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Renewable Electricity Generation, CO_2 Emissions and Economic Growth: Evidence from Middle-Income Countries in Asia

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ABSTRACT

Over the past three decades there has been a steady growth in total electricity generation in Asia. Although most of this electricity came from natural gas and coal, renewable electricity generation also has significantly contributed to total electricity generation, with hydro being the largest source of renewables-based electricity. In this study, we analyze the dynamics between economic growth, emissions of carbon dioxide (CO_2) and the share of renewable electricity in total electricity generation in eleven Asian developing countries over the period from 1980 to 2010. The Structural Vector Autoregression (SVAR) methodology is used to study the interactions among the variables and to analyze the impact of expansion of renewable electricity on per capita emissions and economic wellbeing. Our results show that the majority of middle-income countries in Asia are likely to face a trade-off between economic growth and environment sustainability at least in the early years. Therefore, such countries may need to implement policies complementing renewable energy generation and improving energy efficiency.

Keywords: Renewable Energy, Electricity, Carbon Dioxide Emissions, Economic Growth.

Generación de electricidad renovable, las emisiones de CO_2 y crecimiento económico: Evidencia de países de ingresos medios en Asia

RESUMEN

Durante las últimas tres décadas ha habido un crecimiento constante en la generación total de electricidad en Asia. Aunque la mayor parte de la electricidad proviene del gas natural y el carbón, la generación de electricidad renovable ha contribuido de manera significativa a la generación total de electricidad, siendo la *hidraulica* la mayor fuente de electricidad basada en energías renovables. En este estudio analizamos la dinámica entre el crecimiento económico, las emisiones de dióxido de carbono (CO_2) y el peso de la electricidad renovable en la generación total de electricidad en once países asiáticos durante el período de 1980 a 2010. Se aplica la metodología del Vector Autorregresivo Estructural (SVAR) para estudiar las interacciones entre las variables y analizar el impacto de la expansión de la electricidad renovable en las emisiones per cápita y en el bienestar económico. Nuestros resultados muestran que la mayoría de los países de renta media de Asia es probable que se enfrenten a una disyuntiva entre crecimiento económico y sostenibilidad del medio ambiente, al menos en los primeros años, y, por lo tanto, en estos países puede ser necesario aplicar políticas que complementen la generación de energía renovable y la eficiencia energética.

Palabras clave: Energía renovable, electricidad, emisiones de dióxido de carbono, crecimiento económico.

JEL Classification: Q42, C23

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1. INTRODUCTION

Energy is an important input for economic development and the current world's energy supply is largely based on fossil fuels. Electricity, whether it is generated from fossil fuels or produced using renewable energy sources, is one of the most important inputs used in production of goods and services. The growth in renewable energy means creation of new jobs, changing the structure of the economy and has a lot of environmental benefits, however, since 1990 worldwide growth in renewable electricity generation was only 3 per cent on average, with average growth rates in OECD and non-OECD countries being 1.9 per cent and 4.2 per cent respectively (International Energy Agency, 2012). While the contribution of hydro energy has decreased (rom 18.2 per cent in 1990 to 16.1 per cent in 2010), the contribution of other renewable sources used to produce electricity grew from 1.3 per cent in 1990 to 3.4 per cent in 2010 (International Energy Agency, 2012). Out of these sources, during the last decade electricity generation from wind and solar photovoltaic (PV) grew on average by 27 per cent and 42 per cent respectively (International Energy Agency, 2012). As compared to other world regions, in Asia there has been a steady growth in total electricity generation over the past two decades. Although most of this electricity came from fossil fuels (natural gas and coal), a share of renewable electricity generation in total electricity generation has been growing with hydro being the largest source of renewables-based electricity (13.4 per cent in 2008) (International Energy Agency, 2012).

Given the benefits that renewable energy offers in terms of creating jobs, establishing energy security and achieving sustainable development, currently governments of many countries are promoting the use of renewable energy and electricity supply. Yet, the current literature on the subject has not come to conclusion of how exactly the renewable energy contributes towards their economic growth and reduction of environmental pollution and can be divided into three strands. First are the studies investigating the contribution of energy towards economic growth; studies in the second strand focus on the relationship between economic growth (energy consumption) and emissions of greenhouse gases (GHG), and the third strand includes the literature on the relationship between economic growth, energy and emissions. While, literature from the first two strands is voluminous, literature from the third is relatively unexplored.

Overall, using large array of econometric methods (for example based on univariate and panel causality and cointegration tests, Granger causality tests, Structural Equation modeling and other approaches) the literature could not uniformly confirm the relationship between energy consumption from different sources including renewable energy and GDP which in some cases might be non-linear (Narayan *et al.,* 2008; Sadorsky, 2009; Soytas & Sari, 2009). Following Payne (2009, 2010), some of the studies have confirmed the growth hypothesis (energy consumption contributes towards higher economic growth), others analyzed the conservation hypothesis (economic growth drives consumption of energy) and a few studies analyzed the neutrality hypothesis (no causal relationship between economic growth and energy consumption).

Among papers that study the impact of production of energy on economic wellbeing are Domac *et al*., (2005), Awerbuch and Sauter (2006), Chien and Hu (2007). Domac *et al*., (2005) and Awerbuch and Sauter (2006) proposed that the use of renewable energy (bioenergy in Domac *et al.'s* terminology) can lead to the substantial improvements in country's efficiency. Domac *et al.,* (2005) suggested that such improvements could arrive from two sources. First is the business expansion and growth in employment associated with renewable energy projects and second is the import substitution of energy. Using hierarchical regression Chien and Hu (2007) empirically tested Domac *et al.'s* (2005) ideas by investigating whether renewable energy contributes to the improvement in macroeconomic technical efficiency for a panel of 45 economies from 2001 to 2002. They have confirmed the hypothesis that renewable energy improves technical efficiency particularly if decomposed into different categories. Awerbuch and Sauter (2006) have studied the microeconomic consequences of the oil -Gross Domestic Product (GDP) relationship and have found that oil-GDP induced losses (after oil price shock) can be largely reduced through investments in renewable energy due to reduction of negative effects of oil price volatility and by providing energy security.

Similar to the first strand of literature, the relationship between economic growth (or energy consumption) and different polluting substances have also been largely studied using different methodologies and theories (Silva *et al.*, 2011). The existence of relationship between economic growth and pollutants is typically investigated in the context of an Environmental Kuznets Curve (EKC) (see for example Jalil and Mahmud, (2009); Jaunki, (2011); Saboori *et al.,* (2012)). If originally literature focused on developed economies, the more recent literature changed focus to developing economies, GHG other than carbon dioxide (CO_2) and to investigating the role of energy from renewable energy sources in stabilizing or even reducing the concentration of GHG in the atmosphere (see Green *et al.,* (2007)).

In terms of the third strand of literature, the relationship between economic growth, energy and environment has not yet been well established, especially when it comes to supply of renewable energy. To date there is no clear cut answer on how exactly energy supply contributed to GDP in the world with constrained fossil fuel supply and a need to reduce GHG emissions. This is because of several reasons. First, renewable energy sources are used differently in developing and developed nations. According to IAE (2011), in 2010, world Total Primary Energy Supply (TPES) was 12,782 million tons of oil equivalents

(Mtoe), of which 13 per cent, or 1,657 Mtoe, was produced from renewable energy sources. 69.2 per cent of global renewables supply (or 9 per cent of the TPES) can be attributed to developing nations. Such large share of renewables (largely solid biofuels) in developing nations is for non-commercial use (residential heating and cooking), while developed nations, particularly OECD, account for most of the world production and growth of solar and wind energy which can be used for the purposes of generating electricity (International Energy Agency, 2011, 2012). Second, following Domac *et al.,* (2005) developing and developed economies understand and interpret renewable energy supply sector differently. While in developing nations, bioenergy is an important source of fuel for subsistence, which can contribute to income in the off-harvest season, in developed nations renewable energy (solar energy) can be used by the individuals to generate their own electricity for residential use. In developed economies, it is promoted by the governments due to its environmental benefits, job creation, industrial competitiveness and regional development (Domac *et al.,* 2005). Third, in the developed countries there is a direct link between emissions and the supply of energy through climate change mitigation policies such as emissions trading schemes, renewable energy targets and environmental taxes. In the developing countries in Asia such link might not yet been established. For instance, while India and China have started pilot emissions trading schemes in selected provinces and cities, in other countries such initiatives are only at the early stages.

Given the different nature of use of renewable energy sources, the contribution of renewable energy towards economic growth and emissions of GHG in developed and developing nations could be different. Among the few papers in this area are Silva *et al.,* (2011), Azgun (2011) and Tiwari (2011). Silva *et al.,* (2011) studied the impact of renewable energy sources on economic growth and emissions of carbon dioxide CO_2 in four developed countries (Denmark, Portugal, Spain and USA) with annual data over the period 1960 to 2004 using Structural Vector Autoregression (SVAR) methodology. They found that although an increase in the renewable electricity generation may initially harm economic growth for all countries except for the USA, it contributes to reduction in emissions. Azgun (2011) and Tiwari (2011) studied the impact of shock in renewable electricity generation on economic growth and CO_2 in developing economies. Tiwari (2011) used SVAR to analyze the dynamics of hydroelectricity consumption, economic growth and CO_2 emissions in India. He found that a positive shock on hydroelectricity consumption is likely to increase real GDP and cause a reduction in CO_2 emissions. Azgun (2011) used SVAR to examine the impact of the aggregate and sub-components of electricity consumption on the real GDP for Turkey. He found that while the impact of electricity consumption on GDP was somewhat small, the innovations in GDP have a more profound effect on electricity consumption.

In this study, we analyze the dynamics between economic growth, emissions of CO_2 and renewable electricity generation in middle-income (developing) countries of Asia. CO_2, our proxy for environment, was chosen because it is one of the most polluting GHGs and GDP per capita growth was chosen as a proxy of the growth in economic wellbeing. In particular, this paper analyzes how GDP per capita growth and percentage changes in CO_2 emissions have responded to exogenous shocks in the share of renewable electricity supply out of total electricity over the past three decades. The dynamic nature of renewable electricity generation makes this question well suited for SVAR models. SVAR models are extensively used in the applications where variables are jointly determined and the adjustment to the long run equilibrium relationship is not instantaneous which requires inclusion of lags in the model (Hausman *et al*., 2012). In addition, the dynamic nature of the model allows estimating forecast error variance decompositions (FEVDs) and the impulse response functions (IRFs). The former explains the percentage of variance arising from the specific shock, the latter allows tracing out the effect of the exogenous shock over time (Hausman *et al.,* 2012).

Demand for electricity is rapidly increasing in developing countries and if the present growth rates continue, social and economic development in many developing countries would suffer due to major constrains in the availability of energy. The inaccessibility of adequate energy sources and climate change mitigation are the major challenges to the development process in many developing countries. Therefore, renewable energy sources are very attractive and important in electricity generation in developing countries. In particular this refers to developing countries which achieved middle income status since these countries might be in a position to afford investments in renewable energy as compared to low-income countries. Asian countries are the focus of this study due to several reasons. First, economic growth in the Asian region has overtaken the rest of the world. Second, Asia is home for more than half of the world population. Third, energy poverty and access to electricity is a serious issue for Asia: out of 4.1 billion people living in Asia and Pacific, 1.9 billion people depend on burning traditional biomass for energy and 670 million do not have access to electricity services (International Energy Agency, 2011, 2012). The above mentioned reasons are exerting a huge pressure on the electricity generation in middle-income Asian countries.

The paper contributes to the literature in three ways. First, in contrast to previous studies, we focus on the electricity production, not consumption and analyze electricity generation from the renewable resources. Second, to evaluate the effect and extent of economic and environment factors on renewable energy share, we focus on eleven low and upper middle income countries from Asia including China, Fiji, India, Indonesia, Lao People Democratic republic, Malaysia, Pakistan, Papua New Guinea, Philippines, Sri Lanka and Thailand from

1980 to 2010. The choice of these countries was partly dictated by the data availability. Third, we utilize a tri-variate SVAR model. Although SVAR models are routinely used in the macroeconomic literature in the analysis of monetary, fiscal and technological shocks (Enders, 2004), in the energy literature these models are mainly used in the analysis of price or policy shocks. For instance, SVARs have been recently used to model the impact of shocks on biofuels (Cha & Bae, 2011; Zhang *et al.,* 2007) the impact of ethanol on global oil markets (McPhail., 2011), impact of energy consumption and production on other macroeconomic variables (Azgun, 2011; Tiwari, 2011), impact of price shocks on the economy of different countries (Farzanegan & Markwardt, 2009), and model global energy market (Killian, 2010).

The remainder of the paper is organized as follows. Section 2 briefly outlines countries in the middle-income Asia and data used in the paper. Section 3 presents methodology used in the paper. Discussion of the results is provided in Section 4 and Section 5 concludes the paper.

2. MIDDLE-INCOME COUNTRIES IN ASIA

In this paper, countries are classified as middle-income based on the International Monetary Fund (IMF) country classification (International Monetary Fund, 2012). This classification divides nations according to Gross National Income per capita, calculated using the World Bank Atlas method. Based on the 2006 figures revised in 2007, the groups are: low income ($905 or less), lower middle-income ($906 - $3,595), upper middle-income ($3,595 - $11,115) and high income ($11,166 or more) (World Bank, 2012).

There has been a steady growth in the total electricity generation in Asia; however, this growth is largely met with new gas and coal generation. Electricity generation using renewable resources is predominantly from hydro. Geothermal plants in Indonesia and Philippines contribute to electricity generation and expect to increase rapidly with new plants construction in both nations (International Energy Agency, 2011). In this section, we will briefly discuss countries used in the analysis.

China (CHN)

Electricity generation in China is mainly from fossil fuels. Coal dominates the electricity generation at 79 per cent and the next largest share is hydro (17 per cent) The rest of the electricity generation is met through other renewables (2.5 per cent) and nuclear power (1.5 per cent) (Central Intelligence Agency, 2012). China has ambitious nuclear and renewable plans for the coming decade to displace coal slowly. Electricity-related CO_2 emissions have increased over past 10 years even though the emission intensity of coal generation has improved (International Energy Agency, 2011).

Fiji (FJI)

Fiji has a number of renewable energy resources such as hydro, biofuel, geothermal, wind, solar and ocean energy resources. Around 66.8 per cent of the country's electricity requirements are met from renewable energy sources which include; 62.1 per cent hydro, 0.6 per cent wind and 4.1 per cent other renewable resource. Imported petroleum for diesel back-up generators, meets the remaining balance of 33.2 per cent. Currently, the contribution of the electricity sector to GDP is about 3.6 per cent (Fiji Department of Energy, 2010).

India (IND)

Coal dominates the power generation mix in India, though renewable resources now account for approximately 10 per cent of the installed capacity. The total power generation capacity in India in March 2010 was 159 GW. Of this, 64.3 per cent was fossil-fuel-fired power plants (coal, gas, and diesel), 23.1 per cent hydropower, 2.9 per cent nuclear power, and 9.7 per cent renewable energy (Arora D.S. *et al.,* 2010). Emission intensity of CO_2 for electricity generation has increased over the last decade and the National Action Plan has identified hydro, wind and solar as priorities for future development (International Energy Agency, 2011).

Indonesia (IDN)

Indonesia is one of the leading exporters of steam coal in the world and also one of the largest exporters of natural gas. Since 2004, country's oil production has been declining and as a result of not being able to satisfy the oil demand, Indonesia became a net importer of oil. Indonesia is one of the two countries in the South East Asia with abundant sources of geothermal energy. At present renewable energy accounts for a small but growing portion of Indonesia's electricity portfolio. Most renewable energy comes from the hydropower and geothermal industries, but growth in other sectors is likely. Around 25 per cent of the country's electricity requirements are met from renewable energy sources which include; 22 per cent biomass, 2 per cent hydro power and 1 per cent geothermal (International Trade Administration, 2010). The projected primary energy supply in 2025 shows renewable energy playing an increasingly important role, particularly for geothermal and biofuels (Olz & Beerepoot, 2010).

Laos (LAO)

The majority of electricity generation in Laos is done through hydro power which supplies about 97.5 per cent of electricity produced and the rest is generated using fossil fuels. Energy consumption in the country is mainly in the form of traditional fuels such as fuel wood (56 per cent) and charcoal (12 per cent) for cooking and heating in rural areas. This represents around 69 per cent of the total energy consumption (Vostroknutova, 2012).

Malaysia (MYS)

Malaysia has large reserves of natural gas and crude oil and is one of the largest exporters of natural gas in the world. Coal needs of the country are largely covered by imports. Although at present only 6 per cent of the country's electricity generation comes from hydro and biomass (Olz & Beerepoot, 2010). Malaysia is endowed with a variety of renewable energy resources such as biomass, solar, hydro and wind power. The majority of electricity generation is done using coal, natural gas and diesel (Mekhilef, 2010).

Pakistan (PAK)

The current energy supply matrix for Pakistan is a composite of various technologies. Fossil fuels form the bulk of electricity supply contributing 65 per cent (oil, gas, and coal). The hydro energy provides approximately 33 per cent of the electricity supply and nuclear power generation contributes 2 per cent (Khalil *et al.,* 2008).

Papua New Guinea (PNG)

PNG is endowed with renewable energy resources (mostly hydro) and has a vast potential to generate electricity using renewable resources. However, at present about 60 per cent of total electricity generation is through fossil fuels and the rest is produced using hydro power (Central Intelligence Agency, 2012).

Philippines (PHL)

Although Philippines is highly dependent on imports of fossil fuels, the country is one of the largest producers of geothermal energy in the world. To date, the total installed capacity of the Philippines' power generating plants is recorded at 15,937 megawatts. Although coal-fired power plants reflect 26 per cent of power generation followed by oil-based at 23 per cent, the resources such as hydro, natural gas, and geothermal now account for 17 per cent, 15 per cent and 20 per cent respectively (Department of Trade and Industries, 2010). Although currently geothermal energy accounts for about one fifth of the energy demand of the country, it could be developed further (Olz & Beerepoot, 2010).

Sri Lanka (LKA)

Electricity generation in Sri Lanka is primarily from thermal and hydro. Approximately 54 per cent of total electricity is generated using thermal power plants and 45 per cent and 1 per cent and produced from hydro and other renewable sources respectively. Thermal power in Sri Lanka is either generated using diesel, gas, coal or other fuel oils (Central Bank of Sri Lanka, 2011).

Thailand (THA)

Thailand has a relatively diversified energy sector with production of all fossils fuels as well as hydroelectricity. The production is not sufficient to cover country's energy needs: Thailand is a net importer of fossil fuels as well as electricity. Electricity production is predominantly based on thermal and combined cycle generation, with natural gas accounting for 69 per cent and coal about 20 per cent. The remaining is made up of 6 per cent large-scale hydropower, 2 per cent fuel oil, and 3 per cent others (mainly imports from Laos and less than 1 per cent from renewables) (Amatayakul W. & Greacen, 2002). Nevertheless, the uptake of renewable energy sources is actively promoted by the government in a 15-year development plan introduced in 2008 which targets an increase in renewable energy's share of total final energy demand to 20 per cent by 2022 (Olz & Beerepoot, 2010).

In this study we use real per capita Gross Domestic Product (*GDPpc*), CO_2 emissions (CO_2pc) and the ratio of electricity derived from renewable energy sources to total electricity generation (*RETR)* (in billion kilowatt hours). The source of CO_2 emissions and electricity data is the US Energy Information Administration, while GDP (constant 2000 prices in US dollars) is from the World Bank Development Indicators database. For Laos, first four years of GDP data were missing, therefore, for this country we have used data from IMF's World Economic Outlook database. Since this data was in current US$, to get real *GDPpc* for Laos, we have deflated the series using US deflator with base year 2000. In line with previous studies (Apergis & Payne, 2010; Narayan *et al.,* 2008) all variables were transformed to natural logarithms and taken first differences to proxy annual growth rates.

Tables 1 and 2 and Figures 1, 2 and 3 show some interesting patterns for the countries in the sample. Malaysia has the highest average emissions and *GDPpc*, while Laos has the lowest. At the same time Laos has the largest average ratio of renewable electricity to total electricity, followed by Sri Lanka and Fiji. In our sample, eight countries out of 11 have average $RETR$ less than 40 per cent with the smallest average $RETR$ being in Thailand. Jarque Bera normality test statistics reveal that for some series (e.g. Fiji, Malaysia, Pakistan and Thailand $RETR$; China *GDPpc* and CO_2pc**)** a null hypothesis of a normal distribution can be rejected.

Table 1

Descriptive statistics of all variables for countries: levels

		CHN	FJI	IND	IDN	LAO	MYS	PAK	PHL	PNG	LKA	THA
Renewable energy share (*RETR)*	Mean	0.20	0.72	0.22	0.17	0.94	0.14	0.40	0.40	0.34	0.71	0.11
	Median	0.19	0.78	0.18	0.17	0.95	0.12	0.43	0.38	0.30	0.73	0.08
	Maximum	0.26	0.87	0.39	0.21	0.97	0.30	0.59	0.49	0.57	1.00	0.24
	Minimum	0.16	0.16	0.12	0.11	0.89	0.07	0.27	0.27	0.24	0.37	0.05
	Std. Dev.	0.02	0.16	0.08	0.02	0.03	0.07	0.09	0.06	0.09	0.23	0.05
	Skewness	0.59	-1.83	0.85	-0.15	-0.19	0.95	0.27	0.01	1.14	-0.19	1.20
	Kurtosis	2.79	6.53	2.60	2.88	1.47	2.73	2.26	1.82	3.48	1.42	3.15
	Jarque-Bera	1.84 (0.40)	30.20*** (0.00)	3.91 (0.14)	0.13 (0.94)	3.22 (0.20)	4.75* (0.09)	1.09 (0.58)	1.80 (0.41)	7.02** (0.03)	3.40 (0.18)	7.45** (0.02)

Table 1 (continue)
Descriptive statistics of all variables for countries: levels

		CHN	FJI	IND	IDN	LAO	MYS	PAK	PHL	PNG	LKA	THA
GDP per capita *(GDPpc)*	Mean	848.42	1967.86	412.69	717.03	298.48	3385.83	490.86	1067.16	659.74	754.46	1713.35
	Median	657.99	1955.29	367.28	748.32	273.64	3581.95	494.72	1045.46	627.68	704.32	1858.00
	Maximum	2426.33	2335.32	794.80	1145.39	555.52	5168.69	664.71	1383.41	800.99	1308.78	2712.51
	Minimum	186.44	1612.41	230.01	390.01	104.78	1909.62	339.43	896.96	566.87	441.79	785.02
	Std. Dev.	640.38	235.17	160.07	218.71	114.16	1064.66	91.68	128.72	62.80	250.05	617.76
	Skewness	1.01	0.08	0.87	0.12	0.56	0.09	0.32	0.86	0.90	0.67	-0.12
	Kurtosis	2.98	1.72	2.71	1.99	2.66	1.64	2.31	2.92	2.69	2.34	1.72
	Jarque-Bera	5.28** (0.07)	2.16 (0.34)	4.04 (0.13)	1.38 (0.50)	1.71 (0.43)	2.44 (0.29)	1.14 (0.56)	3.84 (0.15)	4.32 (0.12)	2.85 (0.24)	2.19 (0.33)
CO_2 per capita *(CO_2pc)*	Mean	2.72	1.80	0.86	1.07	0.12	4.25	0.61	0.72	0.67	0.44	2.25
	Median	2.30	1.43	0.88	1.08	0.11	4.40	0.65	0.75	0.65	0.39	2.46
	Maximum	6.26	3.22	1.45	1.74	0.20	6.44	0.82	0.87	0.87	0.65	4.15
	Minimum	1.44	1.08	0.43	0.57	0.04	1.96	0.40	0.47	0.53	0.28	0.68
	Std. Dev.	1.29	0.71	0.27	0.37	0.07	1.40	0.13	0.13	0.09	0.13	1.16
	Skewness	1.32	0.78	0.37	0.15	0.14	-0.14	-0.17	-0.44	0.42	0.28	0.02
	Kurtosis	3.60	2.00	2.37	1.85	1.19	1.75	1.95	1.82	2.10	1.40	1.61
	Jarque-Bera	9.41*** (0.01)	4.16 (0.12)	1.20 (0.55)	1.82 (0.40)	4.34 (0.11)	2.13 (0.34)	1.58 (0.45)	2.77 (0.25)	1.93 (0.38)	3.72 (0.16)	2.52 (0.28)

Note: Values in parenthesis correspond to p-values.

Source: Own elaboration.

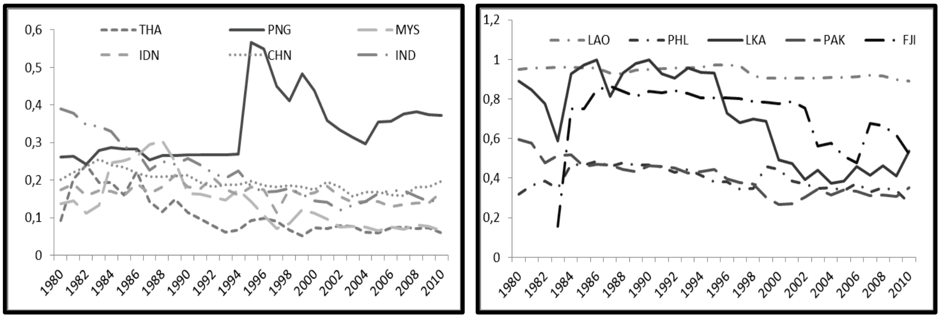
Table 2
Descriptive statistics of all variables for countries: growth rates

		CHN	FJI	IND	IDN	LAO	MYS	PAK	PHL	PNG	LKA	THA
Renewable energy share ($RETR$)	Mean	-0.07	4.44	-3.20	-0.14	-0.22	-2.49	-1.75	1.17	-0.51	-1.68	-1.47
	Median	-0.46	-0.70	-3.68	-0.23	0.04	-3.51	-1.43	0.00	-2.32	-2.09	-4.10
	Maximum	14.01	156.29	14.27	43.66	1.92	61.82	13.83	74.38	30.49	45.62	77.91
	Minimum	-14.73	-29.48	-20.78	-42.58	-5.38	-41.40	-19.35	-20.18	-21.11	-33.22	-45.09
	Std. Dev.	6.51	32.08	9.00	15.76	1.30	21.64	8.28	16.23	10.83	16.19	25.51
	Skewness	0.16	4.12	0.00	0.07	-2.23	0.64	-0.22	3.09	1.10	0.57	0.99
	Kurtosis	2.74	20.16	2.36	4.46	9.78	4.20	2.84	15.08	4.80	4.14	4.31
	Jarque-Bera	0.21 (0.90)	407.61*** (0.00)	0.51 (0.78)	2.71 (0.26)	82.27*** (0.00)	3.84 (0.15)	0.27 (0.87)	230.21*** (0.00)	10.16** (0.01)	3.23 (0.20)	7.08** (0.03)
GDP per capita *(GDPpc)*	Mean	4.83	2.34	4.08	3.46	1.31	3.97	2.44	1.23	0.85	2.34	5.87
	Median	4.66	4.23	3.75	3.73	2.28	3.20	2.23	-1.31	-0.26	2.05	6.71
	Maximum	21.86	25.16	15.17	9.35	52.09	18.86	12.03	32.50	14.11	13.59	16.83
	Minimum	-4.54	-31.87	-6.84	-8.10	-93.54	-8.94	-7.46	-9.21	-10.64	-18.76	-9.40
	Std. Dev.	5.85	13.81	4.24	4.07	21.69	6.02	4.35	7.77	5.89	7.57	6.43
	Skewness	0.94	-0.72	0.37	-0.70	-2.36	0.62	-0.07	2.29	0.45	-0.97	-0.56
	Kurtosis	4.11	3.33	4.58	3.51	14.30	3.57	2.74	9.83	3.00	3.81	2.89
	Jarque-Bera	5.98* (0.05)	2.47 (0.29)	3.78 (0.15)	2.77 (0.25)	187.43*** (0.00)	2.36 (0.31)	0.11 (0.95)	84.52*** (0.00)	1.00 (0.61)	5.52* (0.06)	1.58 (0.45)
CO_2 per capita *(CO_2pc)*	Mean	8.72	1.14	4.15	3.52	5.75	3.29	2.17	0.59	0.78	3.58	4.15
	Median	8.90	0.87	3.65	4.33	4.32	4.37	2.02	0.27	1.54	3.43	4.10
	Maximum	12.84	7.66	7.90	6.92	61.63	7.03	5.62	14.21	5.67	6.72	10.65
	Minimum	2.26	-7.27	-1.00	-15.42	-4.82	-10.10	-1.65	-6.63	-10.36	0.05	-12.29
	Std. Dev.	2.54	3.90	2.32	4.14	11.14	3.92	1.79	4.95	3.74	1.73	4.48
	Skewness	-0.64	-0.26	-0.02	-3.46	4.53	-1.78	-0.03	0.72	-1.75	-0.29	-1.75
	Kurtosis	3.75	2.49	2.16	16.35	23.49	6.05	2.62	3.51	6.07	2.50	7.53
	Jarque-Bera	2.65 (0.26)	0.60 (0.74)	0.85 (0.65)	273.44*** (0.00)	606.21*** (0.00)	26.62*** (0.00)	0.17 (0.92)	2.80 (0.24)	26.19*** (0.00)	0.70 (0.71)	39.63*** (0.00)

Note: Values in parenthesis correspond to p-values.

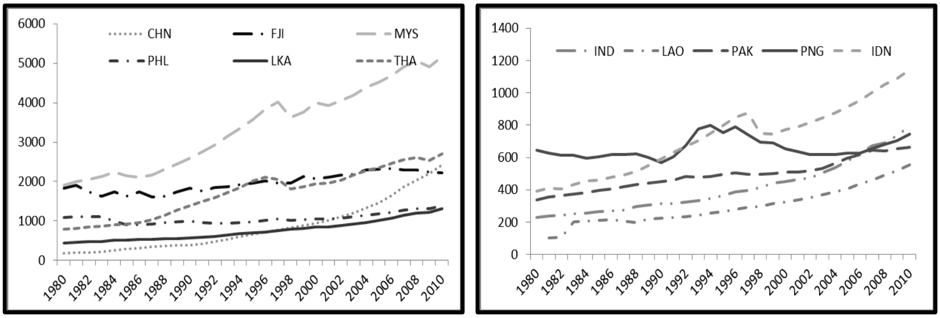
Source: Own elaboration.

Figure 1
Renewable electricity generation to total electricity generation (*RETR*)



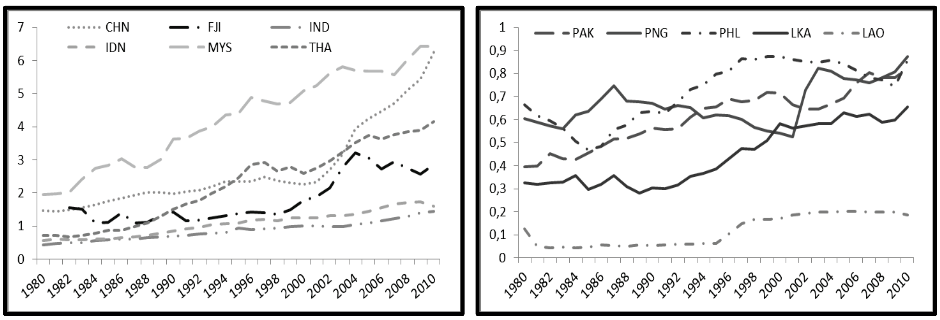
Source: Own elaboration.

Figure 2
GDP per capita (*GDPpc*)



Source: Own elaboration.

Figure 3
CO_2 per capita emissions *(CO_2pc)*



Source: Own elaboration.

3. METHODOLOGY

Although it is common in the literature to use Augmented Dicky Fuller (ADF) and Phillips Perron (PP) unit root tests, such conventional tests suffer from lack of power in small samples. Therefore, to test stationarity properties of the variables we employ the M-tests of Ng-Perron (2001). These tests were originally proposed by Stock (1999), expanded by Perron and Ng (1996) and modified by Ng and Perron (2001) in line with Elliot *et al.,* (1996). In these tests Ng and Perron (2001) applied Generalized Least Squares (GLS) detrending to estimate the deterministic components of an ADF regression. The purpose of such detrending is to achieve non-negligible size and power gains (Ng & Perron, 2001). Ng and Perron (2001) proposed four M-tests including MZa and MZt tests (based on PP unit root tests), MSB (based on Sargan and Bhargava, (1983)) and Modified feasible point optimal test (MPT). In all four tests, the null hypothesis of a unit root is tested against stationary alternative. Ng and Perron argued that for these unit root tests the choice of appropriate lag length is extremely important and proposed the Modified Akaike Information Criterion (MAIC). To prevent size distortions MAIC selects a relatively long lag length if large negative moving-average root near unity is present. To prevent a loss in power, MAIC selects a relatively short lag length in the absence of such root.

In this paper we use SVAR methodology to investigate the interactions among all variables and to identify the impact of the expansion in renewable electricity generation to economic growth and environment proxies. A number of papers in the energy literature (see for example Lee & Chang, 2007; Soytas & Sari, 2009 have used vector auto-regression (VAR) models to analyse the impact of shocks on economic systems. VAR models, where all variables are treated symmetrically using equations explaining evolution of every variable based on its own lags and the lags of all the other variables in the model, are designed to study the linear interdependencies among multiple time series (Piroli *et al.,* 2012). These models can be seen as a 'theory-free' approach to estimate economic relationships (Piroli *et al.,* 2012). Following Ferreira *et al.,* (2005) VAR methodology is often used to study the dynamic impacts of various random shocks on the variables in the model. However, because VAR is a reduced-form approach, first, it does not consider the structural relationships among the variables unless some identification restrictions are assumed (Silva *et al.*, 2011) and second, it could be difficult to interpret the results unless VAR is linked to an economic model (McPhail., 2011). Therefore, compared to a standard VAR approach, SVAR analysis is an attempt to solve the traditional identification problem (Silva *et al.,* 2011) because SVAR allows imposing restrictions on the contemporaneous relationship between the variables in the model (McPhail., 2011) and facilitates the interpretation of the contemporaneous correlations among disturbances (Amisano & Giannini, 1997). Since such restrictions can be based on the economic model or reveal information about the dynamic properties of the economy investigated (Silva *et al.,* 2011, p. 7), SVAR models allow better understanding of the economic behavior. In particular, in this paper we are investigating the impact of changes in the current energy supply mix (i.e. positive shock in the renewable electricity generation) on the economic growth and pollution.

Similar to Silva *et al.,* (2011), we develop a three-variable SVAR. Three variables are defined as a vector $X_t=(RETR_t,GDPpc_t,CO_2pc_t)$ where $RETR_t$ is the growth rate in the ratio of renewable electricity to total electricity generated from all sources, $GDPpc_t$ is growth rate in per capita real GDP and CO_2pc_t is the change in CO_2 emissions per capita. SVAR is represented as

$$B_0X_t=\alpha+\sum_{i=1}^{p}B_iX_{t-1}+\varepsilon_t \quad (1)$$

Where p denotes the lag order of SVAR, ε_t represents the 3x1 vector of structural innovations which are serially and mutually uncorrelated ($E(\varepsilon_t\varepsilon'_t)=I$) and B_0 is a 3x3 non-identity matrix

$$B_0=\begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{23} & b_{33} \end{pmatrix} \quad (2)$$

The reduced form VAR can be written as

$$X_t=B_0^{-1}\alpha+\sum_{i=1}^{p}B_0^{-1}B_iX_{t-1}+e_t \quad (3)$$

Where e_t are the estimated residuals. With known B_0 structural shocks ε_t can be derived from the estimated residuals e_t from the restricted form VAR:

$$\varepsilon_t=B_0e_t \quad (4)$$

However, because coefficients in the structural matrix B_0 are not known, structural parameters are identified by imposing theoretical restrictions (McPhail., 2011). In line with Silva *et al.,* (2011) and Azgun, (2011), we made the following assumptions about SVAR specification. First, in this paper, only long-run restrictions are imposed. This is because in the short run current electricity supply mix is operating at the fixed current capacity, which can be changed if new electricity generation units either based on renewable energy or fossil fuels are built. Second, in the short run, $GDPpc_t$ is not affected, however it gets affected in the long run. Third, CO_2pc_t emissions affect $RETR_t$ in the long run, but not in the short run. Since in the analysed countries, currently there are no nation-wide emissions trading, there is no direct causality relationship between these variables. Last, in turn, $RETR_t$ affects $GDPpc_t$ in both short and long run, $GDPpc_t$ affects per capita emissions CO_2pc_t which in turn do not have a direct effect on both $RETR_t$ and $GDPpc_t$. These restrictions can be rewritten in a form of lower-triangular matrix B_0 with six parameters to be estimated:

$$B_0 = \begin{pmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{pmatrix} \quad (5)$$

The SVAR model was estimated for each country in the sample using the data discussed above using two-stage procedure. In the first stage, we obtained the OLS residuals from the reduced form VAR in Equation (3). For all counties the lag order was chosen according to the conventional lag-selection criteria (Akaike Information Criteria, Schwarz Information Criteria, Final Prediction Error and Hannan-Quinn). For all countries except for Fiji, lag order based on the information lag order was equal to one and for Fiji, two lags were used to estimate the VAR. Diagnostic tests (ARCH effects, normality, serial correlation and structural stability) were performed for each model and no violations were found. Estimation results are provided in Table A1 in Appendix. In the second stage, the SVAR for each country was estimated using a scoring algorithm proposed by Amisano and Giannini (1997) using restrictions identified in (5). The results are shown in Tables A2 in the Appendix.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Unit root tests

Table 3 presents the Ng and Perron's (2001) MZa, MZt, MSB and MPT test statistics. The null hypothesis of the unit root was not rejected for most of the series. The results are consistent among the variables and the countries in terms of a model with a constant (intercept) and no linear trend. In relation to , the null hypothesis of a unit root was not rejected for China, Laos and Sri Lanka. For Malaysia in the model with intercept and trend $RETR$ was found to be nonstationary variable at 1 per cent significance level. CO_2pc was found to be non-stationary I(1) variable for Indonesia in a model with intercept. When the tests were applied to differenced variables, unit root null was rejected for all series. To preserve space, we do not report Ng-Perron test results for the differenced data as the series were found to be stationary.

4.2. Impulse response analysis

To examine the dynamic responses of $GDPpc$ and CO_2pc to shocks in $RETR$, we use impulse response analysis. The impulse response functions (IRF) shows the effects of a one-time shock to one of the innovations on current and future values of endogenous variables (Farzanegan & Markwardt, 2009). Figure 4 shows IRFs based on one standard deviation shock positive shock to $RETR$

for all countries. Consistent with other studies, we consider responses up to ten years ahead.

Table 3
Ng-Perron (2001) unit root tests for series: levels in natural logarithms

		Intercept				Intercept and trend			
		MZa	MZt	MSB	MPT	MZa	MZt	MSB	MPT
RETR	*CHN*	*-3.71*	*-1.36*	*0.37*	*6.61*	*-8.00*	*-1.80*	*0.22*	*11.90*
	FJI	-3.71	-1.36	0.36	6.60	-5.47	-1.59	0.29	16.44
	IND	-0.08	-0.06	0.72	31.59	-5.14	-1.48	0.29	17.17
	IDN	-2.72	-1.17	0.43	8.99	-4.70	-1.45	0.31	18.82
	LAO	-1.71	-0.64	0.37	10.36	-6.14	-1.71	0.28	14.79
	MYS	-2.09	-0.86	0.41	10.26	-14.40*	-2.68*	0.19	6.35*
	PAK	-1.22	-0.67	0.54	16.41	-7.65	-1.75	0.23	12.33
	PNG	-5.51	-1.62	0.29	4.57	-8.44	-2.04	0.24	10.83
	PHL	-4.42	-1.31	0.30	5.82	-6.73	-1.63	0.24	13.65
	LKA	-2.57	-1.07	0.41	9.21	-5.06	-1.53	0.30	17.74
	THA	-1.59	-0.78	0.49	13.41	-2.80	-1.18	0.42	32.55
GDPpc	CHN	-38.24***	-4.25***	0.11***	0.97***	-16.61*	-2.81*	0.17	5.92*
	FJI	-0.48	-0.30	0.62	23.20	-11.57	-2.22	0.19	8.77
	IND	1.27	0.72	0.57	28.26	-0.22	-0.09	0.42	45.58
	IDN	0.62	0.37	0.61	28.01	-3.86	-1.39	0.36	23.59
	LAO	-22.01***	-3.17***	0.14***	1.62***	-23.84***	-3.44***	0.14***	3.91***
	MYS	0.61	0.43	0.71	35.67	-4.93	-1.52	0.31	18.22
	PAK	0.67	0.38	0.57	25.41	-3.30	-1.28	0.39	27.50
	PNG	-3.30	-1.14	0.34	7.28	-4.09	-1.38	0.34	21.70
	PHL	-5.03	-1.32	0.26	5.46	-9.18	-2.00	0.22	10.44
	LKA	-23.22***	-3.23***	0.14***	1.62***	-1.41	-0.54	0.38	35.08
	THA	-0.68	-0.33	0.49	16.27	-8.47	-2.01	0.24*	10.92
CO_2pc	CHN	-1.95	-0.58	0.30	8.81	-13.29	-2.42	0.18	7.72
	FJI	-0.81	-0.42	0.52	17.03	-5.87	-1.71	0.29	15.53
	IND	0.95	0.57	0.61	29.56	-6.78	-1.83	0.27	13.44
	IDN	-27.63***	-3.63***	0.13***	1.15***	-3.99	-1.20	0.30	20.41
	LAO	-0.58	-0.43	0.74	29.02	-2.34	-1.08	0.46	38.74
	MYS	0.69	0.58	0.84	47.75	-4.41	-1.37	0.31	19.70
	PAK	0.37	0.23	0.61	26.92	-5.42	-1.63	0.30	16.76
	PNG	-2.74	-0.85	0.31	7.93	-5.41	-1.55	0.29	16.54
	PHL	-4.53	-1.42	0.31	5.56	-3.20	-1.26	0.39	28.32
	LKA	-1.58	-0.64	0.41	11.34	-5.00	-1.58	0.32	18.20
	THA	-0.34	-0.19	0.56	20.64	-6.54	-1.72	0.26	13.95

*Note: Critical values are from Ng-Perron (2001) Model with intercept:(1) MZa asymptotic critical values for 1, 5 and 10% are -13.8, -8.1, and -5.7; (2) MZt asymptotic critical values for 1, 5 and 10% are -2.58, -1.98, and -1.67; (3) MSB asymptotic critical values for 1, 5 and 10% are 0.174, 0.233, and 0.267, and (4) MPT asymptotic critical values for 1, 5 and 10% are 1.78, 3.17, and 4.45. Model with intercept and trend: (1) MZa asymptotic critical values for 1, 5 and 10% are--23.8, -17.3, and -14.2; (2) MZt asymptotic critical values for 1, 5 and 10% are -3.42, -2.91, and -2.62; (3) MSB asymptotic critical values for 1, 5 and 10% are 0.143, 0.168, and 0.185, and (4) MPT asymptotic critical values for 1, 5 and 10% are 4.03, 5.48, and 6.67. ***, ** and * denote rejection of the null hypothesis at 1%, 5% and 10% significance levels. The lag order was chosen using the modified AIC (MAIC) criteria suggested by Ng and Perron (2001).*

Source: Own elaboration.

For most of the countries the positive shock in renewable electricity has led to increase in CO_2 emissions with the exception of Malaysia and China. In these two countries, a shock in ratio of renewable electricity generation growth has a negative impact on emissions, which reverted after second year and slowly dissipated after sixth year. For the remaining countries, the post shock increase in emissions was rather steep and fast (Laos, Pakistan, Indonesia and India), while for others (PNG and Philippines) it was more gradual. Figures also show that the shock caused a larger negative impact in the first period (see Figure 4), on average it took more years (7) for the shock to dissipate as compared to a case when a shock caused relatively smaller negative impact.

Figure 4
Accumulated response of shock in *RETR* organized by country

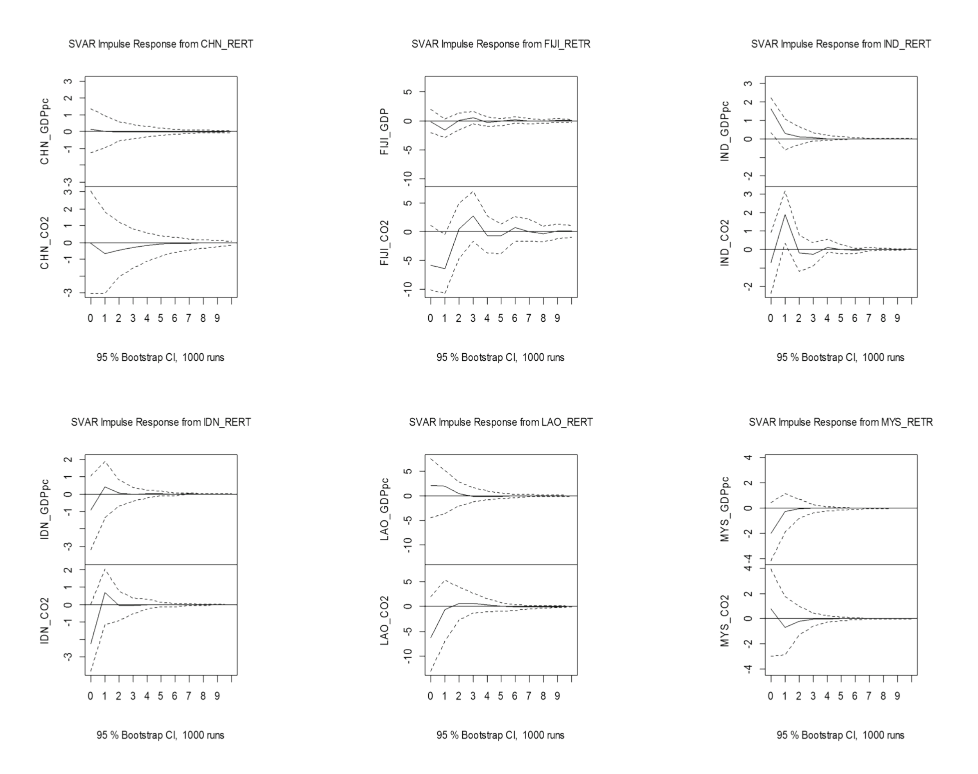
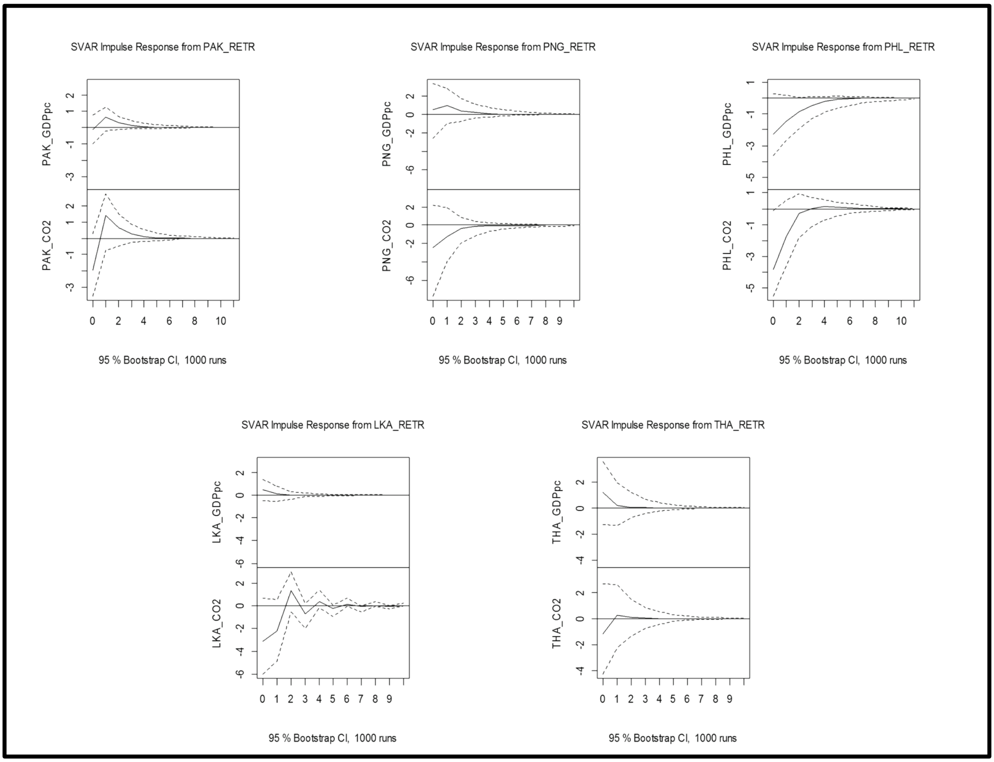


Figure 4 (continue)
Accumulated response of shock in *RETR* organized by country



Source: Own elaboration.

An increase in *RETR* caused a decline of five countries (Laos, India, Thailand -steep drop in first few years and then gradual dissipation, Sri Lanka and China- also a decline in economic activity but faster dissipation of the shock after 3rd year). This finding is in line with Silva *et al.,* (2011), who found that for developed countries positive shocks to *RETR* cause a decline in *GDPpc*. In PNG, Pakistan and Indonesia, an immediate response of a shock was an improvement in economic activity followed by a decline in year 2 and a slow dying in years 3 (Indonesia), 5 (Pakistan) and 7 (PNG). For Philippines and Malaysia, the response of a shock was the immediate decline in economic activity and then a very quick improvement for Malaysia (shock died in year 4) and gradual for Philippines (shock died in year 7). Interesting case is Fiji, where the impact of a shock in *RETR* on economic activity and emissions, was an initial decline in both, then improvement in year 2, followed by a several periods of fluctuations at close to zero levels until effects of the shock finally dissipated in years 6 and 9 respectively.

The important feature for all countries is that the impact of positive shock in *RETR* on both economic activity and emissions is always converging to zero although for some countries it might take longer to adjust to the shock. In addition, the percentage responses of per capita CO_2 emissions are larger in magnitude than the percentage responses of per capita GDP

4.3. Forecast error variance decomposition

While, the IRFs illustrate the response of *GDPpc* and CO_2pc to changes in the *RETR*, in this paper, we also analyze the proportions of movements in the series which are attributed to their own shocks. This is because following Ewing *et al.,* (2007) and Silva *et al.,* (2011), innovations to an individual variable can potentially affect its own changes and changes in other variables in the system. Therefore, we investigate the how much of the forecast error variance in *GDPpc* and CO_2pc can be explained by each variable based on our estimated SVARs for each country in the sample.

Among all countries in the sample, China is a country with the smallest percentage (less than 1 per cent) of *GDPpc* variation which could be explained by *RETR*, while India and Phillippines are the countries with the largest (approximately above 45 per cent). These could be because of the current electricity supply mix with small proportion of renewable electricity. For PNG, Indonesia, Sri Lanka and Thailand, less than 10 per cent of *GDPpc* variation is explained by *RETR*. For Fiji and Pakistan, after first year, on average slightly above 16 per cent and 14 per cent of variation in *GDPpc* respectively was explained by *RETR*. For Malaysia, in all years *RETR* explained slightly over 23 per cent of variation in *GDPpc*. For India in year one, more than 46 per cent of variation in *GDPpc* was explained by *RETR*. In the later years, *RETR* kept on contributing to variation in *GDPpc* at a lower rate, but starting from year 2 the contribution was constant at almost 45 per cent. In Philippines the contribution of *RETR* towards variation in *GDPpc* was growing from 46 per cent in year one to almost 51 per cent in year 6, after which it stabilized but did not drop beyond 50 per cent.

It should also be noted that for most of the countries *GDPpc* contribution to its own variation accounts for more than 75 per cent. Exceptions are India (55 per cent on average) and Philippines (47 per cent). For most of the countries, the explanatory power of *GDPpc* does not increase with time and although for the first several years it might increase it always reaches a peak and then either a declines or a plateaus.

The contributions of CO_2pc to the variation in *GDPpc* for most of the countries are rather small: on average they are less than 1 per cent in India, Malaysia and Sri Lanka; less than 5 per cent in China, Fiji, Philippines and Thailand, between 5 and 10 per cent in Pakistan and PNG and between 10 per cent and 15 per cent in Indonesia and Laos. Stabilization in contributions is the main feature shared by all countries.

Table 4
Percentage of the error variance made in forecasting *RETR*, *GDPpc* and CO_2pc due to shocks in the latter two variables at different time horizons

	% of Forecast error in $GDPpc$ accounted for by			% of Forecast error in CO_2pc accounted for by			% of Forecast error in $GDPpc$ accounted for by			% of Forecast error in CO_2pc accounted for by		
	CHN RETR	**CHN GDP**	**CHN CO_2**	**CHN RETR**	**CHN GDP**	**CHN CO_2**	**FJI RETR**	**FJI GDP**	**FJI CO_2**	**FJI RETR**	**FJI GDP**	**FJI CO_2**
1	0.372	94.593	5.036	0.009	23.745	76.246	0.177	99.708	0.115	25.506	14.988	59.507
2	0.314	95.622	4.064	1.386	23.592	75.022	15.253	84.450	0.296	41.497	12.732	45.771
3	0.302	95.709	3.989	1.814	22.756	75.431	15.167	83.953	0.880	40.254	13.422	46.324
4	0.309	95.549	4.142	1.973	22.277	75.749	16.283	80.489	3.228	41.119	12.674	46.207
5	0.318	95.403	4.279	2.035	22.057	75.908	16.534	80.112	3.354	41.247	12.682	46.072
6	0.323	95.315	4.361	2.059	21.964	75.977	16.496	79.744	3.760	41.021	12.587	46.392
7	0.326	95.271	4.402	2.068	21.928	76.005	16.592	79.459	3.949	41.067	12.538	46.395
8	0.328	95.251	4.421	2.071	21.914	76.015	16.594	79.444	3.962	41.031	12.539	46.430
9	0.328	95.243	4.429	2.072	21.909	76.019	16.606	79.366	4.028	41.021	12.521	46.457
10	0.328	95.240	4.432	2.073	21.907	76.021	16.615	79.354	4.031	41.027	12.521	46.452
	IND RETR	**IND GDP**	**IND CO_2**	**IND RETR**	**IND GDP**	**IND CO_2**	**IDN RETR**	**IDN GDP**	**IDN CO_2**	**IDN RETR**	**IDN GDP**	**IDN CO_2**
1	46.326	53.632	0.042	4.119	15.940	79.941	5.899	86.423	7.678	36.202	11.863	51.934
2	44.705	55.255	0.040	24.304	16.483	59.213	5.195	80.829	13.977	29.557	13.256	57.187
3	44.666	55.257	0.077	23.927	16.439	59.634	5.192	80.634	14.174	28.686	13.866	57.448
4	44.683	55.240	0.077	24.119	16.487	59.394	5.192	80.636	14.172	28.688	13.865	57.447
5	44.681	55.241	0.077	24.170	16.498	59.332	5.192	80.635	14.173	28.687	13.866	57.448
6	44.681	55.241	0.077	24.168	16.495	59.337	5.192	80.635	14.173	28.686	13.866	57.448
7	44.681	55.241	0.077	24.171	16.496	59.333	5.192	80.635	14.173	28.687	13.866	57.448
8	44.681	55.241	0.077	24.171	16.496	59.333	5.192	80.635	14.173	28.687	13.866	57.448
9	44.681	55.241	0.077	24.171	16.496	59.333	5.192	80.635	14.173	28.686	13.866	57.448
10	44.681	55.241	0.077	24.171	16.496	59.333	5.192	80.635	14.173	28.687	13.866	57.448
	LAO RETR	**LAO GDP**	**LAO CO_2**	**LAO RETR**	**LAO GDP**	**LAO CO_2**	**MYS RETR**	**MYS GDP**	**MYS CO_2**	**MYS RETR**	**MYS GDP**	**MYS CO_2**
1	3.195	87.254	9.552	32.585	0.114	67.301	23.863	76.100	0.037	1.514	4.716	93.770
2	5.666	82.714	11.621	24.252	14.074	61.673	23.813	76.127	0.060	2.510	7.543	89.948
3	5.653	82.018	12.328	23.600	15.588	60.812	23.811	76.128	0.061	2.581	7.717	89.702
4	5.637	81.908	12.455	23.731	15.652	60.617	23.811	76.128	0.061	2.583	7.722	89.695
5	5.648	81.895	12.457	23.759	15.644	60.597	23.811	76.128	0.061	2.583	7.722	89.695
6	5.652	81.891	12.457	23.753	15.652	60.595	23.811	76.128	0.061	2.583	7.722	89.695
7	5.652	81.889	12.458	23.751	15.655	60.594	23.811	76.128	0.061	2.583	7.722	89.695
8	5.652	81.889	12.459	23.751	15.655	60.594	23.811	76.128	0.061	2.583	7.722	89.695
9	5.652	81.889	12.459	23.751	15.655	60.594	23.811	76.128	0.061	2.583	7.722	89.695
10	5.652	81.889	12.459	23.751	15.655	60.594	23.811	76.128	0.061	2.583	7.722	89.695
	PAK RETR	**PAK GDP**	**PAK CO_2**	**PAK RETR**	**PAK GDP**	**PAK CO_2**	**PNG RETR**	**PNG GDP**	**PNG CO_2**	**PNG RETR**	**PNG GDP**	**PNG CO_2**
1	0.595	94.383	5.022	21.700	5.471	72.829	1.298	92.913	5.789	8.986	5.163	85.851
2	12.289	82.199	5.511	26.754	13.874	59.372	4.910	88.549	6.541	10.793	4.947	84.260
3	14.193	80.380	5.427	27.771	14.778	57.451	5.259	88.363	6.379	10.935	4.944	84.121
4	14.468	80.116	5.416	27.924	14.905	57.171	5.351	88.295	6.354	10.958	4.959	84.083
5	14.508	80.078	5.414	27.946	14.923	57.131	5.371	88.282	6.348	10.961	4.965	84.073
6	14.514	80.073	5.414	27.949	14.925	57.125	5.375	88.279	6.346	10.962	4.967	84.071
7	14.514	80.072	5.414	27.950	14.926	57.125	5.376	88.278	6.346	10.962	4.968	84.070
8	14.515	80.072	5.414	27.950	14.926	57.124	5.377	88.278	6.346	10.962	4.968	84.070
9	14.515	80.072	5.414	27.950	14.926	57.124	5.377	88.278	6.346	10.962	4.968	84.070
10	14.515	80.072	5.414	27.950	14.926	57.124	5.377	88.278	6.346	10.962	4.968	84.070

Table 4 (continue)
Percentage of the error variance made in forecasting *RETR*, *GDPpc* and CO_2pc due to shocks in the latter two variables at different time horizons

	% of Forecast error in $GDPpc$ accounted for by			% of Forecast error in CO_2pc accounted for by			% of Forecast error in $GDPpc$ accounted for by			% of Forecast error in CO_2pc accounted for by		
	PHL RETR	PHL GDP	PHL CO_2	PHL RETR	PHL GDP	PHL CO_2	LKA RETR	LKA GDP	LKA CO_2	LKA RETR	LKA GDP	LKA CO_2
1	46.444	50.091	3.465	48.350	10.920	40.730	7.779	92.219	0.002	17.083	24.180	58.736
2	49.025	48.389	2.587	48.286	9.106	42.608	7.960	92.034	0.006	22.668	21.323	56.009
3	50.154	47.235	2.612	47.362	9.101	43.538	7.957	92.036	0.007	24.446	20.522	55.032
4	50.452	46.812	2.736	47.068	9.330	43.602	7.959	92.034	0.008	24.955	20.292	54.753
5	50.515	46.681	2.804	47.022	9.429	43.550	7.959	92.033	0.008	25.108	20.223	54.669
6	50.522	46.649	2.829	47.019	9.464	43.516	7.959	92.033	0.008	25.153	20.203	54.644
7	50.521	46.643	2.836	47.023	9.473	43.504	7.959	92.033	0.008	25.167	20.196	54.636
8	50.520	46.642	2.837	47.024	9.475	43.500	7.959	92.033	0.008	25.171	20.195	54.634
9	50.520	46.642	2.838	47.025	9.476	43.500	7.959	92.033	0.008	25.173	20.194	54.633
10	50.520	46.642	2.838	47.025	9.476	43.500	7.959	92.033	0.008	25.173	20.194	54.633
	THA RETR	THA GDP	THA CO_2	THA RETR	THA GDP	THA CO_2						
1	8.602	89.175	2.223	4.028	36.552	59.420						
2	6.759	91.394	1.847	3.309	48.933	47.757						
3	6.512	91.475	2.013	3.161	51.581	45.257						
4	6.484	91.439	2.077	3.136	51.957	44.907						
5	6.482	91.429	2.089	3.133	51.990	44.877						
6	6.482	91.428	2.090	3.133	51.991	44.876						
7	6.482	91.428	2.090	3.133	51.991	44.877						
8	6.482	91.428	2.090	3.133	51.991	44.877						
9	6.482	91.428	2.090	3.133	51.991	44.877						
10	6.482	91.428	2.090	3.133	51.991	44.877						

Source: Authors calculations.

In relation to variations in CO_2pc, for most countries variations in for CO_2pc in percentage terms are more explained by *RETR* than variations in *GDPpc*. This refers to a case when contributions of *RETR* towards the variation in CO_2pc are small as well as for the case when they are large. For China, although the contribution of *RETR* to CO_2pc variation was less than 3 per cent in all periods, it was on a small increasing trend throughout with a drastic increase in the second year. Similar patterns were observed in Malaysia and Thailand, where contributions of *RETR* to explaining variation in CO_2pc are less than 5 per cent in all years and PNG, where the contributions are over 10 per cent on average. While in China and Thailand, contributions of *GDPpc* to variation in CO_2pc are over 21 per cent and 50 per cent respectively on average (for China - highest in year 1 and then fall throughout, for Thailand- increase and reach a plateau in year 6). For PNG and Malaysia, contributions of *GDPpc* to variation in CO_2pc are less than 10 per cent (on average 5 per cent for PNG and 7 per cent for Malaysia). While for PNG there was somewhat small variation in contributions which stabilized from year 7, in Malaysia contributions kept increasing until year 4, after which they did not change. In these two countries, variation in CO_2pc (approximately 90 per cent for Malaysia and 84 per cent for

PNG) was mostly explained by itself with contribution in the first year being the greatest.

Another interesting trend appears in those countries of the sample where contributions of *RETR* towards the variation in CO_2pc are large (over 20 per cent). For these countries, we also notice a smaller contribution of *GDPpc* to variation in CO_2pc. For most of these developing countries, we observe the same pattern: variation in CO_2pc can be mostly explained by itself with average contribution of over 45 per cent. For Laos, India, Pakistan and Sri Lanka, contribution of CO_2pc towards its own variation was the largest in the first year and then declined before stabilizing. For Fiji, in the first four years, the contributions of *RETR* towards the variation in CO_2pc are fluctuating a lot but after year 4 they stabilize at approximately 41 per cent. In case of Indonesia, the largest contribution was reached in year 3, after which it stabilized. This finding is in line with Tiwari (2011) who estimated that for India the larger proportion of forecast error variations in CO_2pc was explained by its own values. Interesting case is Philippines, where contribution of *RETR* towards the variation in CO_2pc was greater than contribution of CO_2pc towards its own variation.

Another interesting finding is similar patterns of maximum values between *GDPpc* and CO_2pc contributions towards CO_2pc variation. Namely, maximum values for *GDPpc* and CO_2pc contributions for most of the countries tend to occur in the same year. For instance, for China and PNG they tend to occur in the first year, for Indonesia this happens in the 3rd year.

Overall, variance decomposition results show that for most (8) of middle-income Asia countries, the ratio of electricity generated from renewable sources to total electricity generated explained very small amount of forecast error variance of per capita GDP. Only for three countries in the sample (India, Malaysia and Philippines), the contribution of this ratio towards forecast error variance of per capita GDP was substantial (on average 44 per cent, 23 per cent and 50 per cent respectively).

We also found that for most of the countries (India, Indonesia, Laos, Pakistan, PNG, Philippines, Sri Lanka) ratio of electricity generated from renewable sources to total electricity generated contributed more to explaining variations in CO_2 per capita emissions than per capita GDP. Similar finding was made by Silva *et al.,* (2011), who found that for some of the developed countries (Portugal and Denmark) the contributions of *RETR* towards the variation in CO_2pc were greater than those of *GDPpc*.

5. CONCLUSION AND POLICY IMPLICATION

In the resource constrained world with limited fossil fuel resources and the need to reduce GHG emissions, developing countries are faced with the need to use energy from fossil fuels more efficiently and increase their renewable energy resources in order to achieve economic growth. The development of renewable energy resources could create local industries and employment, could attract concessionary financing and private sector investment. In addition, development of these resources could diversify energy supply, reduce vulnerability of the economy and improve access to modern energy for remote and isolated communities in middle-income Asian countries.

The relationship between the economic growth, environmental pollution and electricity consumption has been studied for various developed countries using different methodologies (Silva *et al.,* 2011). However, the relationship for renewable energy shares in electricity generation for a group of middle-income Asian countries using SVAR methodology has never been done in the past.

Our results from forecast error variance decomposition revealed that *RETR* contributed more to explaining variations in CO_2pc than did *GDPpc*. In addition, the ratio of electricity generated from renewable sources to total electricity generated explained very small amount of forecast error variance of *GDPpc*.

Impulse response analyses showed an increase in the share of renewable electricity in total electricity generated may cause negative effects on the economic growth at least at the beginning. This happened in Laos, India, Thailand, China and Sri Lanka, but with time the impact of shock in *RETR* on economic growth will dissipate. Of these countries, in China, India, Sri Lanka and Thailand fossil fuels dominate current electricity generation mix. In these counties the amount of renewable electricity generation has been on a declining trend throughout the sample period although in the beginning of the sample Sri Lanka and Thailand had a very large fraction of electricity coming from renewable sources. In these four countries the original response of *GDPpc* to expansion in renewable electricity could be negative due to costs and temporal nature associated with production of renewable electricity. The exception is large scale hydroelectricity where the costs of electricity generation are typically lower. In addition, as resources are being diverted from fossils fuel industry to renewable electricity supply there could be a disproportionate loss of jobs and income in fossil fuel industries as compared to the amount of jobs and income generated in renewable electricity. Jobs in renewable electricity require different skill set and qualifications as compared to coal industry for electricity generation.

However, this argument does not apply to Laos which has substantial hydro resources in generating electricity. Although Laos has the highest *RETR* and at the same time the lowest average CO_2pc and *GDPpc*, renewable electricity generation in Laos has roughly stayed at the same level and did not change over the sample period. This large share of renewable electricity generation has not significantly contributed to economic growth in Laos. Similar to this country, an expansion in renewable electricity in PNG and Pakistan cause a decline in economic wellbeing, which happened after an initial increase. In both countries, although electricity is generated from different sources, the average value of renewable electricity was similar. For other countries in the sample, the initial impact was negative, however, *GDPpc* has improved over time.

Our results indicate that increases in the renewable electricity have led to the increase in emissions of CO_2. Such controversial result could be referred to the type of the renewable energy source used in generating electricity. For example, as noted by Bhattacharya *et al.,* (2003), production of renewable electricity could mean conversion of forests into tree plantations for electricity generation which could increase emissions.

Countries with middle-income may face a trade-off between economic growth and environment sustainability at least in the early years of expansion in renewable electricity. Therefore, they may need to implement policies to complement renewable energy generation and improve energy efficiency. Capacity Building on energy policy making, energy regulations, energy planning and project financing, as well as in the latest technologies and best practices available for improving the efficiency of energy use, and for increasing the use of renewable energies are needed to increase access to energy.

The use of quarterly data rather than annual data may have allowed more precise estimations since the influences of weather conditions and other seasonal effects could be accommodated. However, such data was unavailable for most countries used in the analysis. Also the extension of number of years analysed for each country would have given more significance to the study. However, given that this paper uses data from 1980 to 2010 it captures the period of rapid economic growth, population growth, increase in electricity generation and climate change concerns for the selected countries. Further extension could be the decomposition of renewable electricity based on the generation sources (hydro, biomass, etc.). This could provide an additional insight in explaining why a growth in renewable electricity generation as a share of total electricity has led to the increase in emissions of CO_2. As a way forward, the countries in the sample could be studied together by using a panel econometric model that contemplates spatial heterogeneity among counties and contemporaneous causal order within the same framework.

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APPENDIX

Table A1

Unrestricted VAR (p) estimation results

CHN VAR(1)	CHN RETR	CHN GDP	CHN CO_2	IND VAR(1)	IND RETR	IND GDP	IND CO_2
CHN RETR.L1	0.03571 (0.19948)	-0.00463 (0.068089)	-0.10054 (0.1462)	IND_RETR.L1	-0.1432 (0.2168)	-0.01879 (0.05661)	0.23549** (0.08495)
CHN GDP.L1	0.51479 (0.51662)	0.461622 (0.176338)*	-0.08958 (0.37864)	IND_GDP_L1	0.8986 (0.8911)	0.28507 (0.23268)	-0.16595 (0.34916)
CHN CO_2.L1	0.13546 (0.24086)	0.045448 (0.082212)	0.62027 ** (0.17653)	IND_$CO_{2.L1}$	-0.6731 (0.4016)	0.01765 (0.10485)	-0.15951 (0.15735)
CONST	-4.1455 (4.26974)	4.576239** (1.457388)	2.98434 (3.12934)	CONST	-4.521 (4.4409)	2.87451 (1.15955)	5.91107*** (1.74004)
IDN_ VAR(1)	**IDN RETR**	**IDN GDP**	**IDN CO_2**	**MYS _ VAR(1)**	**MYS RETR**	**MYS GDP**	**MYS CO_2**
IDN_RETR.L1	-0.5919** (0.17)	0.11937* (0.04836)	0.13591 ** (0.04792)	MYS_RETR.L1	0.1238 (0.1887)	0.001476 (0.036162)	-0.00656 (0.055362)
IDN_GDP.L1	-0.1541 (0.7452)	0.28048 (0.21203)	-0.01595 (0.21011)	MYS_GDP.L1	-1.958 (1.0739)	0.150224 (0.20578)	0.297017 (0.315037)
IDN_CO_2.L1	-1.7848* (0.8509)	0.26155 (0.2421)	0.3259 (0.23992)	MYS_CO_2.L1	0.3524 (0.6788)	-0.011939 (0.130074)	0.079621 (0.199135)
CONST	6.5358’ (3.8244)	1.61514 (1.08813)	2.31649* (1.0783)	CONST	2.4106 (5.6527)	2.851044* (1.083172)	2.755645 (1.658272)
PAK__ VAR(1)	**PAK RETR**	**PAK GDP**	**PAK CO_2**	**PNG_ VAR(1)**	**PNG RETR**	**PNG GDP**	**PNG CO_2**
PAK_RETR.L1	-0.02747 (0.24127)	0.09587* (0.04426)	0.2028’ (0.113)	PNG_RETR.L1	-0.02461 (0.19242)	0.067 (0.05183)	-0.0458 (0.09308)
PAK_GDP.L1	-0.20212 (0.96732)	0.27932 (0.17745)	0.7004 (0.4529)	PNG_GDP.L1	0.30132 (0.64766)	0.45135 * (0.17444)	-0.06598 (0.3133)
PAK_CO_2.L1	-0.09003 (0.4487)	0.08715 (0.08231)	0.1529 (0.2101)	PNG_CO_2.L1	-0.56135 (0.40772)	0.1157 (0.10982)	0.19983 (0.19723)
CONST	-1.09247 (2.70157)	1.55487** (0.49559)	1.009 (1.2649)	CONST	1.71037 (3.15798)	0.25553 (0.85059)	1.2458 (1.52764)
PHL__ VAR(1)	**PHL RETR**	**PHL GDP**	**PHL CO_2**	**LKA_ VAR(1)**	**LKA RETR**	**LKA GDP**	**LKA CO_2**
PHL_RETR.L1	-0.2999 (0.2156)	-0.00263 (0.06698)	-0.06794 (0.11022)	LKA_RETR.L1	-0.3359 (0.2143)	0.002538 (0.023397)	-0.18994’ (0.09699)
PHL_GDP.L1	-0.799 (0.6471)	0.47719* (0.20104)	-0.32673 (0.33082)	LKA_GDP.L1	0.8299 (2.0204)	0.144352 (0.220612)	0.41922 (0.91456)
PHL _CO_2.L1	-0.1161 (0.4277)	0.09353 (0.13288)	0.47234* (0.21865)	LKA_CO_2.L1	-0.3489 (0.4494)	0.001515 (0.049074)	-0.23115 (0.20344)
CONST	-0.3674 (2.0297)	0.45369 (0.63065)	1.16761 (1.03774)	CONST	-4.6441 (7.6402)	3.073571** (0.834242)	0.98564 (3.4584)
FJI_VAR(1)	**FJI RETR**	**FJI GDP**	**FJI CO_2**	**LAO VAR(1)**	**LAO RETR**	**LAO GDP**	**LAO CO_2**
FIJI_RETR.l1	-0.09429 (0.23546)	-0.13197’ (0.07084)	-0.57721* (0.23436)	**LAO_ RETR.L1**	0.21799 (0.18378)	0.39433 (1.71365)	2.9433’ (1.5891)
FIJI_GDP.l1	0.50669 (0.94151)	-0.48133 (0.28326)	-0.67114 (0.93711)	**LAO_GDP.L1**	0.01715 (0.01957)	0.06312 (0.18244)	-0.3427’ (0.1692)
FIJI_CO_2.l1	-0.27636 (0.25359)	0.03389 (0.07629)	0.01675 (0.2524)	**LAOS_CO_2.L1**	-0.024’ (0.01321)	-0.0822 (0.12319)	0.3729** (0.1142)
FIJI_RETR.l2	-0.24246 (0.2553)	-0.06998 (0.07681)	-0.19241 (0.25411)	**CONST**	-0.23485 (0.24535)	5.71069* (2.28777)	5.9157** (2.1216)
FIJI_GDP.l2	0.35604 (0.84362)	-0.11059 (0.25381)	-0.196 (0.83968)				
FIJI_CO_2.l2	-0.20984 (0.24463)	-0.05138 (0.0736)	-0.33459 (0.24348)				
const	-1.55218 (2.81746)	1.73723’ (0.84764)	4.72542 (2.80429)				

*Note: Standard errors are shown in parenthesis. Significance levels are: ***,**, * and ‘ for 0.001, 0.01, 0.05 and 0.1 significance levels.*

Source: Own elaboration.

Table A2
Estimated identified long run impact matrix based on the specified restrictions

	CHN RETR	CHN GDP	CHN CO_2	FJI RETR	FJI GDP	FJI CO_2	IND RETR	IND GDP	IND CO_2
RETR	6.76812	0	0	10.983	0	0	8.7539	0	0
GDPpc	0.03566	4.525	0	-1.376	2.16	0	2.0492	2.4511	0
CO_2	-1.92442	5.169	11.18	-9.917	1.959	6.734	0.8616	0.8747	2.744
	IDN RETR	IDN GDP	IDN CO_2	LAO RETR	LAO GDP	LAO CO_2	MYS RETR	MYS GDP	MYS CO_2
RETR	8.3732	0	0	1.49	0	0	28.03	0	0
GDPpc	-0.4657	5.49	0	4.047	12.02	0	-2.312	4.178	0
CO_2	-1.619	1.77	3.974	-5.347	-7.15	14.73	-0.105	2.833	6.619
	PAK RETR	PAK GDP	PAK CO_2	PNG RETR	PNG GDP	PNG CO_2	PHL RETR	PHL GDP	PHL CO_2
RETR	8.361	0	0	18.471	0	0	11.5	0	0
GDPpc	1.0034	2.597	0	2.290	8.273	0	-5.372	4.6205	0
CO_2	0.5431	3.296	4.193	-4.283	1.620	9.388	-5.39	0.5776	6.641
	LKA RETR	LKA GDP	LKA CO_2	THA RETR	THA GDP	THA CO_2			
RETR	13.9138	0	0	21.597	0	0			
GDPpc	0.6242	2.041	0	1.437	7.307	0			
CO_2	-4.4566	3.696	4.677	-0.779	8.96	4.73			

Source: Own elaboration.