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A smarter electricity grid for the Eastern Province of Saudi Arabia: Perceptions and policy implications

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ABSTRACT

Saudi Arabia aspires to transition toward a smarter electricity grid with increased reliance on renewable energy, where customers will use or produce green energy and where smart meters will enable customers to tailor their behavior and decrease their carbon footprint. The success of the transition is dependent on householder acceptance. This research studies the public's disposition toward a smarter grid. The Eastern Province of Saudi Arabia is taken as a case study through a field questionnaire to assess public knowledge about energy sources and environmental impacts on the environments, people's disposition toward a smarter electric grid, and the main motivations for undergoing this transition. A logit model is used to investigate determinants. Stated willingness is taken as a variable representing an individual's disposition. We found that the public is willing to use green energy, accept smart meters, or become co-producers. However, their fear of unknown technologies and perceptions about their high cost are major obstacles to their adoption. Enhancive knowledge, especially about ecological sensitivity, and governmental incentives will help to win public acceptance. Also, government subsidies that lower prices should be cut and dynamic pricing should be implemented to motivate electricity saving behavior.

1. Introduction

The Kingdom of Saudi Arabia is the world's largest oil producer, controlling the world's second largest oil reserves (U. S. Energy Information Administration, 2014). Nevertheless, the country is undergoing considerable growth that may create severe energy problems if no measures are taken. As the nation's population increases, it is anticipated that the overall domestic demand for electricity will grow from 3.4 million barrels of oil equivalent per day in 2010 to 8.3 million barrels of oil equivalent per day in 2028 (Segar, 2014). Half of the electricity production comes from fossil fuel, and an increase in domestic demand will cause a decrease of exportation and associated revenues. Peak load is increasing, especially in the summer due to air-conditioning needs, and it is expected to approach 60 GW by 2023, 75 times its 1975 level (Al-Ajlan et al., 2006). The gap between the base-load and the peak-load will widen if no remedial actions are taken in terms of supply and demand management, including electricity pricing.

In this context, there is an urgent need to revisit the Kingdom's energy policies, from generation to distribution, especially residential consumption, which accounts for almost half of the energy consumption in Saudi Arabia as compared to a global average of about 25% (Al-Ajlan et al., 2006). A paradigm shift toward modernization of the legacy electricity grid is needed (Alaqeel and Suryanarayanan, 2014).

The Saudi Vision 2030, a recently launched plan by the government of Saudi Arabia, is a key step in the transition. The plan aims to diversify Saudi economy hence removing the country's dependence on oil, as the finances of Saudi Arabia have been adversely affected by falling crude prices blamed for a state budget deficit of nearly $100 billion since from 2015 to 2017 (Al Khatteeb, 2015). As part of this innovative plan, the King Salman Renewable Energy Initiative aims to increase renewable energy production, with an initial generation target of 9.5 gigawatts. Meanwhile, the energy ministry aims to maintain its oil production capacity at 12.5 million barrels a day (Maclean et al., 2016).

Expanding renewable energy production will undoubtedly contribute to reducing the dependency on oil while sustainably satisfying growing domestic demand, hence ensuring longer term availability of oil for the external market that is still lucrative (Farnoosh et al., 2014). Such an expansion is certainly feasible as the

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Kingdom year-long high solar intensity offers great potential for utilization. Indeed, due to its location, Saudi Arabia receive the most useful kind of sunlight (Dargin, 2009), with an annual average of about 2200 kWh/m2 solar radiation falling on the Arabian Peninsula (Alawaji, 2001). As stated in (Farnoosh et al., 2014), Saudi Arabia has vast areas subject to strong Global Horizontal Irradiance and fractions of Direct Normal Irradiance which are respectively ideal for Photovoltaic (PV) and concentrating Solar Power (CSP) technologies. Extensive research has been conducted on current applications and future aspects of solar energy in Saudi Arabia, as reviewed (Hepbasli and Alsuhaibani, 2011).

Renewable energy production can be achieved either at through utility-scale solar power stations or at distributed on-site solar systems, with home-owners integrating photovoltaic (PV) into their residential buildings to become co-producers (or "prosumers") of green energy. Several studies have predicted that integrated photovoltaic (BiPV) systems are not feasible in the Gulf Cooperation Council (GCC) region, due either to high initial investment (Taleb and Pitts, 2009), or low electricity prices (Radhi, 2011). But Saudi Arabia is becoming an exception among the Gulf countries as the government instituted electric utility price increases in early 2016 ranging from 49% to 104%. The Saudi Vision 2030 plan is further striving to cut electricity subsidies by 200 billion riyals by 2020 (Nereim et al., 2016).

However, due to their intermittent nature of renewable resources, their integration into the grid must be combined with demand-side management (DSM), including behavioral change through education or financial incentives through dynamic pricing during peak-load periods. Dynamic pricing necessitates the installation of advanced metering infrastructure with bi-directional communication channels that connect consumers to the utility (Strbac, 2008). This "smart" infrastructure allows electricity consumers to respond to prices by either reducing their consumption or shifting it from peak to off-peak periods. The Kingdom certainly will also significantly benefit from grid modernization in terms of positive impacts on the environment (Alnatheer, 2006).

Before undergoing such important and expensive changes, it is important to be aware of potential obstacles that may impede the success. The literature reports on various barriers in many of countries with potential for implementation of a smarter grid. The most important barriers are of financial and economic, such as the high cost of the business initiative for renewable energy generation and insufficient financial support for on-site PV or BiPV systems. Research also suggests that societal acceptance by local stakeholders is a fundamental barrier (Desha et al., n.d.; "Stanford Ovshinsky: Pursuing solar electricity at a cost equal to or lower than that of coal electricity," 2011). For success, the community as a whole should engage in the processes that support smart-grid implementation (Foster et al., 2010).

However, the impact of these barriers on the development and deployment of a smarter grid in KSA has yet to be clarified. Given the lack of a comprehensive study on antecedents of various aspects of a smarter grid that are envisioned and necessary for the near future in Saudi Arabia, and that no study has explored this topic in the Saudi context, we attempt to address these challenges in Saudi. A field study or the Eastern Province of Saudi Arabia and a public engagement questionnaire were used to identify the determinants of successful smart-grid implementation. In particular, we consider (1) a grid that integrates a high level of renewable energy sources; (2) where customers can also become a co-producer by generating their own green energy on a residential scale, and (3) where smart meters enable customers to tailor their behavior in order to reduce their carbon footprints. Hence, obstacles (or enablers) affecting public support for a smarter grid can be determined.

In the subsequent sections, the research methodology is explained, followed by a detailed analysis and interpretation of the gathered data. Finally, conclusions drawn from that study are presented as recommendations to ease the transition toward a smarter grid.

2. Theoretical background and methodology

To test acceptance of a smarter grid, in this study we will focus on individual intention. Several theories in behavioral economics theories consider the effects of psychological, social, cognitive, and emotional factors on economic decisions, including the willingness to pay for or adopt smart meters, buy greener energy, and produce energy. The most known are the Theory of Reasoned Action (TRA) and an extended version in the Theory of Planned Behavior (TPB).

According to Fishbein and Ajzen, who developed the Theory of Reasoned Action (TRA), the strongest predictor of individual's behavior is behavioral intention, which results from the integration of attitudes (individual influence) and subjective norms (normative influence) toward behavior (Ajzen et al., 1977). While belief and positive or negative evaluation of the behavior and its expected consequence affect attitudes, the motivation to obey (e.g., social pressure to perform or refrain from behavior) forms the subject norm (Fig. 1).

However, the TRA has some limitations (Ajzen, 1985). First, it might be difficult to differentiate between attitude and norm, as norms can be formed as attitude and vice versa. Second, the explanatory power of TRA is relatively finite and omits several potential factors, since the degree of control over an individual's intention is not affected by internal psychology factors only but also by external environmental factors (e.g., time, money, limited ability, and the cooperation of others). This explains the very few applications of this method to the smart-grid context.

Ajzen extended the TRA to the Theory of Planned Behavior (TPB) by adding an individual's perceived behavioral control to the original TRA model the determinant of behavioral intention (Ajzen, 1991), as depicted in Fig. 2. Perceived behavioral control refers to people's perception of their control over factors that may facilitate or inhibit their performance. Depending on control beliefs and perceived facilitation, it is presumed to have a motivational impact on one's intention. Control belief is the perception of the presence or absence of requisite resources (e.g., personal capacity or cooperation of others, required information, time) and opportunities to carry out the behavior. To the extent that people have resources and opportunities and intend to perform a behavior, they should carry out the actual behavior (Huijts et al., 2012). Perceived facilitation is one's assessment of the importance of those resources to the achievement of outcomes (e.g., perceived benefits). The inclusion of this factor gives a better explanation of behavior in which it is difficult to engage (Ajzen and Madden, 1986).

This theory is particularly useful for predicting pro-environmental behavior, where individuals often undertake behaviors associated with desired outcomes (Bang et al., 2000). As an example, consumers may have a positive evaluation or favorable attitude toward a less expensive kitchen appliance but may end up purchasing a more expensive model influenced by their positive beliefs about the environmental consequences and facilitated by their income (Ha and Janda, 2012).

Indeed, the TPB model has been successfully applied to a wide variety of behavior related to the smart grid, with variations. Many studies (Alam et al., 2014; Chan, 1998; Chan and Bishop, 2013; Chen and Tung, 2014; Greaves et al., 2013; López-Mosquera et al., 2014) investigated the intent to act in an environmentally friendly behavior. Wang et al. (2017) looked at consumers' willingness to use energy efficient appliances. Others (Albayrak et al., 2013;

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