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## Article

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## Global Emissions: A New Contribution from the Shadow Economy

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### ABSTRACT

Based on the STIRPAT model and the EKC hypothesis, this study provides new evidences on the economic determinants of global emissions. The system- generalized methods of moments estimations are used for the sample of 106 economies in the period of 1995-2012 to investigate the influences of income level, urbanization, industrialization, energy intensity, public expenditure, trade openness, FDI inflow, and especially shadow economy on total greenhouse emissions, CO2 emissions, CH4 emissions, and N2O emissions, respectively. This study contributes to the literature in three folds. First, the industrialization energy intensity are the main drivers for all emissions (excluding N2O). While, urbanization has positive effects on emissions excluding the case of CH4. Other drivers including public spending and economic integration (proxied by trade openness and FDI inflow) are also tested with interesting findings. Second, a higher level of shadow economy increases all emissions excluding CO2. Third, the determinants of emissions vary depending on the countries' income level. The study is supported by a battery of robustness checks and by various estimations in the short and long-run to identify the importance of emissions' drivers.

**Keywords:** Emissions, CO2, CH4, N2O, Public Expenditures, Economic Integration, Shadow Economy.

**JEL Classifications:** F18, F64, O44, Q56, R11, O17

## 1. INTRODUCTION

Greenhouse emissions by human economic activities are increasingly being blamed for global warming and climate change (Spangenberg, 2007). There is today a huge literature focused on environmental economics and focusing on the determinants of emissions. Most of this is aimed at finding a way of stemming global warming (Adom and Adams, 2018; Bye et al., 2018; Chen and Lei, 2018). From a theoretical perspective, there are three models can be mentioned: The IPAT model (influence, population, affluence, and technology) (Ehrlich and Holdren (1971); its extension, the STIRPAT model (stochastic impacts by regression on population, affluence and technology) from Dietz

and Rosa (1997), and the Environmental Kurnet Curve hypothesis. All of which have provided widely accepted explanations for the relationships between economic factors and the environment. Numerous empirical studies have also examined the effects on emissions of the economic factors such as income level, population, urbanization, industrialization, energy intensity, and more general factors such as economic openness and financial development (Andersson, 2018).

This study contributes to these debates by offering new global evidence with a comprehensive investigation into the basic determinants of emissions by four different emissions in terms of both short-run and long-run effects. The emissions' determinants

are further analyzed according to three income groups. Precisely, we investigate three potential drivers of the emissions: Government expenditures, economic integration (trade openness and foreign direct investment, FDI inflow) and the shadow economy are taken into account. The first two generate more economic activity and income, they can potentially generate pollution whereas the shadow economy has the ability to avoid environmental regulations leading to potential higher level of pollution (Schneider and Enste, 2000) (Biswas et al., 2012).

The basis of this article is data of emissions and economic factors of 106 countries in the period 1995-2012 collected from World Development Indicators (World Bank). Shadow economy information (in relation to GDP) is collected from Medina and Schneider (2018). Static two-step system Generalized Methods of Moments (GMM) estimations is recruited to examine the influences of the shadow economy, along with economic integration, public spending, and factors from the STIRPAT model with information on country emissions. Total greenhouse gas emissions - CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O emissions per capita are used to proxy for the total emissions, respectively. We also test the Environmental Kuznet Curve hypothesis by using the square of income level, proxy by the log of GDP per capita. Additionally, the sample is divided into three income groups, specifically low and lower-middle income, upper-middle income, and high income to further investigate the determinants of emissions across income levels.

This article is organized as follows: Section 2 is the literature review. The methodology and data are presented in Section 3. The results are presented and discussed in Section 4 and finally conclusions are outlined, along with implications for policy and suggestions for future research.

## 2. LITERATURE REVIEW

### 2.1. Theoretical Frameworks

Concerns for climate change and global warming mean that reducing emissions is set to be the first priority for global action (Seshadri, 2017; Revesz et al., 2017; Höhne et al., 2017). Accordingly, investigations on the economic determinants of global emissions have gained an increasing attention from both theoretical and empirical perspectives (Zhang and Wang, 2017; Adewuyi and Awodumi, 2017). The well-known Environmental Kuznets Curve (EKC) hypothesis proposes an inverted U-shaped relationship between income level and environmental quality (Sun, 1999; Gill et al., 2018) in which, environmental quality is usually negatively affected due to higher emissions from energy consumption of coal, fuel and gas. Shahbaz et al. (2014), for example, documented the evidence of EKC between industrial development and CO<sub>2</sub> emissions in the case of Bangladesh. Pao and Tsai (2011) found evidence of the EKC hypothesis in Brazil, Russian Federation, India, and China for the period 1980-2007. Ren et al. (2014) found EKC in China industries for the period 2000-2010. EKC is also observed in terms of effectiveness in Tunisia (Abid, 2015), Vietnam (Tang and Tan, 2015), in many countries such as Singapore, Thailand, Denmark, Italy, Iceland,

BRICS, OCED countries, and upper-middle income economies<sup>1</sup> (Dogan and Seker, 2016). Top emitters were Turkey, India, China and Korea (Ertugrul et al., 2016), 37 tourists' induced countries such as US, UK, Argentina, Australia, Belgium, Brazil, Canada, China, France, Germany ... (Qureshi et al., 2017), and the United States (Shahbaz et al., 2017a). Effects are also seen in twelve developing East Asian and Pacific countries for the period 1990 to 2014 including Cambodia, China, Indonesia, Korea, Lao, Malaysia, Mongolia, Philippines, Thailand, Timor-Leste, and in Vietnam (Hanif, 2018) and in Turkey (Pata, 2018). Meanwhile, results from other studies provide an alternative viewpoint of the EKC (Dogan and Seker, 2016; Liu et al., 2017; Ajmi et al., 2015; Kaika and Zervas, 2013; Al-Mulali et al.; Shahbaz et al., 2015a; 2016a; Demiral, 2016; Al-Mulali et al., 2016b; Ozturk et al., 2016). Richmond and Kaufmann (2006) concluded that there is limited support for a turning point in the relationship between income and per capita energy use and/or carbon emissions for OECD nations but no turning point in non-OECD nations.

Another well-known theoretical framework is the IPAT model (the Influence, population, affluence, and technology model) developed by Ehrlich and Holdren (1971). This model offers a specific relationship between human aspects and activities including population (P), affluence (A) and technology (T) to the environment (I). The work of Dietz and Rosa (1997) extended the IPAT model to the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model and named these factors as the main determinants of environmental degradation. In fact, a large empirical literature has used the STIRPAT model to examine the influences of economics on environment through emissions (e.g. Shahbaz et al. (2015b); Sheng and Guo (2016); Lin et al. (2017); Zhang et al. (2017); Zhang and Xu (2017); Shahbaz et al., 2017b).

Sadorsky (2014) collected data from 16 emerging countries over the years 1971-2009 and found that energy intensity and affluence are positive, statistically significant impacts on CO<sub>2</sub> emissions. Similarly, Shahbaz et al. (2015b) studied Malaysia from the period 1970Q1-2011Q4 and documented that urbanization is a major contributor to energy consumption, while affluence raises energy demand and capital stock boosts energy consumption. As a result, rising levels of energy consumption leads to higher emissions. Sheng and Guo (2016) examined at province level in China, over the period 1995 to 2011 and found that rapid urbanization increases carbon dioxide emissions both in the short and long-run. He (2006) studied the total impact of FDI on the industrial SO<sub>2</sub> emission showing that a 1% increase in FDI capital stock increases the industrial SO<sub>2</sub> emission by 0.098% in 29 Chinese provinces. Lin et al. (2017) revealed that urbanization and real economic development have a small impact on CO<sub>2</sub> emissions in no high-income countries. They found that real economic development will lead to a decrease in CO<sub>2</sub> emissions and acceleration of the urbanization process will only cause a small increase in emissions for upper middle-income countries. An obvious conclusion is that the main driving factors of CO<sub>2</sub> emissions remain population,

<sup>1</sup> They also found no evidence of EKC in other countries such as Indonesia, Malaysia, Philippines, USA, Turkey, Cambodia, Russia, G7 countries, and Middle East countries.

affluence, energy intensity and CO<sub>2</sub> emission intensity.

Fotros and Maaboudi (2011) used a multivariate model to examine the relationships between economic growth, trade openness and CO<sub>2</sub> emissions for the period between 1971 and 2006 in Iran. They documented the evidence of a significant negative effect of economic growth on CO<sub>2</sub> emissions, while trade openness was reported to have a significantly positive effect. Recently, Andersson (2018) concluded that trade liberalization, weak environmental institutions, exchange rate policy, and legal and property rights are the major contributors to a rapid increase of emissions in China between 1995 and 2008. In relation to that, Liu and Bae (2018) found that as little as a 1% augmentations of energy intensity, real GDP, industrialization, and urbanization will increase CO<sub>2</sub> emissions in China by 1.1%, 0.6%, 0.3%, and 1.0%, respectively. Furthermore, Chen et al. (2018) concluded that the agglomeration of the industrial enterprises results in more CO<sub>2</sub> emissions but it reduces the intensity of the industrial CO<sub>2</sub> emissions in the sample of 187 Chinese prefecture-level cities over 2005–2013 and Hajilary et al. (2018) showed that energy consumption and its cost, population density, non-oil GDP, and FDI have significant effects on the CO<sub>2</sub> emissions in Iran. Pata (2018) studied data from Turkey between 1974–2014 and found that economic growth, financial development, and urbanization all increase environmental degradation, while total renewable energy consumption, hydropower consumption, and alternative energy consumption had no effect on CO<sub>2</sub> emissions. Mutascu (2018) revealed no co-movement at high frequency between trade openness and CO<sub>2</sub> emissions in France over the period 1960–2013; a finding that confirmed the ‘neutral hypothesis’ in the short term. The interaction between trade and CO<sub>2</sub> emissions is clearly driven by the business cycle, however, the previous inconclusive results necessitate more attention to examine the major determinants of emissions, especially CO<sub>2</sub> emission, from an economic perspective.

## 2.2. The Shadow Economy and CO<sub>2</sub> Emissions

The shadow economy includes all currently unregistered economic activities that take place outside the framework of bureaucratic public and private sector establishments<sup>2</sup> (Schneider and Williams, 2013, Hart, 2008). It is not subject to government scrutiny (Blackburn et al., 2012, Ihrig and Moe, 2004). Linking the shadow economy to the evolution of environmental economics, it is possible to see that the shadow economy must be noted as an undercover determinant of emissions due to its ability to avoid environmental regulation policies. This then leads to a potentially undocumented increase to energy consumption by both higher energy intensity and non-renewable energy use (Schneider and Enste, 2000).

The presence of the shadow economy is further explained by public policy and public administration (Schneider and Enste, 2000) as (i) tax evasion (Tanzi (1982); Tanzi (1999); Frey and Pommerehne (1984); Schneider (1994)), and (ii) the weak quality of government in implementing and enforcing their regulations

(La Porta et al., 1999), namely bureaucracy, regulatory discretion, rule of law, corruption, and a weak legal system (Friedman et al., 2000). It has been suggested that the shadow economy can act as a substitute or a complement to the “official” economic sectors (Choi and Thum, 2005). A feedback challenge is also noted, with the larger shadow economies of developing countries providing a challenge for the implementation of environmental regulations (Baksi and Bose, 2010).

Biswas et al. (2012) used a panel dataset covering the period from 1999 to 2005 in more than 100 countries. They concluded that the relationship between the shadow economy and levels of pollution is dependent on the levels of corruption. Interestingly, Sadorsky (2013) mentioned that urbanization could increase the shadow economy and then energy consumption. Meanwhile, Aïssa et al. (2014) found no evidence of causality between output and trade (exports and imports) with renewable energy consumption for both the short and long term in Africa; however, this result may be due to the existence of large shadow economy (Medina and Schneider (2018)). Similarly, using a sample of 152 countries over the period 1999–2009, Elgin and Oztunali (2014) documented the evidence of an inverse-U relationship between the size of the informal economy and environmental pollution following two mechanisms; finding that scale affects the deregulation effect. In addition, Abid (2015) studied data from Tunisia for the period 1980–2009 and found a monotonically increasing relationship between total GDP (the sum of the formal and informal economy) and CO<sub>2</sub> emissions as well as between formal GDP and CO<sub>2</sub> emissions. The results implied that the informal economy can raise the costs for the environment. However, there remains a lack of comprehensive investigation into the effects of the shadow economy on emissions.

In connecting the relationships between the informal and formal sectors (complementarity or substitution) with the scale effects of deregulation impacts on the shadow economy, there may exist different mechanisms for the shadow economy to exert influence on emissions. In the first scenario, the shadow economy acts as a substitution for official one, any increase in the informal sector will reduce formal economic activities, and the influences of the shadow economy on emissions then depend on the scale effects or the deregulation effects. If the shadow economy has scale effects, it will induce lower levels and intensity of energy consumption reducing therefore the emissions. In contrast, the effects of deregulation will increase the level and intensity of energy consumption inducing higher emissions. Remembering that informal sectors are free from environmental regulations leading to a situation where their economic activities may be more intense in terms of energy use and less environmentally-friendly, it is more likely that the larger shadow economy would increase emissions. As explained by Elgin and Oztunali (2014), the effects of the shadow economy follow the scale or deregulation effects depending on its current size and scale. Noting that the size of the shadow economy is usually inverse to income levels (Medina and Schneider (2018)) so that the influence of the shadow economy on emissions may be marginal, depending also differences across the income levels. In the second scenario, the shadow economy complements official sectors. In such case, the increases in an informal sector raise the total production of the economy inducing

2 In their definition and measurement, the shadow economy does not include illegal or criminal activities, do-it-yourself, charitable or household activities.



therefore higher levels and intensity of energy consumption. Even though the shadow economy is outside any monitored environmental regulation, the direct result is higher emissions. The aim of this article is to identify the determinant affecting the shadow economy's impact on emissions.

### 3. METHODOLOGY AND DATA

In order to answer the research question, we collected the annual data of 106 countries in the period of 1995-2012. The data was also categorized according to three income groups (low and lower-middle income, upper-middle income, and high income economies). The sample and time span were collected to include all of the countries available from World Development Indicators (World Bank). The income classification is according to the World Bank identification (Table A1 in Appendix for country list).

Regarding the emissions, our study implements the STIRPAT model combined with the EKC hypothesis with common determinants including income level, square of income level, urbanization, industrialization, and energy intensity (Lin et al., 2017; Zhang et al., 2017; Liu and Bae, 2018; Zoundi, 2017; Krey et al., 2012). We then added some adjustments since the trade openness and FDI inflow are added to examine the effects of economic integration on emissions (Pao and Tsai, 2011; Ren et al., 2014; Zakarya et al., 2015; Rafindadi et al., 2018) while government expenditures (% of GDP) is incorporated to control for the effects from public spending on emissions (McCright et al., 2014; Galinato and Galinato, 2016; Halkos and Paizanos, 2013). Also, the ratio of the shadow economy to GDP is included as a new determinant of emissions. Meanwhile, four different indicators of emissions including total greenhouse gas emissions, CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub> emissions are used as dependent variables, respectively. These emission variables are used in the form of per capita value to control for the effects of population on emissions in STIRPAT model. All variables (excluding FDI) are presented in logarithms to normalize the data and importantly to interpret coefficients as elasticities (Sadorsky, 2013).

From an econometric perspective, our static model for panel data takes the following forms,

$$Emission_{it} = \alpha_1 + \beta_1 Income_{it} + \beta_2 Income^2_{it} + \beta_3 Urban_{it} + \beta_4 Industry_{it} + \beta_5 Energy_{it} + \beta_6 Fiscal_{it} + \beta_7 Trade_{it} + \beta_8 FDI_{it} + \beta_9 Shadow_{it} + \gamma_i + \varepsilon_{it} \quad (1)$$

in which:  $i, t$  refers to the country  $i$  at year  $t$ . *Emissions* is dependence variable, which is the log of Total greenhouse gas emissions per capita (*TotalE*), the log of CO<sub>2</sub> emissions per capita (*CO2*), the log of Nitrous oxide emissions per capita (*N2O*), and the log of Methane emissions per capita (*CH4*), respectively. The explanatory variables include the log of GDP per capita (*Income*) and its square (*Income*<sup>2</sup>) to proxy for income level and, in order to test the EKC hypothesis. We also use the log of ratio of urban population to total population (*Urban*) to proxy the urbanization, log of ratio of industry value added to GDP (*Industry*) to proxy the industrialization, the log of energy use per \$1000 GDP (*Energy*), the log of ratio of general government final consumption expenditure to GDP (*Fiscal*), the log of ratio of total trade value

to GDP (*Trade*), and the ratio of FDI inflow to GDP (*FDI*), and the log of ratio of shadow economy to GDP (*Shadow*). and are estimated coefficients. is country effects and is residual terms. Details about the data are provided in Table 1.

Then, the dynamic model is applied to help us to estimate both short-run and long-run elasticities of emissions in relation to the changes in economic drivers. The estimation is formulated as follows,

$$Emission_{it} = \alpha_1 + \alpha_2 Emission_{it-1} + \beta_1 Income_{it} + \beta_2 Income^2_{it} + \beta_3 Urban_{it} + \beta_4 Industry_{it} + \beta_5 Energy_{it} + \beta_6 Fiscal_{it} + \beta_7 Trade_{it} + \beta_8 FDI_{it} + \beta_9 Shadow_{it} + \gamma_i + \varepsilon_{it} \quad (2)$$

Finally, the influences of economic factors on each type of emission are regressed for three income levels to examine the heteroscedasticity in determinants of global emissions. The primary data came from the World Development Indicators (World Bank) and the ones related to shadow economy were collected from Medina and Schneider (2018). A summary of these data is provided in the Table 2. Additionally, the correlation matrix between variables is shown in Table 3.

The study sample of this research has a large number of cross sections ( $N = 106$  countries) but a relatively short time window (1995-2012, i.e.,  $T = 17$  years). In estimating equation (1) and (2), we firstly examine the existence of cross-sectional dependence in our sample, the Pesaren's CD test Pesaran (2004) is applied for the logged variables. The results in Table A2 (Appendix) show the existence of a cross-sectional dependence within the variables. The Pesaran (2007)'s CIPS ( $Z(t\text{-bar})$ ) unit root tests are then employed. Due to the relatively short-time period of our sample, we work with variables in terms of logarithms in order to improve their dynamic estimation while the problems of non-stationary treated by using the other estimators with robustness check.

**Table 1: Variables**

Variables	Calculations: In the log forms of (excluding FDI)
Dependent variables	
TotalE	Total greenhouse gas emissions per capita (kg of CO <sub>2</sub> equivalent per person)
CO2	CO <sub>2</sub> emissions per capita (kg per person)
N2O	Nitrous oxide emissions per capita (kg of CO <sub>2</sub> equivalent per person)
CH4	Methane emissions per capita (kg of CO <sub>2</sub> equivalent per person)
Explanatory variables	
Income	GDP per capita (constant 2010 US\$)
Income <sup>2</sup>	Income*Income
Urban	Urban population (% of total)
Industry	Industry, value added (% of GDP)
Energy	Energy use (kg of oil equivalent) per \$1,000 GDP (constant 2011 PPP)
Fiscal	General government final consumption expenditure (% of GDP)
Trade	Trade (% of GDP) s
FDI	Foreign direct investment, net inflows (% of GDP)
Shadow	Shadow economy (% GDP)

**Table 2: Data sources and description**

Data	Sources	N	Mean±SD	Min	Max
Total greenhouse gas emissions per capita (kg of CO2 equivalent per person)	Calculation from WDI <sup>a</sup>	1,842	10047±10376	1021	78767
CO2 emissions per capita (kg per person)	Calculation from WDI <sup>a</sup>	1,907	5853±7343	17.28	70136
Nitrous oxide emissions per capita (kg of CO2 equivalent per person)	Calculation from WDI <sup>a</sup>	1,907	662±599	75.64	7592
Methane emissions per capita (kg of CO2 equivalent per person)	Calculation from WDI <sup>a</sup>	1,907	1744±2498	196.55	23758
GDP per capita (constant 2010 US\$)	WDI	1,902	15670±19846	171	111968
Urban population (% of total)	WDI	1,907	61.31±21.37	8.8	100
Industry, value added (% of GDP)	WDI	1,896	32.21±13.69	11.95	213.69
Energy use (kg of oil equivalent) per \$1,000 GDP (constant 2011 PPP)	WDI	1,902	153.73±101.33	49.12	1067.85
General government final consumption expenditure (% of GDP)	WDI	1,897	15.88±5.55	2.06	69.54
Trade (% of GDP)	WDI	1,898	85.47±51.42	15.64	441.60
Foreign direct investment, net inflows (% of GDP)	WDI	1,875	5.53±19.14	-58.32	451.72
Shadow economy (% GDP)	Medina and Schneider (2018)	1,908	29.80±13.47	6.16	71.95

WDI is World Development Indicators database from Worldbank (2017). a: Is calculated by dividing the emissions to total population of each country

**Table 3: Correlation matrix**

Correlation	CO2	N2O	CH4	TotalE	Income	Urban	Industry	Energy	Fiscal	Trade	FDI	Shadow
CO2	1											
N2O	0.294*** (0.000)	1										
CH4	0.410*** (0.000)	0.664*** (0.000)	1									
TotalE	0.644*** (0.000)	0.670*** (0.000)	0.700*** (0.000)	1								
Income	0.873*** (0.000)	0.374*** (0.000)	0.352*** (0.000)	0.656*** (0.000)	1							
Urban	0.652*** (0.000)	0.371*** (0.000)	0.207*** (0.000)	0.518*** (0.000)	0.705*** (0.000)	1						
Industry	0.321*** (0.000)	0.026 (0.265)	0.405*** (0.000)	0.282*** (0.000)	0.157*** (0.000)	0.148*** (0.000)	1					
Energy	-0.145*** (0.000)	0.088*** (0.000)	0.119*** (0.000)	0.134*** (0.000)	-0.356*** (0.000)	-0.299*** (0.000)	-0.045** (0.050)	1				
Fiscal	0.449*** (0.000)	0.286*** (0.000)	0.126*** (0.000)	0.348*** (0.000)	0.460*** (0.000)	0.342*** (0.000)	-0.044* (0.054)	-0.022 (0.337)	1			
Trade	0.214*** (0.000)	0.040* (0.079)	0.022 (0.337)	0.189*** (0.000)	0.175*** (0.000)	0.094*** (0.000)	0.097*** (0.000)	0.006 (0.779)	0.146*** (0.000)	1		
FDI	0.080*** (0.001)	-0.033 (0.158)	-0.029 (0.216)	0.057** (0.015)	0.094*** (0.000)	0.100*** (0.000)	-0.094*** (0.000)	-0.051** (0.027)	0.055** (0.018)	0.258*** (0.000)	1	
Shadow	-0.617*** (0.000)	-0.266*** (0.000)	-0.147*** (0.000)	-0.468*** (0.000)	-0.747*** (0.000)	-0.466*** (0.000)	0.008 (0.740)	0.210*** (0.000)	-0.355*** (0.000)	-0.102*** (0.000)	-0.042* (0.068)	1

P-value is in (); \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

For our analysis, we use a collection of techniques including the pooled OLS (POOL OLS), fixed effects (FE), random effects (RE) models, PCSE model, and FGLS model for which the robustness tests (for each estimation) have been done. In the existence of cross-sectional dependence for small panel data with a short time window and a large sample, we apply the Panel Corrected Standard Errors model (PCSE) (Marques and Fuinhas, 2012, Jönsson, 2005, Bailey and Katz, 2011) while the residuals for each estimation are tested for potential cross-sectional dependence through the Pesaran (2004) CD test. This test failed confirming the consistency and unbiasedness of PCSE.

Our study employs the two-step system GMM for the estimation of both static and dynamic unbalanced panel data. System generalized methods of moments (GMM) estimators has been applied

in situations where the independent variables are not strictly exogenous. In such circumstances, the traditional fixed effects estimator is inconsistent because the sample mean of the lagged dependent variable is correlated with that of the idiosyncratic error term. That issue becomes particularly serious in dynamic panel data models, which have relatively few time periods and many individual units as ours (Nickell, 1981). In the equation (1), mutual correlations may exist between emissions and FDI or even Trade (due to the pollution halo or pollution haven hypothesis (Asghari, 2013; Liu et al., 2018), while the dynamic panel data in the equation (2) with lagged dependent variable as explanatory variables introduces endogeneity into our model. A solution to the issues raised above can be solved with the Arellano and Bond (1991)'s estimators using GMM constructed from the moment conditions of a set of instruments to offer an efficient

solution. However, a problem of the Arellano-Bond difference GMM estimator is that the variance of the estimates may increase asymptotically and create considerable bias, particularly in the case where the data series are persistent, as the instruments are weak predictors of the endogenous changes. This issue is more likely to happen when the data sample is unbalanced (Roodman, 2006) which is the case of this study. To deal with this problem, we use in this article the extended system GMM estimator proposed by Blundell and Bond (1998) and Blundell and Bond (1998) which showed that the system GMM estimator can reduce the bias associated with the fixed effects in short panels and solve the problem of endogeneity in dynamic panel data and/or the mutual causality between dependent variables and independent variables. It should be noted that the two-step system GMM estimator is more asymptotically efficient than the one-step estimator (which uses a sub-optimal weighting matrix). Following Roodman (2006), the validity of the instruments in GMM is tested by using the Hansen test and the Arellano-Bond's AR(2) test for autocorrelation. It is worth mentioning that the dynamic form of the equation (1) and (2) changes the way to interpret the estimated coefficients from the GMM estimator. With the presence of lagged dependent variable in dynamic models in equation (2), all the estimated coefficients represent the short-run effects of the explanatory variables. This study follows the procedure suggested by Papke and Wooldridge (2005) to estimate the long-run elasticities of the explanatory (variables in the equation (2)). Moreover, for robustness check, our estimations have been regressed first with a static model and secondly with a dynamic model and the regression n. All results of system-GMM estimators are presented from Tables 4 to 13 and are fitted with conditions of robustness and unbiased as the Hansen test and AR(-2) tests are insignificant at 5% suggesting that our estimations are unbiased.

## 4. RESULTS AND DISCUSSION

### 4.1. Total Greenhouse Emissions

As a way of providing a robustness check for our estimation, the equation (1) is estimated firstly with the income, square of income, urbanization, industrialization, and energy intensity. Next, other augmented variables including government expenditure, trade openness, FDI inflow, and shadow economy are added one by one. The results of the determinants of total greenhouse emissions (*TotalE*) are shown in the Table 4 with the consistence in both sign and statistical significance of all coefficients.

It can be seen that income level has a significantly negative effect, the square of income level has significant positive effects, while all remaining variables have a positive effect on the total greenhouse emissions. The signs of income level and square of income level is opposite to the EKC hypothesis according to which the income level and total greenhouse emission is a U-shaped relationship. This opposing result to the expected U-shaped relationship may be due to the fact that the total greenhouse emissions include CO<sub>2</sub> emissions, CH<sub>4</sub> emissions, N<sub>2</sub>O emissions and other emissions, whereas the relationships between income level and each kind of emissions are different.

The significant positive effect of urbanization implies that higher levels of urbanization will increase total greenhouse emissions. The positive effect of industrialization means that the more industrialized economy will raise total greenhouse emissions. Energy intensity also has a demonstrated positive effect on total greenhouse emissions suggesting that the higher levels of energy intensity induces higher emissions.

**Table 4: Determinants of total emissions (static models)**

Dep. Variable: TotalE	Determinants of Total Emissions: Static model (system GMM estimators)				
	Basic	Government expenditure	Trade openness	FDI inflow	Shadow economy
Income	-0.962*** [0.122]	-0.988*** [0.128]	-1.023*** [0.126]	-0.808*** [0.129]	-0.695*** [0.135]
Income^2	0.078*** [0.007]	0.079*** [0.007]	0.080*** [0.007]	0.069*** [0.007]	0.065*** [0.008]
Urban	0.346*** [0.067]	0.321*** [0.061]	0.351*** [0.062]	0.300*** [0.067]	0.270*** [0.062]
Industry	0.601*** [0.031]	0.650*** [0.042]	0.643*** [0.042]	0.601*** [0.046]	0.575*** [0.041]
Energy	0.683*** [0.040]	0.640*** [0.049]	0.641*** [0.047]	0.671*** [0.050]	0.696*** [0.041]
Fiscal		0.121*** [0.043]	0.118*** [0.044]	0.089* [0.051]	0.087* [0.047]
Trade			0.035 [0.026]	0.044 [0.028]	0.021 [0.027]
FDI				0.0001 [0.0002]	0.0002 [0.0002]
Shadow					0.161*** [0.038]
Constant	4.306*** [0.609]	4.295*** [0.639]	4.243*** [0.633]	3.498*** [0.641]	2.448*** [0.605]
N	1731	1720	1720	1686	1686
Countries	105	105	105	105	105
IVs	70	71	72	73	74
AR (2) test (P-value)	0.296	0.282	0.281	0.265	0.270
Hansen test (P-value)	0.172	0.277	0.251	0.228s	0.222

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

**Table 5: Determinants of CO2 emissions (static models)**

Dep. Variable: CO2	Determinants of CO2 Emissions: Static model (system GMM estimators)				
	Basic	Government expenditure	Trade openness	FDI inflow	Shadow economy
Income	3.541*** [0.143]	3.555*** [0.159]	3.412*** [0.153]	3.330*** [0.152]	3.325*** [0.184]
Income^2	-0.155*** [0.008]	-0.156*** [0.009]	-0.149*** [0.008]	-0.145*** [0.008]	-0.148*** [0.010]
Urban	0.069 [0.076]	0.060 [0.082]	0.103 [0.084]	0.170* [0.093]	0.095 [0.098]
Industry	0.442*** [0.042]	0.409*** [0.045]	0.421*** [0.045]	0.461*** [0.054]	0.531*** [0.050]
Energy	0.729*** [0.031]	0.748*** [0.035]	0.717*** [0.037]	0.724*** [0.042]	0.716*** [0.053]
Fiscal		0.030 [0.034]	0.055 [0.043]	0.067 [0.043]	0.081 [0.051]
Trade			0.090*** [0.029]	0.083*** [0.028]	0.079*** [0.026]
FDI				0.0002 [0.0002]	0.0007** [0.0003]
Shadow					-0.263*** [0.053]
Constant	-16.202*** [0.520]	-16.283*** [0.565]	-16.095*** [0.655]	-16.093*** [0.673]	-14.881*** [0.791]
N	1790	1679	1678	1652	1651
Countries	106	106	106	106	106
IVs	70	67	68	69	70
AR (2) test (P-value)	0.246	0.118	0.138	0.135	0.143
Hansen test (P-value)	0.171	0.119	0.129	0.193	0.114

Standard errors are in []; \*, \*\*, \*\*\* are statistical significant at 10%, 5%, 1%, respectively

**Table 6: Determinants of N2O emissions (static models)**

Dep. Variable: N2O	Determinants of N2O Emissions: Static model (system GMM estimators)				
	Basic	Government expenditure	Trade openness	FDI inflow	Shadow economy
Income	0.349** [0.151]	0.567*** [0.200]	0.616*** [0.208]	0.989*** [0.211]	1.036*** [0.200]
Income^2	-0.006 [0.009]	-0.018 [0.011]	-0.020* [0.012]	-0.040*** [0.012]	-0.038*** [0.012]
Urban	0.172* [0.088]	0.154* [0.089]	0.142 [0.086]	0.143 [0.087]	0.068 [0.091]
Industry	-0.136*** [0.041]	-0.164*** [0.042]	-0.149*** [0.050]	-0.264*** [0.057]	-0.311*** [0.053]
Energy	0.514*** [0.039]	0.549*** [0.044]	0.559*** [0.043]	0.600*** [0.047]	0.604*** [0.049]
Fiscal		-0.056* [0.032]	-0.064* [0.035]	-0.096** [0.048]	-0.085 [0.053]
Trade			-0.076*** [0.023]	-0.076*** [0.028]	-0.094*** [0.033]
FDI				-0.004*** [0.001]	-0.004*** [0.0005]
Shadow					0.248*** [0.069]
Constant	0.795 [0.629]	-0.050 [0.795]	-0.0005 [0.837]	-1.403* [0.818]	-2.268*** [0.755]
N	1790	1779	1779	1745	1745
Countries	106	106	106	106	106
IVs	68	69	70	71	72
AR (2) test (P-value)	0.263	0.349	0.296	0.300	0.196
Hansen test (P-value)	0.081	0.097	0.104	0.146	0.112

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

All of these results are consistent with the stated theory of the STIRPAT model, documented in many previous empirical studies (Sadorsky, 2014; Xu and Lin, 2015; Rafiq et al., 2016; Ouyang and Lin, 2017; Zhang et al., 2017; Zhang and Xu, 2017; Liu and Bae, 2018).

The significant positive effect of government spending on total greenhouse emissions means that the higher consumption of government spending will increase the total emissions. It implies that the activities in public spending should be seen as a harmful factor to the environment. Interestingly, the result is opposite to



**Table 7: Determinants of CH4 emissions (static models)**

Dep. Variable: CH4	Determinants of CH4 Emissions: Static model (system GMM estimators)				
	Basic	Government expenditure	Trade openness	FDI inflow	Shadow economy
Income	0.208 [0.198]	0.013 [0.231]	0.045 [0.228]	0.162 [0.245]	0.314 [0.250]
Income^2	0.0005 [0.011]	0.011 [0.013]	0.012 [0.013]	0.005 [0.014]	-0.001 [0.014]
Urban	-0.129 [0.080]	-0.063 [0.084]	-0.190** [0.085]	-0.196** [0.084]	-0.220*** [0.084]
Industry	0.753*** [0.048]	0.773*** [0.053]	0.815*** [0.053]	0.742*** [0.056]	0.697*** [0.056]
Energy	0.426*** [0.046]	0.425*** [0.048]	0.401*** [0.051]	0.416*** [0.047]	0.417*** [0.047]
Fiscal		0.007 [0.041]	-0.024 [0.039]	-0.060 [0.043]	-0.054 [0.045]
Trade			-0.178*** [0.030]	-0.175*** [0.025]	-0.176*** [0.025]
FDI				-0.0005** [0.0002]	-0.0006*** [0.0002]
Shadow					0.201*** [0.057]
Constant	1.051 [0.765]	1.588* [0.863]	2.575*** [0.944]	2.326** [0.957]	1.058 [0.964]
N	1790	1779	1779	1745	1745
Countries	106	106	106	106	106
IVs	68	69	70	71	72
AR (2) test (P-value)	0.207	0.228	0.157	0.206	0.212
Hansen test (P-value)	0.125	0.147	0.139	0.259	0.168

Standard errors are in []; \*, \*\*, \*\*\* are statistical significant at 10%, 5%, 1%, respectively

**Table 8: Determinants of Total and CO2 emissions by income groups (static models)**

Static model (system GMM estimators)	Dep. Var: TotalE			Dep. Var: CO2		
	Low and lower-middle income	Upper-middle income	High income	Low and lower-middle income	Upper-middle income	High income
Income	-7.606*** [1.539]	-1.258 [1.789]	2.027** [0.778]	17.489*** [1.968]	5.980*** [1.713]	3.913*** [0.764]
Income^2	0.520*** [0.105]	0.114 [0.104]	-0.071* [0.038]	-1.138*** [0.136]	-0.294*** [0.102]	-0.159*** [0.039]
Urban	0.951*** [0.093]	-0.439* [0.225]	0.030 [0.052]	0.052 [0.127]	-0.110 [0.120]	-0.114*** [0.026]
Industry	0.624*** [0.112]	0.431*** [0.102]	0.370*** [0.067]	0.117 [0.164]	0.402*** [0.077]	0.601*** [0.068]
Energy	0.396*** [0.135]	0.764*** [0.099]	0.661*** [0.063]	0.855*** [0.122]	1.243*** [0.038]	0.723*** [0.052]
Fiscal	0.068 [0.093]	0.512*** [0.103]	-0.383*** [0.053]	0.154* [0.091]	-0.257*** [0.065]	-0.115** [0.046]
Trade	0.039 [0.081]	0.158* [0.085]	-0.031 [0.036]	-0.103 [0.070]	-0.009 [0.039]	0.076*** [0.023]
FDI	0.027*** [0.006]	-0.008** [0.003]	0.0003 [0.0002]	0.017*** [0.005]	0.009*** [0.003]	0.001*** [0.0003]
Shadow	0.188* [0.095]	0.024 [0.112]	0.227*** [0.019]	-0.812*** [0.073]	-0.123* [0.065]	0.122*** [0.044]
Constant	27.046*** [5.723]	5.624 [7.709]	-7.797* [4.221]	-61.773*** [7.304]	-27.35*** [7.219]	-19.582*** [3.813]
N	579	456	651	581	487	677
Countries	35	28	42	35	29	42
IVs	33	27	39	33	27	37
AR (2) test (P-value)	0.784	0.168	0.234	0.804	0.643	0.273
Hansen test (P-value)	0.330	0.823	0.156	0.561	0.152	0.155

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

previous results from Halkos and Paizanos (2016) who claimed that implementation of expansionary fiscal spending in US provided an alleviating effect on emissions. The fact that US is an advanced economy whereby their government policy and therefore

expenditures may focus on greener energy consumption through mechanisms such as government subsidies and regulation leads to a positive effect on the environment through the reduction of emissions. Similar reform in fiscal policy toward green strategies

**Table 9: Determinants of N2O and CH4 emissions by income groups (static models)**

Static model (system GMM estimators)	Dep. Var: N2O			Dep. Var: CH4		
	Low and lower-middle income	Upper-middle income	High income	Low and lower-middle income	Upper-middle income	High income
Income	-12.335*** [2.229]	-0.712 [1.844]	-16.68*** [2.01]	-5.566*** [1.471]	3.179* [1.790]	-4.350*** [1.190]
Income^2	0.833*** [0.153]	0.055 [0.104]	0.826*** [0.099]	0.388*** [0.105]	-0.168 [0.102]	0.236*** [0.061]
Urban	1.000*** [0.158]	0.077 [0.246]	0.293*** [0.074]	0.272* [0.135]	-0.204 [0.140]	-0.242*** [0.056]
Industry	0.062 [0.091]	0.136 [0.200]	-0.397*** [0.076]	0.137 [0.092]	0.925*** [0.109]	0.798*** [0.102]
Energy	-0.228 [0.144]	0.421*** [0.120]	0.385*** [0.103]	0.107 [0.088]	0.438*** [0.106]	0.302*** [0.044]
Fiscal	0.026 [0.050]	0.693*** [0.087]	0.338*** [0.095]	-0.100* [0.051]	0.465*** [0.106]	-0.302*** [0.077]
Trade	0.083 [0.062]	0.080 [0.061]	-0.172** [0.074]	-0.018 [0.053]	-0.225*** [0.068]	-0.186*** [0.033]
FDI	0.010*** [0.001]	-0.022*** [0.004]	-0.002*** [0.0005]	0.031*** [0.006]	-0.002 [0.003]	-0.001*** [0.0004]
Shadow	0.350* [0.198]	0.396*** [0.109]	-0.152*** [0.050]	0.362*** [0.083]	0.439*** [0.102]	0.369*** [0.043]
Constant	46.543*** [8.265]	1.886 [8.113]	88.78*** [10.21]	23.387*** [5.125]	-14.046* [7.780]	24.564*** [5.632]
N	581	487	677	581	487	677
Countries	35	29	42	35	29	42
IVs	35	29	39	33	29	37
AR (2) test (P-value)	0.796	0.861	0.630	0.093	0.381	0.530
Hansen test (P-value)	0.404	0.265	0.119	0.764	0.368	0.426

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

is also documented in Sweden (Shmelev and Speck, 2018), another advanced economy. However, our study uses a large sample of countries (106 economies) with various stages of development across countries, noting that public spending in countries at a less developed stage of economic evolution would focus more on economic development (Aghion et al., 2014; Schalck, 2014; Bobașu, 2015) that will be more harmful to environment through higher emissions. Results from this study should raise the suggestion that reform towards “greener” policies could be a useful action in order to tackle with climate change.

Economic integration (including trade openness and FDI inflow), has a positive effect on total greenhouse emissions but insignificant. Actually, the positive effects reflect the pollution-haven hypothesis (Birdsall and Wheeler, 1993; Javorcik and Wei, 2004; He, 2006; Rezza, 2013) of economic integration. However, the insignificance of the estimated coefficients may be due to the broad sample countries in our study, we have 106 economies with various characteristics of economics (and economic integration) making the effects of economic integration are not really statistically significant.

Our main aim was to document the determinants of impact from the shadow economy, we find that shadow activities have a positive significant effect on total greenhouse emissions suggesting that the bigger a shadow economy, the greater the level of total greenhouse emissions. The result present a ‘deregulation effect’, whereby a larger (smaller) informal economy is associated with higher (lower) pollution levels (Elgin and Oztunali, 2014). The result is consistent with our expectation and the foreshadowing

of previous studies (Abid, 2015; Sadorsky, 2013) that the informal economic activities are out of control of government and regulations, especially the environmental regulations, thus creating therefore conditions for the shadow economy to operate with less responsibility to environmental issues. The result reinforces concerns in the escalating battle against with global warming and climate change due to the existence of the large informal shadow economy across countries (Medina and Schneider, 2018).

## 4.2. CO2 Emissions

For the static model, the results of determinants of CO2 emissions are presented in the Table 5. The procedure followed for robustness is identical to that described above in relation to total greenhouse emissions.

The significant positive effect of income level and the significant negative effect of square of income level suggest that the EKC hypothesis is observed in the case of CO2 emissions. This means that the income and CO2 emissions have an inverted-U relationship as expected by theory outlined in our literature review and many empirical studies (Qureshi et al., 2017; Solarin and Shahbaz, 2015; Danish et al., 2017; Gill et al., 2018). Other variables have the same sign as with the determinants of total greenhouse emissions but the effects of urbanization and public spending are not all significant while the industrialization, energy intensity have a significant effect on the CO2 emissions. These results highlight the active role played by industrialization and technological factors in global warming.

Interestingly, economic integration (including both trade openness and FDI inflow) has a significant effect on the CO2 emissions.

**Table 10: Determinants of total emissions: Short- and long-run effects**

Dep. Variable: TotalE	Dynamic two- step system-GMM			
	Full sample	Low and lower-middle	Upper-middle	High income
TotalE(-1)	0.752*** [0.003]	0.754*** [0.015]	0.847*** [0.008]	0.913*** [0.011]
Income	-0.195*** [0.034]	-1.454*** [0.383]	0.587** [0.231]	0.664*** [0.107]
Income^2	0.016*** [0.002]	0.097*** [0.026]	-0.029** [0.013]	-0.031*** [0.005]
Urban	0.089*** [0.012]	0.222*** [0.055]	-0.081** [0.039]	-0.030*** [0.006]
Industry	0.171*** [0.010]	0.106*** [0.035]	0.061** [0.023]	0.047*** [0.011]
Energy	0.166*** [0.010]	0.091*** [0.029]	0.089*** [0.012]	0.026*** [0.006]
Fiscal	0.018* [0.010]	-0.038 [0.031]	0.107*** [0.023]	-0.054*** [0.013]
Trade	0.007 [0.007]	0.045* [0.026]	0.013 [0.020]	-0.013*** [0.006]
FDI	0.00005 [0.00007]	0.007*** [0.002]	-0.0001 [0.001]	0.0001*** [0.00003]
Shadow	0.036*** [0.010]	0.102*** [0.028]	-0.024 [0.019]	0.018*** [0.005]
Constant	0.641*** [0.152]	5.282*** [1.460]	-2.141* [1.072]	-2.730*** [0.578]
Long-run coefficients				
Income	-0.784*** [0.139]	-5.906*** [1.563]	3.832** [1.504]	7.649*** [1.643]
Income^2	0.066*** [0.008]	0.394*** [0.108]	-0.187** [0.087]	-0.356*** [0.082]
Urban	0.359*** [0.051]	0.903*** [0.195]	-0.528** [0.264]	-0.349*** [0.050]
Industry	0.691*** [0.040]	0.429*** [0.140]	0.401*** [0.140]	0.545*** [0.118]
Energy	0.669*** [0.039]	0.368*** [0.108]	0.581*** [0.101]	0.298*** [0.049]
Fiscal	0.073* [0.041]	-0.153 [0.128]	0.700*** [0.125]	-0.621*** [0.142]
Trade	0.028 [0.026]	0.183* [0.105]	0.085 [0.128]	-0.149** [0.067]
FDI	0.0002 [0.0003]	0.028*** [0.007]	-0.001 [0.004]	0.001*** [0.0003]
Shadow	0.144*** [0.040]	0.415*** [0.109]	-0.159 [0.121]	0.206*** [0.075]
N	1400	512	456	613
Countries	105	35	28	42
IVs	86	32	28	40
AR(-2) test (P-value)	0.103	0.323	0.151	0.459
Hansen test (P-value)	0.170	0.199	0.425	0.108

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

This result is consistent with the pollution-haven hypothesis in economic integration, which raises strong issues for global actions and economies with higher levels of economic integration. Meanwhile, the shadow economy has a significantly negative effect on CO<sub>2</sub> emissions. This implies that higher levels of informal economic activities will reduce CO<sub>2</sub> emissions. This finding is opposite to that of previous results of the shadow economy's positive impact on total greenhouse emissions. Actually, Elgin and Oztunali (2014) explained that the informal economy has two opposite effects on pollution: A scale effect and the deregulation effect. Such influence has been observed in our finding for the total greenhouse emissions: The shadow economy has deregulation effects (positive effect), while in the case of CO<sub>2</sub> emissions, the

shadow economy has a scale effect (negative effect). This result suggests a greater need to investigate the effects of the shadow economy on emissions.

### 4.3. N<sub>2</sub>O and CH<sub>4</sub> Emissions

Results for the cases of N<sub>2</sub>O and CH<sub>4</sub> emissions are reported in the Tables 6 and 7

Our results show that income levels have significantly positive effects, while the square of income level has significantly negative effects in the case of N<sub>2</sub>O emissions. This implies the existence of the EKC in the case of N<sub>2</sub>O emissions. Urbanization has a positive influence on N<sub>2</sub>O emissions, while it has negative effects

**Table 11: Determinants of CO2 emissions: Short- and long-run effects**

Dep. Variable: CO2	Dynamic two-step system-GMM			
	Full sample	Low and lower-middle	Upper-middle	High income
CO2(-1)	0.933*** [0.004]	0.779*** [0.041]	0.864*** [0.027]	0.676*** [0.016]
Income	0.504*** [0.030]	1.914*** [0.455]	0.725*** [0.242]	0.985*** [0.267]
Income^2	-0.028*** [0.002]	-0.116*** [0.028]	-0.036*** [0.013]	-0.039*** [0.013]
Urban	0.006 [0.005]	0.067* [0.034]	-0.016 [0.023]	-0.059*** [0.012]
Industry	0.040*** [0.005]	0.018 [0.029]	0.070*** [0.013]	0.206*** [0.023]
Energy	0.034*** [0.006]	0.076* [0.045]	0.148*** [0.038]	0.187*** [0.024]
Fiscal	-0.010** [0.004]	0.003 [0.023]	-0.035 [0.022]	-0.070*** [0.022]
Trade	0.004 [0.004]	-0.003 [0.030]	0.007 [0.007]	0.017 [0.014]
FDI	0.0003*** [0.0001]	0.0002 [0.003]	0.0003 [0.001]	0.0003*** [0.0001]
Shadow	-0.104*** [0.006]	-0.191*** [0.048]	-0.038** [0.016]	0.047*** [0.014]
Constant	-1.632*** [0.124]	-6.233*** [1.662]	-3.168*** [1.100]	-4.388*** [1.419]
Long-run coefficients				
Income	7.547*** [0.296]	8.667*** [1.160]	5.327*** [1.039]	3.039*** [0.828]
Income^2	-0.422*** [0.018]	-0.526*** [0.078]	-0.263*** [0.060]	-0.121*** [0.041]
Urban	0.089 [0.076]	0.305** [0.139]	-0.118 [0.185]	-0.183*** [0.037]
Industry	0.594*** [0.077]	0.082 [0.131]	0.517*** [0.046]	0.636*** [0.065]
Energy	0.505*** [0.062]	0.346** [0.170]	1.088*** [0.082]	0.575*** [0.060]
Fiscal	-0.156** [0.066]	0.012 [0.105]	-0.258** [0.122]	-0.216*** [0.070]
Trade	0.061 [0.058]	-0.013 [0.138]	0.054 [0.048]	0.051 [0.042]
FDI	0.004*** [0.001]	0.001 [0.013]	0.002 [0.004]	0.001*** [0.0002]
Shadow	-1.564*** [0.086]	-0.864*** [0.143]	-0.278** [0.116]	0.146*** [0.043]
N	1651	581	487	677
Countries	106	35	29	42
IVs	101	30	28	40
AR(-2) test (P-value)	0.303	0.574	0.481	0.442
Hansen test (P-value)	0.244	0.324	0.181	0.077

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

on CH4 emissions. Industrialization has a negative effect on N2O emissions, while it has a positive effect on CH4 emissions. Energy intensity has positive impacts on both N2O and CH4 emissions. Economic integration (trade openness and FDI inflow) and public expenditure have negative effects on both N2O and CH4 emissions highlighting the answer to our main question, we find that the shadow economy has positive effects on both N2O and CH4 emissions.

#### 4.4. Emissions by Income Groups

For further detail about the effects of the shadow economy on global emissions, the models are estimated by income levels to investigate whether the shadow economy and pollution is an inverse-U relationship between informal economy and

environmental pollution (the scale and the deregulation effects) (Elgin and Oztunali, 2014). The results are shown in Tables 8 and 9 with interesting findings.

For the case of total greenhouse emissions, we observe a EKC trend in high income economies. Urbanization increases the emissions in low and lower-middle income but decreases the emissions in upper-middle income economies. Industrialization and energy intensity increase the emissions in all groups. Public spending increases the emissions in upper-middle income economies, while the emissions decrease in the case of high income economies. It is same with trade openness. The FDI inflow has pollution-haven in low and lower-middle income economies, but it is pollution-halo in upper-middle income economies. The shadow economy increases



**Table 12: Determinants of N2O emissions: Short- and long-run effects**

Dep. Variable: N2O	Dynamic two-step system-GMM			
	Full sample	Low and lower-middle	Upper-middle	High income
N2O(-1)	0.964*** [0.002]	0.911*** [0.004]	0.972*** [0.005]	0.857*** [0.007]
Income	0.160*** [0.007]	0.385*** [0.098]	-0.282** [0.105]	-0.786*** [0.151]
Income^2	-0.008*** [0.0004]	-0.029*** [0.007]	0.016** [0.006]	0.038*** [0.008]
Urban	-0.004 [0.004]	0.041** [0.019]	0.018 [0.014]	0.078*** [0.011]
Industry	-0.025*** [0.002]	0.037*** [0.010]	0.047*** [0.009]	-0.073*** [0.015]
Energy	0.016*** [0.003]	0.005 [0.012]	-0.004 [0.005]	0.070*** [0.009]
Fiscal	-0.024*** [0.002]	-0.031 [0.020]	0.060*** [0.010]	0.033 [0.021]
Trade	-0.005** [0.002]	-0.022* [0.013]	0.002 [0.003]	-0.004 [0.011]
FDI	-0.0002*** [0.00004]	0.010*** [0.002]	-0.001*** [0.0002]	-0.0006*** [0.0001]
Shadow	0.009** [0.004]	0.062*** [0.009]	0.016*** [0.005]	-0.024 [0.018]
Constant	-0.447*** [0.030]	-1.163*** [0.419]	0.965** [0.442]	4.530*** [0.801]
Long-run coefficients				
Income	4.434*** [0.223]	4.325*** [1.152]	-9.974** [4.911]	-5.513*** [1.065]
Income^2	-0.232*** [0.013]	-0.322*** [0.078]	0.567** [0.284]	0.266*** [0.053]
Urban	-0.117 [0.103]	0.464** [0.205]	0.643 [0.525]	0.547*** [0.082]
Industry	-0.696*** [0.053]	0.420*** [0.114]	1.648*** [0.351]	-0.515*** [0.110]
Energy	0.430*** [0.062]	0.054 [0.139]	-0.159 [0.183]	0.494*** [0.073]
Fiscal	-0.666*** [0.068]	-0.351 [0.215]	2.127*** [0.348]	0.232 [0.145]
Trade	-0.138** [0.059]	-0.252* [0.150]	0.078 [0.109]	-0.027 [0.080]
FDI	-0.005*** [0.001]	0.113*** [0.021]	-0.039*** [0.009]	-0.005*** [0.001]
Shadow	0.251** [0.110]	0.692*** [0.111]	0.566*** [0.176]	-0.165 [0.126]
N	1745	581	487	677
Countries	106	35	29	42
IVs	102	34	29	40
AR(-2)	0.444	0.794	0.135	0.569
test (P-value)				
Hansen test (P-value)	0.277	0.172	0.297	0.245

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

the emissions in both cases of low and lower-middle income and high income, while it has insignificant positive effect in the case of upper-middle income economies.

For the case of CO<sub>2</sub> emissions, the EKC appears for all income groups. The urbanization in high-income economies reduces the levels of CO<sub>2</sub> emissions. Whereas industrialization and energy intensity are still the main drivers for higher emissions in all income economies. Public spending has a positive effect in low and lower-middle income economies, and a negative effect for upper-middle and high income ones. Trade openness reduces CO<sub>2</sub> emission in all cases, while FDI inflows induce higher emissions for all groups. The shadow economy reduces

the emissions in low and middle income, while it increases the CO<sub>2</sub> emission in high income economies. This means that the shadow economy has scale effects in low and middle income, but a deregulation effect on pollution in high income economies.

Regarding to N<sub>2</sub>O emissions, urbanization increases emissions in low and lower middle income and high-income economies. Industrialization, energy intensity, public spending all increase emissions in every income group. Trade openness has significant positive effects in upper-middle income economies. While FDI inflows generate a pollution-haven effect in low and lower middle income, but pollution-halo in upper-middle income economies.

**Table 13: Determinants of CH4 emissions: Short- and long-run effects**

Dep. Variable: CH4	Dynamic two-step system-GMM			
	Full sample	Low and lower-middle	Upper-middle	High income
N2O(-1)	0.955*** [0.002]	0.874*** [0.007]	0.948*** [0.009]	0.993*** [0.004]
Income	0.172*** [0.008]	0.307*** [0.091]	0.459*** [0.165]	-0.193*** [0.038]
Income^2	-0.009*** [0.000]	-0.021*** [0.007]	-0.025** [0.009]	0.009*** [0.002]
Urban	-0.035*** [0.002]	0.012 [0.012]	-0.034** [0.013]	-0.034*** [0.002]
Industry	0.029*** [0.003]	0.006 [0.012]	0.082*** [0.011]	0.006 [0.004]
Energy	0.032*** [0.002]	0.030*** [0.011]	0.041*** [0.008]	0.005** [0.002]
Fiscal	-0.014*** [0.002]	-0.029** [0.012]	0.025*** [0.009]	0.012*** [0.004]
Trade	-0.010*** [0.001]	-0.025 [0.015]	-0.033*** [0.006]	-0.001 [0.002]
FDI	-0.00004* [0.00002]	0.008*** [0.001]	0.002*** [0.0005]	-0.0001*** [0.00002]
Shadow	0.006* [0.003]	0.045** [0.017]	0.020** [0.008]	0.008** [0.003]
Constant	-0.550*** [0.038]	-0.524 [0.316]	-2.071*** [0.742]	1.101*** [0.206]
Long-run coefficients				
Income	3.820*** [0.255]	2.433*** [0.776]	8.847*** [3.197]	-26.597** [13.439]
Income^2	-0.195*** [0.014]	-0.163*** [0.057]	-0.484*** [0.179]	1.270** [0.629]
Urban	-0.782*** [0.062]	0.092 [0.093]	-0.658** [0.266]	-4.700** [2.352]
Industry	0.636*** [0.057]	0.045 [0.092]	1.585*** [0.327]	0.794*** [0.240]
Energy	0.718*** [0.038]	0.236*** [0.084]	0.796*** [0.169]	0.727 [0.446]
Fiscal	-0.309*** [0.048]	-0.228** [0.097]	0.478*** [0.130]	1.626 [1.298]
Trade	-0.227*** [0.032]	-0.195 [0.119]	-0.628*** [0.151]	-0.180 [0.238]
FDI	-0.0009* [0.0005]	0.062*** [0.008]	0.039*** [0.014]	-0.015* [0.008]
Shadow	0.129* [0.066]	0.356*** [0.122]	0.378*** [0.135]	1.172* [0.600]
N	1745	581	487	677
Countries	106	35	29	42
IVs	102	34	30	42
AR(-2) test (P-value)	0.542	0.896	0.416	0.900
Hansen test (P-value)	0.267	0.612	0.587	0.097

Standard errors are in []; \*, \*\*, \*\*\*are statistical significant at 10%, 5%, 1%, respectively

The shadow economy increases the emissions in low and lower-middle income and high-income economies.

Concerning the CH4 emissions, urbanization reduces the emissions in high income economies. Industrialization and levels of energy intensity increase emissions in all cases. Public spending reduces the emissions in upper-middle income and high-income economies. Trade openness increases the emissions in high-income economies. Interestingly, the FDI inflow has a pollution-haven effect in all cases. And the shadow economy has scale effects in cases of low and middle income, while deregulation effect emissions in high income economies.

#### 4.5. Results from Dynamic Models: Short-run and Long-run Effects

The results from dynamic system-GMM estimations are reported from the Tables 10-13. The short-run effects are consistent with all previous results, while the long-run effects are also consistent with short-run effects and even stronger.

Precisely, in the case of total emissions, the outcomes reported are consistent as well as more substantial in the long-run. In both short-run and long-run, the signs of income level and the square of income level are opposite to the EKC hypothesis. The impact of trade openness, FDI inflows and shadow economy are all positive. This can be explained easily: In the long-run, the

policymakers in low and lower-middle-income countries are willing to focus on economic growth rather than environmental quality. As a result, they expand the scale of economic activities which is necessary for economic growth but negatively affects the environment (Rock and Angel, 2007). Additionally, in upper middle and high income economies, the results are in line with the EKC hypothesis (Ertugrul et al., 2016) while the influence of FDI is lower in high income economies while the effect of trade openness and government spending are not so important. This is just because when the people attained a high income, the government as well as people paid more attention toward environmental quality. Interestingly, in all groups of economy, the effect of informal economies are stronger in the long-run, however, it has a correspondingly weaker impact on high income economies due to the fact that shadow economy is usually in opposite trend to the income levels (Medina and Schneider, 2018).

The same result can be found in the case of CO<sub>2</sub> Emissions as the results are consistent and firm in the long-run as well. The results are also consistent with the EKC hypothesis in our full sample as well as in every group of economies. The influences of industrialization, energy, FDI inflow are positive for CO<sub>2</sub> Emission in both the short and long-run, however, the industrialization variable is insignificant in low and lower-middle economies and FDI inflow is the same in low and lower-middle and upper-middle income economies. The effect of government spending is negative in the full sample as well as in all income groups (except for low and lower-middle economies) while trade openness has a positive impact on CO<sub>2</sub> emission but is statistically insignificant. From the perspective of urbanization, it has positive influences in low and lower-middle income economies but shows an opposite trend on high-income economies. Looking at the full sample, it is insignificant as well. The impact of shadow activities is in the same in both runs across groups of the country. Similarly, the outcomes from N<sub>2</sub>O and CH<sub>4</sub> are the same in both the short-run and long-run.

#### 4.6. Robustness Check

The final step in our study is regressing all of the cases above in different methods including POOL OLS, FE, RE, PCSE and FGLS model in order to check the robustness of our estimations. We proceeded with different robustness checks on different aspects. First, we dealt with total emissions and every single emission<sup>3</sup>.

Regarding this issue, the results from all of the methods are in line with the original estimation, except that fiscal variables are insignificant while trade openness is only statistically significant with PCSE. The effect of the shadow economy is entirely consistent among all of the estimations. However, the results from FE and RE are in opposition to each other, which supports the existence of endogeneity so that the use of system GMM is suitable. Second, relating to CO<sub>2</sub> Emission, all of the results from all methods are the same apart from the case of Urbanization, which has a negative effect in case of POOL OLS, FGLS and PCSE model. The sensitivity of urbanization's coefficients have proven that this is due to the different techniques as explained by Sadorsky (2013).

Third, the result of N<sub>2</sub>O emission is seemingly complicated as with FE and RE, the sign of income level and square of income level performs in the manner of an opposite trend with EKC hypothesis and the same outcomes found in the effects of trade openness and shadow economy while the Industry and the energy's outcome have correlation with the original model when regressed by POOL OLS, FGLS and PCSE. Surprisingly, urban and government spending variables have statistically significant results with POOL OLS, FGLS and PCSE model. Finally, the results from CH<sub>4</sub> Emission show the same result in Urbanization, Industry, Energy and Fiscal variables with POOL OLS, FGLS and PCSE methods. However, the income level and square of income level perform result follow the EKC hypothesis while government spending is significant FDI inflows are insignificant compared with the ordinary model. On the contrary, the result from FE and RE show an opposite trend.

In summary, the results from all the above estimations are sometimes different from the ordinary model due to the endogenous issue rising from the relationship among these control variables.

It is worth mentioning that we also did robustness check for the different income groups<sup>4</sup>. In term of Total emissions, in low and lower-middle income countries, the same result can be found in the case of income level, square of income level, urbanization, industry, energy and FDI inflow variables, however, the results from FE and RE estimation show a different sign. In upper-middle income economies, with, POOL OLS, FGLS and PCSE, we found the same result with ordinary estimation except that the income level and the square of income level variables are statistically significant and follow the EKC hypothesis. Again, the result from FE and RE estimation show a different sign. Relating to high-income economies, only industry, energy and shadow economy variables show a similar outcome with our GMM estimations. Second, from the perspective of CO<sub>2</sub> Emission, in low and lower-middle income countries, almost all of the methods performed show the same result with our GMM estimations except trade openness. In upper-middle income economies, only the PCSE model shows the same outcome with our ordinary estimation while all of the other different methods provide the same outcomes for all variable except urbanization and trade openness. Relating to high-income economies, the same outcome has been found among all estimations. This result is a strong suggestion for policy in high-income economies. With N<sub>2</sub>O emissions, in low and lower-middle income countries, the outcome is different among estimation while upper-middle income economies, the same result of all variables are found in all estimation methods but not for the FE and RE due to endogeneity. The same conclusion can be reached in high-income economies with POOL OLS, FGLS and PCSE estimation. In the case of CH<sub>4</sub> Emission in low and lower-middle income countries, in POOL OLS, FGLS and PCSE estimation, we found the same result for all of the examined variables except income level and the square of income level. They display a U-shape in the relationship between income level and CH<sub>4</sub> emission which is in contrast to the EKC hypothesis. Trade openness is only statistically significant when regressed by the PCSE model. Notably, FE and

3 All results from robustness check will be provided under the request

4 All results from robustness check are provided under the request

RE result show an opposite sign with other estimations. Relating to upper-middle income economies, the unique results are found among the entire estimation. Interestingly, square of income level, as well as urbanization and FDI inflow variables, are significant in some methods. Finally, in high-income economies, urbanization, industry, energy, government spending, trade openness and shadow economies have shown the same result with our ordinary estimations while FDI inflows is only significant when regressed through a PCSE estimation.

## 5. CONCLUSION

The determinants of global emissions are still under the strong attention in environmental economies. This study bases on the theoretical framework of STIRPAT model and EKC hypothesis to examine economic determinants of global emissions in an extended model by adding public spending, economic integration (trade openness and FDI inflow) and especially the shadow economy. The data of a sample 106 economies in the period of 1995-2012 including income level, urbanization, industrialization, energy intensity, public expenditure, trade openness, FDI inflows, and especially shadow economy are regressed for the four different emissions including total greenhouse emissions, CO<sub>2</sub> emissions, CH<sub>4</sub> emissions, and N<sub>2</sub>O emissions, respectively.

The study provides a significant contribution to both literature and policy makers. The empirical results show that the larger shadow economy the greater the increases in total greenhouse emissions, CH<sub>4</sub> and N<sub>2</sub>O emissions. Such observations result from the fact that shadow economy is not constrained by environmental regulations making controls are almost impossible and impacting therefore the environment. Notably, the influence of the shadow economy on emissions display marginal differences across the three income levels, with a significant effect on total greenhouse emissions in low and lower-middle income economies and the high-income economies, while it has a insignificant positive effect in the case of upper-middle income economies. The shadow economy has significant a positive impact on N<sub>2</sub>O emission in low and middle-income brackets, while it exhibits a negative effect in high-income brackets. In the case of CH<sub>4</sub>, the shadow economy has a positive effect in all income levels. Finally, the shadow economy increases CO<sub>2</sub> significantly in the case of high-income economies, but it has a negative effect in the case of low and middle-income economies. Furthermore, the long-run effects of the shadow economy on emissions are documented with consistent and stronger effects than short-run effects.

Additionally, this study contributes empirical evidences and thus extends previous studies by further documenting the differences in the effects of income, industrialization, urbanization, energy intensity, fiscal expense, trade openness and FDI inflow on emissions. The effectiveness of the Environmental Kuznet Curve (EKC) is found in the case of CO<sub>2</sub> and N<sub>2</sub>O emissions, where urbanization increases total greenhouse emissions, CO<sub>2</sub> and N<sub>2</sub>O emissions, while it reduces the CH<sub>4</sub> emissions. The effects of urbanization are also different across income levels. It increases the emissions (for all proxy of emissions) in low and lower-middle income economies, but it reduces the emissions in most

emissions (3/4) in upper-middle income ones, and 2/4 emissions in high-income economies. Industrialization induces higher total greenhouse emissions, CO<sub>2</sub> and CH<sub>4</sub> in all cases, while it reduces N<sub>2</sub>O emissions in the case of high income economies. Energy intensity, in the same way as industrialization, is the main driver of higher emissions for all cases of emissions and income levels. Government spending also has significant positive effects on total greenhouse emissions, but is insignificant for the case of CO<sub>2</sub>, and it has negative effects on CH<sub>4</sub> and N<sub>2</sub>O emissions. Interestingly, the effects of government spending are different across the income levels. It has no significant positive effects in low and lower-middle income economies (excluding the case of CH<sub>4</sub>), but it has significant positive effects on emissions in the upper-middle income economies (excluding for CO<sub>2</sub>). Meanwhile, it reduces most of emissions in the case of high income ones. Trade openness induces higher total greenhouse emissions in line with CO<sub>2</sub> emissions but lower levels of CH<sub>4</sub> and N<sub>2</sub>O emissions. Its effects are also different across income levels. The patterns of FDI's effects on emissions are similar to that of trade openness.

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## APPENDIX

**Table A1: Country list**

Armenia	Congo, Rep.	India	Mozambique	Sri Lanka
Low and lower-middle income economies (35)				
Bangladesh	Egypt	Jordan	Nepal	Tajikistan
Benin	El Salvador	Kenya	Nicaragua	Tanzania
Bolivia	Eritrea	Kyrgyz Republic	Nigeria	Togo
Cambodia	Georgia	Moldova	Pakistan	Tunisia
Cameroon	Ghana	Mongolia	Philippines	Ukraine
Congo, Dem.	Honduras	Morocco	Senegal	Yemen, Rep.
Upper-middle income economies (29)				
Albania	Brazil	Dominican Rep.	Mauritius	Russian Federation
Algeria	Bulgaria	Ecuador	Mexico	South Africa
Argentina	China	Iran	Namibia	Thailand
Azerbaijan	Colombia	Kazakhstan	Paraguay	Turkey
Belarus	Costa Rica	Lebanon	Peru	Venezuela
Botswana	Croatia	Malaysia	Romania	
High income economies (42)				
Australia	Finland	Japan	Norway	Spain
Austria	France	Korea, Rep.	Poland	Sweden
Belgium	Germany	Latvia	Portugal	Switzerland
Brunei	Greece	Lithuania	Qatar	Trinidad and Tobago
Chile	Hungary	Luxembourg	Saudi Arabia	UAE
Cyprus	Iceland	Malta	Singapore	United Kingdom
Czech Republic	Ireland	Netherlands	Slovak Republic	United States
Denmark	Israel	New Zealand	Slovenia	Uruguay
Estonia	Italy			

**Table A2: Cross-dependence test**

Variable	CD-test	P-value	Corr	Abs (corr)
Income	233.882***	0.000	0.74	0.83
Urban	133.118***	0.000	0.42	0.89
Industry	19.09***	0.000	0.06	0.48
Energy	117.168***	0.000	0.37	0.65
Fiscal	26.979***	0.000	0.09	0.38
Trade	80.322***	0.000	0.26	0.49
FDI	41.01***	0.000	0.13	0.28
Shadow	185.48***	0.000	0.59	0.65

\*\*\*Is statistical significant at 1% level (p-values close to zero indicate data are correlated across panel groups)