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Systematic analysis of factors affecting solar PV deployment

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ABSTRACT

This article analyzes the determinants of annual installed capacity of photovoltaic power (PV) at a country level. Our results suggest that in the 15 countries studied, the factors promoting the deployment of PV systems are the net consumption of renewable electricity, the existence of a feed-in tariff and sustainable building requirements, as well as the quantity of scientific publications. Meanwhile, the variables that negatively impact the PV deployment are oil reserves and the carbon dioxide emissions from energy consumption. Based on data from 1992 to 2011, the analysis shows that the deployment of PV requires long-term support for scientific research. One successful policy for PV deployment has been the feed-in tariff. Sustainable building requirements also significantly support PV deployment. The deployment of PV is one step towards a low-carbon energy system but the emergence of any renewable energy technology must cope with the energy sector's domination by fossil fuels interests.

1. Introduction

All over the world, changes in energy systems are deeply interlinked with societal development [1,2]. Electricity consumption, which in 2013 represented 18% of total final consumption of fuels in the world [3], is highly correlated with the growth of societies and their productivity. Meanwhile, the world's electricity production grew 97.2%, the population grew 34.8% and the Gross Domestic Product (GDP) increased 82%, over the period 1990–2013 [4]. Currently, the growth of electricity demand increases the use of fossil fuels and hydrocarbons share of global production of electricity was 67.9% in 2013 [3]. Unfortunately, there are some serious problems related to the exploitation of fossil fuel such as scarcity, increasingly difficult extraction, volatility of prices and global warming. Greenhouse gases (GHGs) emissions from the highly fossil-fuel dependent energy sector have driven anthropogenic climate change [5,6]. Globally, in 2013, carbon dioxide (CO_2) emissions from renewable energy (RE) [nuclear, hydro, geothermal, solar, tidal, wind, biofuels and waste] represented only 1% [4] of the anthropogenic emissions of GHGs. However, the share of electricity production from RE of non-hydro sources in the Organization for Economic Co-operation and Development (OECD) countries in 2013 was just 5.7% [3]. Thus, better electricity production options using more affordable and cleaner fuels are needed.

Of all the technologies for renewable electricity production, excluding hydroelectric power, photovoltaic (PV) power had the fastest rate of annual growth from 1990 to 2012 [7] and its cumulative installed capacity in 2014 reached 178,391 MW [8]. However, its share of electricity production from non-hydro sources in OECD countries in 2012 was 8.2% of the total versus wind power that had a share of 48.2%, or solid biofuels that had a 21.9% [7]. As a relatively new technology, PV systems still need support to break into the commercial mainstream. For instance, Chen and Su [9] studied support instruments used in the PV supply chain system in China. They suggested that governments should establish an appropriate subsidy policy to further pursue the development of the PV industry. Nevertheless, many variables may affect the PV market such as the availability of extractable energy resources, energy policies, energy laws, geographic conditions, human resources and regional public awareness.

Academic work focusing on drivers of the PV sector [e.g. 9,10,11,12] includes policy analysis, studies of installed PV capacity, and case studies of PV production. Although there is an increasing number of PV-related case studies, most of the literature of energy drivers has focused its attention on impacts on total RE production, when variability of the impact of the control variables

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is presented on RE technologies [13]. In addition, an integrative perspective on the production, dissemination and use of technologies has not been applied to analyze PV deployment although this method has been useful to study dynamics of innovation in the energy sector [14–16]. Additionally, previous studies show that there are only few of them related to the driving factors behind the growth of specific renewable energies or the impacts of specific policy instruments [9,12,17,18]. Besides, there is still discussion about the factors that drive RE. Results have not been conclusive; for instance, Carley [19] showed that the price of electricity is significant for the deployment of RE, while Shrimali and Kniefel [13] found that the price was not significant, even though both studies analyze the case of the USA.

Therefore, more studies using different methodologies are still needed for the analysis of the driving factors of the development and deployment of PV. The present paper aims to identify factors that have driven the deployment of PV capacity in its exponential growth by using a holistic approach of socio-technical (ST) theory and longitudinal data of a selected sample of countries. Key differences with previous literature are the integrative approach, the evidence that the academic work on PV requires long-term support and that some policy instruments have had no statistically significant effects for PV deployment. Section 2 shows a review of PV systems in the energy sector and the related literature. The data and the methods are presented in Section 3. In Section 4, the results are shown and a discussion is presented in Section 5. Finally, conclusions are presented in Section 6.

2. PV system in the energy sector and related literature review

2.1. Renewable energy in the electric sector

RE includes nuclear power and renewables [20] (see Table 1). Although RE production is increasing all over the world, there remains a huge global dependence on fossil fuel for primary energy supply. For example, its share was 86.6% in 1973 and 81.4% in 2013 [3]. Also, hydrocarbons dominates the global production of electricity, its share was 67.9% in 2013, of which 41.3% was accounted for by coal, 21.7% by natural gas and 4.4% by oil [3]. Scarcity, increasingly difficult extraction, volatility of prices and global warming are some of the serious problems related to the exploitation of fossil fuel for energy production and use. On the other side, renewability and low GHGs emissions are some benefits of RE production. It has been widely accepted that global warming is a consequence of the significant increase in the atmospheric concentration of CO_2. Globally, CO_2 emissions from fuel combustion in 2013 were 32,189.7 million tonnes and CO_2 emissions share by fuel from combustion during primary energy production were from coal (46%), oil (33%), gas (20%), and RE sources (1%) [4]. Thus, diversifying the energy production with RE could reduce the carbon footprint of the energy sector.

Table 1
Grouping of Renewable Energy Sources.

Renewable Energy Sources	a) Nuclear Power		
	b) Renewables	i) Traditional Biomass	
		ii) Modern renewables	- Hydropower
			- Geothermal
			- Solar
			- Tidal
			- Wind
			- Biofuels

Source: Adapted from Ref. [20].

Table 2
Fuel shares of world electricity generation in 2013.

Fuel Source	Share
Fossil Fuels (Coal, oil and natural gas)	67.4%
Nuclear Energy	10.6%
Hydropower	16.3%
Non-hydro sources	5.7%

Source: Adapted from Ref. [3]

Table 3
Electricity Production from non-hydro source in OECD countries in 2012.

Non-hydro source	Share
Wind	48.2%
Solid Biofuels	21.9%
PV	8.2%
Biogas	7.3%
Geothermal	6.0%
Waste	4.0%
Liquid biofuels	0.8%
Solar thermal and Tidal/Wave	0.6%

Source: Adapted from Ref. [7]

However, intermittency in power generation, high costs and considerable upfront investment are some of the issues that holds back RE deployment in the electric sector; it is also important to mention that technology dependence on hydrocarbons is another critical factor. Additionally, RE deployment depends on matching its generation capacity with the constant growth of economies, since demand for electricity increases because it is linked to the growth of economies and their productivity. Global electricity production grew 97.2% (from 11,826.1 to 23,321.6 TWh) over the period 1990–2013 [4]. During the same period, the population grew 34.8% (from 5,278.3 million to 7,117.7 million) and the GDP grew 82% (from 30,998.9 billion to 56,519.0 billion, 2005 USD) [4].

Currently, RE provides some of the electricity demand; in 2013, its share was 32.6% of the total generation [3]. The estimated proportion of world electricity generation in 2013 by fuel is shown in Table 2, as can be seen fossil fuels share was 67.4%. Table 3 shows the share of electricity production from non-hydro sources in OECD countries in 2012 where wind, PV and solid biofuels represented 78.3% of the total; but PV share was only 8.2%. Although the production share of PV was lower than that of wind or solid biofuels, PV had the fastest rate of annual growth of non-hydro electricity production, reaching 46.9%, over the period 1990–2012 (see Table 4).

2.2. PV technology and policy drivers

PV technology might play an important role for power generation in the upcoming years because of its generation

Table 4
Annual growth rates of electricity production from non-hydro renewables (period 1990–2012).

Non-hydro source	Share
Wind	23.1%
Solid biofuels	2.7%
PV	46.9%
Biogas	13.3%
Geothermal	2.2%
Waste	5.7%

Source: Adapted from Ref. [7]