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Modeling residential adoption of solar energy in the Arabian Gulf Region

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ABSTRACT

We present an agent-based model for residential model adoption of solar photovoltaic (PV) systems in the state of Qatar as a case study for the Arabian Gulf Region. Agents in the model are defined as households. The objective of the model is to evaluate PV adoption across households under diverse regulatory and incentive scenarios determined by home ownership status, the falling cost of PV, the reduction of electricity subsidies, the introduction of a carbon tax, and the diffusion of renewable energy innovation. Our study suggests that Qatar's residential PV adoption is strongly promoted by the falling cost of PV and can be further facilitated through the reduction of electricity subsidies and the extension of the electricity tariff to Qatari households, which are currently exempt. The introduction of a carbon tax can also play a role in accelerating residential PV adoption, if above $8 per metric ton of carbon dioxide equivalent. The ensuing PV adoption rates would help facilitate the national targets of 2% electricity production from solar energy by 2020 and 20% by 2030.

1. Introduction

Modeling the diffusion of residential solar photovoltaic (PV) systems in their social, political and economic context is crucial to help stakeholders assess which policies may best support adoption. Current models of renewable energy adoption assume regulatory and incentive frameworks that do not apply to Gulf Cooperation Council (GCC) states, where energy tariffs are strongly subsidized, tax credits are not viable due to the lack of personal income tax, and support for distributed generation through grid access policies such as the Feed-in Tariff and Net Metering is not available. The goal of this study is to address this gap by analyzing the impact of home ownership status, the falling cost of PV, the reduction of electricity subsidies, the introduction of a carbon tax, and the diffusion of innovation on the residential adoption of solar PV technologies in Qatar. Our objective is to develop a social simulation platform that helps policymakers and other stakeholders assess the optimal regulatory framework to promote the adoption of residential PV systems in Qatar and other countries which share a similar geographical, political, economic and social context.

Qatar, like other GCC countries, enjoys strong global horizontal irradiation throughout the year (on average 2163 kW-hours (kWh) per m^2) [1], with long daily average sun peak hours (5.8 [2]), and it is therefore ideally suited for PV applications.[1] Qatar's plans to generate 2% of the nation's total electricity production from solar energy by 2020 and 20% by 2030 are representative of solar energy adoption targets in the region [4]. These solar energy adoption objectives can bring several economic and environmental benefits. For example, Qatar's PV adoption plans could yield natural gas savings of 0.24 Mtoe (million tonnes of oil equivalent) in 2020 [5] and 2.6 Mtoe by 2030 [6]. The natural gas saved could be repurposed for additional trade to increase the country's revenues, or left untapped to extend the lifetime of the country's natural gas reserves, and lower extraction costs, with ensuing reduction of CO_2 emissions by 0.51 million tonnes (Mt) by 2020 [5] and 5.5 Mt by 2030 [6]. The development of a residential PV market would also help diversify national economies across the GCC through innovation and entrepreneurship to accelerate the ongoing transition from a carbon-based to a knowledge-based economy, as mandated by national economic development plans in the GCC [7–12]. Finally,

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[1] Global horizontal irradiation is the relevant solar irradiance input for solar PV systems [3].

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due to continuing economic and population growth, investments to upgrade the national electricity distribution and transmission networks may reach $136bn for the GCC region and $6bn for Qatar by 2020 [13]. These investments could be reduced or eliminated through the introduction of demand response measures aimed at reducing peak consumption in smart grids that integrate storage to manage solar energy variability [14].

Overall, Qatar and other GCC states are well poised for a strong rate of PV adoption. However, a main barrier to adoption remains the lack of a framework to regulate and incentivize renewable energy. Another impediment is the relative lack of awareness about Renewable Energy Technologies (RET). Qatar is the world's third largest reserve of natural gas, which is nearly the sole source of electricity production in the country, and access to energy is therefore not perceived as a problem. Indeed, a recent study on modeling RET innovation diffusion in Qatar using social media data [15] shows that only 8681 out of 110 million messages posted on Twitter between 2007 and 2016 (10% sample) talk about renewable energy. The inclusion of solar energy targets in Qatar National Vision 2030 [7] and the exponential growth of messages about renewable energy in social media during the last decade observed in Ref. [15] indicate that RET awareness is on the rise. However, additional educational efforts are needed to bring about the social and behavioral changes that would provide sufficient public support for RET adoption.

In developing a PV adoption model for Qatar that is representative of the GCC region, our aim is to explore alternative energy policy scenarios where residential PV adoption can be maximized to help achieve national solar adoption targets. After a review of PV adoption models in section 2, we describe the approach developed and the data used in sections 3 and 4. Section 5 provides a discussion of the results and evaluation of the model. Section 6 shows how the model's results can be used to estimate the level of consumer demand that residential PV systems can satisfy in the scenarios explored. Finally, section 7 gives a summary of the insights developed in this study.

2. Background

Complex-systems approaches, including agent-based and system-dynamics modeling techniques, have been used successfully in the development of decision support tools that evaluate policies promoting PV adoption.

Zhao et al. [17] propose a two-level simulation modeling framework to analyze the effectiveness of incentive and regulation policies on the growth rate of distributed PV systems. This model has been adapted to two US regions, with specific applications to Tucson (AZ) and New York (NY).

Paidipati et al. [18] describe a model of market penetration of rooftop PV in each of the 50 US states, which takes into account the technical potential of rooftop PV and payback period for rooftop PV investments.

The SolarDS model [19] simulates PV adoption for residential and commercial buildings in the continental US through 2030 by aggregating regional PV adoption to the state and national levels, where lower PV costs were fostered including net-metering incentives and policies pricing carbon emissions of competing energy sources. This analysis shows that lower PV costs have the largest impact on increasing PV adoption, followed by policy options including net-metering and carbon tax measures.

In their analysis of rooftop PV adoption in Connecticut, Graziano & Gillingham [20] found that PV adoption decreases in higher density housing with a higher share of renters. This study also showed a *neighborhood effect* according to which new PV installations helped increase the number of PV adoptions within a 0.5 mile area in the following year.

These and other approaches to modeling the adoption of renewable energy offer valuable insights in understanding the impact of technological advancement, PV potential, policy and social acceptance on solar PV adoption. However, these efforts are typically based on systemic assumptions which do not apply to Qatar and other GCC states where

- there is no legal framework for renewable energy development regulating private ownership of power generation (http://rise.esmap.org/countries)
- there are no incentive and regulatory schemes to support renewable energy generation through measures such as grid access (e.g. feed-in tariff, net metering) and priority dispatch (http://rise.esmap.org/countries)[2]
- there is no personal income tax, and therefore residential PV adoption cannot be incentivized through production tax credits [21].
- both electricity and the fossil fuel used for its generation are highly subsidized across the GCC, as shown in Table 1 for Qatar
- electricity is free for Qatari households [21].
- there is no carbon pricing mechanism in place (http://rise.esmap.org/countries).

3. Approach

In modeling residential PV adoption for Qatar, we develop an agent-based approach where PV adoption is driven by cost [22,23] and regulated by a number of factors germane to the social, economic and policy context of the GCC region (see below). Agents represent two types of households in the Al Rayyan municipality of Qatar: owners and renters. In the present state of affairs, only Qatari citizens can own property in Al Rayyan and Qatari households are exempt from electricity charges. Therefore, home owners are Qataris who have free electricity, while renters tend to be expatriates who pay for electricity. All household agents are distributed on a grid representing the Al Rayyan territory, so as to satisfy two constraints:

- 21% of households are owners and 79% renters, according to the 2010 census [27] (see section 4)
- where possible, each household is adjacent to 3 households of the same home-ownership type (renter or owner), to reflect the tendency of Qatari and expatriate households to cluster separately.

The more competitive the cost of electricity from residential PV systems is as compared to the electricity tariff, the more likely are household agents to adopt solar PV. Several factors can contribute to make the cost of electricity from residential PV more

Table 1
Electricity and natural gas subsidies in Qatar (billion USD). Source: IEA [16].

Product	2012	2013	2014
Electricity	2.1	2.0	2.3
Gas	1.6	1.5	1.6

[2] Priority dispatch, which is enforced by the European Energy Efficiency Directive, ensures that distribution and transmission system operators consider renewable energy installations first when balancing supply and demand to guarantee grid stability (http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive).