Renewable Electricity Generation, CO₂ 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 (CO₂) 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 CO₂ 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 hidráulica 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 (CO₂) 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
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 (from 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 (CO₂) 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 CO2 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 CO2 in developing economies. Tiwari (2011) used SVAR to analyze the dynamics of hydroelectricity consumption, economic growth and CO2 emissions in India. He found that a positive shock on hydroelectricity consumption is likely to increase real GDP and cause a reduction in CO2 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 CO₂ and renewable electricity generation in middle-income (developing) countries of Asia. CO₂, 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 CO₂ 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 CO₂ 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 CO₂ 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), CO2 emissions (CO2pc) and the ratio of electricity derived from renewable energy sources to total electricity generation (RETR) (in billion kilowatt hours). The source of CO2 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 CO2pc) 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 | 30.20*** | 3.91 | 0.13 | 3.22 | 4.75* | 1.09 | 1.80 | 7.02** | 3.40 | 7.45** |
|   | (0.40) | (0.00) | (0.14) | (0.94) | (0.20) | (0.09) | (0.58) | (0.41) | (0.03) | (0.18) | (0.02) |
Table 1 (continue)
Descriptive statistics of all variables for countries: levels

| Country | CHN | FJI | IND | IDN | IDA | MYS | PAK | PHL | PNG | LKA | THA |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| GDP per capita (GDP\textsubscript{pc}) |
| Mean | 848.42 | 1967.86 | 412.69 | 717.03 | 298.49 | 3385.83 | 490.86 | 1067.16 | 659.74 | 754.46 | 1713.35 |
| Median | 657.99 | 1955.29 | 367.28 | 748.32 | 273.64 | 3561.95 | 494.72 | 1054.46 | 627.68 | 704.32 | 1658.00 |
| Maximum | 2426.33 | 2335.32 | 794.80 | 1145.39 | 555.52 | 5168.69 | 664.71 | 1383.41 | 800.99 | 1306.78 | 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** | 2.16 | 4.04 | 1.38 | 1.71 | 2.44 | 1.14 | 3.84 | 4.32 | 2.85 | 2.19 |

Note: Values in parenthesis correspond to \( p \)-values.
Source: Own elaboration.

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

| Country | CHN | FJI | IND | IDN | IDA | MYS | PAK | PHL | PNG | LKA | THA |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Renewable energy share (RET\%) |
| 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 | 407.61*** | 0.51 | 2.71 | 82.27*** | 3.84 | 0.27 | 230.21*** | 10.16** | 3.23 | 7.08** |

Note: Values in parenthesis correspond to \( p \)-values.
Source: Own elaboration.

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
CO₂ per capita emissions (CO₂pc)

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 $X_t=(RETR_t, GDPpct, CO2pc_t)$ where $RETR_t$ is the growth rate in the ratio of renewable electricity to total electricity generated from all sources, $GDPpct$ is growth rate in per capita real GDP and $CO2pc_t$ is the change in CO2 emissions per capita. SVAR is represented as

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

(1)

Where $p$ denotes the lag order of SVAR, $\varepsilon_t$ 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

$$B_0=
\begin{pmatrix}
  b_{11} & b_{12} & b_{13} \\
  b_{21} & b_{22} & b_{23} \\
  b_{31} & b_{32} & b_{33}
\end{pmatrix}
$$

(2)

The reduced form VAR can be written as

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

(3)

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

$$\varepsilon_t=B_0e_t$$

(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, $GDPpct$ is not affected, however it gets affected in the long run. Third, $CO2pc_t$ 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 $GDPpct$ in both short and long run, $GDPpct_t$ affects per capita emissions $CO2pc_t$ 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:

$$B_0 = \begin{pmatrix}
    b_{11} & 0 & 0 \\
    b_{21} & b_{22} & 0 \\
    b_{31} & b_{32} & b_{33}
\end{pmatrix}$$  \hspace{1cm} (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 $RETR$, 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

| Country | Intercept | Intercept and trend |
|---------|-----------|---------------------|
|         | MZa       | MZt | MSB | MPT | MZa | MZt | MSB | MPT |
| 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 | 51.99 | -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 |

| Country | GDP/pc | Intercept | Intercept and trend |
|---------|--------|-----------|---------------------|
|         | MZa    | MZt | MSB | MPT | MZa | MZt | MSB | MPT |
| 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    |

| Country | CO2/pc | Intercept | Intercept and trend |
|---------|--------|-----------|---------------------|
|         | MZa    | MZt | MSB | MPT | MZa | MZt | MSB | MPT |
| 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 -13.6, -8.1, and -5.7; (2) MZt asymptotic critical values for 1, 5 and 10% are -2.59, -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 CO₂ 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
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$_2$pc 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$_2$pc 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 Philippines 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$_2$pc 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 CO2pc due to shocks in the latter two variables at different time horizons

| CHN RETR | CHN GDP | CHN CO2 | CHN RETR | CHN GDP | CHN CO2 | FJI RETR | FJI GDP | FJI CO2 | FJI RETR | FJI GDP | FJI CO2 |
|----------|---------|---------|----------|---------|---------|----------|---------|---------|----------|---------|---------|
| 1 0.372 94.593 5.036 | 0.009 23.745 76.246 | 0.177 99.708 0.115 | 25.508 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 |

| LAO RETR | LAO GDP | LAO CO2 | LAO RETR | LAO GDP | LAO CO2 | MYS RETR | MYS GDP | MYS CO2 | MYS RETR | MYS GDP | MYS CO2 |
|----------|---------|---------|----------|---------|---------|----------|---------|---------|----------|---------|---------|
| 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 5.663 62.714 11.621 | 24.252 0.174 61.673 | 23.813 76.127 0.060 | 2.510 7.543 89.948 |
| 3 5.653 62.018 12.326 | 23.500 0.158 60.812 | 23.811 76.128 0.061 | 2.581 7.717 89.702 |
| 4 5.637 81.908 12.455 | 23.731 0.152 60.617 | 23.811 76.128 0.061 | 2.583 7.722 89.695 |
| 5 5.648 81.895 12.573 | 23.759 0.154 60.597 | 23.811 76.128 0.061 | 2.583 7.722 89.695 |
| 6 5.652 81.891 12.457 | 23.753 0.152 60.595 | 23.811 76.128 0.061 | 2.583 7.722 89.695 |
| 7 5.652 81.889 12.458 | 23.751 0.155 60.594 | 23.811 76.128 0.061 | 2.583 7.722 89.695 |
| 8 5.652 81.889 12.459 | 23.751 0.155 60.594 | 23.811 76.128 0.061 | 2.583 7.722 89.695 |
| 9 5.652 81.889 12.459 | 23.751 0.155 60.594 | 23.811 76.128 0.061 | 2.583 7.722 89.695 |
| 10 5.652 81.889 12.459 | 23.751 0.155 60.594 | 23.811 76.128 0.061 | 2.583 7.722 89.695 |

| PAK RETR | PAK GDP | PAK CO2 | PAK RETR | PAK GDP | PAK CO2 | PNG RETR | PNG GDP | PNG CO2 | PNG RETR | PNG GDP | PNG CO2 |
|----------|---------|---------|----------|---------|---------|----------|---------|---------|----------|---------|---------|
| 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 84.074 |
| 7 14.514 80.072 5.414 | 27.950 14.926 57.124 | 5.377 88.278 6.346 | 10.962 4.968 84.074 |
| 8 14.515 80.072 5.414 | 27.950 14.926 57.124 | 5.377 88.278 6.346 | 10.962 4.968 84.074 |
| 9 14.515 80.072 5.414 | 27.950 14.926 57.124 | 5.377 88.278 6.346 | 10.962 4.968 84.074 |
| 10 14.515 80.072 5.414 | 27.950 14.926 57.124 | 5.377 88.278 6.346 | 10.962 4.968 84.074 |
In relation to variations in CO$_2$pc, for most countries variations in for CO$_2$pc 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$_2$pc are small as well as for the case when they are large. For China, although the contribution of RETR to CO$_2$pc 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$_2$pc 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$_2$pc 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$_2$pc 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$_2$pc (approximately 90 per cent for Malaysia and 84 per cent for

### Table 4 (continue)
Percentage of the error variance made in forecasting RETR, GDPpc and CO$_2$pc 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$_2$pc accounted for by | % of Forecast error in GDPpc accounted for by | % of Forecast error in CO$_2$pc accounted for by |
|-------|---------------------------------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
| PHL   | PHL GDP PHL CO$_2$ PHL GDP PHL CO$_2$ LKA GDP LKA CO$_2$ LKA GDP LKA CO$_2$ |
| 1     | 46.444 50.091 3.465 48.350 10.920 40.730 7.779 92.219 0.002 17.063 24.180 58.736 |
| 2     | 49.025 48.389 2.587 48.286 9.106 42.608 7.960 92.034 0.006 22.688 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 |

Source: Authors calculations.

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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 CO₂pc are large (over 20 per cent). For these countries, we also notice a smaller contribution of GDPpc to variation in CO₂pc. For most of these developing countries, we observe the same pattern: variation in CO₂pc can be mostly explained by itself with average contribution of over 45 per cent. For Laos, India, Pakistan and Sri Lanka, contribution of CO₂pc 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 CO₂pc 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 CO₂pc was explained by its own values. Interesting case is Philippines, where contribution of RETR towards the variation in CO₂pc was greater than contribution of CO₂pc towards its own variation.

Another interesting finding is similar patterns of maximum values between GDPpc and CO₂pc contributions towards CO₂pc variation. Namely, maximum values for GDPpc and CO₂pc 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 CO₂ 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 CO₂pc 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$_2$pc 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$_2$pc 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 eco-
nomic 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, $GDP_{pc}$ 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 com-
plement 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 availa-
ble 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 sea-
sonal effects could be accommodated. However, such data was unavailable for
most countries used in the analysis. Also the extension of number of years ana-
lysed for each country would have given more significance to the study. How-
ever, 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 CO2 | IND VAR(1) | IND RETR | IND GDP | IND CO2 |
|------------|----------|---------|---------|------------|----------|---------|---------|
| CHN RETR.L1 | 0.03571 | -0.00463 | -0.1054 | -0.1432 | -0.01879 | 0.23549^* |
| CHN GDP.L1 | 0.51479 | 0.461622 | -0.08956 | 0.8986 | 0.28507 | -0.16596 |
| CHN CO2.L1 | 0.13546 | 0.045448 | 0.62027 | -0.6731 | 0.01765 | -0.16596 |
| CONST | -4.1455 | 4.576239 | 2.98434 | -4.521 | 2.87451 | 5.91107 |

| IDN_VAR(1) | IDN RETR | IDN GDP | IDN CO2 | MYS VAR(1) | MYS RETR | MYS GDP | MYS CO2 |
|------------|----------|---------|---------|------------|----------|---------|---------|
| IDN RETR.L1 | -0.5919** | 0.11937* | 0.13591** | MYS RETR.L1 | 0.1238 | 0.001476 | -0.00656 |
| IDN GDP.L1 | -0.1541 | 0.28048 | -0.01596 | MYS GDP.L1 | -1.958 | 0.150224 | 0.297017 |
| IDN CO2.L1 | -1.7848* | 0.26155 | 0.3259 | MYS CO2.L1 | 0.3524 | -0.011939 | 0.079621 |
| CONST | 6.5358 | 1.81514 | 2.31649* | CONST | 2.4106 | 2.851044* | 2.756645 |

| PAK_VAR(1) | PAK RETR | PAK GDP | PAK CO2 | PNG VAR(1) | PNG RETR | PNG GDP | PNG CO2 |
|------------|----------|---------|---------|------------|----------|---------|---------|
| PAK RETR.L1 | -0.02747 | 0.09587* | 0.2028 | PNG RETR.L1 | -0.02461 | 0.067 | -0.0458 |
| PAK GDP.L1 | -0.20212 | 0.27932 | 0.7004 | PNG GDP.L1 | 0.30132 | 0.45135* | -0.06596 |
| PAK CO2.L1 | -0.09003 | 0.08715 | 0.1529 | PNG CO2.L1 | -0.56139 | 0.1157 | 0.19963 |
| CONST | -1.09247 | 1.55487** | 1.009 | CONST | 1.71037 | 0.25553 | 1.2456 |

| PHL_VAR(1) | PHL RETR | PHL GDP | PHL CO2 | LKA_VAR(1) | LKA RETR | LKA GDP | LKA CO2 |
|------------|----------|---------|---------|------------|----------|---------|---------|
| PHL RETR.L1 | -0.2999 | -0.00263 | -0.06794 | LKA RETR.L1 | -0.3359 | 0.002538 | -0.18994 |
| PHL GDP.L1 | -0.799 | 0.47719* | -0.32673 | LKA GDP.L1 | 0.8296 | 0.143532 | 0.41922 |
| PHL CO2.L1 | -0.1161 | 0.09535 | 0.47234* | LKA CO2.L1 | -0.3498 | 0.001515 | -0.23115 |
| CONST | -0.3674 | 0.45369 | 1.16781 | CONST | -4.6441 | 3.073571** | 0.95654 |

| FIJ_VAR(1) | FIJ RETR | FIJ GDP | FIJ CO2 | LAO_VAR(1) | LAO RETR | LAO GDP | LAO CO2 |
|------------|----------|---------|---------|------------|----------|---------|---------|
| FIJ RETR.L1 | -0.09429 | -0.13197 | -0.57721 | LAO RETR.L1 | 0.21799 | 0.39433 | 2.9433 |
| FIJ GDP.L1 | 0.50669 | -0.48133 | -0.67114 | LAO GDP.L1 | 0.01715 | 0.06312 | -0.3427 |
| FIJ CO2.L1 | -0.27636 | 0.03389 | 0.01675 | LAO CO2.L1 | -0.024 | -0.0822 | 0.3792** |
| CONST | -0.24246 | -0.06998 | -0.19241 | CONST | -0.23485 | 5.71069* | 5.9157** |

| APPENDIX | Source: Own elaboration. |

Note: Standard errors are shown in parenthesis. Significance levels are: ***, *, ** and * for 0.001, 0.01, 0.05 and 0.1 significance levels.
### Table A2
Estimated identified long run impact matrix based on the specified restrictions

|       | CHN RETR | CHN GDP | CHN CO₂ | FJI RETR | FJI GDP | FJI CO₂ | IND RETR | IND GDP | IND CO₂ |
|-------|----------|---------|---------|----------|---------|---------|----------|---------|---------|
| 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       |
| CO₂   | -1.92442 | 5.169   | 11.18   | -9.917   | 1.959   | 6.734   | 0.8616   | 0.8747  | 2.744   |
|       | IDN RETR | IDN GDP | IDN CO₂ | LAO RETR | LAO GDP | LAO CO₂ | MYS RETR | MYS GDP | MYS CO₂ |
| 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       |
| CO₂   | -1.619   | 1.77    | 3.974   | -5.347   | -7.15   | 14.73   | -0.105   | 2.833   | 6.619   |
|       | PAK RETR | PAK GDP | PAK CO₂ | PNG RETR | PNG GDP | PNG CO₂ | PHL RETR | PHL GDP | PHL CO₂ |
| RETR  | 8.361    | 0       | 0       | 18.471   | 0       | 0       | 11.5     | 0       | 0       |
| GDPpc | 1.0034   | 2.597   | 0       | 2.290    | 8.237   | 0       | -5.372   | 4.6205  | 0       |
| CO₂   | 0.5431   | 3.296   | 4.193   | -4.283   | 1.620   | 9.388   | -5.39    | 0.5776  | 6.641   |
|       | LKA RETR | LKA GDP | LKA CO₂ | THA RETR | THA GDP | THA CO₂ |          |         |         |
| RETR  | 13.9138  | 0       | 0       | 21.597   | 0       | 0       |          |         |         |
| GDPpc | 0.6242   | 2.041   | 0       | 1.437    | 7.307   | 0       |          |         |         |
| CO₂   | -4.4566  | 3.696   | 4.677   | -0.779   | 8.96    | 4.73    |          |         |         |

Source: Own elaboration.