Energy Policy 36 (2008) 3045–3052

Contents lists available at ScienceDirect

Energy Policy

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

Renewable energy: An efficient mechanism to improve GDP

Taichen Chien [a,*], Jin-Li Hu [b]

[a] Chung-Hua Institute for Economic Research, Taipei, Taiwan
[b] Institute of Business and Management, National Chiao Tung University, Taiwan

ARTICLE INFO

Article history:
Received 12 February 2008
Accepted 16 April 2008
Available online 2 June 2008

Keywords:
Structural Equation Modeling (SEM)
Technical efficiency
Renewable energy

ABSTRACT

This article analyzes the effects of renewable energy on GDP for 116 economies in 2003 through Structural Equation Modeling (SEM) approach. In order to decipher the mechanism of how the use of renewables improves macroeconomic efficiency, we decompose GDP by the "expenditure approach". Although previous theory predicts positive effects of renewables on capital formation and trade balance, the SEM results show that renewables have a significant positive influence on capital formation only. The result that renewables do not have a significant impact on trade balance implies that renewables do not have an import substitution effect. Thus, we confirm the positive relationship between renewable energy and GDP through the path of increasing capital formation, but not for the path of increasing trade balance.

1. Introduction

Climate change has become one of the most important global environmental challenges. As the Stern Review (Stern, 2006) points out, it would be too costly to tackle the challenge of climate change if the world procrastinate in taking actions. The efforts made by the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol are considered inadequate to address the climate change challenge at this moment (Sathaye et al., 2006), yet there are many effective ways to address the climate change issue: adopting environmental sustainable technologies, improving energy efficiency, forest conservation, reforestation, water conservation, or saving energy (Masui et al., 2006). The promotion of renewable energy is another well-accepted solution to the mitigation of CO_2 emission. Furthermore, Chien and Hu (2007) show that increasing the use of renewable energy improves the macroeconomic efficiency of economies.

Many recent publications advocate the use of renewable energy. Krewitt et al. (2007) suggest that renewables could provide as much as half of the world's energy needs by 2050 in a target-oriented scenario to prevent any dangerous anthropogenic interference with the climate system. Increasing renewables to meet energy demand is one of the necessary approaches for the power industry in view of a threatening climate change. Abulfotuh (2007) suggests that one possible solution to the environmental risks brought by the escalating demand for energy is to consider immediate change in the composition of an energy resource portfolio. It is expected that renewables have great potential to solve a major part of global energy sustainability. Increasing the use of renewables in power industries has already been seriously reviewed in some countries. For example, China's electricity sector is expected to accounts for nearly half of its greenhouse gas emissions by 2020 under a business as usual scenario (Steenhof et al., 2007). Non-fossil energy sources, including wind, solar, and thermal power, will make up a bigger share of China's energy resources under a new bill passed in 2005 encouraging the use of renewables (Hu, 2005).

Stimuli to further exploit renewables came in the 1990s from international environmental treaties such as the UN Framework on Climate Change in Rio (1992) and the Kyoto Protocol (1997). In addition to China, there are many government initiatives to increase the use of renewables in the energy portfolio. On 23 January 2008 the European Commission put forth an integrated proposal for Climate Action, which includes a directive that sets an overall binding target for the European Union of 20% renewable energy and a 10% minimum target for the share of biofuels in overall transport petrol and diesel consumption by 2020 (EU, 2008). The present EU share of renewables is 6.5%. The use of wood fuel for energy production in the UK is set to increase in the near future as part of a government commitment to increase renewable sources to 10% by 2010 (Pitman, 2006). The Swedish government adopts a national planning goal of a yearly wind power generation of 10 TWh by 2015 (Soderholm et al., 2007). Further action and commitment on issues such as south–south cooperation and wider NGO participation on renewable energy was stressed at the Beijing International Renewable Energy

* Corresponding author. Tel.: +886 2 25567661.
E-mail address: tcchien@hotmail.com (T. Chien).

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2008.04.012

Conference held in 7–8 November 2005 (Lin et al., 2007). Since energy consumption is inevitable for economic growth, it is important to adjust energy consumption so as to maximize efficiency.

Various new policies to achieve the national target of a renewables ratio in the energy portfolio are adopted in different economies. Lund (2007a) groups policies on renewable energy and efficient energy use into subsidy type and catalyzes measures based on the use of the public financial resources. Lund (2007b) further indicates that more than 99.5% of the materials needed in the new renewable energy source systems are basic construction materials and metals. More than 65 countries now have national goals for accelerating the use of renewable energy and are enacting far-reaching policies to meet those goals. Policies to promote renewable energy have mushroomed in recent years. At least 60 countries have some type of policy to promote renewable power generation. The most common policy is the feed-in law. By 2007, at least 37 countries and 9 states/provinces had adopted feed-in policies, more than half of which have been enacted since 2002 (REN21 and Worldwatch, 2008). Green et al. (2007) suggest encouragement to the development of energy technology to deploy new energy sources.

Renewables are currently accepted as one of the key solutions to climate change and escalating energy demand. Many economies are adopting policies to promote the use of renewables. However, the mechanism of how renewables improve GDP is still unknown.

Domac et al. (2005) propose the hypothetic theory of the mechanism to be studied. We will discuss the theory in details in Section 2. To our knowledge (by the search results dated 15 April 2008), there are no empirical studies on the transmission mechanism between renewables and GDP. There are many factors affecting GDP simultaneously. By the expenditure approach, we narrow down the relevant factors to the four factors mostly directly linked to GDP. Theory predicts that there are mediating variables in the potential paths, and so we use Structural Equation Modeling (SEM) to test all the paths at the same time. The path of how the use of renewables improves GDP can be identified by SEM, which controls all the relevant factors to GDP.

2. Macroeconomic theory of the impact of renewables on GDP

Much attention has been given recently to the notion of 'sustainable energy consumption'. This paper broadens the perspective of environmental economics to include an analysis of renewable usage directly contributing to the important elements of economies or regional development. As mentioned previously, Domac et al. (2005) suggest that renewable energy increases the macroeconomic efficiency by the following process: (1) The business expansion and new employment brought by renewable energy industries result in economic growth. (2) The import substitution of energy has direct and indirect effects on increasing an economy's GDP and trade balance. This article includes tests whether the influences of renewables on GDP are valid.

For energy-importing states, local renewable energy use translates into important local economic and employment multipliers, and we will test the transmission process by path analysis. This article presents a first macroeconomic analysis of economic growth brought by renewable energy usage.

It is well known that GDP is estimated by the commonly used 'expenditure approach' or 'value-added approach'. The expenditure approach estimates GDP by the following equation:

$$GDP = C + I + G + X - M, \tag{1}$$

where C is the final household consumption expenditure; we will use consumption for household consumption through the article; I the gross domestic capital formation; G the general government final consumption expenditure; X the export; and M the import.

The deduction of imports from exports (X–M) is the trade balance. The value-added approach estimates GDP by the following equation:

$$GDP = w + r + i + \pi + \delta, \tag{2}$$

where w is the wage; r the rent; i the interest; π the revenue; and δ the depreciation.

The article evaluates the impact of renewables on GDP by the expenditure approach, because the import substitution effect of renewables seems to have a direct impact on trade balance. The difference between GDP and GNP is that GDP only includes economic output within the national boundary, while GNP includes the output of overseas citizens. GDP is used for the following analysis.

3. The path analysis of the impacts of renewables on GDP

The influences of renewables on GDP are illustrated by Fig. 1. Fig. 1 represents the original constitution of GDP by household consumption, government consumption, capital formation, and trade balance. In Fig. 2, the diagram shows that the use of

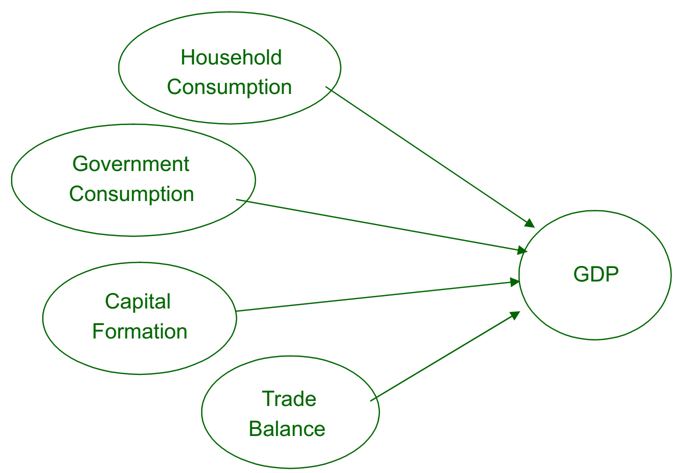

Fig. 1. Conceptual framework of GDP constitution.

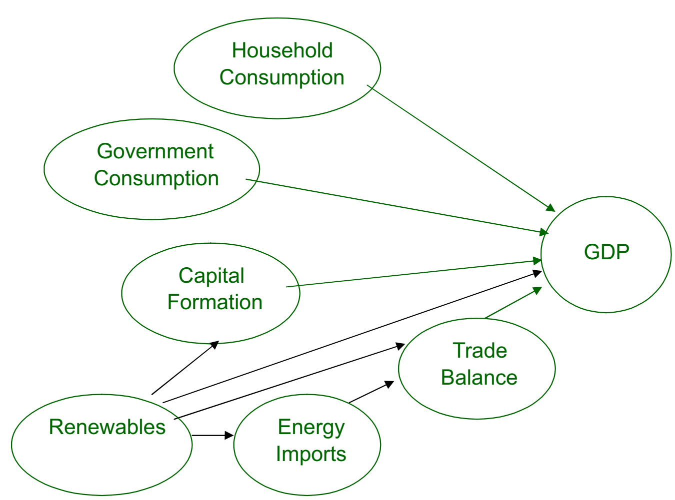

Fig. 2. Conceptual framework of the influences of renewables on GDP.

renewables influences GDP through two paths: (1) the emergence of renewable energy industries brings about business expansion, which results in increased capital formation; and (2) the import substitution of traditional energy by locally produced renewables has direct and indirect effects on increasing an economy's trade balance. The increases of capital formation and trade balance would lead to the increase of GDP.

A very important question for policy makers is to choose from different policy instruments. To identify the most effective instrument, the mechanism for renewables to create economic impacts should be first identified.

Path analysis of SEM is used in this article to test the conceptual model specifying causal relationships between renewables and the other relevant variables. Path analysis can be used to determine whether the theoretical model accounts for the actual relationships in the observed data. The output of path analysis provides significance tests for specific causal paths. The significant links point out where the policies should be executed. Our sample profile contains 116 economies. The 2003 economic indicators of the 116 economies are retrieved from the World Bank Indicators online database (World Bank, 2007). Economies with missing data for any of the relevant variable required by this study are omitted from the sample profile. Table 10 shows the country names of the 116 economies in the sample profile. Chien and Hu (2007) have analyzed the energy profiles of developed (OECD) and developing countries (non-OECD). The results show that technical efficiency is higher in developed economies than in developing economies. The share of renewable energy in total energy supply is higher in developing economies than in developed economies due to the widespread biomass use in the residential sector of developing economies. The share of geothermal, solar, tide and wind fuels in renewable energy is higher in developed economies than in developing economies.

The path coefficients are estimated using the maximum likelihood estimation in the SEM. Since our data such as GDP and the usage of renewables have great differences in standard deviations, the estimation by the SAS package may encounter difficulty in estimating the model. For example, the output may show that not all parameters are identified or near-zero standard errors for parameters estimate t tests. To avoid the problems of inputting raw data, we rescale the six variables so that they are all on approximately the same scale. Aside from the analysis of rescaled raw data, we also conduct an analysis performed on the covariance matrix to produce more valid standard errors for the parameters' estimates.

As we know, $G = GDP - C - I - (X - M)$, and so the variable G is eliminated from our model estimation to avoid multicollinearity. Our theoretical model is composed of the following equations:

$$GDP = a_1 I + a_2 TB + a_3 C + a_4 EI + a_5 RN + E_1, \quad (3)$$

$$I = b_1 RN + b_2 C + E_2, \quad (4)$$

$$TB = c_1 EI + c_2 RN + E_3, \quad (5)$$

$$EI = d_1 RN + E_4, \quad (6)$$

$$C = f_1 EI + f_2 TB + E_5, \quad (7)$$

where I is the capital formation; TB the trade balance; C the consumption; EI the energy imports; RN the renewables; $E1, \ldots, E5$ the residuals.

In Eq. (3), GDP is influenced by capital formation, trade balance, and consumption. From Chien and Hu (2007), it is possible that energy inputs may increase GDP, and so energy imports and renewables are included in Eq. (3), too. In Eq. (4), capital formation is influenced by renewables since theory predicts that increasing the use of renewables will result in business expansion and thus capital could be accumulated. From the economic point of view, the following equations show that if income (Y) is not used in consumption, then it will be used in savings, and savings could be translated into investment (I: capital formation).

$$AE = C + I, \quad (8)$$

$$AE = Y, \quad (9)$$

$$I = I(Y). \quad (10)$$

In macroeconomic theory, when the autonomous expenditure increases from C_0 to C_1, the aggregate demand (AE) increases from AE_0 to AE_1. The equilibrium output (Y) increases from Y_0 to Y_1as a result. If I is a function of Y, I increases as C increases.

In Eq. (5), energy imports influence trade balance, because trade balance equals exports minus imports. The theory proposed by Domac et al. (2005) suggest that the use of renewables results in import substitution by domestic-produced renewable energy, and thus trade balance will increase by the use of renewables. Furthermore, if renewables could cause import substitution, then the imports of energy should be reduced by the increase of renewables (Eq. (6)). In Eq. (7), according to international trade theories, the domestic price of goods increased as the same kinds of goods are exported while the domestic price of goods decreases as same kind of goods are imported. Thus, trade balance (exports–imports) influences consumption through changes in domestic prices. The imports of energy influence domestic energy prices and the consumption of energy. As a result, consumption of energy-related products is also affected.

To sum up, to confirm the relationship between the increase of renewables and the increase of GDP, we need to test whether renewables could increase capital formation or trade balance. The other paths have relevant economic relationships predicted by general economic theories. The initial SEM model is displayed in Fig. 3.

The renewable energy indicators by an economy are collected from Renewables Information (International Energy Agency (IEA), 2005) published by IEA since 2002. Data on household consumption, capital formation, trade balance, energy imports, and GDP are collected from the World Development Indicators database.

Table 1 shows the simple descriptive statistics for the six variables of GDP, capital formation, trade balance, energy imports, renewables, and household consumption, including the means, standard deviations, and correlations. The path coefficients are reported in Table 1.

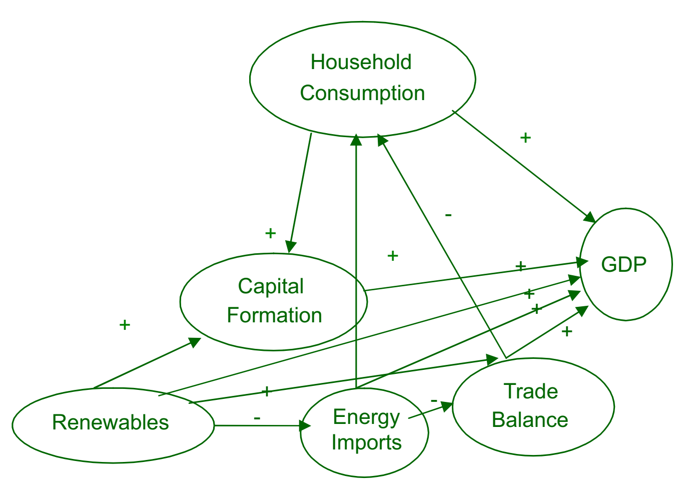

Fig. 3. The initial SEM model.

Table 1
Summary of descriptive statistics for the SEM model

Measure	Means	SD	GDP	Capital formation	Trade balance	Energy imports	Renewables	Consumption
GDP[a]	310.975	113.000	1.000	0.985	−0.744	0.685	0.343	0.995
Capital formation[b]	65.358	220.006	0.985	1.000	−0.671	0.686	0.426	0.966
Trade balance[c]	0.236	493.798	−0.744	−0.671	1.000	−0.529	−0.174	−0.800
Energy imports[d]	−0.243	107.854	0.685	0.686	−0.529	1.000	0.191	0.680
Renewables[e]	113.319	327.367	0.343	0.426	−0.174	0.191	1.000	0.309
Consumption[f]	190.547	775.74	0.995	0.966	−0.800	0.680	0.309	1.000

[a] GDP = 2003 GDP/10^9 (current US$).
[b] Capital formation = 2003 Capital formation/10^{11}(current US$).
[c] Trade balance = 2003 Trade balance/10^{10} (current US$).
[d] Energy imports = 2003 Energy imports/10^9 (kg of oil equivalent).
[e] Renewables = 2003 Renewables × 10 (Mtoe).
[f] Consumption = 2003 Consumption/10^9 (current US$).

Table 2
Estimated path coefficients for the initial SEM model

Endogenous variables	GDP	Capital formation	Trade balance	Energy imports	Consumption
Capital formation	1.284*** (35.192)				
Trade balance	0.167*** (27.871)				−0.960*** (−10.724)
Energy imports	0.003 (0.148)		−2.355*** (−6.406)		2.564*** (6.255)
Renewables	−0.005 (−0.778)	0.095*** (6.739)	−0.114 (−0.944)	0.063** (2.087)	
Consumption	1.194*** (113.6)	0.262*** (44.089)			

Note: Sample size = 116.
**Represents significance at the 5% level.
***Represents significance at the 1% level; and numbers in the parentheses are *t* statistics.

The maximal likelihood estimation results show that the goodness-of-fit indices are greater than 0.839. Bentler and Bonett's normed fit index (NFI) is 0.942, indicating an acceptable fit of the model from the data. Bentler and Bonett's non-normed fit index (NNFI) is 0.718, which is less desirable. Bentler's comparative fit index (CFI) is 0.944, indicating a relatively good fit. However, the χ^2-test appearing above has a large value of 90.973 with 3 degrees of freedom, which indicates that the model does not provide a good fitting of the real data. Although the χ^2-test is a useful index, it is generally accepted that it should be interpreted with caution and supplemented with other goodness of fit indices. Bollen (1989) suggested that the safest recommendation is to always report the χ^2 estimate along with several of the other fit indices (e.g., residuals and NFI). This is because the χ^2-test can be influenced by factors in addition to the validity of the theoretical model such as departures from multivariate normality, sample size, and complexity of the model.

Table 2 shows that all the paths predicted in our model are significant at the 0.05 level except three paths. The three paths failing to reach the 0.05 significance level are the path between energy imports and GDP, the path between renewables and GDP, and the path between renewables and trade balance. It is highly possible that since GDP equals the sum of capital formation, trade balance, consumption, and government expenditure, the variances of the first three variables can already capture almost all of GDP variations. This may explain why the two paths (path between energy imports and GDP, path between renewables and GDP) are not significant.

Theory predicts positive effects of renewables on capital formation and trade balance. The results show that renewables have a significant positive influence on capital formation, but its influence on trade balance is not significant. All the signs of the significant paths are as predicted except for the path between energy imports and renewables. GDP is positively influenced by capital formation, trade balance, and consumption. Capital formation is positively influenced by renewables. Energy imports influence trade balance negatively. Trade balance influences consumption negatively. The imports of energy influence consumption positively.

Contrary to the theory, the relationship between renewables and energy imports is significantly positive. A possible explanation is when an economy is in great demand of energy, it not only exploits more renewables, but also imports more energy, and so the two sources of energy tend to increase together. Combining the results that renewables do not have a significant impact on trade balance and that renewables and energy imports move together, the results show that renewables do not have an import substitution effect and are unable to influence trade balance.

To do a more careful ceteris paribus analysis, we control all of the independent variables other than renewables, so that the effect of renewables on energy imports can be isolated. By holding all the other relevant factors constant, we are able to focus on the unique effect of renewables in the complex causal situation by the following equation:

$$EI = g_1 I + g_2 C + g_3 RN. \quad (11)$$

The results of this analysis (Table 11) show that renewables do not have significant effects on energy imports. Since the increase of renewables does not reduce energy imports, we can conclude that renewables do not have import substitution effect.

To improve the fit of the present model, step-by-step modifications are made. Table 3 shows the rank order of the 10 largest normalized residuals and there are no absolute values of entries in the normalized residual matrix exceeding 2.000. It is clear that no new path could be added into the present model. It is statistically more desirable to drop non-significant paths than to add new paths. The three non-significant path coefficient estimates will be reviewed and dropped one by one.

The modifications start by dropping the path with the smallest *t*-statistic, i.e., the path between energy imports and GDP. Fig. 4

displays the revised SEM model 1. The path coefficient estimates are shown in Table 4.

Table 4 shows that all the paths significant in the theoretical model are again significant at the 0.05 level. The two paths failing to reach the 0.05 significance level are, again, the path between renewables and GDP and that between renewables and trade balance.

The least significant path in revised SEM model 1 (the path between renewables and GDP) is dropped in revised SEM model 2. Fig. 5 displays the revised SEM model 2. The path coefficient estimates are shown in Table 5.

Table 5 shows all the paths significant in the revised SEM model 1 are again significant at the 0.05 level in the revised SEM model 2. The only path failing to reach the 0.05 significance level is the path between renewables and trade balance.

The only insignificant path in revised model 2 (the path between renewables and trade balance) is dropped in the final SEM model. Fig. 6 displays the final SEM model. The path coefficient estimates are shown in Table 6.

All the paths are significant in Table 6, and there are no further modifications that can be made. The mediating effect of capital formation is thus confirmed, i.e., capital formation is the variable that conveys the effect of increasing the use of renewables onto increasing GDP. Notice a single-headed arrow goes from renewables to capital formation, and that a separate single-headed arrow goes from capital formation to GDP. This indicates that renewables have only an indirect effect on GDP. Renewables influence GDP by first influencing capital formation. The goodness of fit indices for the initial SEM model, the revised SEM model 1, the revised SEM model 2, and the final SEM model are displayed in Table 7.

As shown in Table 7, NNFI is improving from the initial SEM model to the revised SEM model 1, from the revised SEM model 1 to the revised SEM model 2, and the final SEM model has the best results. Although the χ^2 values are not desirable, the χ^2 values are normally not essential (Hatcher, 1994).

We finally need to check the R^2 for each endogenous variable in the final SEM model (Table 8). The R^2 for each endogenous variable implies the percent variance explained in that variable in the model and they are as large as desirable. The R^2 of GDP, capital formation, and consumption are relatively high as desired (0.9997 for GDP, 0.951 for capital formation, and 0.745 for consumption). However, the R^2 of the trade balance and energy imports are relatively low (0.244 for trade balance and 0.037 for energy imports). These two R^2 numbers are obviously low due to the facts that there are other variables more significantly influencing the variables of trade balance than energy imports (for example, exchange rate), and that there are other variables more significantly influencing the variables of energy import than renewables (for example, the demand and supply of crude oil). Since the

Table 3
Rank order of the 10 largest normalized residuals for the initial SEM model

Row	Column	Residuals
Renewables	GDP	1.485
Consumption	Renewables	1.424
Renewables	Capital formation	1.297
Trade balance	Capital formation	0.787
Energy imports	Capital formation	0.295
Capital formation	Capital formation	0.275
Capital formation	GDP	0.240
Trade balance	GDP	0.194
Consumption	Capital formation	0.149
GDP	GDP	0.098

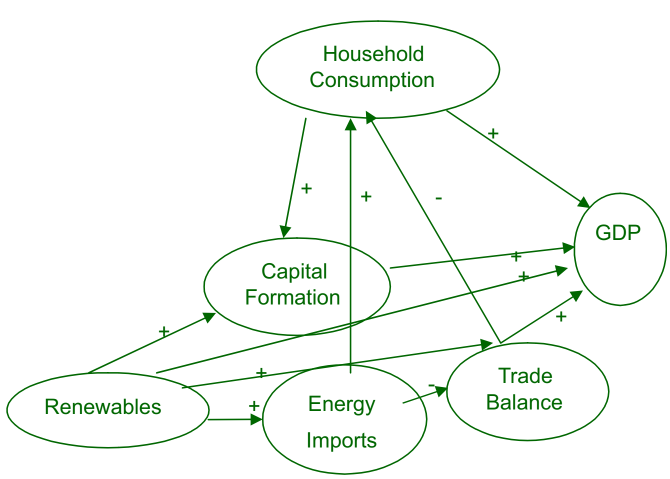

Fig. 4. Revised SEM model 1.

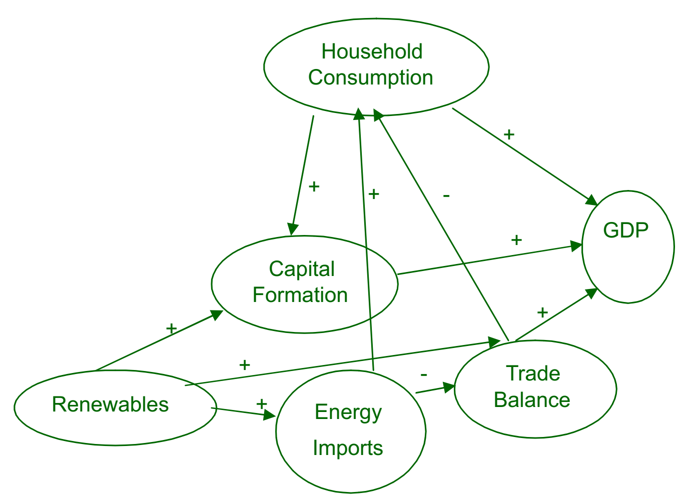

Fig. 5. Revised SEM model 2.

Table 4
Estimated path coefficients for revised SEM model 1

Endogenous variables	GDP	Capital formation	Trade balance	Energy imports	Consumption
Capital formation	1.286*** (35.239)				
Trade balance	0.167*** (27.871)				−0.960*** (−10.724)
Energy imports			−2.355*** (−6.406)		2.564*** (6.255)
Renewables	−0.005 (−0.808)	0.095*** (6.739)	−0.114 (−0.944)	0.063** (2.087)	
Consumption	1.194*** (116.1)	0.262*** (44.089)			

Note: Sample size = 116.
**Represents significance at the 5% level.
***Represents significance at the 1% level; and numbers in the parentheses are *t* statistics.

Table 5
Estimated path coefficients for revised SEM model 2

Endogenous variables	GDP	Capital formation	Trade balance	Energy imports	Consumption
Capital formation	1.264*** (40.792)				
Trade balance	0.169*** (28.169)				−0.960*** (−10.724)
Energy Imports			−2.355*** (−6.406)		2.564*** (6.255)
Renewables		0.095*** (6.739)	−0.114 (−0.944)	0.063** (2.087)	
Consumption	1.200*** (132.3)	0.262*** (44.089)			

Note: Sample size = 116.
**Represents significance at the 5% level.
***Represents significance at the 1% level; and numbers in the parentheses are *t* statistics.

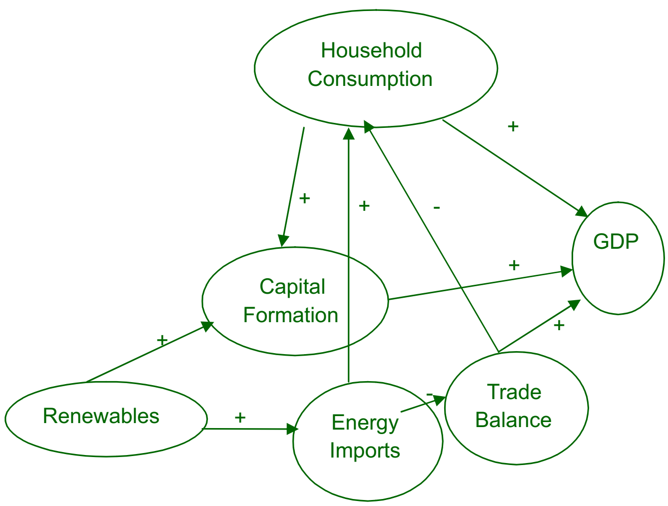

Fig. 6. Final SEM model.

factors influencing these two variables are not in the scope of this article, we will leave it like this and not include new variables in the model.

The 10 largest normalized residuals of the final SEM model are shown in Table 9. They are all below 2.000.

4. Concluding remarks and policy implications

Chien and Hu (2007) use the DEA method to estimate the technical efficiency (TE) for the 45 economies in the years 2001 and 2002. The results show that increasing the share of renewable energy among total energy supply will significantly improve TE. It is worth noting that increasing the input of traditional energy decreases technical efficiency. By substituting traditional energy with renewable energy, an economy's technical efficiency can be significantly improved.

In Chien and Hu (2007) article, the multivariate statistics show that the share of biomass (categorized under "combustible energy and waste" by IEA definition) in renewable energy is not significantly higher in developing economies than in developed economies. Although the traditional use of renewable energy such as biomass is inefficient, their studies show that the share of biomass in renewable energy has no significant effect in an economy's technical efficiency.

Many individual countries such as China have set up feasible renewables objectives for themselves. Governments can adopt various policy instruments to promote the use of renewables, including institutional measures such as sponsoring research on enhancing renewable utilization and legislative measures such as enforcing replacement of traditional fuels by renewables. Subsidies can also provide economic incentives for enterprises and households to use renewables. In February 2003, the British government released an Energy White Paper that concluded the UK could cut its CO_2 emissions by 60% from current levels by the year 2050, using known technologies (including hydrogen for transport and other renewable energy technologies after 2030), at a cost ranging from $\frac{1}{2}$% to 2% of GDP in 2050 (UK Department of Trade and Industry, 2003). As far as we know, there are not yet studies available on how energy policies promoting renewables affect GDP.

In order to understand the mechanism of how the use of renewables improves macroeconomic efficiency, we need to review the relationship between the increase of renewables and the increase of GDP, i.e., we need to test whether renewables could increase capital formation or trade balance. The results show that GDP is influenced positively by capital formation, trade balance, and consumption. Moreover, capital formation is influenced positively by renewables and consumption. Energy imports influence trade balance negatively. Trade balance influences consumption negatively. The imports of energy influence consumption positively.

The path between energy imports and GDP and the path between renewables and GDP are not significant. It is highly possible that since GDP equals the sum of capital formation, trade balance, consumption, and government expenditure, the variances of the first three variables can already capture almost all of GDP variations.

The theory predicts positive effects of renewables on capital formation and trade balance. The results show that renewables have a significant positive influence on capital formation, but their influence on trade balance is not significant. All the signs of the significant path are as theories predicted, except for the path between energy imports and renewables.

Our results show that the relationship between renewables and energy imports is significantly positive. One of the possible explanations is: when an economy is in great demand of energy, it not only exploits more renewable energy but also imports more energy, such that the two sources of energy tend to increase together. The ceteris paribus analysis also indicates that renewables do not have an import substitution effect.

To improve the fit of the model, we modify the initial theoretical model by dropping the three insignificant paths one by one. NNFI and other relevant indices are improving from the initial theoretical model to the final SEM model. Although the χ^2 values are not desirable, the χ^2 values are normally not essential. Thus, we confirm the positive relationship between renewable energy and GDP through the path of increasing capital formation, but not the path of increasing trade balance. Renewables have a direct impact on capital formation but not directly on GDP. The results indicate that a renewable energy policy related to increasing capital formation (e.g., tax incentives for the establishment of renewable industries) would be more efficient than

Table 6
Estimated path coefficients for the final SEM model

Endogenous variables	GDP	Capital formation	Trade balance	Energy imports	Consumption
Capital formation	1.264*** (40.897)				
Trade balance	0.169*** (29.565)				−0.960*** (−11.763)
Energy imports			−2.422*** (−6.093)		2.564*** (6.408)
Renewables		0.095*** (6.789)		0.063** (2.087)	
Consumption	1.200*** (132.0)	0.262*** (45.614)			

Note: Sample size = 116.
**Represents significance at the 5% level.
***Represents significance at the 1% level; and numbers in the parentheses are *t* statistics.

Table 7
Goodness of fit indices for various models

	χ^2	df	*p*	NFI	NNFI	CFI
Initial SEM model	90.973	3	<0.0001	0.942	0.718	0.944
Revised SEM model 1	90.994	4	<0.0001	0.942	0.791	0.944
Revised SEM model 2	91.549	5	<0.0001	0.942	0.833	0.945
Final SEM model	94.288	6	<0.0001	0.940	0.858	0.943

Table 8
R^2 for each endogenous variable in the final SEM model

GDP	0.9997
Capital formation	0.951
Trade balance	0.244
Energy imports	0.037
Consumption	0.745

Table 9
Rank order of the 10 largest normalized residuals in the final SEM model

Row	Column	Residuals
Renewables	GDP	1.877
Consumption	Renewables	1.857
Renewables	Capital formation	1.717
Trade balance	Capital formation	1.292
Trade balance	Trade balance	−0.968
Trade balance	GDP	0.796
Renewables	Trade balance	−0.729
Consumption	Trade balance	0.678
Consumption	Consumption	−0.393
Consumption	GDP	−0.322

policies related to increasing trade balance (e.g., increasing the tax on imported fossil fuels).

5. Limitations and future research

Although the result of the χ^2 test in the final SEM model is not good enough, it is generally accepted that the χ^2 test should be interpreted with caution and supplemented with other goodness of fit indices. This is because the χ^2 test can be influenced by the sample size, yet, in the final SEM model, it is quite impossible to increase the sample size. The number of economies with sufficient data of all the relevant indicators cannot be increased easily. The R^2 of the two endogenous variables of trade balance and energy imports are relatively low in the study results. These two R^2 are low due to the fact that there are other variables beyond the scope of this study more significantly influencing the relevant variables.

Table 10
List of 116 economies in the sample profile

Country name		
Albania	Guatemala	Peru
Algeria	Haiti	Philippines
Argentina	Honduras	Poland
Armenia	Hong Kong, China	Portugal
Australia	Hungary	Romania
Austria	Iceland	Russian Federation
Azerbaijan	India	Saudi Arabia
Bahrain	Indonesia	Senegal
Bangladesh	Islamic Republic of Iran	Serbia and Montenegro
Belarus	Ireland	Slovenia
Belgium	Israel	South Africa
Benin	Italy	Spain
Bolivia	Jamaica	Sri Lanka
Bosnia and Herzegovina	Japan	Sudan
Brazil	Jordan	Sweden
Bulgaria	Kazakhstan	Switzerland
Cameroon	Kenya	Syrian Arab Republic
Canada	Republic of Korea	Tajikistan
Chile	Kuwait	Tanzania
China	Kyrgyz Republic	Thailand
Colombia	Latvia	Togo
Congo, Dem. Rep.	Lebanon	Trinidad and Tobago
Congo, Rep.	Lithuania	Tunisia
Costa Rica	Luxembourg	Turkey
Cote d'Ivoire	Malaysia	Turkmenistan
Croatia	Mexico	Ukraine
Czech Republic	Moldova	United Arab Emirates
Denmark	Morocco	United Kingdom
Dominican Republic	Mozambique	United States
Ecuador	Namibia	Uruguay
Egypt, Arab Rep.	Nepal	Uzbekistan
El Salvador	The Netherlands	Venezuela, RB
Estonia	New Zealand	Vietnam
Ethiopia	Nicaragua	Yemen, Rep.
Finland	Nigeria	Zambia
France	Norway	Zimbabwe
Georgia	Oman	
Germany	Pakistan	
Ghana	Panama	
Greece	Paraguay	

Table 11
Results of the effect of renewables on energy imports

Coefficients (*t*-statistics)	
Constant	-1.919×10^{10} (−2.452**)
Capital formation	0.003 (2.163**)
Consumption	0.010 (0.251)
Renewables	-3.786×10^{8} (−1.376)

The cost gap between renewables and traditional energy still exists at this moment. Having reviewed the merits of renewables, we should not forget that there are still obstacles to overcome to utilize renewable resources more. For example, Wamukonya (2007) reviews the effectiveness of solar home systems in Africa and finds that these systems are not cost-effective and questions the wisdom of using public funds to support the systems. Anderson and Leach (2004) also indicates that if renewable energy technologies eventually supply a significant share of total energy supply, then the energy storage problem has to be solved in advance. As far as we know, there are not yet studies available on how energy policies promoting renewables affect GDP. There seems to be a long way to go to fully utilize renewable resources.

References

Abulfotuh, F., 2007. Energy efficiency and renewable technologies: the way to sustainable energy future. Desalination 209, 275–282.

Anderson, D., Leach, M., 2004. Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen. Energy Policy 32, 1603–1614.

Bollen, K.A., 1989. Structural Equations with Latent Variables. Wiley, New York.

Chien, T., Hu, J.L., 2007. Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. Energy Policy 35, 3606–3615.

Domac, J., Richards, K., Risovic, S., 2005. Socio-economic drivers in implementing bioenergy projects. Biomass and Bioenergy 28, 97–106.

EU, 2008. Energy for a Changing World. Accessible at 〈http://ec.europa.eu/energy/energy_policy/index_en.htm〉.

Green, C., Baksi, S., Dilmaghani, M., 2007. Challenges to a climate stabilizing energy future. Energy Policy 35, 616–626.

Hatcher, L., 1994. A Step-by-Step Approach to Using SAS for Factor Analysis and Structural Equation Modeling. SAS Inc., Cary, NC.

Hu, C., 2005. Legislature passes renewable energy bill. China Daily.

International Energy Agency (IEA), 2005. Renewables Information 2005 edition. OECD/IEA, Paris.

Krewitt, W., Simon, S., Graus, W., Teske, S., Zervos, A., Shaefer, O., 2007. The 2 degrees C scenario—A sustainable world energy perspective. Energy Policy 35, 4969–4980.

Lin, G., Eskeland, G.S., Kolshus, H.H., 2007. Green electricity market development: lessons from Europe and the US. Energy Policy 35, 144–155.

Lund, P.D., 2007a. Effectiveness of policy measures in transforming the energy system. Energy Policy 35, 627–639.

Lund, P.D., 2007b. Upfront resource requirements for large-scale exploitation schemes of new renewable technologies. Renewable Energy 32, 442–458.

Masui, T., Hanaoka, T., Hikita, S., Kainuma, M., 2006. Assessment of CO_2 reudctions and economic impacts considering energy-saving investments. Energy Journal 1, 175–190.

Pitman, R.M., 2006. Wood ash use in forestry—a review of the environmental impacts. Forestry 79, 563–588.

REN21, Worldwatch, 2008. Renewables 2007 Global Status Report. Accessible at 〈http://www.ren21.net/pdf/RE2007_Global_Status_Report.pdf〉.

Sathaye, J., Shukla, P.R., Ravindranath, N.H., 2006. Climate change, sustainable development and India: global and national concerns. Current Science India 90, 314–325.

Soderholm, P., Ek, K., Pettersson, M., 2007. Wind power development in Sweden: global policies and local obstacles. Renewable and Sustainable Energy 11, 365–400.

Steenhof, P.A., Fulton, W., 2007. Scenario development in China's electricity sector. Technological Forecasting and Social Change 74, 779–797.

Stern, N., 2006. Stern Review: the Economics of Climate Change. Accessible at 〈http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm〉.

UK Department of Trade and Industry, 2003. Our energy future-creating a low carbon economy. Energy White Paper. TSO, London.

Wamukonya, N., 2007. Solar home system electrification as a viable technology option for Africa's development. Energy Policy 35, 6–14.

World Bank, 2007. World Development Indicators. Accessible at 〈http://www.worldbank.org〉.