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Clean energy, non-clean energy, and economic growth in the MIST countries

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HIGHLIGHTS

- This novel study can provide more robust bases to strengthen sustainable energy policy settings.
- Fossil fuel/nuclear energy use and economic growth is bidirectional causality.
- Renewable energy consumption long term causes economic growth.
- There is substitutability between renewable and fossil fuel energy.
- Clean and non-clean energy partnerships can achieve a sustainable energy economy.

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ABSTRACT

This paper explores the causal relationship between clean (renewable/nuclear) and non-clean energy consumption and economic growth in emerging economies of the MIST (Mexico, Indonesia, South Korea, and Turkey) countries. The panel co-integration tests reveal that there is a long-term equilibrium relationship among GDP, capital formation, labor force, renewable/nuclear, and fossil fuel energy consumption. The panel causality results indicate that (1) there is a positive unidirectional short-run causality from fossil fuel energy consumption to economic growth with a bidirectional long-run causality; (2) there is a unidirectional long-run causality from renewable energy consumption to economic growth with positive bidirectional short-run causality, and a long-run causality from renewable to fossil fuel energy consumption with negative short-run feedback effects; and (3) there is a bidirectional long-run causality between nuclear energy consumption and economic growth and a long-run causality from fossil fuel energy consumption to nuclear energy consumption with positive short-run feedback effects. These suggest that MIST countries should be energy-dependent economies and that energy conservation policies may depress their economic development. However, developing renewable and nuclear energy is a viable solution for addressing energy security and climate change issues, and creating clean and fossil fuel energy partnerships could enhance a sustainable energy economy.

1. Introduction

In the past decade, using panel data to study the causal relationships between renewable and non-renewable energy consumption (Apergis and Payne, 2011a, 2011b, 2012a, 2012b, 2013) and nuclear energy consumption (Lee and Chiu, 2011; Nazlioglu et al., 2011; Apergis and Payne, 2010), respectively and economic growth have attracted significant research interest. Indeed, it is important to understand the extent to which different types of energy consumption contribute to the economic growth process. The causalities between energy consumption and economic growth have different directions, so as to generate different policy implications. Under the assumption of positive correlation between energy consumption and economic growth, the presence of unidirectional causality from energy consumption to economic growth or bidirectional causality between them would suggest that energy conservation policies that reduce energy consumption may lead to decline in economic growth. In contrast, unidirectional causality from economic growth to energy consumption or no causality in either direction suggests that energy conservation policies will have little or no impact on economic growth (Apergis and Payne, 2013). However, various empirical study outcomes show different and even conflicted results with each other. According to Ozturk (2010), the main reasons of this inconsistence come from the differences in country

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Table 1
Empirical results on the causal relationship between different types of energy consumption and economic growth using panel data.

Author	Methodology	Period	Countries or economies	Results
Panel A: causal relationship between renewable and non-renewable energy consumption and economic growth				
Apergis and Payne (2011a)	Panel VECM	1990–2007	25 developed and 55 developing countries	**R↔Y** **NR↔Y**
Apergis and Payne (2011b)	Panel VECM	1990–2007	16 emerging market economies	**R↔Y** **NR↔Y**
Apergis and Payne (2012a)	Panel VECM	1990–2007	80 countries	**R↔Y** **NR↔Y**
Apergis and Payne (2012b)	Panel VECM	1990–2007	6 Central America countries	**R↔Y** **NR↔Y**
Apergis and Payne (2013)	Panel VECM	1990–2007	9 South America countries	**R↔Y** **NR↔Y**
Panel B: causal relationship between nuclear energy consumption and economic growth				
Apergis and Payne (2010)	Panel VECM	1980–2005	16 countries	**N→Y**
Apergis et al. (2010)	Panel VECM	1984–2007	19 developed and developing countries	**N↔Y**
Nazlioglu et al. (2011)	Panel causality approach (Kónya, 2006)	1980–2007	14 OECD countries	**N↮Y**
Lee and Chiu (2011)	Panel VECM	1971–2006	6 highly industrialized countries	**Y→N**

Notes: R, NR, N, and Y are renewable, non-renewable, nuclear energy consumption and real GDP, respectively. →, ↔, and ↮ indicate unidirectional causality, bidirectional causality, and neutral causality, respectively.

characteristic, time period, econometric methodology, and types of energy consumption. In the recent articles of Apergis and Payne (2011a, 2011b, 2012a, 2012b, 2013) and Pao and Fu (2013a), non-renewable energy consumption, which includes clean (nuclear) and non-clean (fossil fuel) energy sources, is considered to be aggregate energy consumption. In this study, the aggregate non-renewable energy consumption is further partitioned into nuclear and fossil fuel energy consumption, so as to explore the relationships between renewable, nuclear, and fossil fuel energy consumption, respectively and economic growth (Pao and Fu, 2013b). The dual goals are to distinguish the relationship between disaggregate consumption of clean and non-clean energy and economic growth, and to verify the substitutability of clean for non-clean energy consumption. Thus, the pitfalls of policy decision based on aggregate energy consumption alone can be avoided.

Another reason of using the proposed disaggregated analysis is to achieve the vision of transition to a global green economy. If the world's enormous demand for clean energy is to be met, nuclear power complemented by new renewable sources of energy is urgently needed (Macusani Yellowcake, 2011). Currently, nuclear power plants supply approximately 5.7% of the global energy and 13–14% of the global electricity needs. Additionally, by 2018, renewable power will make up a quarter of the world's energy mix, up from 20% in 2011. With the increasing importance of sustainable development, clean energy sources (e.g., nuclear and renewable) have become the major components in the energy matrix. Therefore, two types of clean energy, renewable and nuclear, alongside fossil fuel non-clean energy consumption impact on economic growth are investigated. The proposed model is a novel study and provides more robust bases to strengthening the sustainable energy policy settings.

For developing and emerging market economies, clean energy plays a significant role in the growth prospects and reduces negative environmental and health impacts. Such is the case in MIST (Mexico, Indonesia, South Korea, and Turkey), the next tier of large emerging economies with abundance of clean resources and increasing demand for energy. The MIST nations are expected to exhibit high growth over the next 20–30 years, but they are also in the top 20 countries producing carbon emissions. Developing clean energy is critical to offer a viable alternative for sustainable economies. A brief description of clean energy resources and recent developing achievements of these countries are as follows. For wind power, Mexico's annual growth rate in wind power capacity was the highest in the world in 2012. The country intends to increase its wind energy capacity to 15% of the country's electricity mix to diversify its energy portfolio. South Korea has initiated a massive wind energy program to reduce the country's huge fossil fuel imports. Indonesia will cooperate with the United Nations Development Program to develop wind power generation projects. Turkey's wind power capacity will increase 16-fold by 2020 to meet the demand for an annual growth rate of 7% in electricity. For hydropower, the electricity sector in Mexico obtains approximately 19% of its total installed capacity from hydropower. In South Korea, hydroelectric generation represents 40% of the country's energy supply. Indonesia also has great potential to develop mini hydroelectric power plants (1 MW–10 MW of capacity). In Turkey, 32–35% of the electricity demand could be met by hydro power plants by 2020. For geothermal power, the installed capacities in Indonesia, Mexico, and Turkey rank the third, the fifth, and the tenth, respectively in the world. Indonesia added the most geothermal capacity in 2012, and Turkey was second. In fact, Turkey is the world's seventh richest country for geothermal energy potential. South Korea also has substantial geothermal potential; 2% of geothermal energy developed from surface to a depth of 5 km will be equivalent to approximately 200 times the country's annual primary energy consumption in 2006 (Lee et al., 2010). For solar energy, Mexico's solar thermal resources are among the best in the world. The quality of its PV is also among the world's best. Solar thermal and PV power generation will account for 5% of Mexico's energy supply by 2030 and up to 10% by 2050. South Korea is currently ranked among the top 10 installers of solar power in the world. Indonesia is one of the most important emerging solar markets in Southeast Asia. Turkey is located in an advantageous position for solar power because it has average 7.2 hours a day of sunny weather throughout the year. Solar energy is the most important alternative clean energy source in Turkey. For bio-energy, Mexican bio-energy power may account for 16.17% of the total energy consumption by 2030 (Islas et al., 2007). The government of South Korea plans to increase the use of biomass to 30.8% of new renewable energy by 2030 (Bioenergy Crops, 2012). Indonesia has one of the best biomass energy potentials because it has one of the highest levels of energy for photosynthesis per unit area. Biomass may be able to replace fossil fuel in Indonesia (Panjaitan, 2013). In Turkey, biomass energy is generally used as non-commercial fuel in traditional methods and accounts for approximately a fourth of domestic energy production. However, traditional biomass energy production should be gradually reduced to allow the development of modern biomass energy production (IZKA, 2012). For nuclear power, currently Indonesia and Turkey are almost no nuclear power consumption, but South Korea generates approximately a third or more of its power from nuclear energy. The Mexican government also actively supports the expansion of nuclear energy, which could reduce their dependency on natural gas and also increase the amount of carbon-free power generation to 35% of the country's power by 2024. Turkey's plans for nuclear power are a key aspect of the country's objective of 8% growth, which is based in part on reducing the country's huge energy imports. Indonesia also plans to build nuclear power to support the country's energy needs. Because there is a wealth of clean energy resources in MIST, this paper explores, when both clean and non-clean energy have considerable percentage of consumption, the relative influence of each type of energy consumption on economic growth. Policymakers could balance the use of different energy resources to achieve wealthy, grow, and prosperity in a clean environment.

In this study, we employ a neo-classical one-sector aggregate production model, in which capital, labor, renewable/nuclear energy consumption, and fossil fuel energy consumption are treated as separate inputs, to investigate the relative influence of each type of energy consumption on economic growth. Within this framework, a vector error correction model (VECM) is employed to test for multivariate co-integration and Granger causality.

The remainder of this paper is structured as follows. Section 2 presents a brief literature review. Section 3 describes the analytical model and econometric methodology. Section 4 presents the empirical results of both data analysis and causality analysis. The final section presents conclusions and policy implications.

2. Brief literature review

Since the beginning of the 21st century, many researchers have studied the relationship between renewable and non-renewable energy consumption and economic growth, as well as the substitutability between the two energy sources using panel data. Table 1 presents a summary review of the literature. Within a framework of production function, the multivariate co-integration techniques and VECM are commonly used. Apergis and Payne (2011a) found a bidirectional short- and long-run causality between renewable and non-renewable energy consumption and economic growth, a negative unidirectional short-run causality from renewable energy consumption to non-renewable energy consumption with positive feedback effects for two panels of 25 developed countries and 55 developing countries. Their findings affirm the importance of both energy sources for sustainable economic development in both developing and developed countries. In addition, they also suggested that increases in the consumption of renewable energy can replace non-renewable energy sources. On the other hand increases in non-renewable energy consumption may in turn increase renewable energy consumption to reduce carbon emissions. Apergis and Payne (2011b) found a unidirectional short-run causality from economic growth to renewable electricity consumption with bidirectional long-run causality, and a bidirectional short- and long-run causality between non-renewable electricity consumption and economic growth for a panel of 16 emerging markets. Their findings suggest that as the economy continues to grow, there will be more resources to promote the development of the renewable energy industry and that there will eventually be a long-term interdependence between renewable electricity consumption and economic growth, leading emerging markets to depend heavily on non-renewable energy to meet the demand. Apergis and Payne (2012a) found a bidirectional short- and long-run causality between renewable and non-renewable energy consumption and economic growth, and a negative bidirectional short- and long-run causality between renewable and non-renewable energy consumption for a panel of 80 countries. Their findings indicate that renewable and non-renewable energy consumption can replace each other, and enhancing both energy sources has a positive impact on economic growth. Apergis and Payne (2012b) found a unidirectional short-run causality from renewable electricity consumption to economic growth with bidirectional long-run causality, a bidirectional short- and long-run causality between non-renewable electricity consumption and economic growth, and a negative bidirectional short- and long-run causality between renewable and non-renewable energy consumption for a panel of 6 Central America countries. The interdependence between the two energy sources reveals the importance of a mix of energy consumption in Central America. Apergis and Payne (2013) found a bidirectional short- and long-run causality between renewable and non-renewable electricity consumption and economic growth, and a negative bidirectional short- and long-run causality between renewable and non-renewable electricity consumption for a panel of 9 South America countries. The interdependence between the two energy sources parallels the results by Apergis and Payne (2011a, 2012a, 2012b). In the above studies, the total non-renewable energy consumption includes fossil fuel and nuclear energy consumption, although nuclear energy is a part of the solution to meet the country's growing demand for clean energy. To clearly differentiate the relative influences of clean and non-clean energy consumption on economic growth, this study uses fossil fuel energy to replace the previous model of non-renewable energy, and uses nuclear or renewable energy to represent clean energy.

Several studies that explore the causality between nuclear energy consumption and economic growth using panel data are shown in panel B of Table 1. Within a multivariate panel framework, Apergis and Payne (2010) found a unidirectional long-run causality from nuclear energy consumption to economic growth with bidirectional short-run causality for a panel of 16 countries. They suggested that an increase in nuclear power production would have a positive impact on economic growth and the environment. Apergis et al. (2010) presented evidence of bidirectional long-run causality between economic growth and nuclear energy consumption for a panel of 19 developed and developing countries. They found that economic growth can enhance nuclear power consumption, though increasing the production of nuclear power will have a negative impact on economic growth. Their findings may be due to the inefficient use of nuclear power as well as the high cost of disposing of radioactive waste. Using Kónya's (2006) panel Granger causality approach, Nazlioglu et al. (2011) found a unidirectional causality from nuclear energy consumption to economic growth for Hungary, reverse causality for the UK and Spain, and no causality for eleven other OECD countries. These findings suggest that nuclear power may be a relatively small component of overall production in most OECD countries. Lee and Chiu (2011) found that nuclear energy and oil can replace each other, and there is a unidirectional long-run causality from economic growth to nuclear energy consumption with no short-run causality for a panel of 6 highly industrialized countries. They suggested that these countries that are dependent on imported energy should establish long-term economic and energy policies to stimulate their development of nuclear energy, and energy conservation policy in these countries is feasible. To differentiate clearly the relative influences of clean and non-clean energy consumption on economic growth, this paper will study the impact of renewable/nuclear and fossil fuel energy consumption on economic growth in the MIST emerging markets.

3. Model and methodology

To investigate the relationships between the different types of energy consumption and economic growth and to verify the substitutability between total renewable/nuclear and fossil fuel energy sources in MIST economies, this study employs a framework based on the conventional neoclassical aggregate energy-dependent production function, in which the capital, labor, and energy are treated as separate inputs (Kümmel et al., 1985). That is

$$Y_t = f(E_t, K_t, L_t), \tag{1}$$

where Y is the aggregate output or real GDP, E is the energy-related variables, K is the capital stock, L is the labor force, and subscript t is the time. This model describes that economic output Y of value added is created by the cooperation of the production factors capital K, labor L, and energy E. Eq. (1) can be used to explore the existence of a long-run equilibrium relationship among real GDP, capital stock, labor force, and energy consumption, and to analyze the causal relationships of short and long-run dynamics between variables by employing multivariate co-integration and Granger causality techniques. Apergis and Payne, 2011a, 2011b, 2012a, 2012b, 2013 used variables of renewable (R) and non-renewable (NR) energy to replace variable E in Eq. (1). This study uses clean and non-clean energy variables to replace E in Eq. (1), then the production modeling framework is given as follows:

$$Y_{it} = f(C_{it}, F_{it}, K_{it}, L_{it}), i = 1, \ldots, N; t = 1, \ldots, T \tag{2}$$

where the subscripts i and t are country and time respectively, and Y is the aggregate output or real GDP, K is the real gross fixed capital formation, L is the total labor force, C is the clean energy consumption of total renewable (R) or total nuclear (N), and F is the non-clean fossil fuel energy consumption.

In the empirical analysis, we test the existence of a long-run relationship among the variables in Eq. (2), and explore the short- and long-run dynamic relationships between variables using the error-correction model (ECM). This analysis includes three steps. First, we verify the order of integration for each variable in Eq. (2) because the various co-integration tests are valid only if the variables have the same order of integration. Six panel-based unit root tests, Levin et al. (2002), Breitung (2000), Im et al. (2003), Fisher-type tests using ADF and PP test (Maddala and Wu (1999) and Choi (2001)), and Hadri (2000) are employed, using the following autoregressive specification

$$y_{it} = \rho_i y_{it-1} + \delta_i X_{it} + \varepsilon_{it}, \tag{3}$$

where i and t are time and country, respectively. The X_{it} represents exogenous variables in the model including any fixed effects or individual time trend, ρ_i is the autoregressive coefficient, and ε_{it} are assumed to be mutually independent normally distributed error terms. Series y_{it} is stationary, if $|\rho_i| < 1$. On the other hand, series y_{it} contains a unit root if $|\rho_i| = 1$. The LLC, BRT, and HD panel unit root tests all assume that there is a common unit root process, so ρ_i is identical across cross-sections. The IPS, ADF, and PP panel unit root tests all allow for individual unit root processes; therefore, ρ_i can vary across cross-sections. LLC, BRT, IPS, ADF, and PP tests employ a null hypothesis of a unit root while the HD test uses a null of no unit root.

Next, when all of the series in Eq. (2) have the same integration order, three panel co-integration tests without structural breaks, including the Pedroni (1999, 2004), Kao (1999), and Johansen Fisher (Maddala and Wu, 1999) methods, and the panel co-integration test with structural breaks proposed by Westerlund (2006), are used to determine whether a long-term equilibrium relationship exists among the variables in Eq. (4) as follows:

$$Y_{it} = \beta_{0i} + \beta_{1i} C_{it} + \beta_{2i} F_{it} + \beta_{3i} K_{it} + \beta_{4i} L_{it} + u_{it}, \tag{4}$$

where the error term u_{it} represents deviations of real income from the long-term equilibrium relationship. The parameter estimates in Eq. (4) can be interpreted as elasticity estimates because Eq. (4) is in logarithm form. The existence of co-integration indicates that there are long-run equilibrium relationships among the variables.

Following Engle and Granger (1987), the lagged residuals from Eq. (4) serve as the error correction term (ECT) in the estimation of the VECM as follows

$$\Delta Y_{it} = \gamma_{10i} + \sum_{j=1}^{p_{11}} \gamma_{11ij} \Delta Y_{it-j} + \sum_{j=1}^{p_{12}} \gamma_{12ij} \Delta C_{it-j} + \sum_{j=1}^{p_{13}} \gamma_{13ij} \Delta F_{it-j} + \sum_{j=1}^{p_{14}} \gamma_{14ij} \Delta K_{it-j} + \sum_{j=1}^{p_{15}} \gamma_{15ij} \Delta L_{it-j} + \lambda_{1i} ECT_{it-1} + \varepsilon_{1it} \tag{5a}$$

$$\Delta C_{it} = \gamma_{20i} + \sum_{j=1}^{p_{21}} \gamma_{21ij} \Delta Y_{it-j} + \sum_{j=1}^{p_{22}} \gamma_{22ij} \Delta C_{it-j} + \sum_{j=1}^{p_{23}} \gamma_{23ij} \Delta F_{it-j} + \sum_{j=1}^{p_{24}} \gamma_{24ij} \Delta K_{it-j} + \sum_{j=1}^{p_{25}} \gamma_{25ij} \Delta L_{it-j} + \lambda_{2i} ECT_{it-1} + \varepsilon_{2it} \tag{5b}$$

$$\Delta F_{it} = \gamma_{30i} + \sum_{j=1}^{p_{31}} \gamma_{31ij} \Delta Y_{it-j} + \sum_{j=1}^{p_{32}} \gamma_{32ij} \Delta C_{it-j} + \sum_{j=1}^{p_{33}} \gamma_{33ij} \Delta F_{it-j} + \sum_{j=1}^{p_{34}} \gamma_{34ij} \Delta K_{it-j} + \sum_{j=1}^{p_{35}} \gamma_{35ij} \Delta L_{it-j} + \lambda_{3i} ECT_{it-1} + \varepsilon_{3it} \tag{5c}$$

$$\Delta K_{it} = \gamma_{40i} + \sum_{j=1}^{p_{41}} \gamma_{41ij} \Delta Y_{it-j} + \sum_{j=1}^{p_{42}} \gamma_{42ij} \Delta C_{it-j} + \sum_{j=1}^{p_{43}} \gamma_{43ij} \Delta F_{it-j} + \sum_{j=1}^{p_{44}} \gamma_{44ij} \Delta K_{it-j} + \sum_{j=1}^{p_{45}} \gamma_{45ij} \Delta L_{it-j} + \lambda_{4i} ECT_{it-1} + \varepsilon_{4it} \tag{5d}$$

$$\Delta L_{it} = \gamma_{40i} + \sum_{j=1}^{p_{51}} \gamma_{51ij} \Delta Y_{it-j} + \sum_{j=1}^{p_{52}} \gamma_{52ij} \Delta C_{it-j} + \sum_{j=1}^{p_{53}} \gamma_{53ij} \Delta F_{it-j} + \sum_{j=1}^{p_{54}} \gamma_{54ij} \Delta K_{it-j} + \sum_{j=1}^{p_{55}} \gamma_{55ij} \Delta L_{it-j} + \lambda_{5i} ECT_{it-1} + \varepsilon_{5it} \tag{5e}$$

where

$$ECT_{it} = Y_{it} - \hat{\beta}_{0i} - \hat{\beta}_{1i} C_{it} - \hat{\beta}_{2i} F_{it} - \hat{\beta}_{3i} K_{it} - \hat{\beta}_{4i} L_{it}, \tag{6}$$

Δ is the first difference operator, j is the lag length determined by Akaike information criterion (AIC), and ε is the serially uncorrelated error term. Note that the time series in the first difference of the natural logarithm can be interpreted as a growth rate of this variable. Short-run causality is determined by the statistical significance of the partial F-statistic associated with the lagged independent variables in Eqs. (5a)–(5e). Long-run causality is

Table 2
Summary statistics of variables from actual data, 1990–2010.

Countries	Mean					
	Y	*R*	*F*	*N*	*K*	*L*
Mexico	557.90 (95.95)	361.91 (51.67)	5658.80 (790.58)	77.88 (25.88)	113.97 (30.68)	40.08 (5.76)
Indonesia	181.10 (45.57)	143.85 (47.23)	3878.27 (1076.28)		41.37 (11.48)	98.29 (13.08)
South Korea	541.41 (155.82)	40.86 (8.84)	6586.12 (1637.79)	982.97 (347.30)	162.79 (30.79)	22.51 (1.75)
Turkey	274.17 (66.28)	359.37 (75.80)	2791.43 (779.35)		56.26 (17.85)	22.38 (1.76)

Notes: *Y*, *R*, *N*, *F*, *K*, and *L* are real GDP, renewable energy consumption, nuclear energy consumption, fossil fuel energy consumption, real gross fixed capital formation, and labor force, respectively. Figures in parenthesis indicate standard deviation.

determined by the statistical significance of the *t*-statistic on the respective ECTs.

4. Data and empirical findings

4.1. Data analysis

Annual data for the MIST country's real GDP (Y), real gross fixed capital formation (K), and total labor force (L) from 1990 to 2010 were obtained from the World Development Indicators (WDI). Data for total renewable energy consumption (R), nuclear energy consumption (N), and total fossil fuel energy consumption (F) were extracted from the Energy Information Administration (EIA), though Indonesia and Turkey (IT) have no nuclear data. Both real GDP and real gross fixed capital formation are measured in billions of US dollars at year 2000 prices. Renewable, nuclear, and fossil fuel energy consumptions are measured in trillion BTUs (British thermal unit). The total labor force is measured in millions.

Table 2 displays the summary statistics associated with the six variables mentioned above for the actual data of each MIST country. From 1990 to 2010, the means of the real GDPs range between 557.90 billion in Mexico and 181.10 billion in Indonesia. The means of the renewable energy consumption range from 361.91 trillion BTUs in Mexico to 40.86 trillion BTUs in South Korea. The means of fossil fuel energy consumption range between 6586.12 trillion BTUs in South Korea and 2791.43 trillion BTUs in Turkey. The means of nuclear energy consumption are 982.97 and 77.88 trillion BTUs in South Korea and Mexico, respectively. The means of capital formation range between 162.79 billion in South Korea and 41.37 billion in Indonesia. The means of the labor forces range between 98.29 million in Indonesia and 22.38 million in Turkey. In 2010, the averages of global real GDP, renewable energy consumption, nuclear energy consumption, fossil fuel energy consumption, capital formation, and labor force are 222.21 billion, 188.01 trillion BTUs, 125.76 trillion BTUs, 2022.97 trillion BTUs, 72.33 billion, and 17.58 million, respectively. Real GDP, labor force, clean energy consumption, and fossil fuel energy consumption in the MIST countries are higher than the global averages, but capital formation in Indonesia and Turkey is lower than global average. These findings indicate that MIST emerging markets have high growth along with high pollution, but they are very committed to solving environmental problems.

Figs. 1–6 show the changing trends and Table 3 shows the percentage growth rates in 2010 for each time-series of MIST countries. Here, five-year, ten-year, and fifteen-year compound annual growth rates (CAGR) are calculated as growth between 2005 and 2010, between 2000 and 2010, and between 1995 and 2010, respectively. For real GDP, renewable, and fossil fuel energy consumption, Indonesia and Mexico had the highest and the lowest 5 and 10 year CAGRs, respectively. The ranges of 5-year CAGRs are between 1.75% and 5.73% in real GDP, between 4.09%

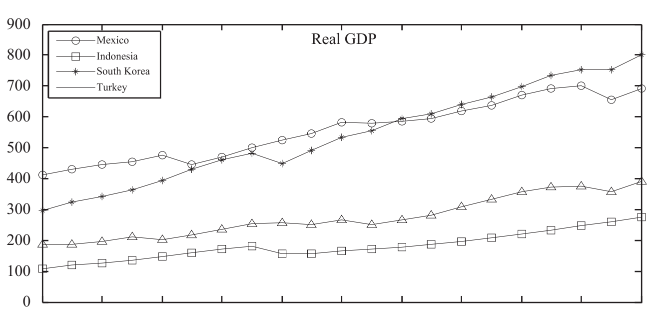

Fig. 1. Real GDP in billions of constant 2000 US dollars (before taking logarithm).

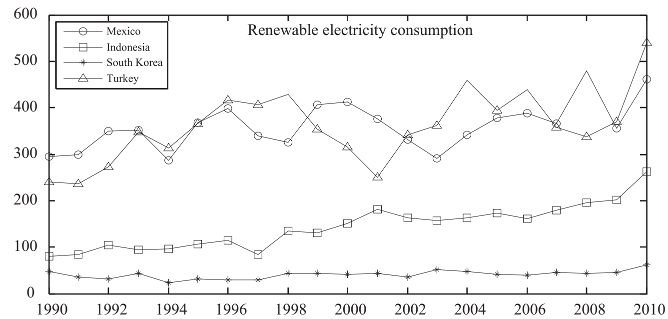

Fig. 2. Renewable electricity consumption in trillion BTUs (before taking logarithm).

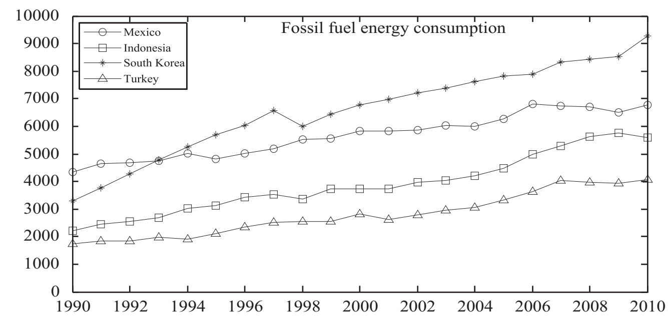

Fig. 3. Fossil fuel energy consumption in trillion BTUs (before taking logarithm).

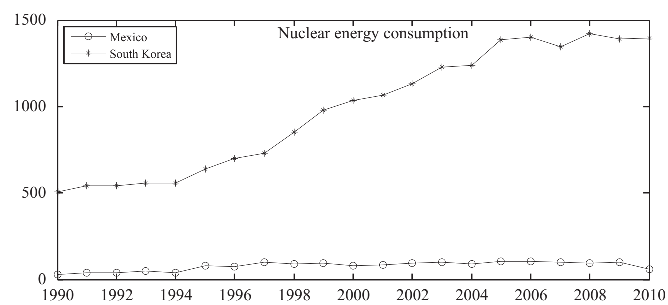

Fig. 4. Nuclear energy consumption in trillion BTUs (before taking logarithm).

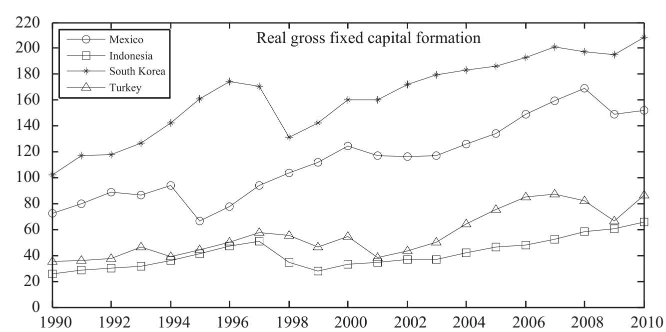

Fig. 5. Real gross fixed capital formation in billions of constant 2000 US dollars (before taking logarithm).

and 8.81% in renewable energy consumption, and between 1.59% and 4.52% in fossil fuel energy consumption. The results show that Indonesia's economic growth and energy consumption have been driven by a demand that defied the global uncertainty. More than 60% of Indonesia's GDP is generated by domestic consumption. For MIST countries as a whole, the average of 5-year CAGR in renewable energy consumption is higher than the 10- and 15-year CAGRs, while the 5-year CAGRs in fossil fuel energy consumption is lower than the 15-year CAGR. Overall, except for the nuclear energy consumption, the averages of 5-year CAGRs of MIST countries in renewable energy consumption, fossil fuel energy consumption, and real GDP are higher than the global average. The empirical results suggest that MIST are emerging economies of rich developing countries and display efforts to reduce GHG emissions. In light of these special phenomena, this study investigates the causal relationship between renewable/nuclear and fossil fuel energy consumption and economic growth and analyzes the substitutability between renewable/nuclear and fossil fuel energy consumption in MIST between 1990 and 2010.

4.2. Panel co-integration test results

This analysis begins with the unit root tests. The results of six panel-based unit root tests, including LLC, BRT, IPS, ADF, PP, and HD, are presented in Table 4 for the renewable energy consumption model in MIST panel and in Table 5 for the nuclear energy consumption model in MS (Mexico and South Korea) panel. They indicate that each variable in Eq. (4) is a first order integration, i.e., I (1). Next, the Pedroni, Kao, and Johansen Fisher panel co-integration tests, as shown in Tables 6 and 7, reveal the existence of at least one co-integrating vector for the combination of (Y, R, F, K, L) or (Y, N, F, K, L) at a 5% significance level. We also conduct the panel co-integration test with structural breaks developed by Westerlund. The 5% critical value is 2.155. The test statistics of the Lagrange multiplier are −1.26 and −2.09 in MIST and MS, respectively when we allow for one structural break. We are unable to reject the null hypothesis of panel co-integration. That is, real GDP, renewable/nuclear energy consumption, capital formation, fossil fuel energy consumption, and labor force, share a common trend in the long run. This result is robust to possible cross-country dependence and still holds when allowing for structural breaks. The panel co-integration equation for renewable (R) or nuclear (N) energy consumption can be written as

$$Y = -1.737 + 0.182R + 0.730F + 0.352K - 0.277L \\ (0.157)^{***}(0.006)^{***}(0.040)^{***}(0.034)^{***}(0.019)^{***} \quad (7a)$$

$$Y = -1.986 + 0.086N + 0.821F + 0.201K - 0.097L \\ (0.558)^{***}(0.041)^{**}(0.082)^{***}(0.105)^{*}(0.211) \quad (7b)$$

Figures in parentheses denote standard errors, and *, ** and *** denote significance at the 10%, 5%, and 1% levels, respectively. According to the unit root test and the JB-statistic (Jarque and Bera, 1980), the series of residuals for Eqs. (7a) and (7b) are I (0) and normally distributed, and their R^2 statistics are 0.991 and 0.969. These coefficients in Eqs. (7a) and (7b) imply that a 1% rise in renewable energy consumption is associated with a 0.182% increase in real GDP, that a 1% rise in nuclear energy consumption is associated with a 0.086% increase in real GDP, and that a 1% rise in fossil fuel energy consumption is associated with a 0.73–0.82% increase in real GDP. In comparison, the renewable energy consumption elasticities of real GDP range from 0.074 to 0.427 (Apergis and Payne, 2013, 2011b, 2012b, 2011a, 2012a), and the nuclear energy consumption elasticities of real GDP range from 0.32 to 0.89 (Apergis and Payne, 2010; Lee and Chiu, 2011). The renewable energy consumption elasticity of 0.182 in MIST is in the middle of 0.074 and 0.427, while the nuclear energy consumption elasticity of 0.086 in MS is very low. The low nuclear elasticity may be because the percentage of total electricity production from nuclear energy of 4.08% is lower in Mexico relative to both the 16 country panel (Apergis and Payne, 2010) and the 6 country panel (Lee and Chiu, 2011). The results of this paper suggest that

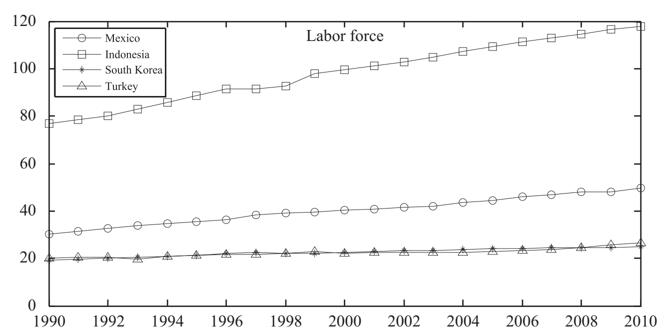

Fig. 6. Labor force in millions (before taking logarithm).

Table 3
Percent compound annual growth rates in variables to 2010.

	Mexico	Indonesia	South Korea	Turkey	Average	The World
Panel A: real GDP (billions of constant 2000 US dollars)						
5 year growth	1.75	5.73	3.82	3.19	3.24	2.24
10 year growth	1.80	5.23	4.16	3.87	3.40	2.51
15 year growth	3.00	3.70	4.23	3.93	3.69	2.80
Panel B: renewable energy consumption (trillion BTUs)						
5 year growth	4.09	8.81	8.71	6.48	6.12	4.31
10 year growth	1.14	5.71	4.03	5.53	3.73	3.30
15 year growth	1.52	6.19	4.76	2.62	2.83	2.70
Panel C: fossil fuel energy consumption (trillion BTUs)						
5 year growth	1.59	4.52	3.53	3.95	3.27	2.28
10 year growth	1.49	4.13	3.23	3.65	2.98	2.75
15 year growth	2.29	3.92	3.31	4.40	3.31	2.38
Panel D: nuclear energy consumption (trillion BTUs)						
5 year growth	−11.46		0.17		−0.48	−0.12
10 year growth	−3.30		3.01		2.66	0.62
15 year growth	−2.38		5.34		4.79	1.07
Panel E: real gross fixed capital formation (billions of constant 2000 US dollars)						
5 year growth	3.24	7.06	2.05	2.98	3.14	1.71
10 year growth	2.41	7.21	2.59	4.81	3.36	2.28
15 year growth	5.90	3.16	1.67	4.67	3.40	3.03
Panel F: labor force (millions)						
5 year growth	2.28	1.53	0.78	2.81	1.76	1.25
10 year growth	2.11	1.70	0.94	1.91	1.73	1.52
15 year growth	2.27	1.93	1.00	1.48	1.83	1.57

Table 4
Results of panel unit roots tests for MIST countries, 1990–2010.

Var.	Individual unit root			Common unit root			
	IPS	ADF	PP	LLC	BRT	HD (homo.)	HD (hetero.)
Y	3.585	3.399	11.070	2.983	−0.988	6.189***	6.166***
R	−1.009	13.04	12.516	−1.273	−0.173	2.963***	3.224***
F	−0.250	9.111	12.432	−1.013	0.386	8.864***	12.215***
K	0.321	4.993	5.292	−0.942	1.199	5.143***	5.171***
L	1.048	13.185	11.592	−0.842	0.990	15.400***	5.739***
ΔY	−1.708**	23.701***	44.502***	−3.069***	−3.638***	−0.435	−0.142
ΔR	−8.617***	65.610***	149.603***	−9.432***	−2.827***	−0.188	−0.356
ΔF	−4.379***	34.034***	49.936***	−4.357***	−3.073***	1.253	0.397
ΔK	−6.700***	50.293***	44.594***	−6.359***	−4.710***	−1.074	−0.896
ΔL	−2.826***	23.813***	43.391***	−2.112***	−4.761***	1.258	0.383

Notes: Intercepts were included in IPS, ADF, PP, LLC, and HD test equations. The intercept and time trend were included in BRT test equations. Lag lengths were selected using AIC. The null hypothesis for HD tests is no unit root. For the other five tests, the null hypothesis is a unit root.

*** Indicate 1% levels of significance.
** Indicate 5% levels of significance.

Table 5
Results of panel unit root tests for MS countries, 1990–2010.

Var.	Individual unit root			Common unit root			
	IPS	ADF	PP	LLC	BRT	HD (homo.)	HD (hetero.)
Y	0.187	2.628	2.961	−0.744	−0.466	4.422***	4.392***
N	−0.737	5.631	5.861	−1.223	1.811	7.371***	7.055***
F	0.576	1.408	4.603	−0.588	−0.800	1.916**	4.125***
K	−0.093	3.391	3.771	−1.215	−0.783	2.812***	2.672***
L	−1.099	6.703	7.474	−0.968	0.680	3.464***	3.457***
ΔY	−3.987***	21.739***	23.842***	−5.017***	−2.359***	0.632	0.509
ΔN	−4.697***	24.909***	24.389***	−1.766**	−2.882***	−0.303	1.239
ΔF	−3.598***	19.746***	25.556***	−4.267***	−3.290***	1.222	0.968
ΔK	−5.419***	28.769***	25.159***	−5.150***	−3.822***	−0.737	−0.670
ΔL	−3.803***	20.012***	20.019***	−3.998***	−2.525***	0.578	0.509

Notes: Intercepts were included in IPS, ADF, PP, LLC, and HD test equations. The intercept and time trend were included in BRT test equations. Lag lengths were selected using AIC. The null hypothesis for HD tests is no unit root. For the other five tests, the null hypothesis is a unit root.

*** Indicate 1% levels of significance.
** Indicate 5% levels of significance.

Table 6
Results of panel co-integration tests for MIST countries, 1990-2010.

Test methods	Statistics	
Pedroni test		
Within dimension test statistics		
Panel ν-stat.	3.757***	
Panel ρ-stat.	1.398	
Panel PP-stat.	−1.385*	
Panel ADF-stat.	−1.776**	
Between dimension test statistics		
Group ρ-stat.	2.053	
Group PP-stat.	−2.487***	
Group ADF-stat.	−1.895**	
Kao test		
ADF-stat.	−2.552***	
Johansen Fisher test		
Null hypothesis	Trace	Max. eigenvalue
$r=0$	29.35***	21.44***
$r\leq 1$	13.61*	9.34
$r\leq 2$	8.96	5.87

Notes: The null hypothesis is no co-integration for the three co-integration tests. In test equations, the intercept and time trend were included for Pedroni, whereas only the intercept was included for Fisher and Kao test. Lag lengths were selected using AIC for Kao test. r is the number of co-integration vectors.

*** Indicate 1% levels of significance.
** Indicate 5% levels of significance.
* Indicate 10% levels of significance.

renewable energy's influence on income is stronger than that of nuclear power, but that fossil fuel energy has the most influence on income in emerging markets such as MIST. In fact, new renewables play a significant role in the development of rural and remote areas for transmission and distribution. Producing new renewables energy can offer a viable alternative for sustainable economies.

4.3. Panel causality tests

The existence of a panel long-run co-integration relationship among real GDP, renewable/nuclear energy consumption, fossil fuel energy consumption, capital formation, and labor force suggests that there must be Granger causality in at least one direction. Therefore, to shed light on the direction of the causality, we performed VECM-based panel causality tests by using both annual data and estimated quarterly data. Tables 8 and 9 report the panel causality results for renewable energy consumption and nuclear energy consumption. Both the short-run Wald F-test results and the long-run t-test results are shown for each VECM.

By using actual annual data, the causality tests for MIST panel show pretty good performance, and the value of R^2 is larger than 0.84 for each equation in part A of Table 8. In part A of Table 9 for MS panel, the values of R^2, which are between 0.54 and 0.76, can be considered as relatively small. The performance difference between MIST and MS may come from the MIST test using

4×21 observations, versus MS test using only 2×21 observations. In order to strengthen the associated causality findings, this study employs the Gandolfo′s (1981) interpolation technique and the cubic spline interpolation method to generate quarterly estimates from annual time series for VECM. Five flow annual time series, including real GDP (Y), real gross fixed capital formation (K), total renewable energy consumption (R), nuclear energy consumption (N), and total fossil fuel energy consumption (F) are converted to quarterly estimates by using Gandolfo′s technique, and total labor force (L) time series is converted to quarterly estimates by using cubic spline curve. Furthermore, Gandolfo′s technique has been widely applied in a number of empirical studies (Tang, 2008; Ogun, 2010; Tang and Chua, 2012), and its detail formulation is given in Appendix A. Therefore, the quarterly sample data from 1991:Q1 to 2009:Q4 are used to run VECM for both panels. Based on the panel unit root tests, each quarterly series is a first order integration, I (1) for both panels. Next, based on the panel co-integration tests, there exists long-run co-integration relationship among variables. Finally, the results of panel causality tests using quarterly data are shown in part B of Tables 8 and 9 for MIST and MS, respectively. By comparing parts A and B, we see that the long-run causality tests results are consistent, while the short-run causality tests results show slightly inconsistent. By comparing to part A, the average values of R^2 are 0.07 and 0.25 higher in part B for MIST panel and MS panel, respectively. Due to the number of annual observations in MS is only half of the number of annual observations in MIST, using quarterly data in MS could substantially improve the value of R^2 comparing with the quarterly data in MIST, while most of the results of causality tests remain unchanged. This improvement may come from the increases of degree of freedom in the statistic tests, since there are more data items in the quarterly estimates.

The results reported in Table 8 indicate bidirectional causality between R and Y and unidirectional causalities from F to both Y and R in the short-run. With respect to the long-run dynamics, the ECTs in the Y, F, and L equations are statistically significant. This indicates bidirectional causalities between each of Y, F, and L, and unidirectional causalities from R to both F and Y but no causality running from both F and Y to R in the long run. The results suggest that economic growth, labor force, and fossil fuel energy consumption would each respond to bring the system back into equilibrium following a shock, but renewable energy consumption would not. The adjustment to long-run equilibrium induced by changes in real GDP would take approximately eight years. In comparison, these findings are not totally consistent with those of Apergis and Payne (2011a, 2011b, 2012a, 2012b, 2013). One reason of these differences may be because our study employs clean (renewable or nuclear) and non-clean (fossil fuel) energy consumption in co-integration and ECM equations, while previous study employs renewable and non-renewable energy

Table 7
Results of panel co-integration tests for MS countries, 1990–2010.

Test methods	Statistics	
Pedroni test		
Within dimension test statistics		
Panel ν-stat.	3.162***	
Panel ρ-stat.	0.609	
Panel PP-stat.	−1.442*	
Panel ADF-stat.	−1.603*	
Between dimension test statistics		
Group ρ-stat.	1.519	
Group PP-stat.	−4.933***	
Group ADF-stat.	−2.090**	
Kao test	*t*-Statistic	
ADF-stat.	−2.36***	
Johansen Fisher test		
Null hypothesis	Trace	Max. eigenvalue
$r=0$	30.21***	12.08***
$r\le 1$	20.58***	13.68***
$r\le 2$	9.50***	7.99***
$r\le 3$	4.23	2.96

Notes: The null hypothesis is no co-integration for the three co-integration tests. In test equations, the intercept and time trend were included for Pedroni, whereas only the intercept was included for Fisher and Kao test. Lag lengths were selected using AIC for Kao test. r is the number of co-integration vectors.

*** Indicate 1% levels of significance.
** Indicate 5% levels of significance.
* Indicate 10% levels of significance.

Table 8
Results of panel causality tests for MIST countries.

Dependent variable	Sources of causation (independent variables)						R^2
	Short-run *F stat.*			Long-run *t stat.*			
	ΔY	ΔR	ΔF	ΔK	ΔL	*ECT*	
Part A: causality tests using actual annual data, 1990–2010							
(5a) ΔY		37.64(+)***	7.85(+)***	1.43(−)	29.94(−)***	−2.67** [−0.12]	0.94
(5b) ΔR	8.61(+)***		4.87(−)**	7.03(−)***	2.24(+)	0.88 [0.25]	0.84
(5c) ΔF	0.14(+)	0.46(−)		31.35(−)***	65.41(−)***	1.87* [0.13]	0.84
(5d) ΔK	1.98(−)	3.94(+)**	2.81(+)*		14.33(+)***	0.19 [0.06]	0.96
(5e) ΔL	18.02(−)***	0.33(−)	1.51(−)	14.28(+)***		−3.17* [−0.40]	0.87
Part B: causality tests using estimated quarterly data, 1991:Q1–2009:Q4							
(5a) ΔY		18.88(+)***	16.00(+)***	7.58(−)***	8.24(+)***	−1.79* [−0.0028]	0.99
(5b) ΔR	14.65(+)***		5.69(−)***	3.32(−)**	4.97(−)***	0.59 [0.0052]	0.93
(5c) ΔF	1.01(−)	0.97(+)		0.49(+)	0.60(+)	−2.06** [−0.0036]	0.90
(5c) ΔK	7.35(−)***	14.13(+)***	5.49(+)***		9.66(+)***	−0.10 [−0.0005]	0.97
(5e) ΔL	21.68(−)***	1.69(−)	0.80(+)	18.55(+)***		−1.84* [−0.0002]	0.99

Notes: The lag lengths were selected using AIC. (+)/(−) represents whether the sum of the lagged coefficients on the independent variable is positive or negative, respectively. The coefficients of ECT are in brackets.

*** Indicate 1% levels of significance.
** Indicate 1% levels of significance.
* Indicate 1% levels of significance.

Table 9
Results of panel causality tests for MS countries.

Dependent variable	Sources of causation (independent variables)						R^2
	Short-run *F stat.*			Long-run *t stat.*			
	ΔY	ΔN	ΔF	ΔK	ΔL	*ECT*	
Part A: causality tests using actual annual data, 1990–2010							
(5a) ΔY		0.73(−)	8.12(+)***	0.79(−)	16.02(−)***	−1.79* [−0.15]	0.66
(5b) ΔN	2.61(+)		0.15(−)	15.78(−)***	5.85(+)**	−1.84* [−0.52]	0.70
(5c) ΔF	1.44(−)	17.66(+)***		6.96(+)**	7.33(−)**	0.02 [0.004]	0.54
(5d) ΔK	1.01(−)	16.43(+)***	0.01(−)		1.35(−)	−1.94* [−0.38]	0.63
(5e) ΔL	15.04(−)***	19.51(+)***	1.56(+)	10.64(+)***		−0.47 [−0.02]	0.76
Part B: causality tests using estimated quarterly data, 1991:Q1–2009:Q4							
(5a) ΔY		24.27(+)***	51.15(+)***	4.06(+)**	15.62(−)***	2.26** [0.0113]	0.87
(5b) ΔN	0.95(−)		1.92(+)	33.76(+)***	2.44(−)*	−5.14*** [−0.1642]	0.89
(5c) ΔF	0.75(−)	14.69(+)***		5.16(+)**	7.09(−)***	−0.31 [−0.0001]	0.88
(5d) ΔK	34.29(+)***	67.31(+)***	7.05(−)***		27.87(+)***	9.89*** [0.0783]	0.90
(5e) ΔL	4.52(−)**	2.83(+)*	0.14(+)	6.63(+)***		0.53 [0.0003]	0.99

Notes: The lag lengths were selected using AIC. (+)/(−) represents whether the sum of the lagged coefficients on the independent variable is positive or negative, respectively. The coefficients of ECT are in brackets.

*** Indicate 1% levels of significance.
** Indicate 1% levels of significance.
* Indicate 1% levels of significance.

consumption, and non-renewable energy usually includes both clean (nuclear) and non-clean (fossil fuel) energy sources.

In summary, the finding of unidirectional short-run causality from fossil fuel energy consumption to economic growth and bidirectional long-run causality between them suggests that the MIST countries should be an energy-dependent economies and that energy conservation policies may depress their economic development. This result is similar to those reported by Apergis and Payne (2011a, 2011b, 2012a, 2012b, 2013) in which there is a bidirectional long-run causality between economic growth and non-renewable energy consumption (including fossil fuel and nuclear). Second, the finding of unidirectional long-run causality from renewable energy consumption to economic growth and bidirectional short-run causality between them suggests that expanding renewable energy projects could enhance economic growth of MIST countries in both the short and long term. The converse is also true. As MIST's economy continues to grow, there will be more resources available to stimulate their renewable energy industry. Furthermore, while Apergis and Payne (2011a, 2011b, 2012a, 2012b, 2013) found bidirectional long-run causalities between economic growth and non-renewable energy consumption (including fossil fuel and nuclear), respectively and renewable energy consumption, the results of this study indicate no long-run causality running from either economic growth or fossil fuel energy consumption, respectively to renewable energy consumption. Findings imply that the governments of the MIST countries have a strong desire to promote renewable energy for sustainable development and to reduce their GHG emissions, regardless of economic growth. Finally, our finding of unidirectional long-run causality from renewable to fossil fuel energy consumption suggests that the expansion of renewable energy projects can curb environmental degradation and carbon emissions, and create an opportunity to move towards an energy-independent economy in the long term. Furthermore, while Apergis and Payne (2012a, 2012b, 2013) found a negative bidirectional short-run causality between renewable and non-renewable energy consumption (not fossil fuel), the result of this study differs somewhat. The negative impact of fossil fuel energy consumption on renewable energy consumption without feedback suggests that MIST emerging markets depend heavily on fossil fuel energy to meet demand, and there is an alternative relationship between renewable and fossil fuel energy.

For nuclear energy consumption in MS countries, the short-run results in Table 9 exhibit unidirectional causalities from *F* to *Y*, *N* to *F*, and *N* to *Y*, and no causalities from *F* and *Y* to *N*. With respect to the long-run dynamics, the ECTs in *Y*, *N*, and *K* equations are statistically significant, implying that there are bidirectional long-run causalities between each of *Y*, *N*, and *K*, unidirectional causalities from *F* to both *Y* and *N*, and that the three factors *Y*, *N*, and *K* would respond to bring the system back to equilibrium when a shock occurs. In comparison, the finding of bidirectional long-run causality between nuclear energy consumption and economic growth is consistent with Apergis et al. (2010) results for a panel of 19 developed and developing countries and partially consistent with those reported by Apergis and Payne (2010) and Lee and Chiu (2011), but contradict Nazlioglu et al. (2011). Nazlioglu et al. (2011) found no causality between nuclear energy consumption and economic growth for 11 out of 14 OECD countries, none of which were emerging economies. Lee and Chiu (2011) found a unidirectional long-run causality from economic growth to nuclear energy consumption for a panel of 6 highly industrialized countries, all of which are developed countries. Apergis and Payne (2010) found reverse causality for a panel of 16 countries, and the mean percentage of total electricity production from nuclear energy of these countries is very high. In summary, for the relationship between nuclear energy consumption and economic growth, nuclear power countries or developed countries relatively inclined to unidirectional causality, while emerging or developing countries more or less inclined to bidirectional causality.

Overall, the finding of no causalities from either fossil fuel energy consumption or economic growth to nuclear energy consumption in the short run suggests that nuclear power generation is stable and unlikely to be affected by fluctuations in economic growth and fossil fuel energy. The positive impact of nuclear energy consumption on fossil fuel energy consumption may be due to the huge energy demand in Mexico and South Korea's emerging markets as well as the high cost of disposal of radioactive waste for nuclear power. In the long run, the findings of causality running from fossil fuel energy consumption to nuclear energy consumption and bidirectional causality between economic growth and nuclear energy consumption suggest that an increase in fossil fuel energy consumption may lead to the consumption of nuclear energy in considering energy security and climate change issues, an increase in nuclear energy consumption may lead to the economic growth, and then that economic growth enhances nuclear power consumption in the long term. However, limiting nuclear and fossil fuel energy use would hamper economic growth or energy security, and economic growth enhances nuclear power consumption in MS countries.

5. Conclusions and policy implications

In light of the high volatility of energy prices, high growth in energy demand, and global warming caused by fossil fuels, clean energy (such as hydroelectricity, new renewables, and nuclear energy) has become an important alternative to fossil fuel energy. The aim of this study is to explore the causal relationship between clean and non-clean energy consumption and economic growth in the MIST countries in the period of 1990 to 2010. Two types of clean energy consumptions, renewable and nuclear, and fossil fuel non-clean energy consumption, are studied. The simultaneous use of clean and non-clean energy consumption in the framework of production function was intended to allow us to distinguish the relative influence of each type on economic growth and to analyze the substitutability between the different types of energy sources. Such disaggregate analysis can provide more robust bases to strengthening the sustainable energy policy settings in the MIST countries.

The panel co-integration tests reveal that there is a long-term equilibrium relationship between real GDP, capital formation, labor force, renewable/nuclear, and fossil fuel energy consumption for MIST/MS countries. This result is robust to possible cross-country dependence and still holds when allowing for structure breaks. For the two complete panels, the mean estimate of the fossil fuel energy consumption elasticity of real GDP is near 0.78, and the estimates of the renewable and nuclear energy consumption elasticity of real GDP are 0.18 and 0.09, respectively. This finding implies that a 1% rise in fossil fuel, renewable, or nuclear energy consumption entail a 0.78%, 0.18%, or 0.09% increase in real GDP, respectively. These findings suggest that the main driving force behind real GDP is fossil fuel, while renewable energy's influence on income is stronger than that of nuclear power in MIST if capital formation and labor force do not change. In fact, for emerging market, new renewables can play a significant role in the development of rural and remote areas for transmission and distribution. Producing new renewables energy can offer a viable alternative for sustainable economies.

The dynamic relationship between clean and non-clean energy consumption and economic growth provides conclusions for each of the three different types of energy consumption. First, there is a unidirectional long-run causality from renewable energy consumption to economic growth with positive bidirectional short-run causality for the MIST countries. This finding suggests that the expansion of renewable energy projects can enhance economic growth in MIST countries and also that as MIST's economy continues to grow, there will be more resources to stimulate their renewable energy industry. Furthermore, the findings of no long-run causality from either economic growth or fossil fuel energy consumption to renewable energy consumption imply that the governments of the MIST countries have a strong desire to promote renewable energy for sustainable development and to reduce their GHG emissions, regardless of economic growth. Second, there is a bidirectional long-run causality between nuclear energy consumption and economic growth but no short-run causality from either fossil fuel energy consumption or economic growth to nuclear energy consumption for MS countries. This result suggests that the generation of nuclear power is stable and unlikely to be affected by fluctuations in economic growth or fossil fuel energy, and also that MS emerging countries will increase their nuclear energy demand as their income increases in the long-run. However, limiting nuclear energy use would hamper economic growth in MS countries. For the relationship between nuclear energy consumption and economic growth, the results of comparative analysis show that nuclear power countries or developed countries more inclined to unidirectional causality, while emerging or developing countries more inclined to bidirectional causality. Third, there is a positive unidirectional short-run causality from fossil fuel energy consumption to economic growth with bidirectional long-run causality between them. This finding suggests that MIST countries should be energy-dependent economies and that economic growth will increase fossil fuel energy demand but also that limiting fossil fuel energy use would hamper economic growth. The development of both renewable and nuclear energy sources is a viable solution for addressing energy security and climate change issues.

For alternative energy issues, our empirical results show that there is a long-run causality running from fossil fuel energy consumption to nuclear energy consumption with short-run positive feedback effects. This finding suggests that the demand for fossil fuel energy will have significant impact on nuclear energy development in considering energy security and climate change issues. The finding of positive impact of nuclear energy consumption on fossil fuel energy consumption may be due to the high cost of nuclear radioactive waste disposal as well as the huge energy demand in MS emerging markets. Second, there is a long-run causality running from renewable to fossil fuel energy consumption. This finding suggests that expanding renewable energy projects in MIST countries could curb environmental degradation and carbon emissions and create an opportunity to move towards an energy-independent economy. Furthermore, the negative impact of fossil fuel energy consumption on renewable energy consumption without feedback suggests that MIST emerging markets depend heavily on fossil fuel energy to meet the demand, and there is an alternative relationship between renewable and fossil fuel energy.

In conclusion, this study not only clarifies the relationship between renewable/nuclear (clean energy) and fossil fuel (non-clean) energy consumption but also demonstrates the impact of clean energy use on economic growth. For emerging markets, the results show that increasing renewable or nuclear energy consumption enhances economic growth and that creating partnerships of clean and non-clean energy might enhance the sustainable energy economy. Thus, the governments should introduce incentivizing policies, such as investment subsidies, tax rebates, tax incentives, sales tax, and green certificate trading, to promote the development of a clean energy economy. For energy-dependent economies, to ensure energy security and stability, minimize the impact of high oil price volatility on macroeconomics, and reduce GHG emissions, the development of nuclear power must also continue to play a role but may give rise to the high cost of nuclear radioactive waste disposal, nuclear safety, and security risks. Additionally, in order to reduce emissions and not to adversely affect economic growth, energy conservation policies by increasing energy efficiency are also important.

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Appendix A

Based on the quadratic interpolation algorithm of Gandolfo (1981), the formulas to generate quarterly estimates from annual time series are as follows:

$$\text{1st Quarter}: z_i^{(1)} = 0.0546875 z_{t-1} + 0.234375 z_t - 0.0390625 z_{t+1} \quad (A.1)$$

$$\text{2nd Quarter}: z_i^{(2)} = 0.0078125 z_{t-1} + 0.265625 z_t - 0.0234375 z_{t+1} \quad (A.2)$$

$$\text{3rd Quarter}: z_i^{(3)} = -0.0234375 z_{t-1} + 0.265625 z_t + 0.0078125 z_{t+1} \quad (A.3)$$

$$\text{4th Quarter}: z_i^{(4)} = -0.0390625 z_{t-1} + 0.234375 z_t + 0.0546875 z_{t+1} \quad (A.4)$$

where z_{t-1}, z_t, and z_{t+1} are three successive annual observations of a continuous flow variable $z(t)$.

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