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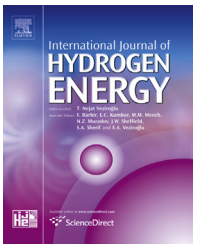

How does hydrogen-based renewable energy change with economic development? Empirical evidence from 32 countries

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ABSTRACT

The hydrogen-based renewable energy resource base is sufficient to meet several times the present world energy demand. This paper analyzes the drivers promoting hydrogen-based renewable energy utilization, focusing on a group of 32 countries by applying panel data techniques. The pooled ordinary least square estimator and fixed effect estimator are employed for comparison. Grey relational analysis is used to explore the relationships at a national level between renewable energy development and its influencing factors. The main results over our time span indicate that: (1) GDP per capita is a significantly positive contributor to renewable energy consumption, while oil price does not present a strong relationship in the use of renewables; (2) social awareness about climate change and concerns for energy security is not enough to motivate the switch from traditional to renewable energy sources; (3) the role of urbanization in renewable energy consumption relies on different stages of the urbanization process, resulting in opposite trends in renewable energy development between developing and developed countries. The results show that the market mechanism is not entirely responsible for encouraging the use of renewables and the role of climate change and energy security concerns in renewables use should be enhanced. By analyzing the results, policy implications are provided for the sustainable development of renewable energy.

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Introduction

Renewable energy (hereafter RE), especially hydrogen-based renewables, which can be considered as a substitute for fossil fuels, is vital for social development from the aspects of environmental benefits, energy security, climate change and clean production [1–4]. As is well documented, energy consumption in emerging countries is growing very rapidly, while that of developed countries is at a balanced level. The world's huge energy demand has promoted the utilization of renewables and the transition to hydrogen economy over the past decades, especially the first decades of the 21st century, and has surpassed all expectations. The Renewables Global Status Report points out that RE accounted for an estimated 19.2% of the world's primary energy use in 2014, and 173 countries defined their renewable targets in 2015 [5]. Further, the achievement of the Millennium Development Goals and the sustainability of clean production require the development of hydrogen-based renewable energy system [6,7]. None of the Millennium Development Goals can be met without major improvements in the quality and quantity of energy services in developing countries. It is suggested that hydrogen-based renewables can play a vital role in this path, assisting developing countries in expediting their economic development and alleviating rural poverty [8].

Analysis on the drivers of RE development is central to sustainable development [9]. A future hydrogen-based renewable energy system needs technical change and the infrastructure building. The world needs to move faster and more decisively if we are serious about ensuring access to clean and sustainable energy for all people by 2030 [10]. First, many developing economies are now finding themselves facing an energy security issue similar to that of most developed economies [11,12], such as the relatively higher energy dependency of China and Japan. Hydrogen-based renewable energy systems can enhance energy security and achieve China's CO_2 emissions peak through technological diversification and minimizing dependence on foreign imports of energy fuels [4,13]. For example, China's Blue Book on Hydrogen Energy Infrastructure has been released in October 2016. Hydrogen energy and fuel cell integration are included in Energy Technology Innovation Plan (2016–2030) [14]. Second, RE can help to disentangle the issue of energy poverty, mobilizing national actions to ensure universal access to modern energy services [15]. Bhide and Monroy (2011) analyzed the current status of energy development in India and suggested a sustainable method to eradicate energy poverty there through RE technologies [16]. Last, while fossil-fueled economic growth, through the release of greenhouse gases, is a major contributor to climate change, RE can be an efficient tool to cope with that change. The special report from the Intergovernmental Panel on Climate Change (IPCC) analyzes the challenges and opportunities of RE development in addressing climate change [17]. Sapkota et al. (2014) examined the role of RE technologies in climate change adaptation in rural areas of Nepal through the Long-range Energy Alternatives Planning model and estimated the potential emissions reduction by the use of different renewable technologies [18].

While the drivers of energy consumption have been well studied, there are relatively few studies on the determinants of RE development. The empirical work has been primarily focused on USA, Europe and the G7 countries generally. Sadorsky (2009) analyzed the relationships between CO_2 emissions, GDP, oil prices and RE consumption in G7 countries and concluded that GDP and CO_2 are the major drivers for RE consumption [19]. Marques et al. (2010) applied a panel data model to study the drivers of RE in European countries and concluded that energy security was a stimulator for RE use [20]. After examining the role of different energy sources in economic growth, Marques and Fuinhas (2011) pointed out the negative effect of RE in promoting economic growth [21]. Menz and Vachon (2006) developed a regression equation through the OLS method for the wind power sector in 30 American states and discussed the contribution of different policy regimes on wind power development [22]. However, there is a lack of empirical research on the determinants of RE in developing countries [23]. Although Europe and the USA have taken a leading role in the RE market, China and Brazil has become emerging contributors to the world's RE consumption. The internal mechanisms of RE development in developing countries and their comparison with that of developed economies are relevant to further understand the determinants that have promoted or hampered RE development in the world.

Based on the previous studies, this paper chooses various countries that are deploying RE and applies panel data techniques to explore the influencing factors governing RE development. Due to the differences in economic development levels and situations surrounding energy use, these 32 countries have been classified either as developing countries or developed countries for comparison purposes. Twenty-one countries facing energy security issues out of the original 32 have been selected as the sample to research the role of energy security concerns in RE development, and Grey relational analysis is utilized to explore the relationships between RE consumption and its impact factors. Thus, this paper will help to identify challenges and opportunities for RE use and shed some light on future world RE policies. Most importantly, given the increasingly important role of emerging economies in the RE market, this analysis fills in gaps in the RE research on developing nations.

The remainder of this paper is structured as follows. In Section Methodologies, the theoretical framework and data resources supporting the Panel Data model and Grey relational analysis used are explained, while the results and discussion are presented in Section Results and discussion. Finally, Section Conclusion and policy implications presents policy implications and the concluding remarks. This last part also highlights the contributions that the present study seeks to make as well as the future direction of this research.

Methodologies

Conceptual framework for the determinant analysis of renewable energy development

Fig. 1 depicts the framework for the impact factor analysis of renewable energy development. The 32 chosen countries are divided into developing and developed countries based on

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