additionally, due to the large number of cities of this size, they are considered the most decisive actors for increasing Europe's competitiveness while also making spatial development more sustainable [6].

The urban population distribution also plays an important role from an energy point of view, since the density of a city is considered to have a direct impact on residential electricity demand. In general, "compact" urban areas are expected to have lower electricity demand compared to "dispersed" urban areas, although this last city type could have greater PV supply potential due to a larger number of detached houses [7]. Furthermore, it is usually easier for smaller communities located in rural surroundings to achieve high renewable energy share, compared to large cities, where only a portion of the total energy demand is likely to be met by renewable energy technologies installed within the city boundary [8].

The reduced costs of renewable energy sources (mainly wind and photovoltaic), smart grid technologies development, and the liberalization of the energy markets have facilitated the increased penetration of distributed generators (DGs) to produce energy closer to consumption centers, reducing costs and increasing reliability [9,10]. Moreover, ICT developments have facilitated the efficient control of distributed energy resources (DERs) by providing with real-time tools to guarantee efficient and reliable operation [11]. In European buildings, which are responsible for 40% of the total energy consumption in Europe, ICT is estimated to be able to achieve energy as high as 20% by 2020 [12,13]. The adoption of automatic meter reading technology or smart electricity meters has facilitated the introduction of demand side management programs, the provision of accurate billing (avoiding estimated consumption values), as well as the integration of renewable sources (e.g. PV), smart appliances and to a limited extent, the introduction of building energy storage technologies [14]. Additionally, the analysis of the impact from information extracted from the smart meter data and provided to consumers has indicated energy savings of up to 18% in some cases [15]. The combination of Internet-of-Things (the Internet based interconnection of uniquely identifiable embedded computing devices used in our everyday life activities) and different ICT has the potential to further help increase energy efficiency and reduce the environmental footprint of our homes and cities [16].

Road transportation contributes one-fifth of the total CO_2 emissions in the EU, and thus has also been identified as a significant contributor to greenhouse gas (GHG) emissions, promoting a higher priority focus on the development of low-carbon and carbon-free technologies for transportation [17]. Development of cost-competitive second and third generation biofuels as well as large-scale market penetration of the electric drive vehicle (EV) for commercial and private use have become the main focuses of investments in research, development and demonstration programs [18]. With a large penetration of EVs in the residential sector, the high energy storage capacity of their batteries can be used for load balancing purposes and to increase renewable energy self-consumption. The combination of sustainable energy and transport technology has been shown to reduce any negative impacts on the existing infrastructure in [19], where by using smart charging technology, self-consumption of PV power was increased from 49% to 62–87%, and the energy sent to the grid was reduced from 12.4 MW h to between 9.1 and 3.4 MW h. Furthermore, economies of scale from wider adoption of EVs could lead to cheaper battery technologies which could boost the development of cost-efficient building energy storage systems.

This paper covers a gap in the literature, which typically focuses on evaluating only one main sector or individual technologies whereas, if cities are to become more energy efficient and sustainable, a holistic approach including different parts of the energy and urban systems need to be considered. Moreover, the analyses and solutions presented in this paper are based on the needs and priorities of 6 European mid-sized cities, and the results will be useful to other cities with similar characteristics, based on their environmental, economic and political objectives.

This paper aims at presenting the adoption of energy efficiency technology related results obtained from the analysis carried out in relation to the PLEEC project [20] as well as consumers' perspective and experiences with energy efficient and sustainable solutions used in the building and transportation sectors in Sweden. In addition, we present a case study identifying the potential for public transportation efficiency improvements since public transportation is one of the prioritized key fields identified by the cities from the PLEEC project. The city of Västerås in Sweden was selected for the case study presented in this paper, due to good data availability and the country's relative experience with the evaluated technologies. However, the obtained results can be extrapolated to other similar mid-sized cities in Europe in correspondence to the ranking methodology proposed by [21].

2. Methodology

The methods used in this paper include the rigorous analysis of results obtained in relation to the EU FP-7 funded PLEEC project, with special focus on technology related energy efficiency improvements and adoption. Based on the most relevant sectors identified by the project's participating cities, we carried out an analysis of consumers' experiences with using of energy efficient technologies with a particular focus on electric vehicles and smart meters. The case study presented in this paper is based on data collected from biogas and electric buses used in the city of Västerås, Sweden.

2.1. Technology selection and analysis

In order to identify the most successful and innovative technologies used by different cities, a list of 28 different projects targeting energy efficiency improvements were analyzed. A resulting number of 119 different technologies were extracted and associated with the corresponding key field and domain defined under the PLEEC project, where their impact on energy efficiency was highest.

All these technologies were divided into several domains and key fields, as a result of the collective contribution of city representatives and key field experts in city planning and energy systems. This classification facilitated the categorization of all the different technologies involved in city energy systems so that their impact on each key field and domain could be compared. The selected domains and key fields are shown in Table 1.