Renewable and Sustainable Energy Reviews 25 (2013) 381–392

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Renewable energy, non-renewable energy and economic growth in Brazil

Hsiao-Tien Pao [a,*], Hsin-Chia Fu [b]

[a] Department of Management Science, National Chiao Tung University, Taiwan
[b] College of Engineering, Huaqiao University, Quanzhou, China

A R T I C L E I N F O

Article history:
Received 21 June 2011
Received in revised form
25 April 2013
Accepted 7 May 2013
Available online 31 May 2013

Keywords:
Renewable sources
Non-hydroelectric renewable energy
Non-renewable energy
Granger causality
Brazil

A B S T R A C T

This study employs Brazil's yearly statistics from 1980 to 2010 to explore the causal relationships between the real GDP and four types of energy consumption: non-hydroelectric renewable energy consumption (NHREC), total renewable energy consumption (TREC), non-renewable energy consumption (NREC), and the total primary energy consumption (TEC). The cointegration test reveals a long-run equilibrium among Brazil's real GDP, labour, capital, and each of the four types of consumption. The development of the Brazilian economy has close ties with capital formation and labour force. The influence of NHREC/TREC on real output is positive and significant, while the impacts by NREC/TEC are insignificant. The results from the vector error correction models reveal a unidirectional causality from NHREC to economic growth, a bidirectional causality between economic growth and TREC, and a unidirectional causality from economic growth to NREC or TEC without feedback in the long-run. These findings suggest that Brazil is an energy-independent economy and that economic growth is crucial in providing the necessary resources for sustainable development. Expanding renewable energy would not only enhance Brazil's economic growth and curb the deterioration of the environment but also create an opportunity for a leadership role in the international system and improve Brazil's competition with more developed countries.

Contents

1. Introduction

According to the 2012 International Energy Outlook by the Energy Information Administration, the worldwide total renewable energy consumption has been increasing. The growth rate

* Corresponding author. Tel./fax: +886 3 5131578.
E-mail addresses: htpao@mail.nctu.edu.tw, htpao123@gmail.com (H.-T. Pao).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.05.004

was 4.40% in the first decade of the 21st century, including hydropower and non-hydropower growth rates of 3.18% and 12.89%, respectively. During 2011, renewable energy sources supplied an estimated 16.7% of global final energy consumption, and global new investment in renewables increased by 17% due to cost reductions and technological innovations in renewable energy [1]. New renewable (including small hydro, modern biomass, wind, solar, geothermal, and biofuels) technologies are very suitable for local power generation in rural and remote areas, where the transportation costs of crude oil or natural gas are often prohibitively high, as are those of power transmission. Most developing countries have started to identify and implement programs and policies to improve the structure of the ongoing rural renewable energy markets. Thus, rural energy markets increased more and are more attractive to potential investors. The International Energy Agency estimates that annual investment in the rural energy sector needs to increase more than fivefold to achieve the wide use of new renewables energy by 2030. All of these factors point to a brighter future for renewable energy.

1.1. Brief literature review

Empirical studies of the relationship between energy consumption and economic growth have been conducted intensively for different economic regions or countries over the past two decades (e.g., [2–14]). Most of the literature has focused on the relationship between electricity consumption and income, or the nexus of energy-income-emissions. These nexus suggest that economic growth is closely related to energy consumption because economic or industrial activities require energy consumption. On the other hand, more efficient energy development or use requires the financial support of a strong economy. Therefore, the directions of causality between different types of energy consumption and economic growth merit examination.

In the early 21st century, the relationship between renewable energy consumption and economic growth has attracted significant research interest. The commonly employed methodologies include the forecast error variance decomposition analysis model, the bivariate error correction model, the Toda–Yamamoto procedure within a framework of production function, and the multivariate error correction model within a framework of production function. Using a generalised forecast error variance decomposition analysis, Sari and Soytas [15] found that different energy consumption items have different effects on real output and energy consumption appears to be almost as important as employment with respect to economic development in Turkey, where lignite, waste, oil and hydraulic power comprise the top four among all alternative sources of energy. For the US, Ewing et al. [16] found out that unexpected shocks to coal, natural gas and fossil fuel energy sources have the greatest impacts on the variation of real output, while renewable energy consumption of several types also exhibit considerable explanatory power. Nevertheless, consumption of none of the energy sources above can explain the forecast error variance of industrial output better than employment. Using a bivariate panel error correction model, Sadorsky [17] presented evidence of bidirectional causality between non-hydroelectric renewable energy consumption and economic growth in emerging economies. Using the Toda–Yamamoto procedure within the framework of a production model for analysing data of the US, Payne [18] found no evidence of a causal relationship between total renewable or non-renewable energy consumption and real output, although Payne [19] and Yildirim et al. [20] found unidirectional causality from biomass energy consumption to real output. Using a multivariate panel error correction model within a framework of production model, Apergis and Payne [21] found evidence of bidirectional short- and long-run causality between non-hydroelectric renewable energy consumption and economic growth for OECD countries. Apergis and Payne [22, 23] discovered evidence of bidirectional short- and long-run causality between total renewable energy consumption and economic growth for Eurasia and Central America countries, respectively. However, no publications explore the causal relationships between renewable/non-renewable energy consumption and economic growth in sustainable countries such as Brazil. In the past two decades, Brazil has achieved a development model that combines social inclusion with sustained economic growth and the balanced use of natural resources [24]. Moreover, over the next 10 years, the projected annual GDP growth rate will reach approximately 5.1% [25]. Therefore, this study attempts to analyse the above relationships in Brazil.

1.2. Renewable energy in Brazil

Brazil currently hosts one of the cleanest energy matrices of the industrialised world, with 44.1% of energy coming from renewable sources, and approximately 89% of all electricity supply coming from renewable energy sources, with 81.7% of all electricity supply coming from hydropower. However, non-hydro renewable electricity has a very high compound annual growth rate of 10.01%. Brazil's renewable power capacity is the world's third largest after China and the United States. Its hydropower capacity is the world's second largest after China, and continues to increase rapidly [1].

Two leading and far-reaching programs, The Alternative Energy Sources Incentive Program (PROINF) and The Ten Year Energy Expansion Plan (PDE), have been proposed by the Brazilian government to enhance Brazil's manufacturing sector and to create a scenario of sustainable energy supply in technical, environmental, and economic aspects. The PROINF, developed in 2002, attempts to increase the production of electric energy using renewable sources such as biomass, small hydro, and wind plants. PROINFA aims to increase the share of new renewables (biomass, wind, and small hydro) to 10% of the electricity consumption of Brazil in 2020 [25]. The Ten Year Energy Expansion Plan aims to ensure the balanced expansion of energy supply and to assist in creating a solid foundation for economic growth in the country [26]. In addition, there are a large number of renewable energy projects in progress, such as constructing many new wind farms, launching the 'My Home, My Life' programme using solar energy for all new houses, constructing small hydroelectric plants to meet the energy demands of small urban centres and rural areas, and executing waste management projects to help poor families become suppliers of biomass power plants by using waste from acai to enhance the manufacturing sector and to help the country's economy. Furthermore, to cope with the Brazilian renewable energy policies and plans, many governmental or private new renewable energy manufacturers, e.g., Soletrol Inc. for solar energy, Vestas and Gamesa Inc. for wind turbine, Sade Vegesa Inc. for small hydro turbine, and the Brazilian Association of Industry Biomass and Renewable Energy Council, have been established to meet the demands of the new renewable energy trend.

For hydropower in Brazil, construction of two huge hydroelectric dams, Santo Antonio and Jirau, began in 2008 on the Madeira in Brazil. While respecting the environment, the planning of new dams can provide approximately 11% of the country's electricity. These projects create employment opportunities and promote substantial investments of the consortium into dam construction. Moreover, Brazil has a large number of small hydroelectric plants to meet the energy demands of small urban centres and rural areas. This heavy reliance on hydroelectric power illustrates the risk inherent in unreliable water sources. In the early 2000s, a drought in Brazil prompted severe energy shortages and hurt the country's economy which highlighted the urgent need to diversify its energy portfolio. Recently, the main components