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Economic growth and environmental degradation in Vietnam: Is the environmental Kuznets curve a complete picture?

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ABSTRACT

Based on a sample of 1974–2016 annual data of Vietnam, we show that the EKC does not exist in the short run but only in the long run. However, the N-shape describes better the long-run income-pollution relationship. This implies that Vietnam can expect a temporary reduction in CO_2 emissions at a given stage of economic growth. However, this will be followed by a further increase of CO_2 emissions after reaching another income turning point. The Vietnamese government should thus focus on long-term economic and environmental strategies. A robustness check shows that these results are not impacted by the variables' selection.

1. Introduction

Vietnam has undergone rapid economic development in recent years, averaging 6.4% per year in the 2000s (World Bank, 2015). In 1986, the government launched a *Renovation* initiative*,* the so-called *Doi Moi*. This program consisted of several key political and economic actions designed to improve the economic environment, which had been negatively impacted by the post-war difficulties. The major outcome of the plan was the shift from a poor closed economy to an open emerging economy with more private firms.[1] The result of the *Renovation* has been significant, as income per capita increased more than eightfold between 1985 and 2014, from 100 USD to 2100 USD, respectively (World Bank 2015). Nevertheless, the intensive economic development, industrialization and urbanization have substantially augmented the energy consumption and environmental pressures. According to a report published by the World Bank in 2015, the volume of CO_2 emissions has doubled in the last three decades (from 14 million tons in 1980 to 80 million tons in 2005). As a consequence, the measures implemented in Vietnam by the Poverty Reduction Support Credit Programs (supported by the World Bank) focus on specific strategies related to pollution prevention and control, environment-related valuation actions, and the efficient management of forest and water resources. Furthermore, Vietnam was engaged in the COP21 agreement with a global objective to reduce the volume of CO_2 emissions to maintain de rise of the temperature at $+2\,^{\circ}C$ in 2100. According to this agreement, Vietnam can receive the help of developed countries in the establishment and execution of environmental policies. It is thus important to understand the relationship between economic growth and CO_2 emissions to draw appropriate economic and environmental policies.

In this context, the income growth in Vietnam raises the question about its impact on the environment. Regarding the environmental Kuznets curve (EKC), one can wonder whether the EKC exists in this emerging country, even though previous studies

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[1] See Dana (1994) for more information.

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have shown its superior adaptability to high-income nations (Saboori, Sapri, & Baba, 2014). This question is the focus of our study. Indeed, the EKC is a hypothesized relationship between various indicators of environmental degradation and income per capita. It stipulates that during the early stage of economic growth, pollution increases but then, at a given income level (called the *turning point*), the trend reverses and pollution decreases thanks to economic growth (Stern, 2004). This phenomenon is described by an inverted U-shaped curve. Kuznets (1955), who received a Nobel Prize in 1971, suggested that as per capita income improves, income inequality initially becomes greater, but the gap then narrows after the income turning point. At the beginning, this theory had not been widely explored in the field of environmental economics until 1991, with the pioneering studies of Grossman and Krueger (1991, 1995) and Shafik and Bandyopadhyay (1992). These studies were then followed by many others that tested the existence of the EKC in different countries and periods (e.g., Bryun, Van Den Bergh, & Opschoor, 1998; Cole, 2004; Esteve & Tamarit, 2012; Galeotti, Lanza, & Pauli, 2006; Hettige, Mani, & Wheeler, 2000; Iwata, Okada, & Samreth, 2010; Liddle & Messinis, 2015; Lindmark, 2002; Romero-Avila, 2008). Yet, the EKC has rarely been tested in Vietnam: to our knowledge, only Al-Mulali, Saboori, and Ozturk (2015) and Tang and Tan (2015) have done so. The former did not find evidence to support the EKC hypothesis for the 1981–2011 period, whereas the latter confirmed it for the 1976–2009 period. It should nevertheless be noted that these studies focused only on the cointegration relationship between CO_2 emissions and GDP per capita. In our opinion, this is not sufficient to draw conclusions about the existence of the EKC, a point of view also supported by Tutalmaz (2012).

In this context, our study extends the EKC literature in several ways. First, we use annual data (1974–2016) to investigate the case of Vietnam, a country that has rarely been explored. Second, we analyse the relationship between income per capita and CO_2 emissions, including energy consumption, industry and agriculture value added, foreign direct investment (FDI), urbanization, government size and trade openness[2] in considering the collinearity issue following the method of Narayan and Narayan (2010). For that, we study the short-run and long-run relationships between economic growth and CO_2 emissions via linear, quadratic and cubic regressions. The linear regression allows for the collinearity issue to be verified, the quadratic regression allows detecting the EKC while the cubic regression allows investigating the N-shaped relationship between economic growth and CO_2 emissions. The N-shaped relationship implies that the decrease in CO_2 emissions after the first income turning point is only temporary and may rise again after another income turning point is reached. So, the N-shape provides a more complete picture than the EKC about the impact of economic growth on the environment. This point is an important contribution of our study because this has not been found on Vietnam, to the best of our knowledge. However, the N-shape phenomenon has been observed by several authors on various countries (e.g., Moomaw & Unruh, 1997, Friedl & Getzner, 2003, Martınez-Zarzoso & Bengochea-Morancho, 2004, Brajer, Mead, & Xiao, 2008, Onafowora & Owoye, 2014). Regarding the methodology, a unit root test (Perron 1997) and an ARDL bounds test (Pesaran, Shin, & Smith, 2001) are applied to study the cointegration between the variables. To further understand their links, we also test the Granger causality between CO_2 emissions and the considered determinant factors. Finally, to check the robustness of our results, we also re-estimate the empirical results in including additional potential determinant factors of CO_2 emissions to see whether the variables' selection has an impact on the findings.

The rest of the paper is organized as follows. Section 2 presents a literature review on the EKC hypothesis and the determinants of CO_2 emissions. Section 3 describes the data and methodology. Section 4 interprets the results. Section 5 checks the robustness of the results in including additional variables in the regressions. Section 6 concludes with insights for policy implications.

2. Literature review: the EKC hypothesis and the determinants of CO_2 emissions

The literature review is divided into two parts. Part 1 summarizes previous studies that have tested the EKC hypothesis for CO_2 emissions. Part 2 focuses on the determinants of CO_2 emissions. Our contribution to the extant literature will also be highlighted.

2.1. *The EKC hypothesis: supported or not?*

Over the years, the existence of the EKC has been extensively examined by the academic community, using various environmental degradation indicators. For example: CO_2 emissions (e.g., Apergis, 2016; Du, Wei, & Cai, 2012 and Lean & Smyth, 2010); SO_2 emissions (e.g., Jayanthakumaran & Liu, 2012; Park & Lee, 2011); NO_x emissions (He & Wang, 2012); CH_4 emissions (e.g., Roca & Serrano, 2007); and water waste/quality (e.g., Orubu & Omotor, 2011; Wong & Lewis, 2013). The present research focuses on CO_2 emissions because CO_2 is the main driver of the greenhouse effect (according to the United States Environmental Protection Agency). That is why in Table 1, we present a selection of past studies on the EKC using CO_2 emissions (see Kaika & Zervas, 2013, for a more detailed review).

Overall, Table 1 shows that most academics have demonstrated the existence of the EKC (e.g., Jalil & Mahmud, 2009, Iwata et al., 2010, Chen, 2012, Wang, Zhou, Zhou, & Wang, 2011, Esteve & Tamarit, 2012a, Fosten, Morley, & Taylor, 2012, Jayanthakumaran, Verma, & Liu, 2012, Saboori et al., 2014, Kanjilal and Ghosh 2013, Tiwari et al. 2013, Boutabba, 2014, Bouznit & Pablo-Romero, 2016, Moosa, 2017). The considered countries in these studies are China, France, Taiwan, Spain, United Kingdom, India, Malaysia, Algeria and Australia. However, some other studies did not find results supporting the EKC hypothesis (e.g., Abid, 2017; Agras & Chapman, 1999; Bryun et al., 1998; Lantz & Feng, 2006; Rodriguez, Pena-Boquete, & Pardo-Fernandez, 2016; Unruh & Moomaw, 1998). The considered countries for which the EKC hypothesis is not hold are Netherlands, USA, Western Germany, some regions of

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[2] The selection of these variables is justified in Section 2. We would like to thank an anonymous referee for suggesting adding new variables (the two last ones) in order to check to robustness of the first results.

Table 1
Review of EKC studies on CO_2 emissions.

Authors (year)	Countries (period)	Pollutants	Methods	Existence of EKC
Bruyn et al. (1998)	Netherlands, UK, USA, Western Germany (1961–1993)	CO2, NOx, SO2	Regressions estimations	No
Unruh and Moomaw (1998)	Panel of countries (1950–1992)	CO2	Nonlinear dynamic techniques	No
Agras and Chapman (1999)	Panel of countries (1971–1989)	CO2	Regressions estimations corrected for autocorrelation	No
Sun (1999)	Panel of countries (1972–1995)	CO2	Peak-theory of energy intensity	Yes in some countries
Lindmark (2002)	Sweden (1870–1997)	CO2	Regressions estimations	Yes or No following the periods
Martinez-Zarzoso and Bengochea-Morancho (2004)	22 OECD countries (1975–1998)	CO2	Pooled mean group estimation	Yes, N-shape also exists for some countries
Auci and Becchetti (2006)	173 countries (1960–2004)	CO2	Long-run fixed effect panel estimations	Yes or No following the periods
Galeotti et al. (2006)	OECD (1960–1997) and non OECD countries (1971–1997)	CO2	Weibull functional form	Yes for OECD countries but No for non-OECD countries
Lantz and Feng (2006)	Canada (five regions, 1970–2000)	CO2	Panel data estimations with pooled and fixed effects	No
Romero-Avila (2008)	86 countries (1960–2000)	CO2	Cointegration techniques with structural changes	No due to different integration orders of the variables
Akbostanci et al. (2009)	Turkey (58 provinces, 1968–2003 and 1992–2001)	CO2, SO2, PM10	Panel data estimations	No for CO2, N-shape for SO2 and PM10
Jalil and Mahmud (2009)	China (1975–2005)	CO2	ARDL estimated by OLS, causality tests	Yes
Fodha and Zaghdoud (2010)	Tunisia (1961–2004)	CO2, SO2	Cointegration analysis	No for CO2 but Yes for SO2
He and Richard (2010)	Canada (1948–2004)	CO2	Semiparametric and flexible nonlinear parametric modeling method	Little evidence for EKC
Iwata et al. (2010)	France (1960–2003)	CO2	ARDL approach for cointegration and Granger causality	Yes
Chen (2011)	Taiwan (1970–2000)	CO2	Johansen method for cointegration and Granger causality	Yes
Iwata et al. (2011)	OECD (1960–2003)	CO2	ARDL bounds testing	Yes for Finland, Japan, Korea, Spain.
Nasir and Rehman (2011)	Pakistan (1972–2008)	CO2	Johansen method for cointegration and Granger causality	Yes in the long run but No in the short run
Wang et al. (2011)	China (28 provinces, 1995–2007)	CO2	Cointegration, Regressions estimations, Causality	Yes
Esteve and Tamarit (2012a)	Spain (1857–2007)	CO2	Threshold cointegration and nonlinear ajustment	Yes
Fosten et al. (2012)	United Kingdom (1830–2003)	CO2, SO2	Nonlinear threshold cointegration and error correction methodology	Yes
Jayanthakumaran et al. (2012)	China and India (1971–2007)	CO2	ARDL bounds testing	Yes
Saboori et al. (2012)	Malaysia (1980–2009)	CO2	ARDL and VECM	Yes
Kanjilal and Ghosh (2013)	India (1971–2008)	CO2	Cointegration tests with unknown structural breaks	Yes
Saboori and Sulaiman (2013)	Malaysia (1980–2009)	CO2	Johansen-Juselius maximum likelihood approach for cointegration and Granger causality	Yes only for disaggregated energy consumption measure (oil, coal, gas, electricity, oil)
Tiwari et al. (2013)	India (1965–2009)	CO2	Narayan and Pop (2010) unit root test, ARDL bounds testing of Peseran et al. (2001) for cointegration	Yes
Boutabba (2014)	India (1971–2008)	CO2	ARDL bounds testing	Yes
Onafowora and Owoyye (2014)	Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, South Africa (1970–2010)	CO2	ARDL bounds testing and Granger causality	Yes in Japan and South Africa and N-shape in the long run for the other countries
Al-Mulali et al. (2015)	Vietnam (1981–2011)	CO2	ARDL bounds testing	No
Baek (2015)	Artic countries (Canada, Denmark, Finland, Iceland, Norway, Sweden, US, 1960–2010)	CO2	ARDL bounds testing and Granger causality	Little evidence for EKC
Tang and Tan (2015)	Vietnam (1976–2009)	CO2	Cointegration and causality	Yes
Apergis (2016)	15 countries (1960–2013)	CO2	Panel data cointegration	Yes for 12 countries
Bouznit and Pablo-Romero (2016)	Algeria (1970–2010)	CO2	ARDL bounds testing	Yes
Rodriguez et al. (2016)	15 OECD countries (1979–2004)	CO2	Fixed-effect panel data estimation	No
Abid (2017)	EU and MEA countries (1990–2011)	CO2	GMM-system	No
Moosa (2017)	Australia (1960–2014)	CO2	FMOLS	Yes

Canada, OECD countries, EU countries and MEA countries. In the meanwhile, some studies showed mixed results varying in function of the country and period considered. For example, within a panel of countries, Sun (1999) found that for some of them, the EKC hypothesis is supported while it is not the case for some others. The same results were also found by Galeotti et al. (2006), Iwata, Okada, and Samreth (2011), Onafowora and Owoye (2014), and Apergis (2016). Furthermore, some studies found that the validation of the EKC hypothesis can vary in function of the considered period (e.g., Auci & Becchetti, 2006; Lindmark, 2002); while some studies found that it depends on the pollutants considered, such as CO_2, SO_2 and PM_{10} (e.g., Akbostanci, Türüt-Asik, & Tunç, 2009; Fodha & Zaghdoud, 2010); and some other studies found that the results can differ in function of the time horizon considered, long term or short term (e.g., Nasir & Rehman, 2011), or in function of the energy source causing pollution, such as oil, coal, gas, electricity, etc. (e.g., Saboori & Sulaiman, 2013).

Finally, our literature review shows that the validation of the EKC hypothesis can vary in function of the country-specific factors, study period and underlying methods. We also note that the EKC hypothesis holds mainly in high-income states like France (Ang, 2007; Iwata et al., 2010), Canada (Hamit-Haggar, 2012), Spain (Esteve & Tamarit, 2012), and other OECD countries (Saboori et al., 2014); as well as in upper-middle-income countries, such as China (Jalil & Mahmud, 2009), Turkey (Ozturk & Acaravci, 2013), and Tunisia (Fodha & Zaghdoud, 2010), among others. Furthermore, research on the EKC hypothesis in Vietnam has been very limited, although the recent economic growth has created favourable grounds for solid empirical analysis. To our knowledge, only Al-Mulali et al. (2015) and Tang and Tan (2015) have investigated the EKC hypothesis in the context of Vietnam. Al-Mulali et al. (2015) designed a carbon emissions model based on the ARDL cointegration method for the 1981–2011 period. The outcomes highlighted that the EKC hypothesis is not supported and both the short-run and long-run relationships between economic growth and environmental degradation are positive. Tang and Tan (2015) focused on the 1976–2009 timeframe using cointegration and causality testing and confirmed the EKC hypothesis. In our opinion, the cointegration results are not enough to draw firm conclusions about the existence of the EKC and a quadratic model between economic growth and CO_2 emissions is needed to answer this question.

Other studies on Vietnam investigated the linear link between energy consumption and economic growth, rather than the EKC hypothesis. Binh (2011) showed the strong unidirectional causality running from energy consumption to economic growth, but not vice versa. However, Canh (2011) found long-term causality running from per capita GDP to energy consumption. Loi (2012) discovered the long-run bidirectional causality between these two variables, with weak short-run unidirectional causality from economic growth to energy consumption. Linh and Lin (2014) observed a bidirectional connection between energy consumption and CO_2 emissions and, more recently, Tang, Tan, and Ozturk (2016) reported the unidirectional causality from energy consumption to economic growth. Thus, these studies have not drawn clear conclusions about the energy–growth nexus, and the discrepancies in the findings might have been caused by the difficulty of assessing the socioeconomic costs of Vietnam's environmental degradation. According to Nguyen (2008), the total environmental damage should grow to 19,656 million USD by 2025, or about 7.5% of the estimated GDP. Bass et al. (2010) highlighted three environmental issues: emissions, carbon dioxide damage, and the net loss of Vietnam's forests, which would reduce the gross national income by 2.1% per year. In addition to the immediate costs of dealing with the environmental crisis, the costs of recovery and prevention will have to be figured in. As an example, the total financial losses related to the oil spill in 2001 were estimated at 250 billion VND (Vietnamese Dongs) and the clean-up costs for the polluted waters and beaches reached 60 billion VND (Vietnam Environment Monitor 2003).

Our study contributes to the literature with an investigation into the existence of the EKC in Vietnam by estimating linear, quadratic and cubic carbon functions, taking into account the collinearity issue raised by Narayan and Narayan (2010). The quadratic model tests the inverted U-shaped curve, while the cubic model tests the N-shaped curve, which has not been studied for Vietnam yet. We assume that the N-shaped curve will help us to more precisely describe the relationship between economic growth and pollution, as the EKC is thought to express this relationship incompletely for an emerging country (e.g., Brajer et al., 2008; Onafowora & Owoye, 2014).

2.2. Determinants of CO_2 emissions

After reviewing various studies on the EKC hypothesis, the determinants of CO_2 emissions are addressed in order to justify our decision to include economic growth, energy consumption, industry and agriculture value added, FDI and urbanization in the carbon emissions function of Vietnam. The literature on the factors that impact CO_2 emissions is vast. Table 2 shows several recent studies that suggest classifying these determinants into four groups: economic activities, energy sources, household consumption behaviours, and macroeconomic factors.

The first group is related to economic activities and includes factors such as economic growth and sectorial activities, such as manufacturing, cement production, tourism, transportation, financial development, FDI, etc. See for example: Kin et al. (2010), Narayan and Narayan (2010), Jaunky (2011), Wang et al. (2011), Arouri, Youssef, M'henni, and Rault (2012), Anderson and Karpestam (2013), Camarero, Picazao-Tadeo, and Tamarit (2013), Omri (2013), Cowan, Chang, Inglesi-Lotz, and Gupta (2014), and Abbasi and Riaz (2016). The second group is related to energy sources and encompasses factors like oil, coal, renewable energies, nuclear energies, and so on. See for example: Shao, Yang, Yu, and Yu (2011), Shafiei and Salim (2014), Jaforullah and King (2015), Tajudeen (2015), Ahmad et al. (2016), and Grant, Jorgenson, and Longhofer (2016). As for the third group, which is related to household consumption, previous studies have revealed the importance of income, age, wealth, education, marital status, and other factors. See for example, Kerkhof, Benders, and Moll (2009), and Xu, Han, and Lv (2016). The fourth group, dealing with macroeconomic determinants, includes fiscal policies, environmental policies, corruption, population, urbanization, climate change, etc. See for example, Halkos and Paizanos (2016), Mustapa and Bekhet (2016), and Yang, Sun, Wang, and Li (2015). Some other studies mixed different groups of variables to study the determinants of CO_2 emissions, such as Ziegler, Schwarzkopf, and Hoffman (2012),

Table 2
CO_2 emissions determinants: a review.

Authors (year)	Countries (period)	Methods	CO2 emissions Determinants
Group 1: Economic activities (economic growth and sectorial activities)			
Kim et al. (2010)	Korea (1992–2006)	Smooth Transition Autoregressive (STAR) model	Economic growth, industrial production
Narayan and Narayan (2010)	43 developing countries (1980–2004)	Short-run and long-run elasticities	Economic growth
Jaunky (2011)	High-income countries (1980–2005)	Short-run and long-run elasticities	Economic growth
Wang et al. (2011)	China (provincal panal data, 1995–2007)	Panel cointegration and VECM	Energy consumption, economic growth
Arouri et al. (2012)	MENA countries (1981–2005)	Bootstrap panel unit root tests and cointegration techniques	Energy consumption, economic growth
Anderson and Karpestam (2013)	10 countries (1973–2007)	Short-run and long-run carbon function	Economic growth, energy intensity, carbon intensity
Camarero et al. (2013)	OECD countries (1960–2008)	Phillips and Sul (2007) convergence test	Energy intensity
Omri (2013)	MENA countries (1990–2011)	Simultanenous equations models with panel data	Energy consumption, economic growth
Cowan et al. (2014)	BRICS (1990–2010)	Panel data causality	Electricity consumption, economic growth
Abasi and Riaz (2016)	Pakistan (1971–2011)	ARDL approach, ECM model, Granger causality	Economic growth, financial development
Group 2: Energy sources (oil, coal, renewable energies, ect.)			
Shao et al. (2011)	Shanghai (1994–2009)	Two-step system GMM method	Coal consumption, energy consumption, R&D intensity
Shafiei and Salim (2014)	OECD countries (1980–2011)	Stochastic impacts by regression on population, affluence and technology (STIRPAT)	Renewable and non-renewable energy consumption, urbanization
Jaforullah and King (2015)	USA (1965–2012)	VECM causality	Renewable energy consumption, energy prices, nuclear energy consumption
Tajudeen (2015)	Nigeria (1971–2012)	Structural time series model	Energy efficiency, energy demand and its factors (consumers' preferences, lifestyles, values)
Ahmad et al. (2016)	India (1971–2014)	ARDL and VECM models	Economic growth, energy consumption (total, gas, oil, electricity and coal)
Grant et al. (2016)	World (2009)	Multi-level regression analyses using a fixed effect model	Fossil-fuel power plains age, size, location
Group 3: Households' behavior (age, wealth, education, marital status, etc.*)*			
Kerkhof et al. (2009)	Netherlands, UK, Sweden, Norway (1997–2005)	Hybrid approach of process analysis and input-output analysis	Households expenditures, energy supply, population density, district heating
Xu et al. (2016)	China (2011)	Survey, Shapley decomposition method	Residential consumption with high carbon intensity, household characteristics (employment, income, burdens, financial assets)
Group 4: Macroeconomic factors (fiscal policies, envionmental policies, corruption, population, urbaniation, climate change, ect.)			
Halkos et al. (2016)	USA (1973–2013))	Impulse responses	Fiscal policy
Mustapa and Bekhet (2016)	Malaysia (1990–2012)	An optimisation model	Environmental policies on the transportation sector (removal of fuel price subsidies)
Yang et al. (2016)	China (1998–2012)	Environmental Total Factor Productivity (ETFP) and GMM	Interregional economic convergence
Mix of 1st and 2nd groups			
Sharma (2011)	69 countries (1985–2005)	Dynamic panel data model	Trade openness, income, energy consumption, electric power consumption, primary energy consumption, urbanization
Wang (2012)	98 countries (1971–2007)	Dynamic panel threshold model (DPTM)	Oil consumption and economic growth
Kohler (2013)	South Africa (1960–2009)	ARDL bounds testing	Energy consumption, economic growth, foreign trade
Marques, Fuinhas, and Nunes (2016)	France (2010–2014)	ARDL bounds testing	Economic growth, nuclear sources
Narayan, Saboori, and Soleymani (2016)	181 countries (1960–2008)	Cross-correlation	Economic growth
Robaina-Alves et al. (2016)	Portugal (2000–2008)	Logarithmic Mean Divisia Index (LMDI)	Tourism activity, energy mix, carbon intensity, energy intensity
Mix of 2nd and 3rd groups			
Ziegler et al. (2012)	USA and Germany (2007–2008)	Interviews and multivariate probit models	Fuel consumption in vehicle use
Mix of 2nd and 4th groups			
Chen et al. (2016)	China (1997–2012)	Decoupling Elasticity Index	Coal consumption, environmental expenditure and policy, economic growth
Mix of 1st and 4th groups			

(*continued on next page*)

Table 2 (*continued*)

Authors (year)	Countries (period)	Methods	CO2 emissions Determinants
Omri et al. (2014)	54 countries (1990–2011)	Simultanenous equations models with panel data	Economic growth, FDI
Kasman and Duman (2015)	New EU member and candidate countries (1992–2010)	Panel unit root, cointegration and causality tests	Economic growth, energy consumption, trade, urbanization
Cansino, Roman, and Ordonez (2016)	Spain (1995–2009)	Structural Decomposition Analysis (SDA)	Carbonization, energy intensity, technology, structural demand, consumption pattern and economic growth
Shahbaz et al. (2016)	Australia (1970–2012)	ARDL bounds testing	Energy, population, globalization, growth
Zhu et al. (2016)	ASEAN-5 countries (1981–2011)	Panel quantile regression analysis	Energy consumption, economic growth, population, trade openess, industrial structure, FDI, financial development

Chen, Cheng, Song, and Wang (2016), Omri, Nguyen, and Rault (2014), Kasman and Duman (2015), Casino et al. (2016), Shahbaz, Bhattacharya, and Ahmed (2016); Shahbaz, Jam, Bibi, and Loganathan (2016), and Zhu, Duan, Guo, and Yu (2016).

As shown in Table 2, economic growth and energy consumption are the main drivers of CO_2 emissions for all countries (from low to high income). For this reason, we embedded these two common factors in the long-run and short-run carbon functions. However, since we investigate a specific country, we need to take its specificities into account. In addition, Oldfield (2010) demonstrated that the structural economic change has a significant impact on the natural environment. For these reasons, we decide to consider variables related to the economic structure in the carbon function of Vietnam for which Du and Fukushima (2009) stated that the most important effects of *Doi Moi* have been the increase of industrialization, accompanied by a decrease in agricultural activities, the rise of FDIs, and urbanization. These four factors thus reflect the foundation changes in the economic structure of Vietnam since 1986. To check this information, we use the data provided by World Bank which shows that the industry value added represented 27.35% of GDP in 1985 compared with 38.5% in 2007.[3] As for the agriculture value added, the trend was counter with 40.17% and 18.66%, respectively, in 1985 and 2007. In the case of FDIs, the net inflow was −80,000 USD in 1985 relative to 6.7 billion USD in 2007. With all these significant changes in the economic structure, the urban population grew from 19.56% (of the total population) in 1985 to 28.5% in 2007 and continues to increase. The results of Du and Fukushima (2009) and the data of World Bank lead us to include four additional variables in the carbon emissions function of Vietnam: industry and agriculture value added, FDI and urbanization. These variables were also used in previous studies as determinants of CO_2 emissions (see Table 2). For a robustness check on the impact of the variables' selection on the results, we further include two additional variables which are government size and trade openness. The next section will detail all the variables used in this study.

3. Data and methodology

This section is divided into three parts. The first one details the data and carbon emissions functions used to detect the EKC and N-shape. The second presents the ARDL bounds testing approach to examine the cointegration between the variables. The last is devoted to the VECM Granger causality test.

3.1. Data, short-run and long-run carbon functions

The data sample covers the period from 1972 to 2016 and is collected from the World Bank database (World Development Indicators, 2018). The data on GDP (in constant 2010 US$), energy use (kg of oil equivalent), industry and agriculture value added (in constant 2010 US$), FDI net inflows (in constant 2010 US$), urbanization (urban population), government size (% of government expenditure in the GDP), trade openness (% of exports and imports in the GDP) and CO_2 emissions (metric tons). The GDP, industry and agriculture value added, and FDI are real terms (in constant 2010 US$). The government size is measured by the share of public spending to the national GDP (Anderson & van den Berg, 1998; Ekinci, 2011; Frankel & Rose, 2005; Hossain, 2011). The trade openness is measured by the sum of exports and imports to the GDP (Manteli, 2015; Semancikova, 2016). As a reminder, the government size and trade openness are used only in the robustness check to test the impact of the variables' selection (see Section 5). We use the total population to convert variables into per capita units. We work with annual frequency data covering the period of 1974–2016. Furthermore, we transform the variables into natural logarithmic form to reduce the potential statistical inconveniences of the raw data (such as skewed-to-the-right distributions), following Yang and Zhao (2014) and others. Based on studies in the existing literature, the general functional form of carbon emissions with the presence of a structural break is constructed as follows:

$$C_t = f(Y_t, E_t, I_t, A_t, FDI_t, URB_t) \tag{1}$$

$$C_t = f(Y_t, Y_t^2, E_t, I_t, A_t, FDI_t, URB_t) \tag{2}$$

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[3] 2007 is chosen to be compared because it was the year when the industry value added reached its peak.

$$C_t = f\,(Y_t, Y_t^3, E_t, I_t, A_t, FDI_t, URB_t) \tag{3}$$

where Y_t is real GDP per capita, C_t is CO_2 emissions per capita, E_t is energy consumption per capita, I_t is real industry value added per capita, $A_t$is real agriculture valued added per capita, FDI_t is real FDI net inflows per capita and $URB_t$is urban population per capita. The long-run empirical form of Eq.(1) is modeled as noted below:

$$ln\,C_t = \alpha_1 + \alpha_Y\,ln\,Y_t + \alpha_E\,ln\,E_t + \alpha_I\,ln\,I_t + \alpha_A\,ln\,A_t + \alpha_{FDI}\,ln\,FDI_t + \alpha_{URB}\,ln\,URB_t + \mu_t \tag{4}$$

Further, we include the squared term of real income per capita ($lnY_t^{\,2}$) to examine the inverted U-shaped relationship between economic growth and carbon emissions, following Stern (2004), Halicioglu (2009), Esteve and Tamarit (2012), and others. Thus, we build the long-run empirical equation of the EKC hypothesis as follows:

$$ln\,C_t = \alpha_1 + \alpha_Y\,ln\,Y_t + \alpha_{Y^2}\,ln\,Y_t^2 + \alpha_E\,ln\,E_t + \alpha_I\,ln\,I_t + \alpha_A\,ln\,A_t + \alpha_{FDI}\,ln\,FDI_t + \alpha_{URB}\,ln\,URB_t + \mu_t \tag{5}$$

where $lnY_t^{\,2}$ are natural logs of squared of real GDP per capita. The economic growth–CO_2 emissions nexus has an inverted U-shape if $\alpha_Y > 0$ and $\alpha_{Y^2} < 0$ and a U-shape if $\alpha_Y < 0$ and $\alpha_{Y^2} > 0$ (Saboori & Sulaiman, 2013). The turning point is calculated by $Y^* = \exp\left({-\alpha_Y}\big/{2\alpha_{Y^2}}\right)$ since we use natural log values of the data.

The results of the quadratic model can be biased due to the collinearity between GDP and its square (Arouri et al., 2012; Jaunky, 2011; Narayan & Narayan, 2010). Therefore, we apply the method proposed by Narayan and Narayan (2010) to compare the short-run coefficient to the long-run coefficient related to income. When short-run elasticities are higher than long-run elasticities, the EKC hypothesis is supported. To apply this method, the short-run carbon functions are presented further on in this section. On the other hand, Moomaw and Unruh (1997), and others, suggested that the augmented EKC should be investigated by incorporating the cubic term of real GDP per capita into the carbon emissions function, as follows:

$$ln\,C_t = \alpha_1 + \alpha_Y\,ln\,Y_t + \alpha_{Y^2}\,ln\,Y_t^2 + \alpha_{Y^3}\,ln\,Y_t^3 + \alpha_E\,ln\,E_t + \alpha_I\,ln\,I_t + \alpha_A\,ln\,A_t + \alpha_{FDI}\,ln\,FDI_t + \alpha_{URB}\,ln\,URB_t + \mu_t \tag{6}$$

The relationship between economic growth and carbon emissions is N-shaped if $\alpha_Y > 0$, $\alpha_{Y^2} < 0$, and $\alpha_{Y^3} > 0$. Moomaw and Unruh (1997), and later Friedl and Getzner (2003), showed that carbon emissions start rising again as economic growth reaches the second threshold of income per capita. The N-shaped economic growth–carbon emissions link thus implies that a rise in carbon emissions is temporary after the second threshold point (Friedl & Getzner, 2003). In this case, the turning points are calculated as follows (Brajer et al., 2008):

$$Y_1^* = exp\left(\left[-\alpha_{Y^2} - (\alpha_{Y^2}^{\,2} - 3\alpha_Y\alpha_{Y^3})^{\frac{1}{2}}\right]/(3\alpha_{Y^3})\right)$$

$$Y_2^* = exp\left(\left[-\alpha_{Y^2} + (\alpha_{Y^2}^{\,2} - 3\alpha_Y\alpha_{Y^3})^{\frac{1}{2}}\right]/(3\alpha_{Y^3})\right)$$

The above equations refer to the long-run relationships between the variables. To investigate short-run relationships, we apply the error correction model (ECM). The linear, quadratic and cubic empirical equations for the ECM version are modeled as follows:

$$\Delta\,ln\,C_t = \alpha_1 + \alpha_Y\,\Delta\text{ln}Y_t + \alpha_E\,\Delta\,ln\,E_t + \alpha_I\,\Delta\,ln\,I_t + \alpha_A\,\Delta\,ln\,A_t + \alpha_{FDI}\,\Delta\,ln\,FDI_t + \alpha_{URB}\,\Delta\,ln\,URB_t + \rho ECM_{t-1} + \mu_t \tag{7}$$

$$\Delta\,ln\,C_t = \alpha_1 + \alpha_Y\,\Delta\,ln\,Y_t + \alpha_{Y^2}\,\Delta\,ln\,Y_t^2 + \alpha_E\,\Delta\,ln\,E_t + \alpha_I\,\Delta\,ln\,I_t + \alpha_A\,\Delta\,ln\,A_t + \alpha_{FDI}\,\Delta\,ln\,FDI_t + \alpha_{URB}\,\Delta\,ln\,URB_t + \gamma ECM_{t-1} + \mu_t \tag{8}$$

$$\begin{aligned}\Delta\,ln\,C_t = {} & \alpha_1 + \alpha_Y\,\Delta\,ln\,Y_t + \alpha_{Y^2}\,\Delta\,ln\,Y_t^2 + \alpha_{Y^3}\,\Delta\,ln\,Y_t^3 + \alpha_E\,\Delta\,ln\,E_t + \alpha_I\,\Delta\,ln\,I_t + \alpha_A\,\Delta\,ln\,A_t + \alpha_{FDI}\,\Delta\,ln\,FDI_t + \alpha_{URB}\,\Delta\,ln\,URB_t \\ & + \theta ECM_{t-1} + \mu_t\end{aligned} \tag{9}$$

where Δ is the difference operator and ρ, γ *and* θ are estimates of ECM_{t-1} in the linear, quadratic and cubic regressions. The ECM_{t-1} estimates show the speed of adjustment of the short-run to the long-run equilibrium path. The significance of the ECM_{t-1} coefficient with a negative sign validates the cointegrating relationship between the variables.

3.2. ARDL bounds testing

The ARDL bounds testing (Pesaran et al., 2001) was used to estimate the cointegration or the long-run relationships between the variables. One of its advantages is the flexibility related to the integrating orders of the variables. For example, it is possible to examine the cointegration even if the integrating orders are not the same, as in the case of I(1)/I(0) or I(0)/I(1) for a couple of variables. The bounds testing approach also resolves the endogeneity issue that may occur because of the lagged values of the response variables in the model (Narayan & Smyth, 2008). Another major benefit is related to its consistency with small samples. Not least, a dynamic unrestricted ECM (UECM) can be obtained using ARDL bounds testing via simple linear transformations. The UECM integrates short-run dynamics with the long-run equilibrium without losing any information in the long run. The empirical equation of the ARDL bounds testing approach is presented in Eq.(10):

Table 3
Descriptive statistics and correlation matrix.

Variables	C_t	Y_t	E_t	A_t	F_t	I_t	U_t
Mean	−0.5000	6.4865	5.8959	5.1747	0.6658	5.2253	3.1609
Median	−0.7970	6.4017	5.6929	5.1049	2.8105	5.2084	3.1082
Maximum	0.6021	7.4923	6.5011	5.6011	4.9901	6.4510	3.5518
Minimum	−1.3382	5.8260	5.5239	4.8264	−8.5350	3.7901	2.9277
Std. Dev.	0.6940	0.5634	0.3685	0.2548	4.1060	0.7923	0.2044
Skewness	0.4112	0.3636	0.6208	0.3489	−0.7727	−0.0377	0.5080
Kurtosis	1.5334	1.6565	1.7249	1.6140	2.1854	1.6424	1.8221
Jarque-Bera	5.1835	4.2783	5.8073	4.4146	5.5956	3.3891	4.4367
Probability	0.0748	0.1177	0.0548	0.1099	0.0609	0.1836	0.1087
Sum	−22.0024	285.4091	259.4198	227.6911	29.2985	229.9160	139.0827
Sum Sq. Dev.	20.7111	13.6504	5.8421	2.7932	724.9718	26.9988	1.7970
C_t	1						
Y_t	0.2832	1					
E_t	0.3712	0.2106	1				
A_t	−0.2705	0.3106	0.2904	1			
F_t	−0.1738	−0.3843	0.1516	−0.3802	1		
I_t	0.2948	0.2947	−0.2409	0.2163	−0.1654	1	
U_t	−0.3480	0.4835	0.5258	0.3474	0.3205	0.1060	1

Notes: *, **, and *** show the significance at 1%, 5% and 10% levels, respectively. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *F* denotes the value of FDI inflows, *URB* denotes the part of urban population.

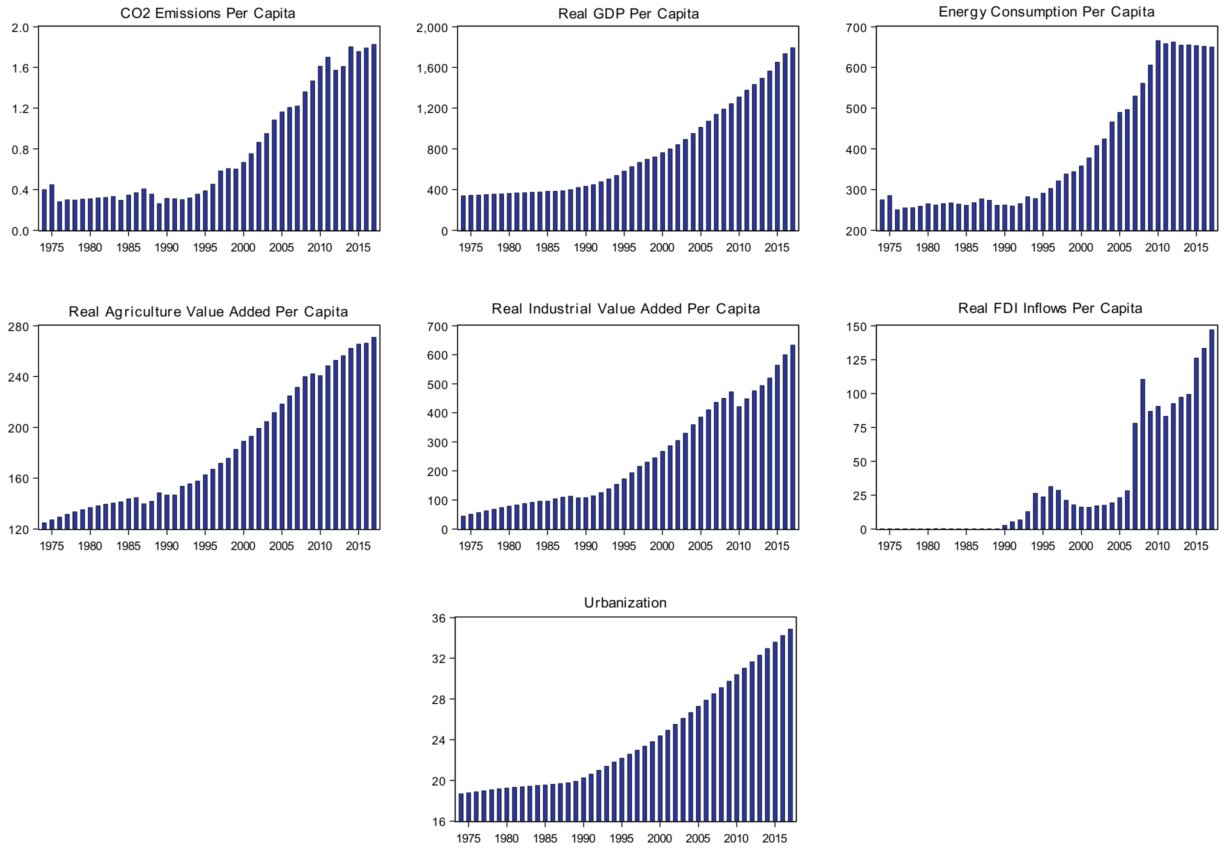

Fig. 1. Time trends of the considered variables.

Table 4
Unit root analysis.

Variables	ADF Test		PP Test	
	T-statistic	P.value	T-statistic	P.value
lnC_t	−2.5981	0.2671	−2.5881	0.2871
$\Delta\, ln\, C_t$	−6.9217*	0.0000	−6.8871*	0.0000
lnY_t	−2.7686	0.2163	−2.6190	0.2743
ΔlnY	−6.9089*	0.0000	−7.8567*	0.0000
lnE_t	−2.7364	0.22881	−2.1351	0.5119
$\Delta\, ln\, E_t$	−5.2363*	0.0006	−5.4421*	0.0004
lnI_t	−1.9220	0.5886	−2.0604	0.5524
$\Delta\, ln\, I_t$	−4.2127*	0.0095	5.8970*	0.0001
lnA_t	−1.6373	0.7608	1.5518	0.7953
$\Delta\, ln\, A_t$	−5.0556*	0.0010	−5.5640*	0.0002
$lnFDI_t$	−2.8128	0.2009	−3.1896	0.1000
$\Delta\, ln\, FDI_t$	−5.9374*	0.0001	−7.8569*	0.0000
$lnURB_t$	−3.0945	0.1208	−2.0356	0.5658
$\Delta\, ln\, URB_t$	−5.9067*	0.0000	−9.8920*	0.0000

Variables	Kim-Perron Test at Level		Kim-Perron Test at 1st Difference	
	T-statistic	Break date	T-statistic	Break date
lnC_t	−3.3260	1987	−9.5089*	1989
lnY_t	−3.4183	2002	5.9089*	1991
lnE_t	−4.0729	2001	−8.9087*	2010
lnI_t	−3.5171	1994	−5.6201	2010
lnA_t	−3.2876	1986	−5.4213**	2008
$lnFDI_t$	−1.8976	1990	−6.4882*	1992
$lnURB_t$	−3.4406	1998	−6.8227*	1989

Note: * and ** show the significance at 1% and 5% levels, respectively. The figure inside the parentheses denotes the optimal lag. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *FDI* denotes the value of FDI inflows, *URB* denotes the part of urban population.

$$\begin{aligned}\Delta\, ln\, C_t = {} & \alpha_1 + \alpha_T T + \alpha_C\, ln\, C_{t-1} + [\alpha_Y\, ln\, Y_{t-1} + \alpha_{Y^2}\, ln\, Y_{t-1}^2 + \alpha_{Y^3}\, ln\, Y_{t-1}^3] + \alpha_E\, ln\, E_{t-1} + \alpha_I\, ln\, I_{t-1} + \alpha_A\, ln\, A_{t-1} + \alpha_{FDI}\, ln\, FDI_{t-1} \\ & + \alpha_{URB}\, ln\, URB_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta\, ln\, C_{t-i} + \left[\sum_{i=1}^{q} \alpha_i \Delta\, ln\, Y_{t-i} + \sum_{i=0}^{r} \alpha_i\, ln\, Y_{t-1}^2 + \sum_{i=0}^{r} \alpha_i \Delta\, ln\, Y_{t-1}^3\right] + \sum_{i=0}^{s} \alpha_i \Delta\, ln\, E_{t-i} + \sum_{i=0}^{u} \alpha_i \Delta\, ln\, I_{t-1} \\ & + \sum_{i=0}^{v} \alpha_i \Delta\, ln\, A_{t-1} + \sum_{i=0}^{w} \alpha_i \Delta\, ln\, FDI_{t-i} + \sum_{i=0}^{x} \alpha_i \Delta URB_{t-1} + \mu_t \end{aligned} \tag{10}$$

To test the cointegration between the variables, we first computed the F-statistic developed by Pesaran et al. (2001) for $H_0: \alpha_Y = \alpha_{Y^2} = \alpha_{Y^3} = \alpha_E = \alpha_I = \alpha_A = \alpha_{FDI} = \alpha_{URB} = 0$, against the alternative hypothesis $H_0: \alpha_Y \neq \alpha_{Y^2} \neq \alpha_{Y^3} \neq \alpha_E \neq \alpha_I \neq \alpha_A \neq \alpha_{FDI} \neq \alpha_{URB} \neq 0$. We then compared this statistic to the upper critical bound (UCB) and lower critical bound (LCB) developed by Pesaran et al. (2001). The results show cointegration between the variables if the computed F-statistic is higher than the UCB. The variables are not cointegrated if the computed F-statistic is lower than the LCB. If the computed F-statistic falls between the lower and upper critical bounds, the cointegration between the variables is uncertain. For a robustness check, we also used the critical values proposed by Narayan (2005) and those in the presence of structural breaks (Shahbaz, Hoang, Mahalik, & Roubaud, 2017).[4] Further, we ran tests to examine the stability of the ARDL bounds estimates by applying the CUSUM and CUSUMsq of Brown, Durbin, and Evans (1975).

3.3. The VECM Granger causality test

In the next step, we tested the causality between the variables using the ECM, as detailed below:

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[4] The upper and lower critical bounds are automatically produced by E.Views 9.1 while applying the bounds testing approach.

Table 5

The ARDL cointegration analysis.

Estimated models	Optimal lag	F-statistic	Diagnostic Analysis		
			$\chi_{Serial}{}^2$	$\chi_{ARCH}{}^2$	$\chi_{NORMAL}{}^2$
Linear model					
$C_t = f(E_t, Y_t, I_t, A_t, FDI_t, URB_t)$	(2, 2, 1, 2, 1, 1, 2)	6.234*	1.3202 [6]	0.8714 [2]	0.6436
$Y_t = f(E_t, C_t, I_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 2, 2, 2, 2)	1.517	3.4563 [3]	3.8810 [2]	1.1734
$E_t = f(C_t, Y_t, I_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 2, 2, 1, 2)	8.210*	0.3245 [2]	0.2040 [3]	0.9876
$I_t = f(E_t, Y_t, C_t, A_t, FDI_t, URB_t)$	(2, 2, 1, 2, 2, 2, 2)	7.4567*	1.1215 [1]	1.2346 [2]	1.1816
$A_t = f(E_t, Y_t, I_t, C_t, FDI_t, URB_t)$	(2, 1, 2, 1, 2, 1, 2)	5.434*	2.4335 [2]	0.4389 [2]	1.3465
$FDI_t = f(E_t, Y_t, I_t, A_t, C_t, URB_t)$	(2, 2, 2, 2, 2, 2, 2)	9.872*	1.0345 [3]	0.3184 [3]	0.4453
$URB_t = f(E_t, Y_t, I_t, A_t, FDI_t, C_t)$	(2, 2, 2, 2, 2, 1, 2)	6.3456*	2.2625 [2]	1.2160 [1]	0.5464
Quadratic model					
$C_t = f(E_t, Y_t, Y_t^2, I_t, A_t, FDI_t, URB_t)$	(2, 2, 1, 1, 2, 1, 1, 2)	7.0294*	1.3025 [1]	0.7892 [1]	0.5406
$Y_t,\ Y_t^2 = f(E_t, C_t, I_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 2, 2, 2, 2, 2)	2.1081	2.0503 [3]	1.2820 [2]	0.5704
$E_t = f(C_t, Y_t, Y_t^2, I_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 2, 2, 2, 1, 2)	8.067*	0.2208 [2]	0.2141 [3]	0.5603
$I_t = f(E_t, Y_t, Y_t^2, C_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 1, 2, 2, 2, 2)	7.5487*	1.1005 [1]	1.24435 [2]	1.2006
$A_t = f(E_t, Y_t, Y_t^2, I_t, C_t, FDI_t, URB_t)$	(2, 1, 1, 2, 1, 2, 1, 2)	6.0302*	2.2315 [2]	0.4487 [2]	1.2400
$FDI_t = f(E_t, Y_t, Y_t^2, I_t, A_t, C_t, URB_t)$	(2, 2, 2, 2, 2, 2, 2, 2)	10.0701*	1.1242 [3]	0.3099 [3]	0.5442
$URB_t = f(E_t, Y_t, Y_t^2, I_t, A_t, FDI_t, C_t)$	(2, 2, 2, 2, 2, 2, 1, 2)	6.5246*	2.2002 [2]	1.2410 [1]	0.4502
Cubic model					
$C_t = f(E_t, Y_t, Y_t^2, Y_t^3, I_t, A_t, FDI_t, URB_t)$	(2, 2, 1, 1, 1, 2, 1, 1, 2)	8.0001*	1.2305 [1]	0.7982 [1]	0.5604
$Y_t,\ Y_t^2,\ Y_t^3 = f(E_t, C_t, I_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 2, 2, 2, 2, 2, 2)	2.2308	1.5323 [3]	0.9890 [2]	0.7040
$E_t = f(C_t, Y_t, Y_t^2, Y_t^3, I_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 2, 2, 2, 2, 1, 2)	8.6071*	0.2023 [2]	0.2439 [3]	0.5065
$I_t = f(E_t, Y_t, Y_t^2, Y_t^3, C_t, A_t, FDI_t, URB_t)$	(2, 2, 2, 2, 1, 2, 2, 2, 2)	6.8987*	1.2356 [1]	1.5453 [2]	1.2465
$A_t = f(E_t, Y_t, Y_t^2, Y_t^3, I_t, C_t, FDI_t, URB_t)$	(2, 1, 1, 1, 2, 1, 2, 1, 2)	6.2316*	1.4375 [2]	0.7307 [2]	1.2045
$FDI_t = f(E_t, Y_t, Y_t^2, Y_t^3, I_t, A_t, C_t, URB_t)$	(2, 2, 2, 2, 2, 2, 2, 2, 2)	9.1681*	1.2432 [3]	0.3798 [3]	1.0405
$URB_t = f(E_t, Y_t, Y_t^2, Y_t^3, I_t, A_t, FDI_t, C_t)$	(2, 2, 2, 2, 2, 2, 2, 1, 2)	7.0098*	2.2002 [2]	1.2410 [1]	0.4502

Significance level	Critical bounds by Pesaran et al. (2001)		Critical Bounds by Narayan (2005)	
	$I(0)$	$I(1)$	$I(0)$	$I(1)$
1%	3.60	4.90	4.000	5.395
5%	2.87	4.00	3.077	4.284
10%	2.53	3.59	2.657	3.776

Notes: ** indicates the significance at 5% level. [] indicates the lag order used while applying the LM test ($X_{Serial}{}^2$), as well as the ARCH test ($X_{ARCH}{}^2$). ($X_{Serial}{}^2$), ($X_{ARCH}{}^2$) and ($X_{Normal}{}^2$) indicate the serial correlation LM test, autoregressive conditional heteroskedasticity test, and normality test, respectively. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *FDI* denotes the value of FDI inflows, *URB* denotes the part of urban population.

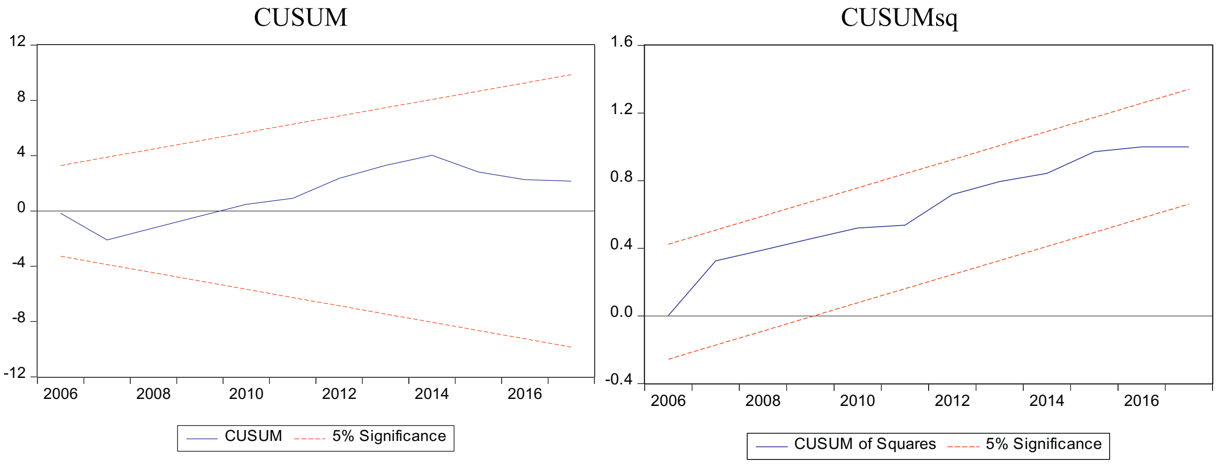

Fig. 2. Plot of the cumulative sum and cumulative sum of the squares of recursive residuals.

$$(1-L)\begin{bmatrix} \ln C_t \\ \ln Y_{t-1} \\ \ln Y_{t-1}^2 \\ \ln Y_{t-1}^3 \\ \ln E_t \\ \ln I_t \\ \ln A_t \\ \ln FDI_t \\ \ln URB_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \\ \alpha_7 \\ \alpha_8 \\ \alpha_9 \end{bmatrix} + \sum_{i=1}^{p}(1-L)\begin{bmatrix} b_{11i}b_{12i}b_{13i}b_{14i}b_{15i}b_{16i}b_{17i}b_{18i}b_{19i} \\ b_{21i}b_{22i}b_{23i}b_{24i}b_{25i}b_{26i}b_{27i}b_{28i}b_{29i} \\ b_{31i}b_{32i}b_{33i}b_{34i}b_{35i}b_{36i}b_{37i}b_{38i}b_{39i} \\ b_{41i}b_{42i}b_{43i}b_{44i}b_{45i}b_{46i}b_{47i}b_{48i}b_{49i} \\ b_{51i}b_{52i}b_{53i}b_{54i}b_{55i}b_{56i}b_{57i}b_{58i}b_{59i} \\ b_{61i}b_{62i}b_{63i}b_{64i}b_{65i}b_{66i}b_{67i}b_{68i}b_{69i} \\ b_{71i}b_{72i}b_{73i}b_{74i}b_{75i}b_{76i}b_{77i}b_{78i}b_{79i} \\ b_{81i}b_{82i}b_{83i}b_{84i}b_{85i}b_{86i}b_{87i}b_{88i}b_{89i} \\ b_{91i}b_{92i}b_{93i}b_{94i}b_{95i}b_{96i}b_{97i}b_{98i}b_{99i} \end{bmatrix} \times \begin{bmatrix} \ln C_t \\ \ln Y_{t-1} \\ \ln Y_{t-1}^2 \\ \ln Y_{t-1}^3 \\ \ln E_t \\ \ln I_t \\ \ln A_t \\ \ln FDI_t \\ \ln URB_t \end{bmatrix} + \begin{bmatrix} \alpha \\ \beta \\ \delta \\ \varnothing \\ \vartheta \\ \omega \\ \rho \\ \gamma \\ \theta \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \\ \varepsilon_{6t} \\ \varepsilon_{7t} \\ \varepsilon_{8t} \\ \varepsilon_{9t} \end{bmatrix} \tag{11}$$

where $(1-L)$ represents the difference operator, $ECT_{t\text{-}1}$ is the lagged residual term derived from the long-run relationship, and ε_{1t}, ε_{2t}, ε_{3t}, ε_{4t}, ε_{5t}, ε_{6t}, ε_{7t}, ε_{8t}, ε_{9t} are the error terms, assumed to be normally distributed with a zero mean and a finite covariance matrix. The long-run causality is highlighted by the significance of the t-statistic related to the coefficient of the error correction term ($ECT_{t\text{-}1}$), while the short-run causality is highlighted by the statistical significance of the F-statistic (Wald-test) in the first differences. The interpretation of $b_{12,\,i} \neq 0\ \forall\, i$ is that economic growth Granger causes CO_2 emissions, whereas $b_{21,\,i} \neq 0\ \forall\, i$ indicates that the causality runs from CO_2 emissions to economic growth. In addition, the joint significance of both $ECT_{t\text{-}1}$ and the estimates of the lagged independent variables shows the joint long-run and short-run causal relationships.

4. Results and discussions

In this section, we present the main descriptive statistics and results of the unit root tests before examining the cointegration between the variables by bounds testing. As cointegration was found, we verified the long-run EKC and N-shaped hypotheses in Vietnam via the estimation of Eqs.(4), (5) and (6), and Eqs.(7), (8) and (9) for the short run. Finally, we deepened the analysis by examining the causality between the variables.

4.1. Descriptive statistics and unit root tests

Table 3 presents the main descriptive statistics and correlation matrix between the variables. Fig. 1 presents the trends of the seven time-series, highlighting the tendency toward rising CO_2 emissions, income per capita, energy consumption, agriculture and industry value added and urban population in Vietnam over the 1974–2016 period. FDI net inflows were more volatile and increased strongly in 2007, confirming the interest of foreign investors in Vietnam.

In order to investigate the presence of cointegration, we first tested the unit root properties of the variables. In the first step, we applied the ADF test by Dickey and Fuller (1979, 1981) and the ADF test by Kim and Perron (2009). The results are reported in Table 4. We note that none of the series are stationary at levels but are so at the 1st difference. This indicates that they are all integrated at order 1. However, to provide more robust results, we also took into account potential structural breaks in the series using the Kim, Lee, and Nam (2010) test, which detects a single unknown structural break in the deterministic trend of the series. The results are presented in the bottom part of Table 4.

Based on the Kim et al. (2010) test, we found an $I(1)$ integration order for all series. Thus, we conclude that CO_2 emissions, economic growth, energy consumption, industry and agriculture value added, FDI and urbanization contain a unit root in the presence of a structural break for 1987, 2002, 2001, 1994, 1986, 1990 and 1998, respectively. Most of these break points are in the late 1980s and early 1990s, corresponding to Vietnam's transition from a centrally planned to a market-based economy (Riedel, 2002).

Next, we investigated the cointegration between the variables via ARDL bounds testing and present the results in Table 5. As mentioned in Section 3, the F-statistic was calculated and compared with two critical bounds computed based on the methods of Pesaran et al., 2001 and Narayan (2005). As the F-statistic changes at various lag lengths, we chose the optimal lag length following the minimum value of AIC (2nd column, Table 5). The ARDL analysis reveals that our computed ARDL-F statistic is higher than the upper critical bounds at 1% and 5% levels when considering carbon emissions, energy consumption, industrial value added, agricultural value added, foreign direct investment and urbanization as dependent variables. This result is confirmed regardless of the selected critical bounds (Pesaran et al. (2001) or Narayan (2005)). This indicates the presence of six cointegration vectors and makes us reject the null hypothesis of no cointegration. On the other hand, the null hypothesis is accepted when using economic growth as dependent variable (the ARDL-F statistic is below the lower critical bound). Though this exception, the former cointegration vectors show that all variables are cointegrated for Vietnam over the 1974–2016 timeframe. Hence, we conclude that considered variables are cointegrated in the sample period for Vietnam, which implies a significant long-run relationship between the variables and confirms the findings of Tang and Tan (2015) and Tang et al. (2016).

To check the stability of the ARDL model, we applied the CUSUM and CUSUMsq tests recommended by Brown et al. (1975) to examine the constancy of the parameters. The results in Fig. 2 show that CUSUM and CUSUMsq are between the upper and lower critical bounds (red lines) at the 5% significance level, confirming the stability of the ARDL estimates.[5] The diagnostic analysis indicated the absence of serial correlation ($\chi_{Serial}{}^2$) and autoregressive conditional heteroscedasticity in the model.

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[5] We do not provide the CUSUM and CUSUMsq results for quadratic and cubic models to save space, but the results also show the stability for these models. More details are available upon request from the authors.

Table 6

Long-run carbon functions.

Dependent Variable = lnC_t

	Linear model		*Quadratic model*		*Cubic model*	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	−1.7397	−0.7001	−1.8139	−0.151314	2.2093	1.0200
lnY_t	0.1842*	3.2016	1.8572*	2.7808	24.2890**	2.6158
lnY_t^2	....	....	−0.1456**	−2.6336	−10.0987**	−2.6561
lnY_t^3	....	....	....	....	0.9364*	2.6575
lnE_t	0.2333*	8.8124	0.2340*	8.6859	0.3501*	3.7477
lnI_t	0.4075**	2.2263	0.4071**	2.121971	0.6660*	3.2892
lnA_t	−0.3271*	−2.8448	−0.3273**	−2.681120	−0.4262*	−3.5840
$lnFDI_t$	−0.0185**	−2.2972	−0.0186**	−2.023342	−0.0193*	−2.9742
$lnURB_t$	−0.3056**	−2.1396	−0.3039**	−2.45021	−0.3603**	−2.3241
R^2	0.9866		0.9879		0.9875	
$Adj-R^2$	0.9844		0.9854		0.9856	
D.W. test	2.0977		2.0891		2.1456	
F-Statistics	45.6571*		37.9045*		38.8765*	
P-value	0.0000		0.0000		0.0000	

Note: * and ** indicate the significance at the 1% and 5% levels, respectively. D.W. denotes the Durbin-Watson test for the autocorrelation of residual terms. F-statistics are for testing the overall significance of the models. *P*-value is for the significance level. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *FDI* denotes the value of FDI inflows, *URB* denotes the part of urban population.

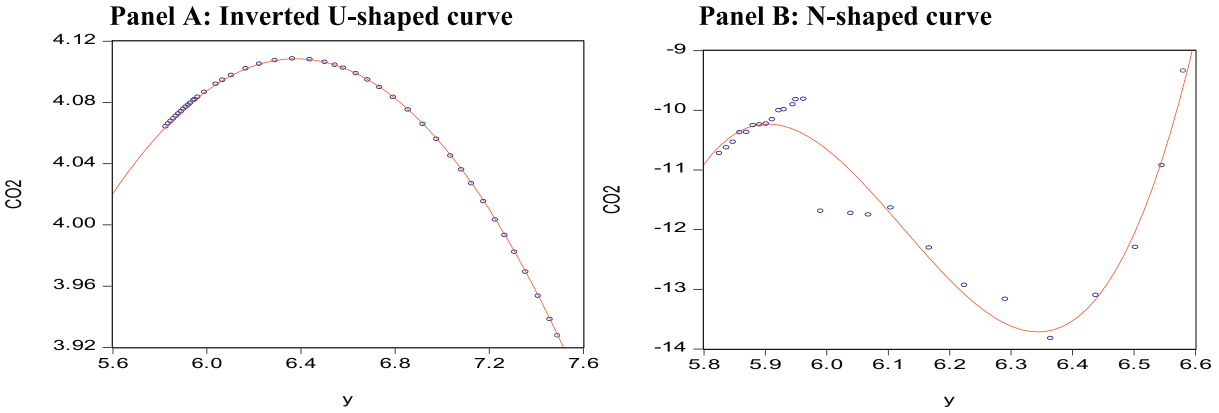

Fig. 3. The N-shaped phenomenon in Vietnam.

The significant long-run relationship between economic growth and CO_2 emissions led us to test the existence of the EKC and N-shape while considering the collinearity issue via short-run and long-run linear, quadratic and cubic carbon functions. The next section details the results.

4.2. Long-run and short-run carbon functions: Is the EKC a complete picture?

4.2.1. Long-run results

Table 6 presents the findings of Eqs.4, 5 and 6 (Section 3) and shows that energy consumption is positively and significantly linked with CO_2 emissions in all three models (linear, quadratic and cubic). Ceteris paribus, a 1% increase in energy consumption will lead carbon emissions to increase by between 0.2333% and 0.3501%, according to the coefficients for $\ln E_t$ in the three models. This positive relationship was also found by Fodha and Zaghdoud (2010) in Tunisia, Binh (2011) in Vietnam, Ozturk and Acaravci (2013) in Turkey and, Linh and Lin (2014), indicating that energy consumption is a major contributor to environmental degradation. Furthermore, the impact of economic growth on carbon emissions is positive and significant in the three regressions. This positive relationship is similar to that identified by Al-Mulali et al. (2015), who found that economic growth deteriorates environmental quality by increasing carbon emissions. Furthermore, the industrialization in Vietnam participates to the degradation of environment through an increase in CO_2 emissions (with significant and positive coefficients related to the *lnI* variable). By contrast, a rise in agriculture valued added, foreign direct investments and urbanization reduce CO_2 emissions. The sign of these coefficients remains the same in both quadratic and cubic regressions.

Indeed, previous studies show mixed results about the impact of industrial and agriculture value added, foreign direct investment

Table 7
Short-run carbon functions.

Dependent Variable = $\Delta \ln C_t$

	Linear model		*Quadratic model*		*Cubic model*	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	−0.0366	−1.3271	−0.009021	−0.1662	−0.0176	−0.2135
$\Delta \ln Y_t$	−0.7470	−0.7294	1.4258	0.7294	2.8773	−0.3060
$\Delta \ln Y_t^2$	....	....	−3.0157	−0.5836	−28.4966	−0.1271
$\Delta \ln Y_t^3$	....	....	....	....	8.5870	0.3009
$\Delta \ln E_t$	0.2490*	7.8894	0.2413*	6.9921	2.1060*	6.1177
$\Delta \ln I_t$	0.8718*	3.2586	0.7526**	2.2261	0.7813**	2.1573
$\Delta \ln A_t$	−0.2137**	−2.2925	−0.2047**	−2.1458	−0.2666**	−2.5581
$\Delta \ln FDI_t$	−0.0076	−1.1145	−0.0071	−1.0301	−0.0035	−0.4997
$\Delta \ln URB_t$	0.2460	0.9440	0.41391	1.0629	0.46156	1.1279
ECM_{t-1}	−0.6926*	−4.7237	−0.6782*	−4.5192	−0.7004*	−3.9383
R^2	0.7337		0.7363		0.7503	
$Adj - R^2$	0.6805		0.6743		0.7089	
D.W Test	1.9746		2.0213		1.9087	
F-Statistics	13.7779*		11.8709*		9.6830*	
P-value	0.0000		0.0000		0.0000	

Note: *, ** and *** indicate the significance at the 1%, 5% and 10% levels, respectively. D.W. denotes the Durbin-Watson test for the autocorrelation of residual terms. F-statistics are for testing the overall significance of the models. P-value is for the significance level. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *FDI* denotes the value of FDI inflows, *URB* denotes the part of urban population.

and urbanization on environmental degradation. For example, the result about the negative relationship between industrial value added and carbon emissions is contradictory with the finding of Brahmasrene and Lee (2017) who found a positive link between these two variables in South-East Asia. On the other hand, the finding that FDI improves the environmental quality, by lowering carbon emissions, is consistent with Tang and Tan (2015) for Vietnam. The negative relationship between urbanization and carbon emissions is contradictory with the finding of Ab-Rahim and Xin-Di (2016) who noted that urbanization leads to economic growth and energy consumption which, in resulting, stimulates CO_2 emissions in ASEAN + 3 countries.

More importantly, in the quadratic regression, the coefficient for economic growth is positive and significant (1.8572), whereas the coefficient for squared economic growth is negative and significant (−0.1456). Thus, the existence of the EKC in Vietnam is supported since the significant signs of these coefficients suggest an inverted U-shaped relationship between economic growth and CO_2 emissions (Section 3).

As for the cubic regression, the coefficients for economic growth (positive at 24.2890), its square (negative at −10.0987), and its cube (positive at 0.9364) correspond to the required signs for the existence of the N-shape (Section 3) and are all statistically significant. In this case, the economic growth–CO_2 emissions nexus is further described by an N-shaped curve, corresponding to the findings of previous studies on other countries. For example, Martınez-Zarzoso and Bengochea-Morancho (2004) found an N-shaped curve with CO_2 emissions as the pollutant for various OECD countries from 1975 to 1998. An N-shaped curve implies that CO_2 emissions increase at early stages of economic growth, reach the first turning point, and then decrease until a second turning point before rising again. Thus, the growth in carbon emissions is temporary after the second threshold point, with other factors than economic growth contributing to carbon emissions (Friedl & Getzner, 2003).

The presence of both the EKC and N-shaped relationships between carbon emissions and economic growth has been found by several authors (e.g., Martınez-Zarzoso & Bengochea-Morancho, 2004; Brajer et al., 2008). The coexistence of these two forms is possible because the N-shaped curve encompasses the inverted U-shaped curve (see Fig. 3), with the latter appearing in the first part of the former. Hence, the inverted U-shape is only one part of the curve describing the relationship between economic growth and CO_2 emissions in Vietnam, while the N-shape curve provides a more complete picture. This finding is important because it indicates that the decrease in CO_2 emissions at a given stage of economic growth is only temporary and the country should therefore take steps to limit the risk that they increase again at a later stage. However, the coexistence of these two shapes is found via two different regressions (quadratic and cubic). Thus, when the cubic regression is not taken into consideration, it appears that the data fit only the inverted U-shaped curve, which would result in a misleading conclusion about the link between economic growth and CO_2 emissions in Vietnam. Fig. 3 shows this double pattern computed from the quadratic (A) and cubic (B) regressions.

This finding underlines the importance of considering the N-shaped hypothesis when studying the relationship between CO_2 emissions and economic growth. Furthermore, it is important to note the difference in the inverted U-shaped parts in Panels A and B (the first part of the N curve). Obviously, this difference is due to the change in the coefficient of the squared term in the quadratic and cubic regressions (from −0.1456 to −10.0987). This suggests that excluding the cubic term can lead to an unrealistic estimation

Table 8
The VECM Granger causality test with structural breaks for the linear model.

Dependent Variables	Type of causality							
	Short run							Long Run
	$\Sigma\Delta\, ln\, C_{t-1}$	$\Sigma\Delta\, ln\, Y_{t-1}$	$\Sigma\Delta\, ln\, E_{t-1}$	$\Sigma\Delta\, ln\, I_{t-1}$	$\Sigma\Delta\, ln\, A_{t-1}$	$\Sigma\Delta\, ln\, F_{t-1}$	$\Sigma\Delta\, ln\, U_{t-1}$	ECM_{t-1}
$\Delta\, ln\, C_t$	….	0.1203 [0.8871]	23.3334* [0.0000]	4.2106** [0.0258]	2.1564 [0.1352]	1.2651 [0.2984]	0.0677 [0.9347]	−0.6334* [−2.9816]
$\Delta\, ln\, Y_t$	0.1352 [0.8740]	….	0.3705 [0.6937]	1.0856 [0.3515]	4.8103** [0.0160]	0.2449 [0.7844]	2.2924 [0.1197]	….
$\Delta\, ln\, E_t$	17.5309* [0.0000]	0.4171 [0.6631]	….	6.4730* [0.0051]	1.7523 [0.1925]	1.0888 [0.3509]	0.8833 [0.4250]	−0.5297** [−2.6403]
$\Delta\, ln\, I_t$	3.4521** [0.0462]	1.3213 [0.2835]	4.4216** [0.0218]	….	5.3063** [0.0114]	1.8691 [0.1737]	1.5854 [0.2232]	−0.4642* [−3.3262]
$\Delta\, ln\, A_t$	2.3176 [0.1178]	2.3605 [0.1136]	2.2396 [0.1259]	5.0977** [0.0132]	….	6.1378** [0.0064]	1.0878 [0.3513]	−0.1033** [−4.4325]
$\Delta\, ln\, F_t$	1.1416 [0.3342]	1.7175 [0.1985]	0.7098 [0.5009]	1.1659 [0.3268]	6.4540* [0.0051]	….	0.4593 [0.6365]	−0.7681* [−3.3906]
$\Delta\, ln\, U_t$	0.5334 [0.5927]	3.6258** [0.0403]	0.5512 [0.5826]	8.5464* [0.0013]	4.6988** [0.0177]	1.9642 [0.1598]	….	−0.2345* [−3.8971]
Long-run and short-run joint causality								
	$\Sigma\Delta\, ln\, C_{t-1}$, ECT_{t-1}	$\Sigma\Delta\, ln\, Y_{t-1}$, ECT_{t-1}	$\Sigma\Delta\, ln\, E_{t-1}$, ECT_{t-1}	$\Sigma\Delta\, ln\, I_{t-1}$, ECT_{t-1}	$\Sigma\Delta\, ln\, A_{t-1}$, ECT_{t-1}	$\Sigma\Delta\, ln\, F_{t-1}$, ECT_{t-1}	$\Sigma\Delta\, ln\, U_{t-1}$, ECT_{t-1}	
$\Delta\, ln\, C_t$	….	4.3467** [0.0245]	15.8926 [0.0000]	2.8232*** [0.0576]	4.5678* [0.0231]	5.0987** [0.0152]	4.2356** [0.0251]	
$\Delta\, ln\, Y_t$	….	….	….	….	….	….	….	
$\Delta\, ln\, E_t$	11.6914* [0.0000]	12.8976* [0.0000]	….	4.6982* [0.0091]	11.9876* [0.0000]	4.2376** [0.0249]	13.0098* [0.0000]	
$\Delta\, ln\, I_t$	3.0606** [0.0449]	2.9095*** [0.0529]	4.0601** [0.0167]	….	4.7213* [0.0089]	3.2772** [0.0489]	4.8571* [0.0079]	
$\Delta\, ln\, A_t$	4.4078** [0.0120]	3.0578** [0.0452]	5.5976** [0.0100]	5.7331* [0.0036]	….	6.1377* [0.0025]	2.8220*** [0.0577]	
$\Delta\, ln\, F_t$	9.8097* [0.0001]	10.8765* [0.0000]	9.8765* [0.0000]	5.3736* [0.0054]	4.3029** [0.0132]	….	5.8123* [0.0026]	
$\Delta\, ln\, U_t$	72.2191* [0.0000]	21.4587* [0.0000]	32.8971* [0.0000]	42.8091* [0.0000]	23.8915* [0.0000]	34.6541* [0.0000]	….	

Note: *, ** and *** indicate the significance at the 1%, 5% and 10% levels, respectively. The long-run causality is outlined by the significance of the t-statistic in relation to the coefficient of the error correction term (ECM_{t-1}), while the short-run linkage is highlighted by the statistical significance of the F-statistic (Wald-test) in the first differences of the variables. The figures between [] and () denote the P-value and the t-statistic, respectively. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *F* denotes the value of FDI inflows, *U* denotes the part of urban population. This note is also applied to Tables 9 and 10 below.

of the link between economic growth and CO_2 emissions and thus to a misleading estimation of the turning point, as shown in Fig. 3. Furthermore, our results show that the cubic regressions are of higher quality in the estimation because their AIC and BIC criteria are lower.[6] We thus recommend that future research should consider the cubic term of economic growth in the carbon emissions function.

For Vietnam, the N-shaped curve for the growth–carbon nexus indicates that there are factors other than economic growth contributing to environmental degradation. However, slowing economic progress to save environment is not a solution and any reduction in carbon emissions is merely transitory. This suggests that at very high-income levels, the scale effect of economic activity becomes so large that its negative impact on the environment cannot be counterbalanced by the positive impact of the composition effect (Friedl & Getzner, 2003, Martinez-Zarzoso and Bengochea-Morancho 2004).[7] All policy implications of these results are

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[6] AIC and BIC are information criteria showing the quality of the estimation procedure. The lower their value, the higher the quality of the estimation. We would like to thank an anonymous Referee for his/her suggestion to include them in the analysis.

[7] Grossman and Krueger (1991) were the first to break down the impact of economic growth on the environment into three independent effects, namely scale, technique and composition. The scale effect is related to economic growth while the technique effect is related to the square of economic growth. The scale effect is supposed to be positive since a larger scale of economic activities leads to a higher use of resources that in turn increases environmental degradation. As for the technique effect, the impact can be positive or negative depending on the technological development. The positive impact, which deepens environmental degradation, is explained by the application of outdated technologies. On the other hand, the negative impact, which decreases environmental degradation, is driven by a higher use of energy-saving technologies. Furthermore, the composition of economic activities can have positive or negative ramifications on the environment because of different pollution intensities from different sectors. This impact channel, called the composition effect, will be negative (decreasing environmental degradation) if the economic structure changes from "dirtier" to "cleaner" activities and positive (increasing environmental degradation) if the reverse is true. For more details, see, for example, Mohapatra, Adamowicz, and Boxall (2016), who explored the decomposition of the EKC in Canada.

Table 9

The VECM Granger causality test with structural breaks for the quadratic model.

Dependent Variables	Type of causality							
	Short run							Long run
	$\Sigma\Delta\, ln\, C_{t-1}$	$\Sigma\Delta\, ln\, Y_{t-1}, \Sigma\,\Delta\, ln\, Y_{t-1}{}^2$	$\Sigma\Delta\, ln\, E_{t-1}$	$\Sigma\Delta\, ln\, I_{t-1}$	$\Sigma\Delta\, ln\, A_{t-1}$	$\Sigma\Delta\, ln\, F_{t-1}$	$\Sigma\Delta\, ln\, U_{t-1}$	ECM_{t-1}
$\Delta\, ln\, C_t$	….	0.1857 [0.8143]	20.9876* [0.0000]	5.0987** [0.0241]	1.9876 [0.1501]	1.3568 [0.2876]	1.1234 [3018]	−0.5431* [−3.0987]
$\Delta\, ln\, Y_t$, $\Delta\, ln\, Y_t^2$	0.2313 [0.8001]	….	0.4041 [0.6011]	1.1870 [0.3121]	5.0989** [0.0150]	0.2625 [0.7534]	2.2500 [0.1200]	**….**
$\Delta\, ln\, E_t$	19.8790* [0.0000]	0.3893 [0.6565]	….	7.9870* [0.0021]	1.6532 [0.2021]	1.2098 [0.3102]	1.0987 [0.3970]	−0.3456** [−2.5678]
$\Delta\, ln\, I_t$	3.5346** [0.0432]	1.3675 [0.2650]	4.5234** [0.0209]	….	5.6767* [0.0109]	1.9087 [0.1726]	1.6098 [0.2190]	−0.3345** [−2.7654]
$\Delta\, ln\, A_t$	2.4356 [0.1123]	2.4567 [0.1089]	2.3456 [0.1155]	5.1980** [0.0125]	….	6.8765* [0.0054]	1.1089 [0.3345]	−0.1123* [−3.4567]
$\Delta\, ln\, F_t$	1.2345 [0.3301]	1.8978 [0.1898]	0.9087 [0.4545]	1.2098 [0.3131]	6.8765* [0.0041]	….	0.5467 [0.6285]	−0.5643** [−2.6758]
$\Delta\, ln\, U_t$	0.6457 [0.5787]	4.0987** [0.0378]	0.6571 [0.5234]	9.0897* [0.0009]	5.0678** [0.0167]	2.0987 [0.1452]	….	−0.2135** [−2.5671]
Long-run and short-run joint causality								
	$\Sigma\Delta\, ln\, C_{t-1}$, ECM_{t-1}	$\Sigma\Delta\, ln\, Y_{t-1}, \Sigma\,\Delta\, ln\, Y_{t-1}{}^2$, ECM_{t-1}	$\Sigma\Delta\, ln\, E_{t-1}$, ECM_{t-1}	$\Sigma\Delta\, ln\, I_{t-1}$, ECM_{t-1}	$\Sigma\Delta\, ln\, A_{t-1}$, ECM_{t-1}	$\Sigma\Delta\, ln\, F_{t-1}$, ECM_{t-1}	$\Sigma\Delta\, ln\, U_{t-1}$, ECM_{t-1}	
$\Delta\, ln\, C_t$	….	11.1279* [0.0000]	14.8765* [0.0000]	4.6587** [0.0221]	9.0879* [0.0000]	10.3467* [0.0000]	6.9087** [0.0110]	
$\Delta\, ln\, Y_t$, $\Delta\, ln\, Y_t^2$	….	….	….	….	….	….	….	
$\Delta\, ln\, E_t$	12.8976* [0.0000]	11.9876* [0.0000]	….	4.7986* [0.0085]	11.0987* [0.0000]	5.3346** [0.0201]	13.9876* [0.0000]	
$\Delta\, ln\, I_t$	7.8956* [0.0021]	3.8796** [0.0456]	5.0989** [0.0234]	….	9.0563* [0.0045]	12.0945* [0.0000]	21.2009* [0.0000]	
$\Delta\, ln\, A_t$	5.9876* [0.0103]	9.7654* [0.0008]	10.0347* [0.0000]	8.6712* [0.0009]	….	7.6133* [0.0017]	4.9876* [0.0203]	
$\Delta\, ln\, F_t$	10.0934* [0.0000]	20.0132* [0.0000]	16.1678* [0.0000]	13.7892* [0.0000]	15.9087* [0.0000]	….	5.9087* [0.0023]	
$\Delta\, ln\, U_t$	40.4040* [0.0000]	23.4690 [0.0000]	29.2909* [0.0000]	44.5672* [0.0000]	16.8934* [0.0000]	37.8965* [0.0000]	….	

analysed in the conclusion section.

4.2.2. Short-run results

Table 7 shows the results of the carbon function in the short run. The linear model indicates that economic growth has a negative and insignificant impact on carbon emissions (a coefficient of −0.7470). Energy consumption significantly adds to CO_2 emissions (a positive coefficient of 0.2490). Industry value added increases carbon emissions while agriculture value added declines them. FDI and urbanization do not have significant effects on CO_2 emissions. The estimates of lagged error terms are negative and significant at the 1% level for the linear, squared and cubic models. These coefficients show the short-run adjustment speed to the long-run equilibrium path in the carbon emissions function for the Vietnamese economy. We note that short-run deviations are corrected by 69.26%, 67.82% and 70.04% each year to reach the long-run equilibrium following the linear, squared and cubic empirical models, respectively. This highlights that the short-run adjustment would require almost 1 year and 6 months achieving the long-run equilibrium in all cases. The absence of autocorrelation is confirmed by the Durbin-Watson test.

More importantly, the short-run EKC is not supported because the coefficients for the linear and squared terms of economic growth are not significant in the quadratic model. The findings of the cubic model reveal that the short-run N-shaped relationship is not supported neither because the first two coefficients (related to the linear and squared terms) are not significant. This finding thus suggests that it is important to distinguish between the short run and long run when studying the nexus between economic growth and CO_2 emissions. According to various authors (e.g., Arouri et al., 2012; Jaunky, 2011; Narayan & Narayan, 2010), the issue related to collinearity between income and its square should be considered. To do so, we used the method proposed by Narayan and Narayan (2010) to compare the long-run coefficient of economic growth (Table 6) with the short-run coefficient (Table 7) of the linear regressions. The results show that short-run elasticity is greater than its long-run counterpart (−0.7470 vs. 01842, for short-run and long-run coefficients, respectively). As indicated by Narayan and Narayan (2010), this empirical finding confirms the presence of an EKC and thus, the robustness of the results obtained from the quadratic regression.

The next part of this section is devoted to the causality analysis among CO_2 emissions and the considered variables in Vietnam.

Table 10

The VECM Granger causality test with structural breaks for the cubic model.

Dependent Variables	Type of causality							
	Short run							Long run
	$\Sigma\Delta\ ln\ C_{t-1}$	$\Sigma\Delta\ ln\ Y_{t-1}, \Sigma\ \Delta\ ln\ Y_{t-1}{}^2, \Sigma\ \Delta\ ln\ Y_{t-1}{}^3$	$\Sigma\Delta\ ln\ E_{t-1}$	$\Sigma\Delta\ ln\ I_{t-1}$	$\Sigma\Delta\ ln\ A_{t-1}$	$\Sigma\Delta\ ln\ F_{t-1}$	$\Sigma\Delta\ ln\ U_{t-1}$	ECM_{t-1}
$\Delta\ ln\ C_t$	….	0.2134 [0.7654]	18.9745* [0.0000]	6.0975** [0.0110]	1.8156 [0.1657]	1.4070 [0.2643]	1.1550 [0.2876]	−0.2356** [−2.5672]
$\Delta\ ln\ Y_t$, $\Delta\ ln\ Y_t^2$, $\Delta\ ln\ Y_t^3$	0.2417 [0.7912]	….	0.5467 [0.5873]	1.2345 [0.3018]	5.1290** [0.0134]	0.3478 [0.7181]	2.7658 [0.1015]	−0.1267* [−3.7890]
$\Delta\ ln\ E_t$	17.9015* [0.0000]	0.5678 [0.5454]	….	8.9086* [0.0012]	1.4567 [0.212]	1.6789 [0.2567]	1.1908 [0.3789]	−0.2345* [−2.6782]
$\Delta\ ln\ I_t$	3.9087** [0.0305]	1.4524 [0.2525]	4.8765** [0.0187]	….	5.9875* [0.0101]	2.0956 [0.1589]	1.6690 [0.2450]	−01324** [−0.2.4545]
$\Delta\ ln\ A_t$	2.3465 [0.1213]	2.5565 [0.1077]	2.4545 [0.1090]	5.2098** [0.0123]	….	6.9090* [0.0045]	1.2134 [0.3131]	0.1324* [−2.6572]
$\Delta\ ln\ F_t$	1.4569 [0.3267]	2.0967 [0.1653]	1.0567 [0.4420]	1.2424 [0.2929]	7.0456* [0.0024]	….	0.6534 [0.5987]	−0.5454** [−2.4545]
$\Delta\ ln\ U_t$	0.7070 [0.5656]	4.5678** [0.0286]	0.7073 [0.5019]	10.0543* [0.0004]	5.1673** [0.0155]	….	1.2629 [0.1312]	−0.1424* [−3.0879]
Long-run and short-run joint causality								
	$\Sigma\Delta\ ln\ C_{t-1}$, ECM_{t-1}	$\Sigma\Delta\ ln\ Y_{t-1}, \Sigma\ \Delta\ ln\ Y_{t-1}{}^2, \Sigma\ \Delta\ ln\ Y_{t-1}{}^3$, ECM_{t-1}	$\Sigma\Delta\ ln\ E_{t-1}$, ECM_{t-1}	$\Sigma\Delta\ ln\ I_{t-1}$, ECM_{t-1}	$\Sigma\Delta\ ln\ A_{t-1}$, ECM_{t-1}	$\Sigma\Delta\ ln\ F_{t-1}$, ECM_{t-1}	$\Sigma\Delta\ ln\ U_{t-1}$, ECM_{t-1}	
$\Delta\ ln\ C_t$	….	201.8976* [0.0000]	13.2879* [0.0000]	8.9082* [0.0002]	10.0943* [0.0000]	10.4536* [0.0000]	7.0345* [0.0105]	
$\Delta\ ln\ Y_t$, $\Delta\ ln\ Y_t^2$, $\Delta\ ln\ Y_t^3$	….	….	….	….	….	….	….	
$\Delta\ ln\ E_t$	12.3003* [0.0000]	….	11.0414* [0.0000]	5.0807* [0.0045]	15.9080** [0.0000]	6.6020* [0.0002]	12.2050* [0.0000]	
$\Delta\ ln\ I_t$	6.9807* [0.0055]	10.4204* [0.0000]	9.0807* [0.0023]	….	10.1514* [0.0000]	12.1916* [0.0000]	−01324** [−0.2.4545]	
$\Delta\ ln\ A_t$	3.5346** [0.0432]	1.3675 [0.2650]	4.5234** [0.0209]	….	5.6767* [0.0109]	1.9087 [0.1726]	1.6098 [0.2190]	
$\Delta\ ln\ F_t$	12.9546* [0.0000]	21.9087* [0.0000]	23.8654* [0.0000]	12.4356* [0.0000]	….	22.0098* [0.0000]	12.6789* [0.0000]	
$\Delta\ ln\ U_t$	35.7689* [0.0000]	22.4456* [0.0000]	11.2908* [0.0000]	23.9090* [0.0000]	29.0870* [0.0000]	10.9845* [0.0000]	….	

Table 11

Long-run carbon functions with new variables.

Dependent Variable = lnC_t						
	Linear model		*Quadratic model*		*Cubic model*	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	−6.5980*	−3.3452	−19.0409	−2.2149	32.3243	2.3100
lnY_t	0.0567*	2.0088	2.6856**	2.3706	169.4918**	2.3923
lnY_t^2	….	….	−0.2505**	−2.4850	−25.6281**	−2.4072
lnY_t^3	….	….	….	….	1.2824**	2.4310
lnE_t	0.1403*	6.7809	1.3939*	6.8989	0.4842**	2.1618
lnI_t	0.0976*	5.2432	0.0892*	4.6871	0.0755*	4.1548
lnA_t	−0.9425*	−2.9765	−0.1336**	−2.3656	−3.3490**	−2.7581
$lnFDI_t$	−0.0103**	−2.0556	−0.0175**	−2.6052	−0.0178**	−2.8354
$lnURB_t$	−0.7696**	−2.5768	1.7337	0.8139	−2.7298**	−2.3811
$lnGS_t$	0.1599**	2.6912	0.1992**	2.0753	0.1321**	2.4460
$lnTR_t$	−0.0999**	−2.8050	−0.0891**	−2.6361	−0.0773**	−2.5562
R^2	0.8456		0.8867		0.9956	
$Adj - R^2$	0.8567		0.8657		0.9945	
D.W. test	2.0236		1.6995		1.7856	
F-statistics	6.3457*		5.9867*		6.5790*	
P-value	0.0023		0.0034		0.0015	

Note: * and ** indicate the significance at the 1% and 5% levels, respectively. D.W. denotes the Durbin-Watson test for the autocorrelation of residual terms. F-statistics are for testing the overall significance of the models. *P*-value is for the significance level. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *FDI* denotes the value of FDI inflows, *URB* denotes the part of urban population, *GS* denotes government size and *TR* denotes trade openness.

Table 12
Short-run carbon functions with new variables.

Dependent Variable = $\Delta \ln C_t$

	Linear model		*Quadratic model*		*Cubic model*	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	−1.5177	−1.16016	−0.0297	−0.4436	−0.0283	−0.2611
$\Delta \ln Y_t$	0.7414	0.7086	3.0759	−0.5857	6.0776	−0.5996
$\Delta \ln Y_t^2$	….	….	24.7736	0.4517	−126.8244	0.5665
$\Delta \ln Y_t^3$	….	….	….	….	1022.624	−0.5497
$\Delta \ln E_t$	1.2805*	4.6932	1.2060*	3.7160	1.1060*	3.2444
$\Delta \ln I_t$	0.9815*	4.2892	0.9039*	3.1021	0.8552*	2.9179
$\Delta \ln A_t$	−1.0200	−1.1744	−0.9431	−1.0418	−1.6731	−1.7736
$\Delta \ln FDI_t$	0.0003	0.0360	0.0017	0.1478	0.0037	0.2375
$\Delta \ln URB_t$	4.1611	1.5579	5.7953	1.2944	6.4574	1.3253
$\Delta \ln GS_t$	0.0545	0.7172	0.0518	0.6856	0.0752	0.9276
$\Delta \ln TR_t$	−0.0930**	−1.7629	−0.0757	−1.1253	−0.0374	−0.4630
ECM_{t-1}	−0.9366*	−3.2933	−0.9059*	−3.664	−1.0773*	−3.4640
R^2	0.8256		0.8324		0.8356	
$Adj-R^2$	0.8198		0.8236		0.8298	
D.W Test	1.9934		1.9867		1.6507	
F-statistics	11.9876*		10.4567*		9.7856*	
P-value	0.0000		0.0000		0.0001	

Note: *, ** and *** indicate the significance at the 1%, 5% and 10% levels, respectively. D.W. denotes the Durbin-Watson test for the autocorrelation of residual terms. F-statistics are for testing the overall significance of the models. *P*-value is for the significance level. *C* denotes carbon emissions, *Y* denotes GDP, *E* denotes energy consumption, *I* denotes the industry added value, *A* denotes the agriculture added value, *FDI* denotes the value of FDI inflows, *URB* denotes the part of urban population, *GS* denotes government size and *TR* denotes trade openness.

4.3. Granger causality analysis

After investigating both the long-run and short-run models, we applied the VECM Granger causality test to examine the causal relationships among the variables. The results are detailed in Tables 8, 9 and 10 for the linear, quadratic and cubic versions of the carbon function, respectively. In the long run, economic growth causes CO_2 emissions in the Granger sense. This implies that Vietnam is attaining economic growth at the cost of environmental quality. This empirical evidence is consistent with that of Shahbaz et al. (2014, 2016), who reported that economic growth is responsible for environmental degradation in Tunisia and Portugal. However, Yang and Zhao (2014) documented a feedback effect between economic growth and CO_2 emissions in India. On the other hand, economic growth causes energy consumption while the inverse is not true. This implies that the higher the economic growth, the higher the demand for energy is. Yet, declines in economic growth further decrease energy consumption (Ozturk, 2010), a result similar to that of Tang and Tan (2015) for Vietnam over the 1971–2011 period.

On the other hand, there is bidirectional causality between industry value added, agriculture value added, FDI, urbanization and carbon emissions. Inversely, economic growth Granger causes industry added value, agriculture added value, FDI and urbanization. These results indicate significant interactions between industry value added, agriculture value added, FDI, urbanization and both environmental degradation (carbon emissions) and economic growth in the short run. Overall, we note that agriculture plays a very

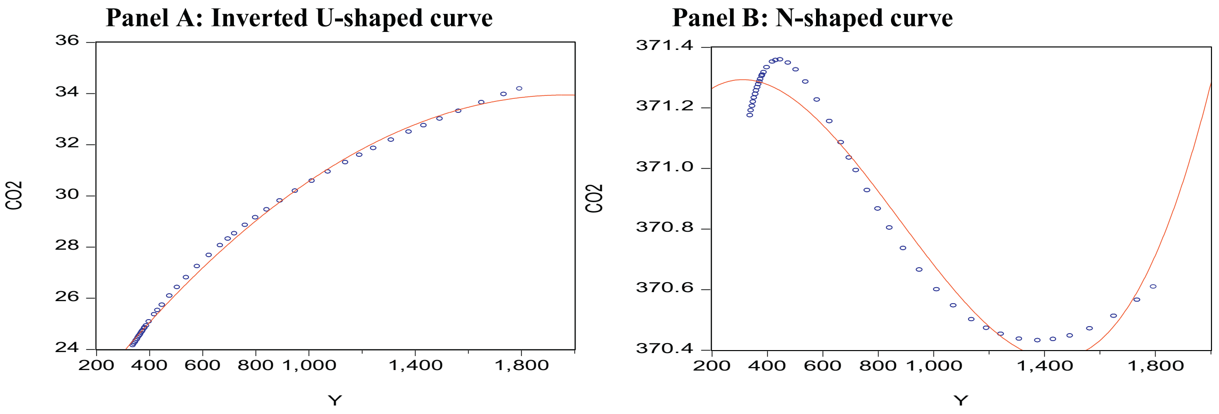

Fig. 4. The N-shaped phenomenon in Vietnam with new variables.

important role in the economic development of Vietnam and has the advantage of not contributing to CO_2 emissions (significant causality from agriculture value added to economic growth but not to carbon emissions). A likely explanation is that agricultural activities in Vietnam are still carried out with low energy-consuming machines. This therefore implies that Vietnam should not abandon the agricultural sector to focus on industry but should instead seek a balance between these two sectors. Surprisingly, the industry valued added does not Granger cause economic growth but only carbon emissions. Furthermore, economic growth Granger causes FDI inflows, while the inverse is not true. This finding suggests that GDP growth is an important signal to foreign investors in their decision to invest in this country. Last, the feedback effects between urbanization and economic growth and between urbanization and carbon emissions are not surprising. As all important economic activities are concentrated in Hanoi and Ho Chi Minh City, which are the two economic centres of Vietnam, many people have moved from the countryside to these two cities. This has contributed to the economic growth but it has also affected the environment, mostly because of the substantial rise in the number of motorbikes.

In the short run, we also found a neutral effect (or no causality) between economic growth and energy consumption. The bi-directional causality was also found for energy consumption and CO_2 emissions in the short run. Furthermore, there is a feedback effect between industry value added (as well as agriculture, and industrial growth) and carbon emissions. On the other hand, agriculture value added does not Granger cause carbon emissions, neither the inverse. Furthermore, there is no causal relationship between industry value added and economic growth, there is unidirectional causality is found running from agriculture value added to urbanization (economic growth). The feedback effect exists between agriculture growth and FDI. FDI does not Granger cause economic growth while the inverse is true. The joint causality results are also reported (the last columns in the right). These results confirm the long-run and short-run outcomes and show that they are reliable and robust.

5. Robustness check: Does the variables' selection matter?

To examine the robustness of the previous empirical results, we further add other potential determinants of carbon emissions such as government size and trade openness. These variables are chosen because government size may affect energy demand and hence CO_2 emissions (Carlsson & Lundström, 2001; Halkos & Paizanos, 2012; Lopez, Galinato, & Islam, 2011; Lopez & Palacios, 2010; Sim, 2006). On the other hand, trade openness affects carbon emissions via income effect, technique effect and composition effect[8] (Al-Mulali et al., 2015; Baek, Cho, & Koo, 2009; Chebbi, Olarreaga, & Zitouna, 2010; Halicioglu, 2009; Khalil & Inam, 2006; Managi, Hibiki, & Tsurumi, 2009; Naranpanawa, 2011; Omri, 2013; Shahbaz et al., 2017). While keeping the composition effect constant, trade openness increases carbon emissions if the income effect dominates the technique effect and vice versa.

The new empirical results for this robustness check are reported in Tables 11 and 12 showing the long-run and short-run carbon functions (linear, quadratic and cubic, respectively). Government size impacts positively on carbon emissions, which is in line with Carlsson and Lundström (2001), who documented that a lower government size (or a higher economic freedom) dilutes carbon emissions. This result is appropriate because a higher spending of the government induces a higher consumption, a higher infrastructure investment, thus a higher energy consumption and higher carbon emissions.

Furthermore, we find that trade openness is negatively and significantly linked with CO_2 emissions. In the same line, Antweiler, Copeland, and Taylor (2001) showed that trade openness worsens pollutant emissions in rich states while decreasing them in poor countries. The same was found in Al-Mulali et al. (2015) considered 23 European states and showed that trade openness helps decrease pollutant emissions. On the other hand, Njindan Iyke and Ho (2017) also pointed out that high trade openness diminishes carbon emissions in the long run, but only to a certain threshold. However, Cole (2004) found that trade openness increases the shift of pollution-intensive activities from rich nations to developing ones. This is in line with Managi et al. (2009) analysis suggesting that trade openness boosts CO_2 pollution in non-OECD members and lowers emissions in the OECD ones. In the meanwhile, Ahmed, Shahbaz, and Kyophilavong (2016) stressed that trade openness in developing countries (Brazil, India, China and South Africa) generates higher carbon emissions. However, some academics claimed that there is no significant relationship between trade openness and CO2 emissions (Copeland & Taylor, 2005; Grossman & Krueger, 1991; Jalil & Mahmud, 2009; Levinson, 2009; Omri, 2013; Soytas, Sari, & Ewing, 2007). For Vietnam, this negative relationship between trade openness and CO_2 emissions suggests that higher imports and exports help the country improve the production process with new technologies that allow decreasing the impact on the environment.

More importantly, this robustness check shows that the long-run relationship between economic growth and carbon emissions remains the same as when the variables government size and trade openness were not included in the regressions, meaning the existence of inverted U-shape and N-shape (see Table 11 and Fig. 4). Furthermore, as indicated previously, in the short run, there is no significant inverted U-shape and N-shape (see Table 12). These results show that our previous findings are not impacted by the variables' selection and are thus robust. We thus conclude that the addition of other potential determinants of CO_2 emissions does not affected our empirical evidence about the N-shaped relationship between economic growth and CO_2 emissions in Vietnam. It thus validates the reliability and soundness of previous empirical results.

6. Conclusion and policy implications

This paper has investigated the relationship between economic growth and CO_2 emissions in Vietnam by building upon the EKC

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[8] Please refer to footnote 7 for more details on these three effects.

hypothesis. Energy consumption, industry and agriculture value added, FDI and urbanization are considered as determinants of CO_2 emissions over the 1972–2016 period using annual data. We first performed both traditional and structural break unit root tests to examine the integrating properties of the variables. The ARDL bounds testing approach was applied to examine the cointegration between the variables. The causal linkage among the variables was verified via the VECM Granger causality test. Our results indicate a cointegration relationship among the variables. Energy consumption, economic structure (industry and agriculture value added), FDI and urbanization significantly impact CO_2 emissions in Vietnam. More importantly, the long-run nexus between economic growth and CO_2 emissions was both inverted U-shaped and N-shaped while it is not the case in the short run. A robustness check, including two new variables in the regressions (government size and trade openness), shows that the variables' selection does not impact the conclusion about the long-run N-shaped relationship between economic growth and CO_2 emissions in Vietnam.

The long-run N-shaped relationship between economic growth and CO_2 emissions suggests that Vietnam may benefit from a drop in CO_2 emissions at some point, although the country will need to be cautious because the emissions may rise again when a second income turning point is reached. Hence, the government should make environmental decisions that extend the period of decreasing CO_2 emissions before the second turning point. This can be done by developing cleaner production techniques and strict rules for firms, especially through FDI to develop manufacturing activities. To our opinion, the N-shaped result is unsurprising because the main source of energy in Vietnam is coal-fired power plants. For example, half of the generated electricity is from thermal power plants (18%), coal (37%) and other sources by burning oil and gas (United Nations, 2015). To this regard, the COP23 (the 23rd conference of the United Nations in 2017) decided to abandon coal gradually. Thus, Vietnam should anticipate this change to develop new energy sources because energy plays an important role in economic activities.

The causality results indicate that economic growth in Vietnam causes CO_2 emissions in the long run. This implies that Vietnam is attaining economic growth at the cost of environmental quality. Furthermore, economic growth Granger causes energy consumption which implies that energy plays a very important role in the economic development of Vietnam. Together with the previous result that economic growth causes CO_2 emissions, we would suggest the Vietnamese government to focus on renewable energies so that the country can ensure the energy supply, which is essential to economic growth, while reducing the level of CO_2 emissions. As noted by Nguyen and Ha-Duong (2009), the promotion of renewable energies from small hydro, mini hydro, geothermal, solar, wind turbine and biomass sources will be crucial to increase the energy supply in the future. However, barriers still remain, especially the high cost of renewable energies, compared with fossil fuel energy. Therefore, Vietnamese policymakers should set the prices of renewable energies to reflect their full social gains. The second barrier to be overcome is related to investments in research and development, access to new technologies, and skilled manpower to promote renewable technologies (Nguyen & Ha-Duong, 2009).

In Vietnam, agriculture still plays a very important role in the economic development of Vietnam and has the advantage of not contributing to CO_2 emissions (see causality results above). One of the reasons of this result is related to the fact that agricultural activities in Vietnam are still carried out with few energy-consuming machines. Thus, Vietnam should not abandon the agricultural sector to focus on industry but should find a balance between these two sectors. On the other hand, the development of industrial sector, and mostly manufacturing activities, does not significantly Granger cause GDP growth, while it significantly causes environmental degradation. Hence, policymakers in Vietnam should carefully control the FDI inflows for manufacturing activities to correctly assess the balance between economic profit and environmental degradation. Vietnam should also encourage trade openness because this international exchange helps the country develop new technologies allowing the reduction of CO_2 emissions. However, the Vietnam government should optimize public spending because its higher value contributes to higher carbon emissions. In the meanwhile, it is important to maintain the level of GDP because the GDP growth constitutes an important signal to foreign investors in their decision to invest in the country. Last, urbanization is a problem in Vietnam nowadays because all important economic activities are concentrated in Hanoi and Ho Chi Minh City and cause a substantial rise in the number of motorbikes and cars. This can be resolved if the infrastructure is more developed in the countryside. Carbon taxes on motorbikes and cars may be another solution to this urban-environmental issue in Vietnam.

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