Renewable and Sustainable Energy Reviews 55 (2016) 1248–1259

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Smart plugs: Perceived usefulness and satisfaction: Evidence from United Arab Emirates

Mohammed Ghazal [a,*], Muhammad Akmal [a], Shilpa Iyanna [b], Kilani Ghoudi [c]

[a] Abu Dhabi University, College of Engineering, Electrical and Computer Engineering Department, Abu Dhabi, United Arab Emirates
[b] Abu Dhabi University, College of Business Administration, Abu Dhabi, United Arab Emirates
[c] United Arab Emirates University, College of Business and Economics, Department of Statistics, AlAin, United Arab Emirates

ARTICLE INFO

Available online 28 August 2015

Keywords:
Sustainable consumption
Mobile computing
Wireless sensor networks
Structural equation modeling
Embedded systems

ABSTRACT

The UAE per capita energy consumption is one of the highest in the world. Since the energy sector is the center of most ecological problems facing the world today, eco-efficiency and eco-innovations are at the top of the sustainability agenda in most countries. The UAE "Green Economy for Sustainable Development" (2012–2021) aims to position the country as a center for the export and re-export of green products and technologies. In light of the above, the focus of this paper is to present a smart plug system for monitoring and controlling household energy consumption using a mobile application. The smart plug system is an essential component in smart grids as it provides real-time high-resolution information for distribution companies to aid them in decision-making. In addition, the study measures the perceived usefulness and satisfaction of the smart plug system and its mobile application in the UAE. The paper makes an important theoretical contribution by including environmental concern as an additional variable to a well-established information systems success model. Our findings suggest that the smart plug system provides users with convenient access to information regarding their personal energy consumption and allows them to control their per capital energy consumptions via the mobile application at very low costs. Further, we validated our theoretical model using structural equation modeling and conclude that environmental concern has an indirect impact on the perceived satisfaction and both an indirect and a direct impact on the perceived usefulness of the smart plug system. The practical implications of our study suggest that per capita energy consumption is likely to significantly decrease with wide adoption of the smart plug system in the UAE.

Contents

1. Introduction

"*W* e recognize that preserving our energy resources will be one of the greatest challenges in our drive towards sustainable

* Corresponding author.
E-mail address: mohammed.ghazal@adu.ac.ae (M. Ghazal).

http://dx.doi.org/10.1016/j.rser.2015.07.096

development. This, however, will not materialize unless the different facets of our society adopt energy conservation principles in their core values. The future generations will be the chief beneficiary of our achievements and the biggest judge of what we accomplish in this field" – H.H. Sheikh Mohammed bin Rashid Al Maktoum The UAE Vice President, Prime Minister and Ruler of Dubai

Sustainable Development has been defined as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" [1]. Energy is central to sustainable development and poverty reduction efforts as it affects all aspects of development – social, economic, and environmental – including livelihoods, access to water, agricultural productivity, health, population levels, education, and gender-related issues (United Nations Development Program). The energy cycle, from energy extraction to energy use, is said to be responsible for many of the environmental problems at the local, national as well as global levels. Documented evidence by the UNDP suggests that many of the environmental problems confronting us today such as deforestation, water pollution, and air quality health problems can be linked back to the energy sector. The most serious problem facing the world today is climate change. Research has shown that energy efficiency is closely linked to climate change (UNDP). The recent years has seen an increased support for improving energy efficiency and the role energy efficiency can play in addressing many of the pressing environmental and energy concerns.

Research suggests that the residential sector accounts for one-fifth of the global energy consumption [2], thus energy efficiency of the housing market has become an important target for policy makers and a promising tool for those seeking to comply with the Kyoto protocol [3]. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets (UNFCCC). In 2005 the United Arab Emirates ratified the Kyoto Protocol to the UN Convention on Climate Change, becoming one of the first major oil-producing countries to do so.

The United Arab Emirates (UAE) has the worlds sixth largest proven oil reserves and the fifth largest natural gas reserves, making the country a critical partner and responsible supplier in global energy markets. Although, UAE is the world's third largest exporter of crude oil, oil exports account for only about one-third of economic activity, as a result of aggressive government policies designed to diversify the UAE economy. Economic growth across the UAE has led to massive increases in the demand for electricity [4]. The demand for energy in the United Arab Emirates is growing at a rate of 9%, three times greater than the global average. Energy demand is expected to exceed 40,000 MW by 2020 [5].

Research shows that buildings, especially residential buildings, account for a large share of energy consumption and offer a natural target for policies that seek to reduce energy consumption and increase energy efficiency [6]. On November 13, 2014, the UAE government revised the water and electricity tariffs for both Emiratis and expatriates which would come into effect from January 1, 2015. Utility tariffs in the UAE have been heavily subsidized by the government. The electricity subsidy in Abu Dhabi, the capital of UAE, for residential buildings ranges from 55% to 90% and the water subsidy ranges from 79% to 100%. Under the new tariff, Emiratis who use up to 30 kW h (kilowatt hours) a day in flats and 400 kW h a day in villas, will continue to pay the existing rate of 5 fils per kW h. But Emiratis who use above this limit have to pay a new tariff of 5.5 fils per kW h. Electricity tariff for expatriates who have a low consumption will pay anything between 15 and 21 fils per kW h. Those who use beyond 20 kW h in flats and 200 kW h in villas will, however, have to pay a higher tariff. Changes to the tariff structure are part of a wider initiative aimed at driving behavioral change in how water and electricity are currently consumed in the Emirate of Abu Dhabi. The change aims to encourage the efficient use of water and electricity, and raise awareness of the importance of reducing consumption to support the sustainable growth of the emirate (i.e. Abu Dhabi) [7]. These efforts are not only limited to the UAE. Reliable and sustainable energy for the future has become a major concern with many developed and developing countries spending a significant capital to invest on smart grids for better energy management and convenience of consumers and utilities [8]. Smart grids are believed to play an important role in delivering enough, and efficient power required for the energy demands of the future. Information and communications technology (ICT) is playing the key role in real-time implementation of smart strategies to incorporate various tasks and responses required for the operation of smart grids. The challenge is to come up with innovative ideas and solutions which will help in monitoring and managing electric power usage, and consequently lead to improving power grids and reducing power consumption.

Gans et al. argue that providing better information and feedback on consumption helps improve energy efficiency in the residential sector, especially when information and feedback is combined with other traditional policy tools such as economic incentives, pricing and regulation [6]. Increased transparency in energy consumption may encourage energy conservation among private consumers [3]. In an attempt to provide information on energy consumption, we have developed a low-cost smart plug that will help individuals monitor their household's energy consumption. Our proposed smart plug design emphasizes ease of deployability and use. As the smart plug is currently in the market test stage, the focus of this study is to measure consumer's perceived usefulness and satisfaction of the smart plug in effectively and efficiently monitoring their energy consumption. To achieve this, we also propose a model to measure the usefulness and satisfaction of smart plugs by extending the IS success model proposed by Seddon and Kiew [9]. We validate the model by running two experiments with and without live interaction with the proposed smart plug. To our knowledge, this is the first study targeting UAE consumers and integrating both the technical description of smart plugs and an analysis of the practical users experience.

The rest of this paper is organized as follows: Section 2 gives a literature review of smart girds and smart metering in general. Section 3 provides a technical overview of the proposed smart plug. Section 4 describes the theoretical model that will be used to measure consumers' perceived usefulness and satisfaction with the proposed system and describes our methodology. Section 5 emphasizes the analysis and key findings. Concluding comments are provided in Section 6.

2. Literature review

Electric power systems constitute one of the most important infrastructure of a modern society. The electric power grid is defined as the combination of entire apparatus of wires and machines that connects the power generation with the customers [10]. It is one of the largest and most complex infrastructures and it is critical to the operation of society and other infrastructures. Power systems have been operating for the last about 100 years using the same fundamental principles. Technology has allowed an improvement of their performance, but it has not revolutionized the basic operating principles. The power system has been driven by a fundamental principle, i.e., to keep a balance in the supply and demand under all operating conditions and to have the amount of generated power equal to the power absorbed by the loads [11]. Although the generation is controllable and the loads are predictable to an extent, the conventional grid system has very limited automation because of an absence of data from the consumer side, which can help with managing and reducing