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ScienceDirect
Energy Procedia 61 (2014) 1902 – 1906
Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Modelling of renewable energy economy in Australia

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Abstract

The Australian economy is dependent on energy use now and in the future because Australia is endowed with abundant, high quality and diverse energy resources, including both renewable and non-renewable resources. The major energy utilization sectors are electricity generation, transport sector and manufacturing which accounts in combination for more than 75% of Australia's total energy consumption. In this article, the time-series energy model for economic growth is reviewed and discussed first, and then an energy economic model is proposed in which decomposing the energy consumption in renewable and non-renewable energy and focuses on resilient strategic investment decisions on the electricity generation and transport sector. The proposed economic model will take a significant role in the long-run reduction of CO_2 and economic growth in Australia.

Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: Energy economy; Renewable energy; Energy consumption; Energy modelling; Energy efficiency.

1. Introduction

Australia is the world's ninth largest energy production, seventeenth largest consumer of non-renewable energy resources and ranks eighteenth on energy consumption per person bases. Australia's energy consumption is primarily composed of non-renewable energy resources (coal, oil, gas and related products), which represent 96% of total energy consumption [1]. Renewables, the majority of which is bioenergy (wood and wood waste, biomass and biogas), account for the remaining 4% consumption. Australia has 33% of the world's uranium resources, 10% of world black coal resources and almost 2% of world conventional gas resources [2]. It has only a small proportion of world crude oil resources. Australia is not only gifted with abundant, high quality and diverse non-renewable energy sources but also has large, widely distributed renewable energy sources like wind, solar, geothermal, hydroelectric, ocean energy and bioenergy resources. Australia's renewable energy resources are largely undeveloped [3, 4]. Modelling by the Australian Energy Market Operator (AEMO) investigated two future scenarios featuring an electricity grid fuelled entirely by renewable resources in 2030 and 2050 [5]. So, modelling of

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Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.238

renewable energy economy is timely for Australia. The time-series energy model available in the literature under the energy consumption-CO_2 emission-economic are summarised and listed in Table 1.

Table 1. Summary of the time-series literature on energy model for economic growth.

Reference	Methods	Findings	Period	Data	Country	RE used?
[6]	Sims	Increased GNP leads to increased energy consumption.	1947-1974	-	USA	No
[7]	Sims	No casual relation bet^n energy cons. & employment.	1973-1984	Monthly	USA	No
[8]	Granger, Sims	Increase employment, increased energy consumption.	1974-1988	Monthly	USA	No
[9]	Granger, Sims	GNP → E, E → GNP No causal relation.	1950-1982	-	Over 6 countries	No
[10, 11]	Trivariate model	Unidirectional causality GDP growth leading to increased energy consumption.	1966-1999	Monthly	Australia	Yes
[12]	Bivariate, Johansen-Jus.	Causality from real GDP to per capital energy consumption.	1960-2000	Annually	Over 100 countries	Yes
[13, 14]	Granger	Long-run causality from electricity consumption to output in Australia.	1960-2002	-	Over 30 countries	Yes
[15]	Distance function approach	Technological change was a important factor counteracting the energy-use and emissions increasing effects of economic growth.	1971–2007	-	Over 85 countries	Yes
[16]	Johansen-Jus, Toda-Yam.	Incorporated capital and labour in addition to energy consumption and real GDP.	1961-2009	-	Australia	Yes
[17]	ARDL	Alternative sources of energy helpful to meet sustained rate of economic growth.	1971–2011	Annually	China	Yes
[18]	GMM	Three bidirectional casual relation between energy consumption & economic growth.	1990-2011	Annual	14 MENA countries	Yes

Several studies from a wide range of countries including Australia, listed in Table 1 deals with the nexus between energy consumption, economic growth, CO_2 emission and casualty among them and with real GDP. To the best of our knowledge, none of the previous studies has been conducted on the interrelationship between CO_2, energy and GDP by decomposing the energy consumption in renewable and non-renewable energy. The objective of this study is to use a production function approach to explain the interrelationship between renewable and non-renewable energy consumption, CO_2 emissions, and economic growth in Australia.

2. Renewable energy model

The extended Cobb-Douglas production framework helps to identify the causality direction between variables [18]. These variables are in fact endogenous. A model has been proposed that consist with the broader literature on the determinants of economic growth cited above, takes the form of, $Y = f(E, C, K, L)$ where, Y is real GDP; E, C, K, and L denote energy consumption (renewable or non-renewable), CO_2 emissions, capital and labor respectively. The logarithmic transformation of the equation can be given by:

$$ln(Y_t) = \alpha_0 + \alpha_1 ln(E_t) + \alpha_2 ln(C_t) + \alpha_3 ln(K_t) + \alpha_4 ln(L_t) + \pi_t \quad (1)$$

Where $\alpha_0 = ln(A_0)$; the subscript t=1, ….., T denotes the time period. The production function in Eq. (1) is used to derive the empirical models to simultaneously examine the interactions between energy consumption (renewable or non-renewable), CO_2 emissions, and economic growth in Australia. Derived equations for the proposed model can be given as follows-

$$ln(Y_t) = \alpha_0 + \alpha_1 ln(RE_t \text{ or } NRE_t) + \alpha_2 ln(CO_{2\,t}) + \alpha_3 ln(K_t) + \alpha_4 ln(L_t) + \pi_t \quad (2)$$

$$ln(NRE_t) = \zeta_0 + \zeta_1 ln(Y_t) + \zeta_2 ln(CO_{2t}) + \zeta_3 ln(K_t) + \zeta_4 ln(L_t) + \varepsilon_t \quad (3)$$

$$ln(RE_t) = \psi_0 + \psi_1 ln(Y_t) + \psi_2 ln(CO_{2t}) + \psi_3 ln(CRE_t) + \psi_4 ln(CE_t) + \psi_5 ln(OC_t) + \psi_6 ln(OP_t) + \varepsilon_t \quad (4)$$

$$ln(CO_{2t}) = \varphi_0 + \varphi_1 ln(Y_t) + \varphi_2 ln(RE_t \text{ or } NRE_t) + \varphi_3 ln(URB_t) + \varphi_5 ln(TOP_t) + \lambda_t \quad (5)$$

The annual data used in this study cover the period from 1990 to 2011 for Australia. The variables in this study include real gross domestic product (GDP), energy consumption (RE and NRE), K, L, CO_2 emissions, carbon recycling renewable energy (CRE), clear energy (CE), real oil price (OP), oil consumption (OC), urbanization (URB), and trade openness (TOP). CO_2 emission, OC and OP data are taken from the British Petroleum Statistical Review of World Energy. Real GDP, K, L, URB, and TOP are sourced from the World Bank's World Development Indicators. CRE, CE, RE and NRE are obtained from the Bureau of Resources and Energy Economics (BREE), Australia.

3. Simulation results and discussions

The above simultaneous equations are estimated by the generalized method of moments (GMM) to report the results and to validate the interrelation between energy-CO_2 emission-GDP using STATA11 software. The interaction between energy variables (Renewable or Non-renewable), CO_2 emission and economic growth proposed in this study is presented in Figure 1. While the parameter estimates remained similar in magnitude and sign, the GMM estimation results are generally found to be statistically more robust. For estimating the three-way linkages between CO_2 emissions–renewable and non-renewable energy–economic growth, K, L, OP, OC, CRE, CE, URB, and TOP are used as instrumental variables. The study found that all the series are stationary in level. Based on the diagnostic tests, the estimated coefficients of Equations (2-5) are given in Table 2.

Table 2. Estimation results for the simultaneous equation model.

Dependent variables	Real GDP (Y)	Non-renewable energy	Renewable energy	CO_2 emissions
Real GDP	-	0.897 (0.000) *	0.244 (0.021) **	0.626 (0.059) ***
Renewable energy	0.021 (0.597)	-	-	-0.147 (0.002) **
Non-renewable energy	0.557 (0.000)*	-	-	0.103 (0.624)
CO_2 emissions	-0.401 (0.000) *	-0.030 (0.851)	0.356 (0.000) *	-
Capital stock	0.155 (0.005) **	-0.119 (0.093) ***	-	-
Labor force	0.350 (0.068) ***	- 0.082 (0.731)	-	-
Carbon recycling RE	-	-	0.091 (0.178)	-
Clear energy	-	-	0.666 (0.000) *	-
Oil consumption	-	-	0.051 (0.896)	-
Oil price	-	-	0.144 (0.004) **	-
Urbanization	-	-	-	0.127 (0.113)
Trade openness	-	-	-	-0.251 (0.000) *
Constant	1.899 (0.011) **	0.938 (0.000) *	0.447 (0.087) ***	0.743 (0.003) **
Hansen j-test (p-value)	12.214 (0.129)	14.661 (0.119)	9.845 (0.234)	16.118 (0.104)
DWH test (p-value)	4.119 (0.041)	4.55 (0.030)	6.11 (0.012)	6.57 (0.005)

Notes: Values in parenthesis are the estimated p-values. Hansen J-test refers to the over-identification test for the restrictions in GMM estimation. DWH test is the Durbin–Wu–Hausman test for endogeneity. *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

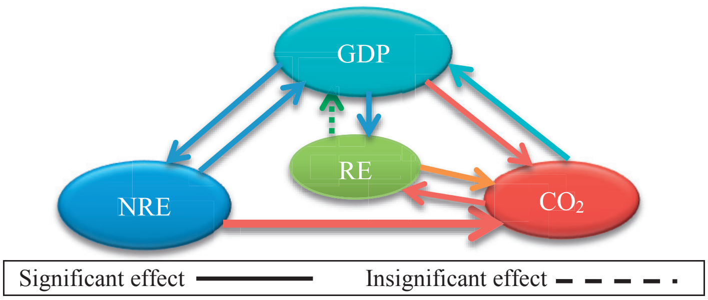

Fig. 1: Casual interactions between energy variables, CO_2 emission and economic growth.

The Durbin–Wu–Hausman (DWH) test was used to test for endogeneity. The null hypothesis of the DWH endogeneity test is that an ordinary least squares (OLS) estimator of the same equation would yield consistent estimates. A rejection of the null indicates that endogenous regressors' effects on the estimates are meaningful, and instrumental variables techniques are required. Then, the validity of the instruments is tested by using Hansen test which cannot reject the null hypothesis of overidentifying restrictions.

4. Conclusion

The study investigated the bi-directional nexus between energy type variables (renewable or non-renewable), CO_2 emissions, and economic growth by using Cobb-Douglas equation. If the emitted carbon can be captured and recycled as energy, it will reduce CO_2 emission, low emitted CO_2 and carbon tax as well as GDP growth. With the renewable energy model guided electricity generation with low emission, consumed CO_2 and recycled carbon as a bio-fuel which can be used in transport sector as a biofuel. The proposed economic model will take a significant role in the long-run reduction of carbon tax as well as economic growth in Australia.

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