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Distributed photovoltaic power generation: Possibilities, benefits, and challenges for a widespread application in the Mexican residential sector☆

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ABSTRACT

Mexico plans to implement a national program to support the adoption of distributed photo-voltaic generation (DPVG) among qualified households. The main objectives of such a program would be to reduce the burden of the substantial federal energy subsidy and increase the share of renewable energy sources used to generate electricity. In this paper we assess the current conditions under which the Mexican residential electricity sector operates, and quantify the potential effects that the massive adoption of DPV systems would have on household expenditure and welfare, subsidy reduction, pollution and water resource usage. Based on the positive results in terms of both economic and environmental effects, our paper provides a significant support for further design and implementation of a DPVG program.

1. Introduction

About 90% of Mexican energy consumption comes from fossil fuels, including most of the electricity generated in the country. Mexico is the 13th largest Greenhouse Gas (GHG) emitter in the world and the second in Latin America -only behind Brazil-, contributing with approximately 1.4% of the global GHG emissions (Damassa et al., 2015; Mexico Gobierno de la Republica, 2015). Among the current and expected consequences of climate change that directly impact on the country, we find more frequent and severe hurricanes and tornadoes, extended droughts that affect the quality and quantity of water resources, adverse effects on agricultural activities (which also put at risk food security), and drastic coastal flooding and erosion episodes. The country's environmental goals, in accordance with the Intended Nationally Determined Contribution affirmed at the climate summit held in Paris in 2015 (COP-21), require that 35% and 43% of domestic energy should come from renewable sources by 2024 and 2030, respectively. Meeting that goal is likely to require, among other steps, significant changes in the current electricity generation mix. The Mexican Energy Reform of December 2013 opened an important window to introduce renewable energies in this sector, particularly solar energy.[1]

To be more concrete, electricity generation explains more than 20% of total GHG emissions in Mexico. The residential sector, in turn, accounts for 25% of total electricity consumed. In this context, taking advantage of the fact that more than 75% of the country has an isolation greater than 5 $kWh/m^2/day$, there seems to exist a very promising energy and environmental policy opportunity for distributed PV solar energy. Other countries, such as Germany and Spain, are currently recognized as the world leaders in installed PV systems. However, Mexico's potential solar resources are far superior and could be

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[1] In December 2015, Mexico's constitution was amended to create competition in the energy sector through the introduction of private investment, including the hydrocarbon sector (upstream, midstream and downstream) and the power sector (generation, transmission and distribution). The amendments maintained the state ownership and control of subsoil resource and were intended to modernize the state energy companies. One of the main goals was to reduce direct intervention of government and replace it with rational economic regulation.

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considered among the largest in the world – see, for example, SENER (2016).

On the other hand, the federal government through the state-owned electricity company (*Comisión Federal de Electricidad*, CFE) promotes excessive residential electricity demand by subsidizing more than 98% of Mexican households. The residential tariff structure consists of a multiple-block scheme and incorporates different regional marginal prices which are linked to average temperatures -i.e. high temperature zones afford lower marginal prices.[2] The fiscal burden associated to the electricity consumption of the residential sector has consistently increased during the last decade and currently represents more than 0.5% of the GDP. Moreover, given the universal and uniform application of this subsidy, the tariff scheme magnifies the inclusion error, wasting valuable resources. All this happens in the context of a country where poverty and inequality are significant social problems.

In addition, the Energy Transition Law of December 2015 mandates the Ministry of Energy to undertake technical analysis to evaluate the potential effects that clean distributed generation and various energy efficiency measures would have on the government electricity subsidy account, household welfare, and the environment. The resulting report conducted by SENER (2017) picked the solar PV technology (over other renewable sources) to concentrate the analysis of the diffusion of distributed clean generation in the residential sector.

As a result, an ambitious plan aiming to deploy distributed photovoltaic systems (DPV) among qualified households -i.e. those able to adopt solar technology in their rooftops- could help solve some of the challenges that Mexico is currently facing. A household adopting a DPV system would be ideally grid-connected so it could balance its excess electricity demand and supply. The potential advantages of DPVG include: first, a reduction of the fiscal burden (which today represents a figure of more than 5 billion of USD per year). Second, the DPVG program could bring significant GHG emissions savings by reducing traditional fossil fuel electricity generation (helping Mexico to comply with the energy and environmental goals).[3] Third, it could make possible to avoid costly future investments in traditional electricity generation, transmission and distribution since households adopting DPV systems would be grid-connected.

In this paper, we provide a comprehensive assessment of the current conditions under which the Mexican residential electricity sector operates. Using the characterization of Mexican households and simulating an scenario of massive DPV system adoption, we measure the potential subsidy savings and the benefits to residential users.[4] Also, from an environmental perspective, we estimate the reduction in air pollution emissions and water resource usage associated to the simulated scenario. Finally, we provide some policy suggestions about how the current electricity consumption subsidy could be (partially) converted into a DPV system adoption subsidy, standing up for an integral selection mechanism aiming to target the poor in an accurate way.

2. Literature review

We analyze the possibilities and the impact that massive rooftop solar panel installation in the Mexican residential sector would have on a set of relevant socio-economic variables: household welfare, government budget, air pollution and water resources usage.[5] The available related literature for Mexico and other emerging countries is relatively scarce and, most of the times, is focused on a narrower set of issues. Grande et al. (2015) analyzes the profitability of DPV systems for a narrow subset of high-consumption users in Mexico. The calculations made in that study do not use micro-data and are based on industry average figures for the year 2010. Alemán-Nava et al. (2014) presents an overview of the renewable energy options available in Mexico without focusing on any particular energy source. Our paper belongs to broader branch of international literature that studies the possibilities of success solar panel technologies have as an alternative clean energy source to traditional power generation -i.e., mainly based on fossil fuels.

In this broader picture, we find mixed evidence to preferences for renewable over conventional energy. Salim and Rafiq (2012) utilizes aggregate data from six major developing countries (Brazil, China, India, Indonesia, Philippines and Turkey) and finds evidence that renewable energy consumption is directly and positively determined by income, and that pollution is inversely associated with renewable energy consumption in three of those six countries. Moving to studies that are grounded on micro data analysis, an early paper by Long (1993) works with several variables that are associated with renewable energy adoption. The author analyzes U.S. data on tax returns, addresses the predictors of energy conservation and renewable energy investments, and finds that energy price changes and subsidies highly influence these expenditures, while the effect of income is not statistically significant. Bradford and Schleich (2012) uses household level data from 11 countries in Europe and finds that energy efficient technology adoption and conservation practices are highly correlated with households characteristics. In particular, the presence of young children makes households more likely to care about savings for environmental reasons, while elder households are more likely to care about financial savings. Similarly, Willis et al. (2011) finds evidence that households composed of people aged 65 and over have different behavioral responses to renewable energy adoption: concretely, they are less prone to adopt micro-generation technologies. Furthermore, Bergmann et al. (2008) finds that urban and rural survey respondents have different preferences for renewable energy projects. Scarpa and Willis (2010) uses a household survey for the U.K. to estimate conditional and mixed logit models, and then derives willingness-to-pay for different micro-generation technologies (solar PV, solar thermal, micro-wind, heat pumps, biomass boilers and pellets stoves). This study finds that while renewable energy adoption is significantly valued by residential users, that value is not sufficiently large to most households due to the high initial capital investment. Lastly, Islam and Meade (2013) models the adoption probability of PV solar panels by households using rich data from a group of Canadian households on attribute preferences and social characteristics.

In our paper, we are not able to isolate and address the DPV adoption problem. Our dataset only allows us to infer different (arbitrary) DPV technology adoption scenarios, and quantify the potential benefits in terms of household expenditure, electric subsidy reduction, and environmental impact. In order to provide an objective measure of these variables, we choose a particular situation that works as an upper bound of the potential effects. Section 4 below explains in detail our empirical exercise.

In a more specific collection of literature, a number of studies analyze the economic feasibility of DPV systems for residential users. Pillai et al. (2014) proposes a metric to estimate the expected benefits of PV systems in the U.K. and India, and finds that most locations in India would favor from DPV systems usage, whereas most locations in U.K. would need some cost reduction to achieve near-term benefits. The

[2] Mexico has one of the most complex tariff and subsidy structures in the world, see for example Komives et al. (2009) and Lopez-Calva and Rosellón (2002).

[3] Using GHG emissions in 2000 as baseline, the General Law of Climate Change (passed in 2012) has two main goals: first a reduction of 30% by 2020, and second a reduction of 50% by 2050. In the same spirit and as part of the extensive and deep Energy Reform of December 2013, the Clean Energy Certificates (a.k.a. RECs) seek to promote greater electricity generation from clean (mainly renewable) energy sources.

[4] A massive adoption scenario of the sort presented in this paper could be thought of as a national-scale program. In the last two decades, Mexico has successfully implemented a series of large-scale social programs which have helped create a good reputation in terms of long-term support and commitment. See, for example, Davis et al. (2014), Lobel and Perakis (2011), and Levy (2007).

[5] Unfortunately, we are unable to analyze the impact that the DPVG scenario would have on traditional energy supply. We do not have access to CFE data on production costs that would be necessary to estimate the associated producer surplus changes.