CHAPTER 10

Most Up-to-Date Methodologic Approaches: Evidence from the Wavelet Coherence Approach

FAIK BILGILI, PHD • ERHAN MUĞALOĞLU, PHD • SEVDA KUŞKAYA, PHD •
H. HILAL BAĞLITAŞ, PHD • PELIN GENÇOĞLU, PHD

INTRODUCTION

The expected outcome of the 21st conference of parties (COP21) and 11th session of the parties to the Kyoto protocol (CMP11) held in Paris in December 2015 is a new international agreement on climate change targeting to keep the increase in global average temperatures below 2°C. Boden, Andres, and Marland (2017) report that the United States and China account for 15% and 30% global share of greenhouse gas emission (GHG), respectively. Besides, China, as the largest developing country, is responsible from 80% increase in worldwide CO_2 emissions backed with high economic growth rates since 2008 (Liu et al., 2013). This abrupt increase in Chinese GHG emissions, at the same time with a gradual emission reduction performance of the United States, proposes the relation between a country's economic growth and environmental position. The environmental Kuznets curve (EKC) hypothesis fundamentally and very basically stands for: While income per capita increases in a country, the environmental damage first rises and then diminishes (Stern, 2004). Panayotou (1993) first defines it as a Kuznets curve because it is similar to the seminal work of Kuznets (1955) explaining the relation between economic growth and inequality. The EKC relation considers an inverted U-shaped curve, which examines a mixed relationship between the environmental degradation and income.

An inverted U-shaped EKC hypothesis can be more generally defined as during a country's low-income level state, where the economy develops, first the environmental pollution increases and then starts to slow down till some income level threshold. After reaching this certain (threshold) income level, this turns out to be an environmental improvement (Grossman & Krueger, 1995; Solarin, Al-Mulali, & Ozturk, 2017; Stern, 2004). The EKC hypothesis indicates an environmental evolutionary progress through a country's economic development that in early stages an economy performs more an energy and natural resource intensive growth where it emits more pollution, thus environmental quality diminishes. The increase in economic activity shifts the previous phase of production to industrial production, in which both technical progress and information technologies become important. At the last stage of economy, technical improvement triggers the new energy-efficient technologies and cleaner energy investments, which later overwhelm the negative effect of economic growth backed environmental degradation (Bo, 2011; Kaika & Zervas, 2013). As a result, environmental pollution growth would be gradually decreasing and later environmental quality would improve (Panayotou, 1993). These just defined three determining effects of the relationship between economic growth and environmental degradation: scale, structural, and technological effects (Bilgili, Koçak, & Bulut, 2016; Bilgili, Öztürk et al., 2016).

The aim of this chapter is to introduce the wavelet methodology, as a state of art method of causality testing, with an applied application. This wavelet-based application will be examining (1) (wavelet coherence) the interrelation between the cycles of income and CO_2 emission data series and (2) (partial wavelet coherence) reconsidering this relation by factoring out some other explanatory variables. Besides, (3) phase difference observations will be able to reveal a lead-lag analysis between these series. After presenting a brief review of the EKC hypothesis testing in Section 2, Section 3 covers the wavelet methodology and empirical data. Section 4 provides an empirical instance of

Environmental Kuznets Curve (EKC). https://doi.org/10.1016/B978-0-12-816797-7.00010-2

wavelet coherency and phase analysis with its results, and lastly Section 5 concludes.

LITERATURE REVIEW

In the early stages of EKC research literature, the validation test of an inverted U-shaped function of income per capita for different polluters has been examined by environmental economists including those of Panayotou (1993), Selden and Song (1994), Shafik (1994), Grossman and Krueger (1995), and Stern, Common, and Barbier (1996), and they all confirm an inverted U-shaped function for different pollution indicators. However, Stern et al. (1996) argue that first of all, due to the simultaneity (the choice of instrumental variables problem) and probable low data quality, the reduced form estimation of EKC parameters would not be econometrically strong enough for a future policy suggestion, and secondly, the EKC literature is mainly observed that it is valid for some specific pollution indicators rather than overall environmental degradation or quality. For instance, while one may expect an upward trend in sulfur dioxide (SO_2) emission, a flat deforestation rate in a specific time-interval is seen (Shafik, 1994). Selden and Song (1994) observed an exhibited EKC for air pollutants in the very long run; however, this may conclude very tricky policy implications, in favor of economic growth, if this very long run is beyond an irreversible environmental deterioration threshold (Panayotou, 1993).

Despite the fact that the EKC relationships are investigated for specific type of environmental damage indicators, such as deforestation, clean water, or ecologic footprint, and pollutants, such as SO_2, nitrous oxides (NO_2), and carbon dioxide (CO_2), Dinda (2004) reviews that inverted U-shaped curve of economic growth prevails mostly with respect to residential air pollutants, for example, carbon monoxide (CO) or solid particulate matter (SPM). Nahman and Antrobus (2005) and Acaravci and Akalin (2017, p. 10) provide brief review surveys of recent EKC studies that use different pollutants. Besides, Shahbaz and Sinha (2016) provide a detailed literature survey on EKC hypothesis testing, which set CO_2 emission as an independent variable. Shahbaz, Dube, Ozturk, and Jalil (2015), Shahbaz, Solarin, Sbia, and Bibi (2015) and Shahbaz and Sinha (2016) review that from the findings of both single- and multicountry data, there is no common convincing conclusion, which either validates or rejects the EKC relation for CO_2 emissions. On the other hand, Al-mulali, Weng-Wai, Sheau-Ting, and Mohammed (2015) investigate the existence of EKC hypothesis in 93 countries from various income levels by testing EKC hypothesis for ecologic footprint rather than air pollutants or CO_2 because carbon emissions are only responsible just for the half of total environmental degradation. This work has found out that there is an existing inverted U-shaped relationship except lower-middle income and low-income countries.

Shahbaz and Sinha (2016) state that although there are a vast number of studies for testing the validation of EKC hypothesis, most of these researches perform common model specifications. In addition to the specification of a model with respect to different environmental pollution indicators, we may also group the studies on the EKC validation regarding to (1) the estimation methodology used and depending on, (2) how income enters, and (3) which extra explanatory variables are inserted into estimation equation. The data methodology of EKC hypothesis can be primarily grouped into time series analysis and panel data analysis. Time series analysis typically stands for a single-country investigation of the EKC, whereas panel data analysis enables to simplify the result of EKC hypothesis for a group of countries. Each group of data reveals different results describing the association between environmental indicators and economic growth. The estimation methodology has a long variety; for example: ordinary least squares (OLS), autoregressive distributed lag (ARDL), dynamic OLS (DOLS), generalized method of moments (GMM), panel least squares (PLS), vector error correction method (VECM), etc. A recent summary of EKC validation literature using cointegration and causality tests is given in Table 10.1. The EKC hypothesis investigations of single- (time series) and multicountry (panel data) cases are presented in section (A) and (B), respectively. In addition to as usual methods, a summary of literature that uses methods for testing EKC hypothesis with parameter estimations other than causality and cointegration methods is presented in Table 10.2.

Income per capita, or sometimes rate of income growth (Coondoo & Dinda, 2002), can be included into EKC estimation equation with itself (linear), its second power (quadratic), and/or third power (cubic) forms. Depending on the estimated values of the parameters defining income, the EKC relation between environmental pollution indicators and income would be concluded. For instance, in any EKC testing equation, if all of the parameter estimates are not significantly different from zero, then there will be no relation between environmental degradation and economic growth. Moreover, there occurs an inverted U-shaped curve that confirms the EKC hypothesis, if the level and the second power of income have

TABLE 10.1
Environmental Kuznets Curve (EKC) Studies.

Author	Country	Data	Variable	Method	Result	EKC
SECTION A: SINGLE-COUNTRY CASE (TIME SERIES)[a]						
Jalil and Feridun (2011)	China	1953–2006	FD, EG, EC, CE, RLL	ARDL	(EC, GDP, TO) ⇒ CE	Valid
Nasir and Rehman (2011)	Pakistan	1972–2008	CE, GDP, TRD	Johansen cointegration	EG ⇒ EC.	Valid
Xu (2011)	China	1990–2009	CE, GDP, INV, FIXC, M1	ARDL, Granger causality	(INV, GDP, FIXC) ⇒ CE	Valid
Ahmed and Long (2012)	Pakistan	1971–2008	CE, EG, EC, TRL, POP	ARDL	(POP(−), TRL(+)) ⇒ CE	Valid
Esteve and Tamarit (2012)	Spain	1857–2007	CE, GDP	Threshold cointegration and nonlinear adjustment	Nonlinear causality exists	Valid
Hamit-Haggar (2012)	Canada	1990–2007	EC, CE, EG	Granger causality	Short-run: CE ⇒ EC; EG ⇒ EC Long-run: EC ⇒ EG.	Valid
Saboori, Sulaiman, and Mohd (2012)	Malaysia	1980–2009	GDP, CE, EG	ARDL, VECM	Long-run EG ⇒ CE	Valid
Shahbaz, Lean, and Shabbir (2012)	Pakistan	1971–2009	EC, CE, EG, and TO	ARDL	EG ⇒ CE	Valid
Abdallah, Belloumi, and Wolf (2013)	Tunisia	1980–2010	TVA, EC, CE	Johansen cointegration	TVA ⇒ CE	Not valid
Saboori and Sulaiman (2013b)	Malaysia	1980–2009	ECD, EC, EG, CE	ARDL	EKC is valid for ECD but not for EC	Not observed
Shahbaz, Ozturk, Afza, and Ali (2013)	Turkey	1970–2010	EI, EG	VECM, Granger causality	EG//CE	Valid
Tiwari, Shahbaz, and Hye (2013)	India	1966–2011	EG, CE, TO	ARDL, Granger causality	(TO, EG) ⇔ CE	Valid
Katircioğlu (2014)	Singapore	1971–2010	TOD, CE	Granger causality	TOD(−) ⇒ CE.	Valid
Loganathan, Shahbaz, and Taha (2014)	Malaysia	1974–2010	CTAX, EG, EDEG	Granger causality	CTAX, EG, EDEG are cointegrated	Valid
Onafowora and Owoye (2014)	Selected countries	1970–2010	EG, EC, POP, TO, CE	ARDL, Granger causality	mixed results GDP ~ CE	Not observed
Shahbaz, Khraief, Uddin, and Ozturk (2014)	Bangladesh	1975–2010	ELC, CE, TO, IND	ARDL, IAA	ELC ⇒ CE,IND; FD ⇒ TO; TO ⇒ IND	Valid
Shahbaz, Uddin, Rehman, and Imran (2014)	Tunisia	1971–2010	EG, EC, TO, CE	ARDL, IAA, VECM	EG ⇒ CE; TO ⇒ EC	Valid

Continued

TABLE 10.1
Environmental Kuznets Curve (EKC) Studies.—cont'd

Author	Country	Data	Variable	Method	Result	EKC
Tan, Lean, and Khan (2014)	Singapore	1975–2011	CE, EC, GDP	Granger causality	CE(−) ⇒ EG	Valid
Abid (2015)	Tunisia	1980–2009	EG, CE, GDP	Cointegrated VECM, Granger causality	EG ⇒ CE; GDP ⇔ EC	Not valid
Ahmed, Shahbaz, Qasim, and Long (2015)	Pakistan	1980–2013	EDEG, EG, EC, TO, POP	ARDL, VECM	(EG, TO) ⇒ EC; EG ⇔ EC	Valid
Ajmi, Hammoudeh, Nguyen, and Sato (2015)	G7 countries	1960–2010	CE, EC, GDP	Time-varying Granger causality	EKC is not supported	Not valid
Tang and Tan (2015)	Vietnam	1976–2009	CE, EC, FDI, EG	Cointegration, Granger causality	CE ⇔ GDP; EC ⇒ (CE, EC, FDI, GDP)	Valid
Ahmad et al. (2016)	India	1971–2014	EC, CE, EG	ARDL, VECM	EG ⇔ CE; EC(+) ⇒ CE Valid	
Bento and Moutinho (2016)	Italy	1960–2011	CE, GDP, NREP, REP, TRD	ARDL, Granger causality	TRD ⇒ (CE,NREP); GDP ⇒ NREP; NREP ⇒ REP	Valid
Ertugrul, Cetin, Seker, and Dogan (2016)	Selected developing countries	1971–2011	GDP, EC, TO, CE	ARDL with structural break, VECM, Granger causality	EKC is not valid for all selected countries	Not observed
Shahbaz, Solarin, and Ozturk (2016)	19 African countries	1971–2012	GDP, EI, GLB	ARDL	EKC is not valid for all countries	Not observed
Ahmad et al. (2017)	Croatia	1992–2011	GDP, CE	ARDL, VECM	In the short-run, EG ⇒ CE; in the long run EG ⇔ CE	Valid
Ali, Abdullah, and Azam (2017)	Malaysia	1971–2012	EC, CE, EG, FD, TO	ARDL, Granger causality	EC ⇔ CE; (EC, EG,FD) ⇒ CE	Valid
Charfeddine (2017)	Qatari	1970–2015	EG, EC, TO, UR, FD, EDEG, ECF	Cointegration with Markov switching model	EKC is valid only for CE	Not observed
Danish, Zhang, Wang, and Wang (2017)	Pakistan	1970–2012	REC, NREC, CE	ARDL, causality testing	CE ⇔ REC; CE ⇔ NREC	Valid
Kharbach and Chfadi (2017)	Morocco	2000–11	GDP, CE, POP, EG	Cointegration	EG(−) ⇒ CE	Valid

Shahbaz, Solarin, Hammoudeh, and Shahzad (2017)	USA	1960–2016	GDP, EX, IM, TO, BEC, CE	ARDL, VECM	Inverted U- and N-shaped EKC for EG and CE	Valid
Shahzad, Kumar, Zakaria, and Hurr (2017)	Pakistan	1971–2011	EC, TO, FD, CE	ARDL, Granger causality	EC ⇔ FD	Valid
Solarin et al. (2017)	China and India	1965–2013	CE, HEC,UR, GDP	ARDL, Granger causality	GDP ⇔ CE; HEC ⇔ CE	Valid
Bello, Solarin, and Yen (2018)	Malaysia	1971–2016	HEC, FFC, EDEG, GDP, UR	ARDL, VECM	GDP ⇔ EDEG	Valid
Zambrano-Monserrate, Silva-Zambrano, Davalos-Penafiel, Zambrano-Monserrate, and Ruano (2018)	Peru	1980–2011	GDP, CE, RELC, NGC PC	ARDL, VECM	(GDP, RELC, NGC, PC) ⇒ CE	Not valid
SECTION B: MULTICOUNTRY CASE (PANEL DATA)[a]						
Pao and Tsai (2011)	BRICS countries	1980–2007	CE, EC, FDI, GDP, EG, FD	Panel cointegration	EC ⇒ CE; GDP ⇔ CE; GDP ⇔ EC;	Valid
Zilio and Recalde (2011)	Latin America and the Caribbean	1970–2007	EC, GDP	Cointegration approach	//	Not valid
Arouri, Youssef, Mhenni, and Rault (2012)	12 MENA countries	1981–2005	CE, EC, GDP	Panel cointegration	//	Not observed
Ozcan (2013)	12 Middle East countries	1990–2008	CE, GDP, EG, EC	Panel causality	Mixed results GDP ∼ CE	Not observed
Saboori and Sulaiman (2013a)	ASEAN countries	1971–2009	CE, EC, GDP	ARDL, VECM	CE ⇔ CE	Valid
Farhani and Shahbaz (2014)	MENA region	1980–2009	RELC, NRELC, CE, GDP	Granger causality	(RELC, NRELC, GDP) ⇒ CE; EC ⇔ CE	Valid
Baek (2015)	12 major nuclear-generating countries	1980–2009	NE, EC, GDP, CE	Cointegration	NE(−) ⇒ CE	Valid
Omri, Daly, Rault, and Chaibi (2015)	MENA region	1990–2011	FD, CE, TRD, EG, TO	Simultaneous-equation panel	TO ⇔ FD; CE//FD; FD ⇒ EG; TO ⇒ CE	Valid

Continued

TABLE 10.1
Environmental Kuznets Curve (EKC) Studies.—cont'd

Author	Country	Data	Variable	Method	Result	EKC
Shahbaz, Dube et al. (2015), Shahbaz, Solarin et al. (2015)	Sub-Saharan African countries	1980–2012	EG, CE, EI, GDP	VECM, Granger causality	EI ⇒ (EG,CE); EG ⇒ CE	Valid
Al-Mulali and Ozturk (2016)	27 advanced economies	1990–2012	CE, GDP, REC, NREC, TO, UR, ENP	Panel Kao and Fisher cointegration, panel VECM, Granger causality	GDP, EC, UR ⇒ CE; (REC, TO, ENP) (–) ⇒ CE.	Valid
Al-Mulali, Ozturk, and Solarin (2016)	7 selected regions	1980–2010	CE, GDP, UR,TO, FD	Pedroni and Fisher type cointegration, Granger causality	EKC is restrictively valid	Valid
Apergis (2016)	15 countries	1960–2013	CE, GDP	Time varying panel cointegration	EKC is valid for only 12 countries	Valid
Dogan and Seker (2016)	Top renewable energy countries	1985–2011	GDP, REC, NREC, TO, FD, CE	Heterogeneous panel with cross-section dependence, cointegration	REC(–) ⇒ CE; (NREC, GDP, FD) (+) ⇒ CE	Valid
Jebli, Youssef, and Ozturk (2016)	OECD countries	1980–2010	CE, GDP, REC, NREC, IM, EX	Panel Granger causality	REC ⇔ IM; REC ⇔ NREC; NREC ⇔ TRD; EX ⇒ REC; TRD ⇒ CE; GDP ⇒ REC.	Valid
Moutinho and Robaina (2016)	European countries	1991–2010	REP, CE, GDP	Cointegration and causality	EKC is mainly determined by REP between 2001 and 2010	Valid
Youssef, Hammoudeh, and Omri (2016)	Countries within income levels	1990–2012	EDEG, GDP, EG, EC, FD	Simultaneous two-equation models and causality	EG ⇔ EDEG	Valid
Ahmed (2017)	BRICS countries	1991–2013	EC, TO, EG, FD	Panel cointegration and causality	EKC is valid between (EC,FD); (EC,TO)	Valid
Ahmed, Rehman, and Ozturk (2017)	Selected South Asian countries	1971–2013	CE, EC, GDP, TO, POP	Panel cointegration	EC, TO, POP ⇒ CE; EC ⇔ TO	Valid

Charfeddine and Mrabet (2017)	19 MENA countries	1975–2007	ECF, EDEG, GDP	Granger causality, VECM	ECF ⇔ GDP	Valid
Dong, Sun, and Hochman (2017)	BRICS countries	1985–2016	CE, GDP, NGC, REC	Cointegration, AMG	CE ⇔ (NGC, REC)	Valid
Zhang et al. (2017)	China	1990–2014	EG, WPD	Granger causality, cointegration	EG ⇔ WPD	Valid
Zoundi (2017)	25 selected African countries	1980–2012	CE, GDP, RELC, POP, EC	ARDL, causality	GDP(+) ⇒ CE; in the long-run RELC(–) ⇒ CE	Not valid
Boutabba, Diaw, and Lessoua (2018)	17 sub-Saharan African countries	1995–2013	IGT, CE, GDP, CE	Panel cointegration, causality	In the long-run (GDP, IGT) ⇔ CE; in the short-run IGT ⇒ CE	Valid
Le and Quah (2018)	14 countries selected from Asia and Pacific	1984–2012	CE, EC, EG	Cointegration, Granger causality	EKC is valid only for developed countries	Not observed
Saleem, Jiandong, Zaman, Elashkar, and Shoukry (2018)	Next 11 countries	1975–2015	ED, POP, EDEG, GDP, EG	Cointegration	EDEG ⇔ GDP; ED ⇒ EG	Valid
Ulucak and Bilgili (2018)	Countries within income levels	1961–2013	GDP, ECP	Cointegration	Cointegrated relation between GDP and EFP	Valid

[a] See Notes (1, 2, 3) given in Appendix.

TABLE 10.2

A Summary of Environmental Kuznets Curve (EKC) Validation Literature (With Methods Other Than Causality Methods).[a]

Author(s)	Country	Period	Variables	Methodology	Conclusion
Grossman and Krueger (1991)	NAFTA	1972—88	Economic growth and air quality	Panel data	N-shaped EKC (for SO_2, and SPM dark matter)
Shafik and Bandyopadhyay (1992)	149 countries	1960—90	Economic growth and environmental quality	Panel data	Positive relation
Panayotou (1993)	30 developed and developing countries	1982—94	Economic development and environmental degradation	Cross-section data	Inverted U-shaped EKC
Grossman and Krueger (1995)	42 countries	1977—88	Income and environmental indicators	Regression	N-shaped EKC (for relationship with arsenic and income)
Holtz-Eakin and Selden (1995)	130 countries	1951—86	Economic growth and CO_2	Panel data	Positive relation
Roberts and Grimes (1997)	47 countries	1962—91	The economic development and CO_2	OLS	Inverted U-shaped EKC (for high income countries)
De Bruyn, Bergh, and Opschoor (1998)	Netherlands, UK, US, and Western Germany	1961—93	Economic growth and emissions	Panel data	Inverted U-shaped EKC
Kaufman et al. (1998)	23 countries	1974—89	Income and SO_2	Panel data, pooled OLS	Inverted U-shaped EKC
Suri and Chapman (1998)	33 counties	1971—91	Economic growth, trade, and pollutants	FGLS	Inverted U-shaped EKC
Torras and Boyce (1998)	19—42 countries	1977—91	Income, inequality, and pollution	Regression	Inverted U-shaped EKC
Galeotti and Lanza (1999)	110 countries	1971—96	GDP per capita and CO_2	Panel data	Inverted U-shaped EKC
Koop and Tole (1999)	76 developing countries	1961—92	GDP per capita and deforestation	Regression	Nonsignificant relationship
List and Gallet (1999)	48 US states	1929—94	Income and emission	Panel data	Inverted U-shaped EKC
Dinda, Coondoo, and Pal (2000)	33 countries	1979—82, 1983—86, 1987—90	Economic growth and air quality	OLS and LAE regressions	U-shaped EKC
Hettige, Mani, and Wheeler (2000)	13 countries	1975—94	Economic development and industrial pollution	OLS	Inverted U-shaped EKC (without water pollutant)
Panayotou, Peterson, and Sachs (2000)	17 OECD countries	1870—1994	Income and CO_2	FGLS panel data	Inverted U-shaped EKC
Dijkgraaf and Vollebergh (2001)	24 OECD countries	1960—97	GDP per capita and pollution	Panel data	Inverted U-shaped EKC

Seppala, Haukioja, and Kaivo-oja (2001)	Germany, Japan, US, Netherlands, Finland	1975–94	Economic growth and direct material flows	Regression	Nonsignificant relationship
Stern and Common (2001)	73 countries	1960–90	GDP per capita and SO_2	OLS, GLS	Inverted U-shaped EKC
Harbaugh, Levinson, and Wilson (2002)	45 countries	1971–92	National income and pollution	Regression	Inverted U-shaped EKC
Lindmark (2002)	Sweden	1870–1997	Economic growth, technology, oil price, and CO_2	Structural time series	Inverted U-shaped EKC
Halkos (2003)	73 OECD and non-OECD countries	1960–90	Economic growth and SO_2	GMM	Inverted U-shaped EKC
Bhattarai and Hammig (2004)	20 Latin American, 12 Asian, and 23 African countries	1980–95	National income and deforestation	Panel data	Inverted U-shaped EKC
Cole (2004)	18 OECD countries	1980–97	GDP and air pollutant, trade	Regression	Inverted U-shaped EKC
Martínez-Zarzoso and Bengochea-Morancho (2004)	22 OECD countries	1975–98	Income and CO_2	Panel data	N-shaped EKC
Shi (2004)	50 countries	1951–99	GNI and CO_2	Panel	Inverted U-shaped EKC
Aldy (2005)	US states	1960–99	Income and CO_2	OLS and FGLS	Inverted U-shaped EKC
Bertinelli and Strobl (2005)	122 countries	1950–90	GDP per capita, CO_2, and SO_2	Semiparametric kernel regression	U-shaped EKC
Galeotti and Lanza (2005)	108 countries	1971–95	GDP per capita and CO_2 per capita	Linear and log-linear model	N-shaped EKC
Azomahou, Laisney, and Van (2006)	100 countries	1960–96	GDP per capita and CO_2	Panel (nonparametric)	Positive relation
Culas (2007)	14 tropical developing countries from Latin America, Africa, and Asia	1972–74	Income and deforestation	Pooled regression	Inverted U-shaped EKC (only Latin America)
Kunnas and Myllyntaus (2007)	Finland	1800–2003	Economic growth and air pollution	Regression	Positive relation
Managi and Jena (2008)	India	1991–2003	Income and environmental productivity	Panel	Negative income effect
Akbostancı, Türüt-Aşık, and Tunç (2009)	Turkey	1992–2001	Income and environmental degradation	Panel	N-shaped EKC
Aslanidis and Iranzo (2009)	77 non-OECD countries	1971–97	Income and environmental degradation	Regression	Positive relation (for low-income countries)

Continued

TABLE 10.2
A Summary of Environmental Kuznets Curve (EKC) Validation Literature (With Methods Other Than Causality Methods).[a]—cont'd

Author(s)	Country	Period	Variables	Methodology	Conclusion
Lee, Chiu, and Sun (2009)	89 countries	1960—2000	Income and environmental quality	GMM	N-shaped EKC (for whole) Inverted U-shaped EKC (for middle income, American European countries)
He and Richard (2010)	Canada	1948—2004	GDP per capita and CO_2 per capita	Semiparametric and flexible nonlinear parametric model	Positive relation
Bo, Suying, Junbiao, and Haishan (2011)	China	2000—08	Agricultural output per capita and carbon intensity of agricultural land	Regression	Inverted U-shaped EKC
Gao (2011)	Hennan providence (China)	1994—2009	GDP per capita and pollution emissions	Regression	Inverted U-shaped EKC (only the industrial waste water emission)
Iwata, Okada, and Samreth (2011)	28 countries	1960—2003	GDP per capita, CO_2, and nuclear	Pooled mean group	Positive relation
Borhan and Ahmed (2012)	Malaysia	1996—2006	GDP per capita and water pollution	Simultaneous equations	EKC valid
Borhan, Ahmed, and Hitam (2012)	ASEAN-8	1965—2010	GDP per capita and CO_2	Simultaneous equations	EKC valid
Hitam and Borhan (2012)	Malaysia	1965—2010	GDP growth, FDI, and the environmental degradation	Regression	EKC valid
Apergis and Ozturk (2015)	14 Asian countries	1990—2011	GDP per capita and CO_2	GMM	Inverted U-shaped EKC
Sahli and Rejeb (2015)	21 MENA countries	1996—2013	GDP per capita and CO_2	Dynamic panel data	EKC valid
Ersin (2016)	13 developed countries	1870—2011	GDP per capita and CO_2	Dynamic panel-STAR	EKC valid
Ozokcu and Özdemir (2017)	26 OECD countries	1980—2010	Economic growth, energy, and environmental degradation	Panel data	N-shaped EKC and inverted- N-shaped EKC
Adu and Denkyirah (2018)	7 West African countries	1970—2013	Economic growth and environmental pollution	Panel data	Nonsignificant relationship

[a] See Notes (4) presented in Appendix.

significantly positive and negative parameter estimates, respectively. Empirical applications, which analyze the confirmation of EKC hypothesis in China, reveal consistent results with the inclusion of quadratic and cubic form of income. The EKC research papers, which use the quadratic form of income in estimation equation, mostly support an inverted U-shaped function of income particularly for the post-1970 period CO_2 emissions of China, including those of Jalil and Mahmud (2009), Pao and Tsai (2011), Jalil and Feridun (2011), Jayanthakumaran, Verma, and Liu (2012), Onafowora and Owoye (2014), Ertugrul et al. (2016), and Jin, Duan, Shi, and Ju (2017).

Finally, the EKC estimation equations usually consist of other explanatory variables other than income per capita. These most frequently included independent variables such as trade openness, energy consumption, renewable energy consumption and/or fossil fuel consumption, urbanization, and sectoral shares in national income. Suri and Chapman (1998) notify that the EKC relation exposes by the trade flow of manufacturing goods from industrialized to developing countries and vice versa. Energy consumption especially based on fossil fuel is mainly characterized with the primary driver of growth, besides it is argued for environmental degradation. On the contrary, the receovery in environmental quality stems from renewable energy consumption.[1] Therefore, the associated causality between energy consumption, economic growth, and environmental support researches to comprehend the structural changes in the economy, namely the inflection of inverse U-shaped curve. Furthermore, one of the most important reasons behind the presence of the urbanization or any other social indicators in EKC equation is their power to indicate the structural shifts of developing countries.

METHODOLOGY

The fundamental spectral decomposition techniques of both financial and economic time series are Fourier and wavelet transformations. The Fourier transform, one of the spectral decomposition techniques, is a transformation technique that allows the analysis of the content of a signal in the time domain. In Fourier transform, a function in the time domain is transformed into a function in the frequency domain. Then the Fourier coefficients of the function are analyzed for each frequency (Graps, 1995). Basically, sinusoidal waves for the Fourier series are chosen as the main function. The properties of the emerging dilatation are examined in Burrus, Gopinath, and Guo (1998). The mathematical expression of the Fourier transform is explained by the following equations:

In a function f (£) with period T (Illing, 2008):

$$f(\pounds + T) = f(\pounds) \tag{10.1}$$

To make the function $2pi$ periodic, we can redefine the value of £. A new independent variable, then, is defined as, $t = \frac{2pi}{T}\pounds$, as a result:

$$f(t + 2pi) = f(t) \tag{10.2}$$

Since the function is periodic, we only need to consider behavior in a range of length $2pi$, for example on the interval $(-pi, \ pi)$. After Joseph Fourier (1768–1830), the series of Fourier has been transformed into Eq. (10.3), taking into account the infinite sum of sine and cosine functions.

$$f(x) = \frac{a_0}{2} + \sum_{m=1}^{\infty}[a_m \cos(mt) + b_m \sin(mt)] \tag{10.3}$$

In Eq. (10.4), constant coefficients of a_m and b_m are called Fourier coefficients. Estimation with integers using the orthogonality properties of a_m and b_m coefficients of Eq. (10.3) are presented in Eqs. (10.4) and (10.5).

$$a_m = \frac{1}{pi}\int_{-pi}^{pi} f(t)\cos(mt)dx \tag{10.4}$$

$$b_m = \frac{1}{pi}\int_{-pi}^{pi} f(t)\sin(mt)\,dx \tag{10.5}$$

As it can be seen from the equations above, the Fourier series is a linear component of sinuses and cosines. Each of these sinuses and cosines is a function of frequency. Therefore, the Fourier transform can be considered a separation on the basis of frequency by frequency (Gençay, Selçuk, & Whitcher, 2002).

On the other hand, Fourier analysis can localize signal in frequency domain successfully as it cannot use signal in time domain. It gives the knowledge of the whole time span and does not reveal the time-point information at a particular point. Fourier transformation is, therefore, a successful approach to the analysis of time-invariant signals. That is, the Fourier basic function (sinuses and cosines) is more suitable when working with stationary time series. However, restricting ourselves to stationary time series is not

---

[1] Ozturk (2010), Omri (2014) and Tiba and Omri (2017) provide detailed literature reviews for the studies that investigate the relationship between economic growth, energy consumption and environmental degradation.

very appealing because most economic/financial time series exhibit highly complex patterns (e.g., complex trends, sudden changes, and volatility clustering). Conventional signal analysis tools, such as Fourier analysis, miss these frequency components. For this reason, in a nonstationary time series, Fourier transformation cannot effectively detect complex events (Gençay et al., 2002). For example, the Fourier transformation is not suitable for the nonstationary series, and the transformation is insufficient because it gives the whole time-domain knowledge, not the information of the specific time unit. Because of this deficiency, the wavelet transform is used for complex events through scale-based analyses.

Wavelet transformation is a more recent and more complicated methodology compared with Fourier transformation. It has similar mathematical representation with Fourier transform; however, it comes up with a new property, called scaling. Wavelet has the advantage of localizing signals both in time and frequency domain simultaneously. The wavelet transform, as the best technique for the nonstationary time series, is filtered into different frequency bands, which are divided into segments in the time domain (Zhao, Jiang, Diao, & Qian, 2004). The wavelet function (or mother wavelet function) can be expressed as a linear combination of the scaling function. Nonetheless, with condition $\omega \in \mathbb{R}$ and $\underset{\cdot}{\mathrm{m}} \in \mathbb{R}^{+}$, every scaled and translated wavelet function $\beta_{(m,\omega)}(t)$ can be written in terms of the mother wavelet:

$$\beta_{(\underset{\cdot}{\mathrm{m}},\omega)}(t) = \frac{1}{\sqrt{|\underset{\cdot}{\mathrm{m}}|}}\beta\left(\frac{t-\omega}{\underset{\cdot}{\mathrm{m}}}\right) \tag{10.6}$$

where the term $1\Big/\sqrt{|\underset{\cdot}{\mathrm{m}}|}$ denotes normalization, factor ensuring unit variance of wavelet. The mother wavelet $\beta(.)$ contains two control parameters $\underset{\cdot}{\mathrm{m}}$ (scaled) and ω (located). The parameter $\underset{\cdot}{\mathrm{m}}$ controls the width of the wavelet and indicates the position of the wavelet. Parameter ω is the translation or location parameter that controls the location of wavelet and represents the position of the wavelet in the time domain. When evaluated in terms of frequency, rapidly changing details capture at lower scales, namely high frequencies, while slower details capture higher scales, namely low frequencies. In other words, an increasing $\underset{\cdot}{\mathrm{m}}$ (scaling) capture low frequency (long-run) properties of time series; however, a descending $\underset{\cdot}{\mathrm{m}}$ compresses it to measure high-frequency (short-run) properties. This situation indicates a negative relationship between the frequency and the scale.

The continuous wavelet transform (CWT) is obtained by projection a specific wavelet $\beta(.)$ onto the examined time series $\ddot{\mathrm{X}}(t) \in L^2(\mathbb{R})$ in regard to wavelet $\beta_{(\underset{\cdot}{\mathrm{m}},\omega)}(t)$ is written as:

$$W_{\ddot{\mathrm{X}}}(\underset{\cdot}{\mathrm{m}},\omega) = \int_{-\infty}^{\infty} ¥(t)\frac{1}{\sqrt{|\underset{\cdot}{\mathrm{m}}|}}\beta^{*}\left(\frac{t-\omega}{\underset{\cdot}{\mathrm{m}}}\right)dt \tag{10.7}$$

where $W_{\ddot{\mathrm{X}}}(\underset{\cdot}{\mathrm{m}},\omega)$ represents CWT and * denotes complex conjugation. Because of a function to be accepted as CWT, it must carry out the following conditions (Conraria and Soares, 2014);

- The integral of $\beta(.)$ is zero,

$$\int\limits_{-\infty}^{\infty} \beta(t)dt = 0, \tag{10.8}$$

- It is square of $\beta(.)$ integrates to unity,

$$\int_{-\infty}^{\infty} |\beta(t)|^2 dt = 1, \quad \text{and,} \tag{10.9}$$

- Admissibility condition as is given in Eq. (10.10).

$$¥_{\partial} = \int_{0}^{\infty} \frac{|\theta(\mathcal{N})|^2}{\mathcal{N}} d\mathcal{N} < \infty, \tag{10.10}$$

Wavelets defined as a small wave generally do not have the same properties. In this respect, wavelets are divided into different groups according to their particular features. These types of wavelets include Haar, Daubechies, Symlets, Coiflets, Biorthogonal, Gauss, Mexican Hat, Morlet, Meyer, Shannon, etc. The Morlet wavelet transform has both imaginary and real parts, thereby it allows to analysis both phase and amplitude. The Morlet wavelet, a sine wave damped by a Gaussian envelope, is expressed as:

$$\lambda_{\varphi}(t) = pi^{-1/4}\left(e^{i\varphi t} - \mathrm{e}^{-\varphi^2/2}\right)e^{-t^2/2}, \tag{10.11}$$

where parameter φ denotes the central frequency parameter of Morlet wavelet $\lambda_{\varphi}(t)$. Moreover, $e^{i\varphi t}$ is the complex exponential function, and it is normalized by $pi^{-1/4}$ that provides a function with unit energy (Addison, 2002). $e^{-\varphi^2/2}$ is the correction term, which corrects the nonzero mean of the complex sinusoid, and it is negligible if $\varphi > 5$. This yields a simplified version of Morlet wavelet function written as:

$$\lambda_{\varphi}(t) = pi^{-1/4}e^{i\varphi t}e^{-t/2} \tag{10.12}$$

The value 6 for φ ensures the admissibility condition, where λ is the Fourier period (Farge, 1992). The admissibility condition of wavelets, introduced in Eq. (10.10), is important comes from in fact it ensures that it is possible to recover $\ddot{x}(t)$ from its wavelet transform. When $\emptyset$ is analytic and $\ddot{x}(t)$ real a reconstruction equation formula written as is in Morlet and Grossman (1984),

$$\ddot{x}(t) = (¥_{\emptyset})^{-1} \int_0^{\infty} \left[\int_{-\infty}^{\infty} W_{\ddot{x}}(\underset{.}{m}, \omega) \phi_{(\underset{.}{m},\omega)}(t) d\omega \right] \frac{d\underset{.}{m}}{\underset{.}{m}^2} \tag{10.13}$$

In addition to CWT, preserves the energy or variance of preservation of the examined time series;

$$\|\ddot{x}\|^2 = (¥_{\emptyset})^{-1} \int_0^{\infty} \left[\int_{-\infty}^{\infty} \left| W_{\ddot{x}}(\underset{.}{m}, \omega) \right|^2 d\omega \right] \frac{d\underset{.}{m}}{\underset{.}{m}^2} \tag{10.14}$$

where, the wavelet power spectrum $\left| W_{\ddot{x}}(\underset{.}{m}, \omega) \right|^2$, which shows the distribution energy of $\ddot{X}(t)$ of time series in both frequency and time domain, is shown. In addition, this feature is used to define the wavelet correlation, wavelet variance, and wavelet covariance. The cross-wavelet power[2] of two time series, $W_{xy}(\underset{.}{m}, \omega)$ can be defined as the local covariance between these time series at each scale (frequency band) and each time. The cross-wavelet power of two time series $x(t)$ and $y(t)$ was first presented by Hudgins, Friehe, and Mayer (1993) as below:

$$W_{xy}(\underset{.}{m}, \omega) = W_x(\underset{.}{m}, \omega) \overline{W_y(\underset{.}{m}, \omega)} \tag{10.15}$$

where $W_x(\underset{.}{m}, \omega)$ and $W_y(\underset{.}{m}, \omega)$ are CWT of time series $x(t)$ and $y(t)$ as $W_{xy}(\underset{.}{m}, \omega)$ is the cross-wavelet power. In addition, $\underset{.}{m}$ is scale and ω is location parameter as they appear in CWT formula in Eq. (10.7). After, that is, two time series, the cross-wavelet transforms represent the local covariance between the time series at each scale (Vacha & Barunik, 2012). According to Aguiar-Conraria, Magalhães, and Soares (2013), the wavelet coherency of two time series, $W_x(\underset{.}{m}, \omega)$ and $W_y(\underset{.}{m}, \omega)$can be defined as follows:

$$R_{xy}(\underset{.}{m}, \omega) = \frac{\left| \mathcal{S}\left(W_{xy}(\underset{.}{m}, \omega) \right) \right|}{\left| \mathcal{S}\left(\left| W_{xx}(\underset{.}{m}, \omega) \right| \right) \right|^{1/2} \left| \mathcal{S}\left(\left| W_{yy}(\underset{.}{m}, \omega) \right| \right) \right|^{1/2}} \tag{10.16}$$

where R_{xy} represents the correlation, parameter ranging from one (strong consistency) to zero coherency (no coherency) in both time and frequency domain. In addition, $\mathcal{S}$ refers to the required smoothing parameter. Otherwise, coherency will always be strong consistency (one). The phase difference analysis detects phase relationships between components, for instance, the correlation direction (positive and negative correlation), and lead or lag relation. The phase difference (with $\xi_{x,y} \in [-pi, pi]$) between time series $x(t)$ and $y(t)$ can be depicted as:

$$\xi_{x,y}(\underset{.}{m}, \omega) = \frac{1}{\tan} \left(\frac{\Im\left(W_{xy}(\underset{.}{m}, \omega) \right)}{\Re\left(W_{xy}(\underset{.}{m}, \omega) \right)} \right) \tag{10.17}$$

In Eq. (10.17), $\Im(W_{xy})$ and $\Re(W_{xy})$ are referred to imaginary and real parts, respectively. If $\xi_{xy} \in \left(0, \frac{pi}{2}\right)$, the series move in phase and $x(t)$ leads $y(t)$; If $\xi_{xy} \in \left(0, -\frac{pi}{2}\right)$, the series move again in phase, then, $y(t)$ is leading. If $\xi_{x,y} \in \left(\frac{pi}{2}, pi\right)$, there is antiphase relation, in this case, the series move again out of phase where $y(t)$ is leading. Antiphase relation exists, when phase difference is pi or $-pi$. If $\xi_{x,y} \in \left(-pi, -\frac{pi}{2}\right)$, then, the series follow antiphase relation as $x(t)$ is leading. Finally, a phase difference of zero indicates that $y(t)$ and $x(t)$ move together.

DATA AND WAVELET ESTIMATION OUTPUT

This work considers mainly the inspecting the comovements between GDI and CO_2 (million metric tons of CO_2) in a wavelet model for the United States for the quarterly period from 1980:1 to 2018:2.

The wavelet model in this work first monitors the influence of GDI on CO_2, later, uses as well control variables to be able to capture cleaner output. The control variables are total fossil fuels consumption (fossil, quadrillion Btu), nuclear electric power consumption (nuclear, quadrillion Btu), and total renewable energy consumption (renewables, quadrillion Btu), respectively, for the United States for the same period.

The CO_2, fossil, nuclear, and renewables have been extracted from US Energy Information Administration Monthly Energy Review (EIA, 2018), and the GDI data have been obtained from Fred data through ESTIMA-RATS 9.1 (Federal Reserve Bank of St. Louis, 2018 August). All estimations have been launched by MATLAB 15 program lines.

Fig. 10.1 depicts the US GDI for the period 1980:1–2018:2, and Fig. 10.2 exhibits the US CO_2 emissions (million metric tons) for the period 1980:1–2018:2. Fig. 10.1 explores that GDI of United States tends to increase from the first quarter of 1980 and the second quarter of 2018. Through polynomial trend

---

[2] When $x = y$, we obtain the wavelet power spectrum.

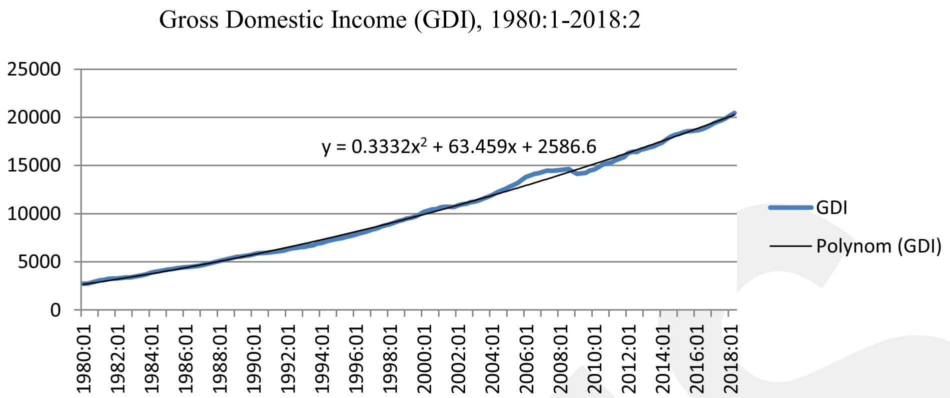

FIG. 10.1 The US gross domestic income.

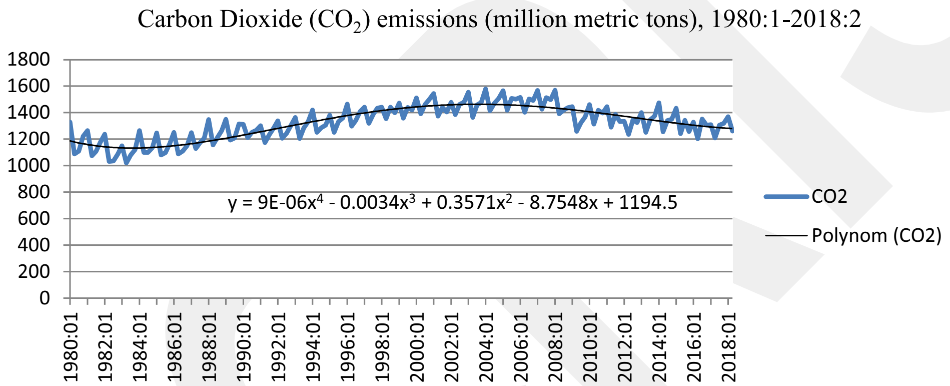

FIG. 10.2 CO_2 emissions.

estimation, one may state that GDI increases by $[63.459 + 0.3332(2x + 1)]$. CO_2 emissions firsts decline until 1984, later increases till 2016, and afterward tends to reduce. The estimated polynomial regression of CO_2 is $y = 9E{-}06x^4 - 0.0034x^3 + 0.3571x^2 - 8.7548x + 1194.5$.

Figs. 10.3—10.5 denote the trends of the fossil fuel consumption (quadrillion Btu), nuclear electric power consumption (quadrillion Btu), and, renewable energy consumption (quadrillion Btu), respectively, in the United States for the period 1980:1—2018:2.

The fossil fuel consumption, nuclear electric power consumption, and renewable energy consumption follow the fourth degree polynomial, third degree of polynomial, and fourth degree of polynomial, respectively. Fossil fuel consumption tends to increase until 2006 and afterward diminishes. Consumption of renewables tends to enlarge at increasing rate, as nuclear electric consumption expands at decreasing rate from March of 1980 to June of 2018.

Estimating the continuous wavelet models, this section reveals the movements between the US GDI and US CO_2 emissions through time series and frequency analyses. Throughout wavelet estimations, one might inspect the trends of CO_2 as GDI increases at different time periods and frequencies.

Figs. 10.6A, 10.7A, and 10.8A show the outputs of wavelet coherency analyses. Figs. 10.6B and C, 10.7B and C, and, 10.8B and C explore the phase differences, which exhibit the radians between two waves at the same frequency and same time point.

All wavelet analyses in this work aim at observing what happens to level of CO_2 as GDI increases at different time periods and different time frequencies.

In wavelet estimations, the black curve (contour) exhibits 5% significance level of the estimation through an ARMA (p, q) model. AR (p) and MA (q) terms of the ARMA model depict the autoregressive terms and moving average (lagged forecast errors) terms, respectively. Our estimations used ARMA (1, 1) and ARMA

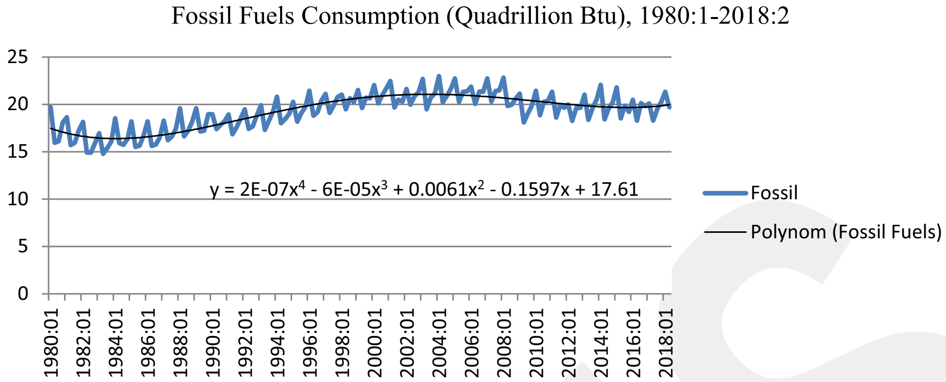

FIG. 10.3 Fossil fuel consumption.

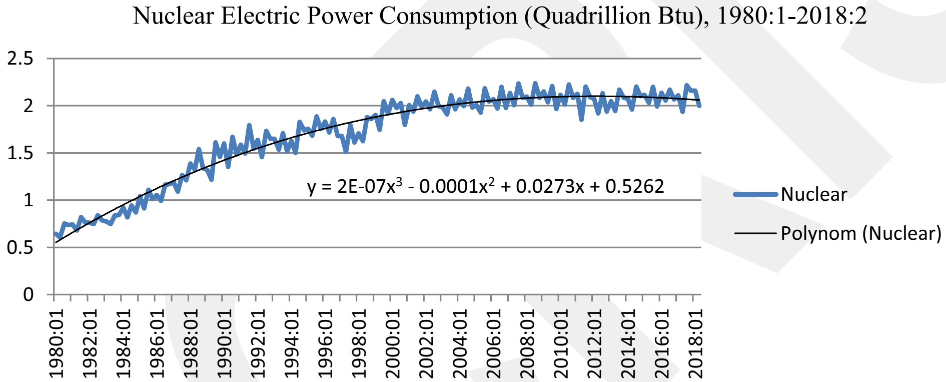

FIG. 10.4 Nuclear electric consumption.

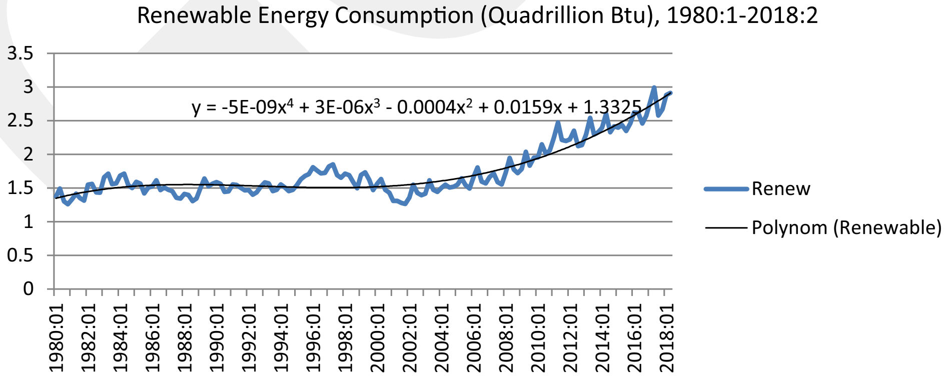

FIG. 10.5 Renewable energy consumption.

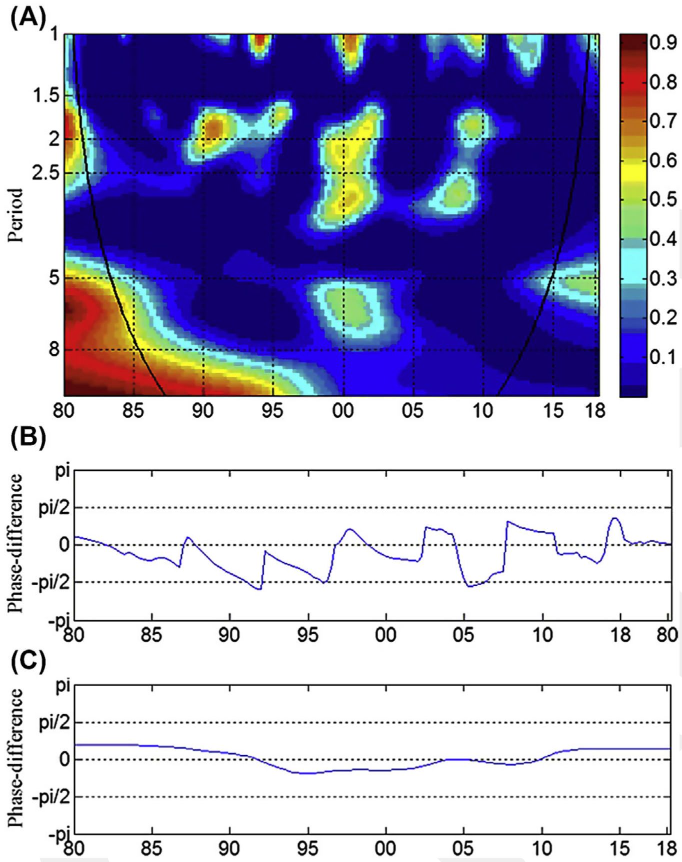

FIG. 10.6 **(A)** Wavelet coherence (GDI-CO_2), 1980:1–2018:2. **(B)** 1–3 frequency band, 1980:1–2018:2. **(C)** 3–8 frequency band, 1980:1–2018:2.

(2, 1) models. The colors to the right of the figures represent the degree of coherency between the variables. It ranges from weak coherency (blue) to strong coherency (red) between the variables. The color code, therefore, explores as well the possible weakest coherence (dark blue) and strongest coherence (dark red). The power of correlation ranging from 0.05 to 0.95 might be considered energy of association. The dark red and dark blue, thereby, correspond to high energy of association and low energy of association between the variables, respectively.

Fig. 10.6A reveals the wavelet coherency between (GDI-CO_2) for the period 1980:1–2018:2. Fig. 10.6A and its phase difference (Fig. 10.6B) reveal little evidence of significant effect of GDI on CO_2 during the first half of the 1990s at 1–3 year frequency band. Figs. 10.6A and C denote that there exists significant association between GDI and CO_2 emissions in 8-year cycle during the second half of the 1980s and the first half of the 1990s and that GDI enhances CO_2 emissions during the same frequency and time points.

When relevant control variables have been added to wavelet estimations, the coherency analyses have become clearer. Figs. 10.7A and 10.8A observe the movements of relevant pairs of variables by considering the relevant control variables of fossil fuels consumption (Fig. 10.7A) and total energy consumption (Fig. 10.8A). Total energy consumption variable includes the consumptions of fossil fuels, nuclear, and renewables.

Fig. 10.7A indicates that (a) GDI and CO_2 have strong energy association during the first half of the 1990s and 2010s in 1-year cycle (frequency); (b) GDI and CO_2 are slightly associated between years 2003 and 2005 in 1-year cycle; and (c) GDI and CO_2 appear to have strong coherency during the first half of the 1980s, the second half of the 1990s, and, for the period 2012–16 at 3-year frequency.

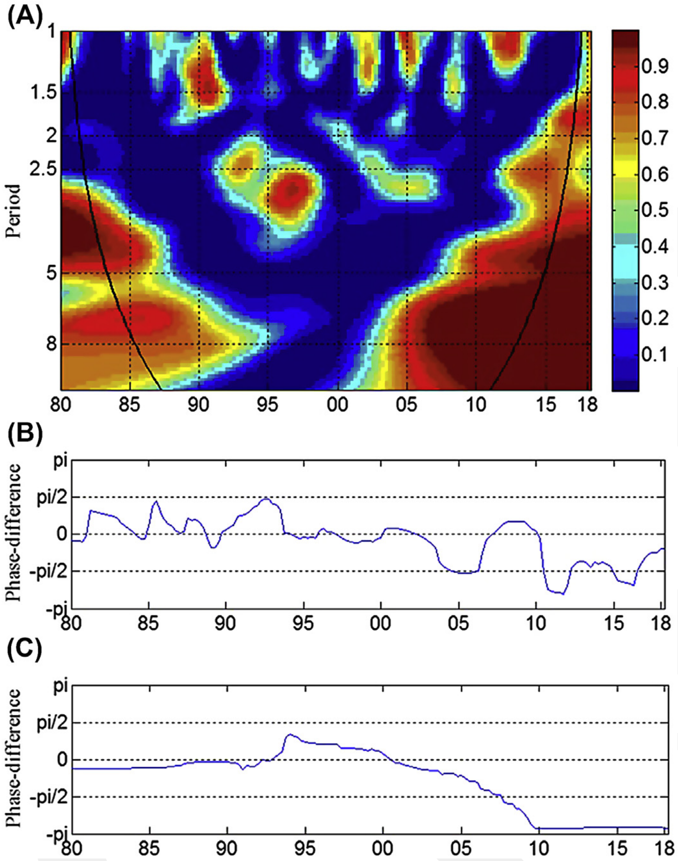

FIG. 10.7 **(A)** Wavelet coherence (GDI-CO_2 || fossil), 1980:1–2018:2. **(B)** 1–3 frequency band, 1980:1–2018:2. **(C)** 3–8 frequency band, 1980:1–2018:2.

The phase difference (Fig. 10.7B) demonstrates that, as GDI increases, the CO_2 increases during the period 1990–94, later, diminishes in 2011–12, and in 2015–16.

As for longer time period (3–8 year frequency), GDI and CO_2 variables present strong coherencies during 1982–90 and 2004–16 (Fig. 10.7C). CO_2 leads GDI during the periods 1982–90 and 2004–07, while GDI causes CO_2 to reduce for the period 2008–16 (Fig. 10.7C).

In Fig. 10.8A, again the wavelet analyses are conducted for the variables of GDI and CO_2 by adding the control variables of fossil, nuclear, and renewable energy consumptions. Considering 1–3 frequency band, strong correlations between GDI and CO_2 are shown in the years 1982–85, 1987–90, 2005, and, 2011–13. The correlation emerges slightly strong during 1998–2000.

Fig. 10.8B yields the evidence that GDI leads CO_2 to increase in 1982–85 and to diminish in 2015. On the other hand, CO_2 is leading positively the GDI variable during periods 1987–90 and 2011–13.

Monitoring 3–8 frequency band in Fig. 10.8A, one might state that GDI and CO_2 follow strong coherencies in time periods of 1982–86 and 2006–16. Fig. 10.8C displays the output that, as GDI increases, CO_2 increases for the period 1982–86 and 2004–06, and shrinks for the period 2011–16.

Following continuous partial wavelet coherency analyses presented in Figs. 10.7A and 10.8A and associated phase difference pictures, we might argue that as GDI of the United States improves initially in the beginning of sample period (second half of 1980 and first half of the 1990s), CO_2 emissions tend to advance, and CO_2 emissions tend to reduce during the quarters of 2008–16.

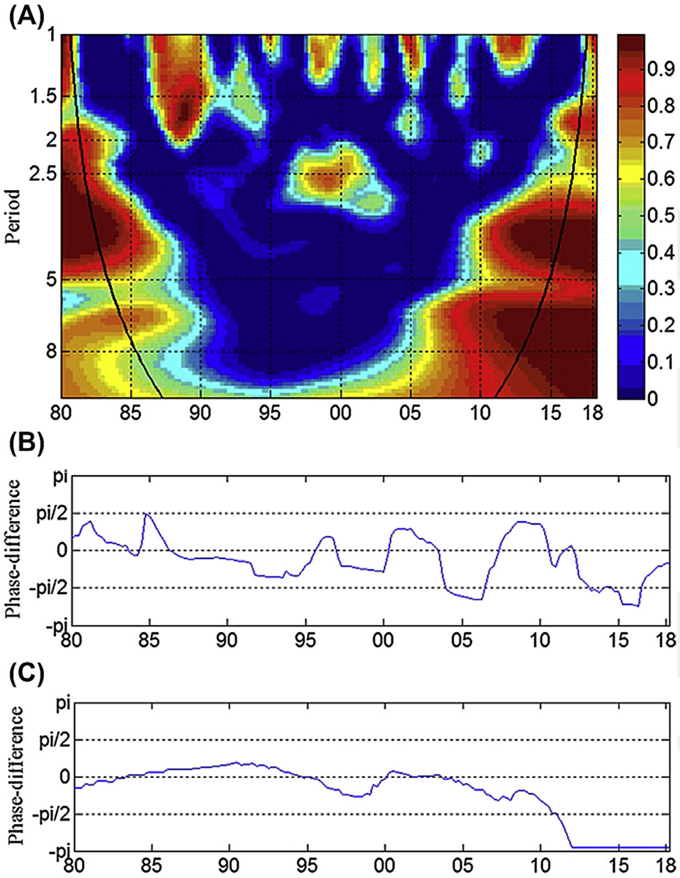

FIG. 10.8 **(A)** Wavelet coherence (GDI-CO_2 || fossil, nuclear, renewable), 1980:1–2018:2. **(B)** 1–3 frequency band, 1980:1–2018:2. **(C)** 3–8 frequency band, 1980:1–2018:2.

CONCLUSION AND POLICY PROPOSALS

The contributions of existing seminal works to the literature of EKC hypotheses are significant. However, time series and panel data estimations of EKC in general follow the same estimated parameters within whole sample period. Although some prominent works consider the structural breaks in cross-section dependence tests of panel data, they reveal eventually constant estimates in observing the effect of GDP (GDI) on environmental degradation for the whole predicted time period. Few articles aim at detecting the relevant estimates of coefficients with one or two structural breaks in a dynamic structure. The dynamic structure of an EKC model can be evaluated through either the effects of leads and lags of independent variable (GDI) on dependent variable (environmental degradation or CO_2 emissions), or, through possible changes in estimated parameters in one or more potential structural breaks. Furthermore, dynamic structure of an EKC model can be examined through all possible shifts in estimated values at all possible different time periods and at all relevant time frequencies. Such analyses, thereby, observe numerous structural breaks within different time cycles (frequencies) and, hence, might result in more efficient, consistent, and unbiased estimators.

This work first reviews intensively the relevant literature evidence to exhibit the EKC estimations' results through time series and panel data estimations.

The work later, underlining the mathematical advantages of wavelet transformation against Fourier transformation, follows continuous wavelet and partial continuous wavelet coherency analyses.

Fourier analysis can localize signal in frequency domain successfully as it cannot use signal in time domain. Wavelet, on the other hand, has the advantage of localizing signals both in time and frequency domain simultaneously.

All wavelet analyses here aim at observing what happens to level of CO_2 emissions as GDI increases at different time periods and at different time frequencies in the United States from the first quarter of 1980 to the second quarter of 2018.

In conclusion, following the quarterly time period 1980:1–2018:2, this book reveals that, as GDI of the United States increases, initially in the beginning of sample period (second half of 1980 and first half of 1990s), CO_2 emissions tend to increase, and, CO_2 emissions tend to decline during the quarters of 2008–16.

This output confirms the EKC hypothesis indicating that the level of environmental deterioration gets worse and later becomes better in the United States, as domestic income of the United States goes up.

Increase in income of representative countries might improve the societies' awareness of environmental deterioration within regions/countries. This statement might be confirmed due to new technologic innovations, more efficient usage of natural resources through environmental awareness, improved market mechanism, and, throughout considerations of optimal intertemporal choices of consumption preferences.

The policy-makers and researchers might inspect the role of components of total energy consumption on environmental quality. For instance, in recent literature, some works underline the positive effects of renewables on environmental improvements as depicted in Ulucak and Bilgili (2018), Bilgili, Koçak, Bulut, and Kuloğlu (2017), Bilgili, Koçak, Bulut, and Kuşkaya (2017), Bilgili, Koçak et al. (2016), and Bilgili, Öztürk et al. (2016). They explore the significant positive impact of renewables on quality level of environment in terms of CO_2 emissions. They recommend that renewables, such as consumption of wood and agricultural products, solid waste, landfill gas and biogas, ethanol, and biodiesel should be stimulated to reduce the environmental degradation. By following these works and other seminal researches, this work might suggest that the US policy-makers continue to follow existing and potential future US energy policies.

Indeed, the US energy policies, since the 1970s, have been following the goals of (1) conservation and energy efficiency, (2) efficient domestic supply of fossil fuels, and (3) efficient production/consumption of electricity and electricity from renewables (Ballotpedia, 2018a). The United States launched Environmental Protection Agency (EPA) in 1971, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1980, Kyoto Protocol in 1997, and, American Recovery and Reinvestment Act (2009) as explained in Ballotpedia (2018b).

On the one hand, the United States has been implementing energy policies to protect environment since the 1970s; on the other hand, the US population has been increasing its demand for goods and commodities since then. This might, in turn, cause the United States to have increasing ecologic deficit, which is the difference between biocapacity and ecologic footprints.

However, according to wavelet analyses of this work, the United States has succeeded to improve her environmental quality after the second half of 2000s and during 2010s due to past and current energy policies of the United States.

Among available policies, the Energy Policy Acts of the United States might have relatively more considerable positive impacts on environment among other energy policies/acts. Hence, this book eventually recommends that policy-makers consider following and updating 1992 Energy Policy Act (EPACT) and 2005 EPACT to lower the CO_2 emissions to reach sustainable intertemporal and intergenerational development.

APPENDIX

Notes (1): Causality Signs: ⇔ (bidirectional causality); ⇒ (uni-directional causality from left to the right); ∼ (mixed results) and//(lack of causality).

Notes (2): Abbreviations for variables: AEC (alternative energy consumption); BEC (biomass consumption); CE (CO_2 emissions); CTAX (carbon tax); EC (energy consumption); ECD (disaggregated energy consumption); ECF (ecological carbon footprint); ED (energy demand); EDEG (environmental degradation); EG (economic growth); EI (energy intensity); ELC (electricity consumption); ENP (energy price); EX (exports); FD (financial development); FDI (foreign direct investment); FFC (fossil fuel consumption); FIXC (fixed capital stock); GLB (globalization level); HEC (hydropower consumption); IGT (intermediate goods trade); IM (imports); IND (industrialization level); INV (investment expenditures); M1 (money supply); NE (nuclear energy); NGC (natural gas consumption); NREC (non-renewable energy consumption); NREP (non-renewable electricity production); PC (petroleum consumption); POP (population density); REC (renewable energy consumption); RELC (renewable energy consumption); REP (renewable electricity production); RLL (ratio of liquid liabilities to national income); TO (trade openness); TOD (tourism development); TRD (international trade), TRL (trade liberalization); TVA (transport sector value added); UR (urbanization); WPD (water pollution discharge).

Notes (3): Methods: IAAA (innovative accounting approach); AMG (causality and augmented mean group estimator); ARDL (Auto autoregressive distributed lag model); VECM (Vector Error Correction Method).

Notes (4): Estimation methods: OLS (ordinary least squares); FGLS (feasible generalized least squares; LAE (least absolute deviations); GMM (generalized method of moments); STAR (structural threshold regression or auto-regression), GLS (generalized least squares).

REFERENCES

Abdallah, K. B., Belloumi, M., & Wolf, D. D. (2013). Indicators for sustainable energy development: A multivariate cointegration and causality analysis from Tunisian road transport sector. *Renewable and Sustainable Energy Reviews*, *25*, 34–43. https://doi.org/10.1016/j.rser.2013.03.066.

Abid, M. (2015). The close relationship between informal economic growth and carbon emissions in Tunisia since 1980: The (ir) relevance of structural breaks. *Sustainable Cities and Society*, *15*, 11–21. https://doi.org/10.1016/j.scs.2014.11.001.

Acaravci, A., & Akalin, G. (2017). *Environment–economic growth nexus: A comparative analysis of developed and developing countries# 7*.

Addison, P. S. (2002). The ıllustrated wavelet transform handbook: Introductory theory and application in science. In *Engineering, medicine and finance* (1st ed.). Taylor&Francis Group, CRS Press.

Adu, D. T., & Denkyirah, E. K. (2018). Economic growth and environmental pollution in West Africa: Testing the environmental Kuznets curve hypothesis. *Kasetsart Journal of Social Sciences*. https://doi.org/10.1016/j.kjss.2017.12.008.

Aguiar-Conraria, L., Magalhães, P. C., & Soares, M. J. (2013). The nationalization of electoral cycles in the United States: A wavelet analysis. *Public Choice*, *156*(3–4), 387–408. https://doi.org/10.1007/s11127-012-0052-8.

Aguiar-Conraria, L., & Soares, M. J. (2014). The continuous wavelet transform: Moving beyond uni- and bivariate analysis. *Journal of Economic Surveys*, *28*(2), 344–375. https://doi.org/10.1111/joes.12012.

Ahmad, N., Du, L., Lu, J., Wang, J., Li, H. Z., & Hashmi, M. Z. (2017). Modelling the CO_2 emissions and economic growth in Croatia: Is there any environmental Kuznets curve? *Energy*, *123*, 164–172.

Ahmad, A., Zhao, Y., Shahbaz, M., Bano, S., Zhang, Z., Wang, S., et al. (2016). Carbon emissions, energy consumption and economic growth: An aggregate and disaggregate analysis of the Indian economy. *Energy Policy*, *96*, 131–143. https://doi.org/10.1016/j.enpol.2016.05.032.

Ahmed, K. (2017). Revisiting the role of financial development for energy-growth-trade nexus in BRICS economies. *Energy*, *128*, 487–495. https://doi.org/10.1016/j.energy.2017.04.055.

Ahmed, K., & Long, W. (2012). Environmental Kuznets curve and Pakistan: An empirical analysis. *Procedia Economics and Finance*, *1*, 4–13.

Ahmed, K., Rehman, M. U., & Ozturk, I. (2017). What drives carbon dioxide emissions in the long-run? Evidence from selected South Asian countries. *Renewable and Sustainable Energy Reviews*, *70*, 1142–1153. https://doi.org/10.1016/j.rser.2016.12.018.

Ahmed, K., Shahbaz, M., Qasim, A., & Long, W. (2015). The linkages between deforestation, energy and growth for environmental degradation in Pakistan. *Ecological Indicators*, *49*, 95–103. https://doi.org/10.1016/j.ecolind.2014.09.040.

Ajmi, A. N., Hammoudeh, S., Nguyen, D. K., & Sato, J. R. (2015). On the relationships between CO_2 emissions, energy consumption and income: The importance of time variation. *Energy Economics*, *49*, 629–638. https://doi.org/10.1016/j.eneco.2015.02.007.

Akbostancı, E., Türüt-Aşık, S., & Tunç, G. I. (2009). The relationship between income and environment in Turkey: Is there an environmental Kuznets curve? *Energy Policy*, *37*(3), 861–867. https://doi.org/10.1016/j.enpol.2008.09.088.

Al-Mulali, U., & Ozturk, I. (2016). The investigation of environmental Kuznets curve hypothesis in the advanced economies: The role of energy prices. *Renewable and Sustainable Energy Reviews*, *54*, 1622–1631. https://doi.org/10.1016/j.rser.2015.10.131.

Al-Mulali, U., Ozturk, I., & Solarin, S. A. (2016). Investigating the environmental Kuznets curve hypothesis in seven regions: The role of renewable energy. *Ecological Indicators*, *67*, 267–282. https://doi.org/10.1016/j.ecolind.2016.02.059.

Al-mulali, U., Weng-Wai, C., Sheau-Ting, L., & Mohammed, A. H. (2015). Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. *Ecological Indicators*, *48*, 315–323. https://doi.org/10.1016/j.ecolind.2014.08.029.

Aldy, J. E. (2005). An environmental Kuznets curve analysis of U.S. State-level carbon dioxide emissions. *The Journal of Environment & Development*, *14*(1), 48–72. https://doi.org/10.1177/1070496504273514.

Ali, W., Abdullah, A., & Azam, M. (2017). Re-visiting the environmental Kuznets curve hypothesis for Malaysia: Fresh evidence from ARDL bounds testing approach. *Renewable and Sustainable Energy Reviews*, *77*, 990–1000. https://doi.org/10.1016/j.rser.2016.11.236.

Apergis, N. (2016). Environmental Kuznets curves: New evidence on both panel and country-level CO_2 emissions. *Energy Economics*, *54*, 263–271. https://doi.org/10.1016/j.eneco.2015.12.007.

Apergis, N., & Ozturk, I. (2015). Testing environmental Kuznets curve hypothesis in Asian countries. *Ecological Indicators*, *52*, 16–22. https://doi.org/10.1016/j.ecolind.2014.11.026.

Arouri, M. E., Youssef, A. B., Mhenni, H., & Rault, C. (2012). Energy consumption, economic growth and CO_2 emissions in Middle East and North African countries. *Energy Policy*, *45*, 342–349. https://doi.org/10.1016/j.enpol.2012.02.042.

Aslanidis, N., & Iranzo, S. (2009). Environment and development: Is there a Kuznets curve for CO_2 emissions? *Applied Economics, 41*(6), 803–810. https://doi.org/10.1080/00036840601018994.

Azomahou, T., Laisney, F., & Van, P. N. (2006). Economic development and CO_2 emissions: A nonparametric panel approach. *Journal of Public Economics, 90*(6–7), 1347–1363. https://doi.org/10.1016/j.jpubeco.2005.09.005.

Baek, J. (2015). A panel cointegration analysis of CO_2 emissions, nuclear energy and income in major nuclear generating countries. *Applied Energy, 145*, 133–138. https://doi.org/10.1016/j.apenergy.2015.01.074.

Ballotpedia. (2018a). *Energy policy in the United States*. https://ballotpedia.org/Energy_policy_in_the_United_States.

Ballotpedia. (2018b). *Environmental policy in the United States*. https://ballotpedia.org/Environmental_policy_in_the_United_States.

Bello, M. O., Solarin, S. A., & Yen, Y. Y. (2018). The impact of electricity consumption on CO_2 emission, carbon footprint, water footprint and ecological footprint: The role of hydropower in an emerging economy. *Journal of Environmental Management, 219*, 218–230. https://doi.org/10.1016/j.jenvman.2018.04.101.

Bento, J. P., & Moutinho, V. (2016). CO_2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. *Renewable and Sustainable Energy Reviews, 55*, 142–155. https://doi.org/10.1016/j.rser.2015.10.151.

Bertinelli, L., & Strobl, E. (2005). The environmental Kuznets curve semi-parametrically revisited. *Economics Letters, 88*(3), 350–357. https://doi.org/10.1016/j.econlet.2005.03.004.

Bhattarai, M., & Hammig, M. (2004). Governance, economic policy, and the environmental Kuznets curve for natural tropical forests. *Environment and Development Economics, 9*(3), 367–382. https://doi.org/10.1017/s1355770x03001293.

Bilgili, F., Koçak, E., & Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO_2 emissions: A revisited environmental Kuznets curve approach. *Renewable and Sustainable Energy Reviews, 54*, 838–845. https://doi.org/10.1016/j.rser.2015.10.080.

Bilgili, F., Koçak, E., Bulut, Ü., & Kuloğlu, A. (2017). The impact of urbanization on energy intensity: Panel data evidence considering cross-sectional dependence and heterogeneity. *Energy, 133*, 242–256. https://doi.org/10.1016/J.ENERGY.2017.05.121.

Bilgili, F., Koçak, E., Bulut, Ü., & Kuşkaya, S. (2017). Can biomass energy be an efficient policy tool for sustainable development? *Renewable and Sustainable Energy Reviews, 71*, 830–845. https://doi.org/10.1016/j.rser.2016.12.109.

Bilgili, F., Öztürk, İ., Koçak, E., Bulut, Ü., Pamuk, Y., Muğaloğlu, E., et al. (2016). The influence of biomass energy consumption on CO_2 emissions: A wavelet coherence approach. *Environmental Science and Pollution Research, 23–19*, 19043–19061. https://doi.org/10.1007/s11356-016-7094-2.

Bo, S. (2011). A literature survey on environmental Kuznets curve. In , *Energy Procedia: Vol. 5. 2010 international conference on energy, environment and development — ICEED 2010* (pp. 1322–1325). https://doi.org/10.1016/j.egypro.2011.03.229.

Boden, T., Andres, R., & Marland, G. (2017). *Global, regional, and national fossil-fuel CO_2 emissions (1751–2014) (V. 2017)*. https://doi.org/10.3334/CDIAC/00001_V2017.

Borhan, H., & Ahmed, E. M. (2012). Green environment: Assessment of income and water pollution in Malaysia. *Procedia — Social and Behavioral Sciences, 42*, 166–174. https://doi.org/10.1016/j.sbspro.2012.04.178.

Borhan, H., Ahmed, E. M., & Hitam, M. (2012). The impact of CO_2 on economic growth in Asean 8. *Procedia — Social and Behavioral Sciences, 35*, 389–397. https://doi.org/10.1016/j.sbspro.2012.02.103.

Bo, L., Suying, F., Junbiao, Z., & Haishan, Y. (2011). Carbon functions of agricultural land use and economy across China: A correlation analysis. *Energy Procedia, 5*, 1949–1956. https://doi.org/10.1016/j.egypro.2011.03.336.

Boutabba, M. A., Diaw, D., & Lessoua, A. (2018). Environment-energy-growth nexus in Sub-Saharan Africa: The role of intermediate goods. *International Economics*. https://doi.org/10.1016/j.inteco.2018.04.003.

Bruyn, S. D., Bergh, J. V., & Opschoor, J. (1998). Economic growth and emissions: Reconsidering the empirical basis of environmental Kuznets curves. *Ecological Economics, 25*(2), 161–175. https://doi.org/10.1016/s0921-8009(97)00178-x.

Burrus, C. S., Gopinath, R. A., & Guo, H. (1998). *Introduction to wavelets and wavelet transforms a primer*. New Jersey: Prentice Hall.

Charfeddine, L. (2017). The impact of energy consumption and economic development on ecological footprint and CO_2 emissions: Evidence from a Markov switching equilibrium correction model. *Energy Economics, 65*, 355–374. https://doi.org/10.1016/j.eneco.2017.05.009.

Charfeddine, L., & Mrabet, Z. (2017). The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries. *Renewable and Sustainable Energy Reviews, 76*, 138–154. https://doi.org/10.1016/j.rser.2017.03.031.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecological Economics, 48*(1), 71–81. https://doi.org/10.1016/j.ecolecon.2003.09.007.

Coondoo, D., & Dinda, S. (2002). Causality between income and emission: A country group-specific econometric analysis. *Ecological Economics, 40*, 351–367. https://doi.org/10.1016/S0921-8009(01)00280-4.

Culas, R. J. (2007). Deforestation and the environmental Kuznets curve: An institutional perspective. *Ecological Economics, 61*(2–3), 429–437. https://doi.org/10.1016/j.ecolecon.2006.03.014.

Danish, B., Zhang, B., Wang, B., & Wang, Z. (2017). Role of renewable energy and non-renewable energy consumption on EKC: Evidence from Pakistan. *Journal of Cleaner Production, 156*, 855–864. https://doi.org/10.1016/j.jclepro.2017.03.203.

Dijkgraaf, E., & Vollebergh, H. R. J. (2001). *A note on testing for environmental Kuznets curves. OCFEB research memorandum 0103, 'environmental policy, economic reform and endogenous technology'*. Working paper series 7.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics*, *49*, 431–455. https://doi.org/10.1016/j.ecolecon.2004.02.011.

Dinda, S., Coondoo, D., & Pal, M. (2000). Air quality and economic growth: An empirical study. *Ecological Economics*, *34*(3), 409–423. https://doi.org/10.1016/s0921-8009(00)00179-8.

Dogan, E., & Seker, F. (2016). The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. *Renewable and Sustainable Energy Reviews*, *60*, 1074–1085. https://doi.org/10.1016/j.rser.2016.02.006.

Dong, K., Sun, R., & Hochman, G. (2017). Do natural gas and renewable energy consumption lead to less CO_2 emission? Empirical evidence from a panel of BRICS countries. *Energy*, *141*, 1466–1478. https://doi.org/10.1016/j.energy.2017.11.092.

EIA, & US Energy Information Administration. (2018). *Total energy data*. https://www.eia.gov/totalenergy/data/monthly/.

Ersin, Ö.Ö. (2016). The nonlinear relationship of environmental degradation and income for the 1870-2011 period in selected developed countries: The dynamic panel-STAR approach. *Procedia Economics and Finance*, *38*, 318–339. https://doi.org/10.1016/s2212-5671(16)30205-2.

Ertugrul, H. M., Cetin, M., Seker, F., & Dogan, E. (2016). The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries. *Ecological Indicators*, *67*, 543–555. https://doi.org/10.1016/j.ecolind.2016.03.027.

Esteve, V., & Tamarit, C. (2012). Threshold cointegration and nonlinear adjustment between CO_2 and income: The Environmental Kuznets Curve in Spain, 1857–2007. *Energy Economics*, *34*(6), 2148–2156. https://doi.org/10.1016/j.eneco.2012.03.001.

Farge, M. (1992). Wavelet transforms and their applications to turbulence. *Annual Reviews*, *24*, 395–457. https://doi.org/10.1146/annurev.fl.24.010192.002143.

Farhani, S., & Shahbaz, M. (2014). What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO_2 emissions in MENA region? *Renewable and Sustainable Energy Reviews*, *40*, 80–90. https://doi.org/10.1016/j.rser.2014.07.170.

Federal Reserve Bank of St Louis. (2018). *Federal Reserve Bank of St. Louis | economic data, monetary rates*. https://www.stlouisfed.org/.

Galeotti, M., & Lanza, A. (1999). Richer and cleaner? A study on carbon dioxide emissions in developing countries. *Energy Policy*, *27*(10), 565–573. https://doi.org/10.1016/s0301-4215(99)00047-6.

Galeotti, M., & Lanza, A. (2005). Desperately seeking environmental Kuznets. *Environmental Modelling & Software*, *20*(11), 1379–1388. https://doi.org/10.1016/j.envsoft.2004.09.018.

Gao, B. (2011). The impacts of economic growth on resources and environment in henan province. *Procedia Environmental Sciences*, *11*, 810–816. https://doi.org/10.1016/j.proenv.2011.12.124.

Gençay, R., Selçuk, F., & Whitcher, B. (2002). *An introduction to wavelets and other filtering methods in finance and economics*. San Diego, CA: Academic Press.

Graps, A. (1995). An Introduction to wavelets. *IEEE Computational Science and Engineering*, *2*, 50–51. https://doi.org/10.1109/99.388960.

Grossman, G., & Krueger, A. (1991). *Environmental impacts of a North American free trade agreement*. https://doi.org/10.3386/w3914.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, *110*, 353–377. https://doi.org/10.2307/2118443.

Halkos, G. E. (2003). Environmental Kuznets Curve for sulfur: Evidence using GMM estimation and random coefficient panel data models. *Environment and Development Economics*, *8*(04), 581–601. https://doi.org/10.1017/s1355770x0300317.

Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics*, *34*(1), 358–364. https://doi.org/10.1016/j.eneco.2011.06.005.

Harbaugh, W. T., Levinson, A., & Wilson, D. M. (2002). Reexamining the empirical evidence for an environmental Kuznets curve. *The Review of Economics and Statistics*, *84*(3), 541–551. https://doi.org/10.1162/003465302320259538.

He, J., & Richard, P. (2010). Environmental Kuznets curve for CO_2 in Canada. *Ecological Economics*, *69*(5), 1083–1093. https://doi.org/10.1016/j.ecolecon.2009.11.030.

Hettige, H., Mani, M., & Wheeler, D. (2000). Industrial pollution in economic development: The environmental Kuznets curve revisited. *Journal of Development Economics*, *62*(2), 445–476. https://doi.org/10.1016/s0304-3878(00)00092-4.

Hitam, M. B., & Borhan, H. B. (2012). FDI, growth and the environment: Impact on quality of life in Malaysia. *Procedia – Social and Behavioral Sciences*, *50*, 333–342. https://doi.org/10.1016/j.sbspro.2012.08.038.

Holtz-Eakin, D., & Selden, T. M. (1995). Stoking the fires? CO_2 emissions and economic growth. *Journal of Public Economics*, *57*(1), 85–101. https://doi.org/10.1016/0047-2727(94)01449-x.

Hudgins, L., Friehe, C. A., & Mayer, M. E. (1993). Wavelet transform and atmospheric turbulence. *Physical Review Letters*, *71*(20), 3279–3282. https://doi.org/10.1103/PhysRevLett.71.3279.

Illing, L. (2008). *Fourier analysis*. http://www.reed.edu/physics/courses/Physics33 1.f08/pdf/Fourier.pdf.

Iwata, H., Okada, K., & Samreth, S. (2011). A note on the environmental Kuznets curve for CO_2: A pooled mean group approach. *Applied Energy*, *88*(5), 1986–1996. https://doi.org/10.1016/j.apenergy.2010.11.005.

Jalil, A., & Feridun, M. (2011). The impact of growth, energy and financial development on the environment in China: A cointegration analysis. *Energy Economics*, *33*(2), 284–291. https://doi.org/10.1016/j.eneco.2010.10.003.

Jalil, A., & Mahmud, S. F. (2009). Environment Kuznets curve for CO_2 emissions: A cointegration analysis for China. *Energy Policy*, *37*, 5167–5172. https://doi.org/10.1016/j.enpol.2009.07.044.

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO_2 emissions, energy consumption, trade and income: A comparative analysis of China and India. *Energy Policy*, *42*, 450–460. https://doi.org/10.1016/j.enpol.2011.12.010.

Jebli, M. B., Youssef, S. B., & Ozturk, I. (2016). Testing environmental Kuznets curve hypothesis: The role of renewable and non-renewable energy consumption and trade in OECD countries. *Ecological Indicators*, *60*, 824–831. https://doi.org/10.1016/j.ecolind.2015.08.031.

Jin, L., Duan, K., Shi, C., & Ju, X. (2017). The impact of technological progress in the energy sector on carbon emissions: An empirical analysis from China. *International Journal of Environmental Research and Public Health*, *14*, 1505. https://doi.org/10.3390/ijerph14121505.

Kaika, D., & Zervas, E. (2013). The Environmental Kuznets Curve (EKC) theory—Part A: Concept, causes and the CO_2 emissions case. *Energy Policy*, *62*, 1392–1402. https://doi.org/10.1016/j.enpol.2013.07.131.

Katircioğlu, S. T. (2014). Testing the tourism-induced EKC hypothesis: The case of Singapore. *Economic Modelling*, *41*, 383–391. https://doi.org/10.1016/j.econmod.2014.05.028.

Kaufmann, R. K., Davidsdottir, B., Garnham, S., & Pauly, P. (1998). The determinants of atmospheric SO2 concentrations: Reconsidering the environmental Kuznets curve. *Ecological Economics*, *25*(2), 209–220. https://doi.org/10.1016/s0921-8009(97)00181-x.

Kharbach, M., & Chfadi, T. (2017). CO_2 emissions in Moroccan road transport sector: Divisia, Cointegration, and EKC analyses. *Sustainable Cities and Society*, *35*, 396–401. https://doi.org/10.1016/j.scs.2017.08.016.

Koop, G., & Tole, L. (1999). Is there an environmental Kuznets curve for deforestation? *Journal of Development Economics*, *58*(1), 231–244. https://doi.org/10.1016/s0304-3878(98)00110-2.

Kunnas, J., & Myllyntaus, T. (2007). The environmental Kuznets curve hypothesis and air pollution in Finland. *Scandinavian Economic History Review*, *55*(2), 101–127. https://doi.org/10.1080/03585520701435970.

Kuznets, S. (1955). Economic growth and income inequality. *The American Economic Review*, *45*, 1–28.

Lee, C., Chiu, Y., & Sun, C. (2009). Does one size fit all? A reexamination of the environmental Kuznets curve using the dynamic panel data approach. *Review of Agricultural Economics*, *31*(4), 751–778. https://doi.org/10.1111/j.1467-9353.2009.01465.x.

Le, T., & Quah, E. (2018). Income level and the emissions, energy, and growth nexus: Evidence from Asia and the Pacific. *International Economics*. https://doi.org/10.1016/j.inteco.2018.03.002.

Lindmark, M. (2002). An EKC-pattern in historical perspective: Carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870–1997. *Ecological Economics*, *42*(1–2), 333–347. https://doi.org/10.1016/s0921-8009(02)00108-8.

List, J. A., & Gallet, C. A. (1999). The environmental Kuznets curve: Does one size fit all? *Ecological Economics*, *31*(3), 409–423. https://doi.org/10.1016/s0921-8009(99)00064-6.

Liu, Z., Guan, D., Crawford-Brown, D., Zhang, Q., He, K., & Liu, J. (2013). Energy policy: A low-carbon road map for China [WWW Document] *Nature*. https://doi.org/10.1038/500143a.

Loganathan, N., Shahbaz, M., & Taha, R. (2014). The link between green taxation and economic growth on CO_2 emissions: Fresh evidence from Malaysia. *Renewable and Sustainable Energy Reviews*, *38*, 1083–1091. https://doi.org/10.1016/j.rser.2014.07.057.

Managi, S., & Jena, P. R. (2008). Environmental productivity and Kuznets curve in India. *Ecological Economics*, *65*(2), 432–440. https://doi.org/10.1016/j.ecolecon.2007.07.011.

Martínez-Zarzoso, I., & Bengochea-Morancho, A. (2004). Pooled mean group estimation of an environmental Kuznets curve for CO_2. *Economics Letters*, *82*(1), 121–126. https://doi.org/10.1016/j.econlet.2003.07.008.

Morlet, J., & Grossmann, A. (1984). Decomposition of hardy functions into square integrable wavelets of constant shape. *SIAM Journal on Mathematical Analysis*, *15*(4), 723–736. https://doi.org/10.1137/0515056.

Moutinho, V., & Robaina, M. (2016). Is the share of renewable energy sources determining the CO_2 kWh and income relation in electricity generation? *Renewable and Sustainable Energy Reviews*, *65*, 902–914. https://doi.org/10.1016/j.rser.2016.07.007.

Nahman, A., & Antrobus, G. (2005). The environmental Kuznets curve: A literature survey. *South African Journal of Economics*, *73*, 105–120. https://doi.org/10.1111/j.1813-6982.2005.00008.x.

Nasir, M., & Rehman, F. U. (2011). Environmental Kuznets Curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy*, *39*(3), 1857–1864. https://doi.org/10.1016/j.enpol.2011.01.025.

Omri, A. (2014). An international literature survey on energy-economic growth nexus: Evidence from country-specific studies. *Renewable and Sustainable Energy Reviews*, *38*, 951–959. https://doi.org/10.1016/j.rser.2014.07.084.

Omri, A., Daly, S., Rault, C., & Chaibi, A. (2015). Financial development, environmental quality, trade and economic growth: What causes what in MENA countries. *Energy Economics*, *48*, 242–252. https://doi.org/10.1016/j.eneco.2015.01.008.

Onafowora, O. A., & Owoye, O. (2014). Bounds testing approach to analysis of the environment Kuznets curve hypothesis. *Energy Economics*, *44*, 47–62. https://doi.org/10.1016/j.eneco.2014.03.025.

Ozcan, B. (2013). The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: A panel data analysis. *Energy Policy*, *62*, 1138–1147. https://doi.org/10.1016/j.enpol.2013.07.016.

Ozokcu, S., & Özdemir, Ö. (2017). Economic growth, energy, and environmental Kuznets curve. *Renewable and Sustainable Energy Reviews*, *72*, 639–647. https://doi.org/10.1016/j.rser.2017.01.059.

Ozturk, I. (2010). A literature survey on energy–growth nexus. *Energy Policy*, *38*, 340–349. https://doi.org/10.1016/j.enpol.2009.09.024.

Panayotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development*. ILO Work. Pap. 45. http://sci-hub.tw/, http://www.ilo.org/public/libdoc/ilo/1993/93B09_31_engl.pdf.

Panayotou, T., Peterson, A., & Sachs, J. (2000). *Is the environmental Kuznets curve driven by structural change? What extended time series may imply for developing countries?*. CAER II Discussion Paper No. 80.

Pao, H., & Tsai, C. (2011). Multivariate Granger causality between CO_2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): Evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy, 36*(1), 685—693. https://doi.org/10.1016/j.energy.2010.09.041.

Roberts, J., & Grimes, P. E. (1997). Carbon intensity and economic development 1962—1991: A brief exploration of the environmental Kuznets curve. *World Development, 25*(2), 191—198. https://doi.org/10.1016/s0305-750x(96)00104-0.

Saboori, B., & Sulaiman, J. (2013a). CO_2 emissions, energy consumption and economic growth in association of Southeast Asian Nations (ASEAN) countries: A cointegration approach. *Energy, 55*, 813—822. https://doi.org/10.1016/j.energy.2013.04.038.

Saboori, B., & Sulaiman, J. (2013b). Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia. *Energy Policy, 60*, 892—905. https://doi.org/10.1016/j.enpol.2013.05.099.

Saboori, B., Sulaiman, J., & Mohd, S. (2012). Economic growth and CO_2 emissions in Malaysia: A cointegration analysis of the environmental Kuznets curve. *Energy Policy, 51*, 184—191. https://doi.org/10.1016/j.enpol.2012.08.065.

Sahli, I., & Rejeb, J. B. (2015). The environmental Kuznets curve and corruption in the Mena region. *Procedia - Social and Behavioral Sciences, 195*, 1648—1657. https://doi.org/10.1016/j.sbspro.2015.06.231.

Saleem, H., Jiandong, W., Zaman, K., Elashkar, E. E., & Shoukry, A. M. (2018). The impact of air-railways transportation, energy demand, bilateral aid flows, and population density on environmental degradation: Evidence from a panel of next-11 countries. *Transportation Research Part D: Transport and Environment, 62*, 152—168. https://doi.org/10.1016/j.trd.2018.02.016.

Selden, T. m, & Song, D. (1994). Environmental quality and development: Is there a Kuznets curve for air pollution emissions? *Journal of Environmental Economics and Management, 27*, 147—162. https://doi.org/10.1006/jeem.1994.1031.

Seppala, T., Haukioja, T., & Kaivo-oja, J. (2001). The EKC hypothesis does not hold for direct material flows: Environmental Kuznets Curve hypothesis tests for direct material flow in five industrial countries. *Population and Environment, 23*(2), 217—238.

Shafik, N., & Bandyopadhyay, S. (1992). *Economic Growth and Environmental Quality, Background Paper for World Development Report, Working Papers*, (p. 904).

Shafik, N. (1994). Economic development and environmental quality: An econometric analysis. *Oxford Economic Papers, 46*, 757—773.

Shahbaz, M., & Sinha, A. (2016). Environmental Kuznets curve for CO_2 emission: A literature survey. Munich pers. *RePEc Arch.*

Shahbaz, M., Dube, S., Ozturk, I., & Jalil, A. (2015). Testing the environmental Kuznets curve hypothesis in Portugal. *International Journal of Energy Economics and Policy, 5*, 475—481.

Shahbaz, M., Khraief, N., Uddin, G. S., & Ozturk, I. (2014). Environmental Kuznets curve in an open economy: A bounds testing and causality analysis for Tunisia. *Renewable and Sustainable Energy Reviews, 34*, 325—336. https://doi.org/10.1016/j.rser.2014.03.022.

Shahbaz, M., Lean, H. H., & Shabbir, M. S. (2012). Environmental Kuznets curve hypothesis in Pakistan: Cointegration and Granger causality. *Renewable and Sustainable Energy Reviews, 16*(5), 2947—2953. https://doi.org/10.1016/j.rser.2012.02.015.

Shahbaz, M., Ozturk, I., Afza, T., & Ali, A. (2013). Revisiting the environmental Kuznets curve in a global economy. *Renewable and Sustainable Energy Reviews, 25*, 494—502. https://doi.org/10.1016/j.rser.2013.05.021.

Shahbaz, M., Solarin, S. A., Hammoudeh, S., & Shahzad, S. J. (2017). Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: The role of biomass energy consumption in the United States. *Energy Economics, 68*, 548—565. https://doi.org/10.1016/j.eneco.2017.10.004.

Shahbaz, M., Solarin, S. A., & Ozturk, I. (2016). Environmental Kuznets Curve hypothesis and the role of globalization in selected African countries. *Ecological Indicators, 67*, 623—636. https://doi.org/10.1016/j.ecolind.2016.03.024.

Shahbaz, M., Solarin, S. A., Sbia, R., & Bibi, S. (2015). Does energy intensity contribute to CO_2 emissions? A trivariate analysis in selected African countries. *Ecological Indicators, 50*, 215—224. https://doi.org/10.1016/j.ecolind.2014.11.007.

Shahbaz, M., Uddin, G. S., Rehman, I. U., & Imran, K. (2014). Industrialization, electricity consumption and CO_2 emissions in Bangladesh. *Renewable and Sustainable Energy Reviews, 31*, 575—586. https://doi.org/10.1016/j.rser.2013.12.028.

Shahzad, S. J., Kumar, R. R., Zakaria, M., & Hurr, M. (2017). Carbon emission, energy consumption, trade openness and financial development in Pakistan: A revisit. *Renewable and Sustainable Energy Reviews, 70*, 185—192. https://doi.org/10.1016/j.rser.2016.11.042.

Shi, J. (2004). *Test of the EKC hypothesis using $CO_{2.}$ panel data*. Resource Economics and Policy Analysis (REPA). Research Group Working Paper 2004-03.

Solarin, S. A., Al-Mulali, U., & Ozturk, I. (2017). Validating the environmental Kuznets curve hypothesis in India and China: The role of hydroelectricity consumption. *Renewable and Sustainable Energy Reviews, 80*, 1578—1587. https://doi.org/10.1016/j.rser.2017.07.028.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World Development, 32*, 1419—1439. https://doi.org/10.1016/j.worlddev.2004.03.004.

Stern, D. I., & Common, M. S. (2001). Is there an environmental Kuznets curve for sulfur? *Journal of Environmental Economics and Management, 41*(2), 162—178. https://doi.org/10.1006/jeem.2000.1132.

Stern, D. I., Common, M. S., & Barbier, E. B. (1996). Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development. *World Development*, *24*, 1151–1160. https://doi.org/10.1016/0305-750X(96)00032-0.

Suri, V., & Chapman, D. (1998). Economic growth, trade and energy: Implications for the environmental Kuznets curve. *Ecological Economics*, *25*(2), 195–208. https://doi.org/10.1016/s0921-8009(97)00180-8.

Tang, C. F., & Tan, B. W. (2015). The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. *Energy*, *79*, 447–454. https://doi.org/10.1016/j.energy.2014.11.033.

Tan, F., Lean, H. H., & Khan, H. (2014). Growth and environmental quality in Singapore: Is there any trade-off? *Ecological Indicators*, *47*, 149–155. https://doi.org/10.1016/j.ecolind.2014.04.035.

Tiba, S., & Omri, A. (2017). Literature survey on the relationships between energy, environment and economic growth. *Renewable and Sustainable Energy Reviews*, *69*, 1129–1146. https://doi.org/10.1016/j.rser.2016.09.113.

Tiwari, A. K., Shahbaz, M., & Hye, Q. M. (2013). The environmental Kuznets curve and the role of coal consumption in India: Cointegration and causality analysis in an open economy. *Renewable and Sustainable Energy Reviews*, *18*, 519–527. https://doi.org/10.1016/j.rser.2012.10.031.

Torras, M., & Boyce, J. K. (1998). Income, inequality, and pollution: A reassessment of the environmental Kuznets curve. *Ecological Economics*, *25*(2), 147–160. https://doi.org/10.1016/s0921-8009(97)00177-8.

Ulucak, R., & Bilgili, F. (2018). A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. *Journal of Cleaner Production*, *188*, 144–157. https://doi.org/10.1016/j.jclepro.2018.03.191.

Vacha, L., & Barunik, J. (2012). Co-movement of energy commodities revisited: Evidence from wavelet coherence analysis. *Energy Economics*, *34*(1), 241–247. https://doi.org/10.1016/j.eneco.2011.10.007.

Xu, J. (2011). Is there causality from investment for real estate to carbon emission in China: A cointegration empirical study. *Procedia Environmental Sciences*, *5*, 96–104. https://doi.org/10.1016/j.proenv.2011.03.054.

Youssef, A. B., Hammoudeh, S., & Omri, A. (2016). Simultaneity modeling analysis of the environmental Kuznets curve hypothesis. *Energy Economics*, *60*, 266–274. https://doi.org/10.1016/j.eneco.2016.10.005.

Zambrano-Monserrate, M. A., Silva-Zambrano, C. A., Davalos-Penafiel, J. L., Zambrano-Monserrate, A., & Ruano, M. A. (2018). Testing environmental Kuznets curve hypothesis in Peru: The role of renewable electricity, petroleum and dry natural gas. *Renewable and Sustainable Energy Reviews*, *82*, 4170–4178. https://doi.org/10.1016/j.rser.2017.11.005.

Zhang, C., Wang, Y., Song, X., Kubota, J., He, Y., Tojo, J., et al. (2017). An integrated specification for the nexus of water pollution and economic growth in China: Panel cointegration, long-run causality and environmental Kuznets curve. *The Science of the Total Environment*, *609*, 319–328. https://doi.org/10.1016/j.scitotenv.2017.07.107.

Zhao, G., Jiang, D., Diao, J., & Qian, L. (2004). Application of wavelet time-frequency analysis on fault diagnosis for steam turbine. In *5th international conference of acoustical and vibratory surveillance methods and diagnostic techniques*. Senlis, France: CETIM. https://doi.org/10.1006/mssp.2002.1517.

Zilio, M., & Recalde, M. (2011). GDP and environment pressure: The role of energy in Latin America and the Caribbean. *Energy Policy*, *39*(12), 7941–7949. https://doi.org/10.1016/j.enpol.2011.09.049.

Zoundi, Z. (2017). CO_2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renewable and Sustainable Energy Reviews*, *72*, 1067–1075. https://doi.org/10.1016/j.rser.2016.10.018.