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Dynamic Linkages of Carbon Emissions, Economic Growth, Energy Consumption, Tourism Indicators and Population: Evidence from Second-tier Cities in Thailand

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ABSTRACT

Tourism is important and can generate economic growth for many countries, including Thailand. Since the government's launch of the 55 second-Tier Cities Tourism Destination Project, second-tier cities in Thailand have become tourist attractions. This study investigates linkages among carbon emissions, economic growth, tourism indicators, energy consumption and population in the 55 second-tier cities using annual data for the 2009–2017 period through panel dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), the autoregressive distributed lag (ARDL) method, the generalized method of moments (GMM) and Granger causality testing. The results show that energy consumption, per capita gross provincial product, the number of domestic and international tourists and the population size directly influence the carbon emissions level. The policy implications for second-tier cities include (1) increasing energy efficiency, for instance by installing alternative energy such as solar, wind and biofuel energy; (2) promoting loans with special interest rates to assist tourism entrepreneurs in providing energy-efficient products; (3) boosting public awareness of energy efficiency, energy savings and environmental pollution; (4) providing special funds and business tax refunds for those who reduce carbon emissions; (5) proactively promoting low-carbon tourism activity among tourists; and (6) introducing and enforcing environmental taxes.

Keywords: Carbon Emission, Economic Growth, Energy Consumption, Tourism Indicator, Population, Second-Tier Tourist Destination Cities
JEL Classifications: Q20, Q42, D70, D81

1. INTRODUCTION

Growth in the tourism sector continues to outpace that of the global economy, with international tourist arrivals growing 5% in 2018 by approximately 1.4 billion people; the sector generates approximately 1.7 trillion USD annually (World Tourism Organization., 2019). Leisure travel is the main purpose of visits to the top 10 destination countries, namely, France, Spain, the United States of America, China, Italy, Turkey, Mexico, Germany, the United Kingdom, and Thailand (World Tourism Organization., 2019). The expansion of this sector, especially in terms of the number of tourists, not only contributes to economic income but also leads to an increase in energy consumption (Tsai et al., 2017). In addition, tourism growth might have indirect effects on greenhouse gas (GHG) emissions through economic growth and energy capacity expansion (Katircioglu et al., 2014); for example, increasing tourism activities raises energy use in various activities, including transportation, catering, accommodation, aviation, and tourism attraction management (Akadiri et al., 2019), which also leads to environmental pollution and degradation (Akadiri et al., 2019). Katircioglu et al. (2014) suggest that energy consumption and carbon emissions from transportation are major contributors to total emissions in the tourism industry. In this respect, an investigation of the relationship among economic growth, tourism, energy consumption, population, and climate change is of interest to both policy makers and practitioners (Katircioglu et al., 2014).

The existing literature focuses on the link among economic growth, energy consumption and carbon emissions in works such as (Ahmad et al., 2019; Bi and Zeng, 2019; L. Zhang and Gao, 2016). Some studies add tourism to their consideration of the former three variables, with inconclusive results (Ahmad et al., 2019; Azam et al., 2018; Dogan et al., 2017; Katircioglu, 2014; Nepal et al., 2019; Qureshi et al., 2017). Only a few studies, on the other hand, focus on the linkage between economic growth, tourism, energy consumption, population, and climate change (Koçak et al., 2020; Shaheen et al., 2019). Due to the continuing increase in tourism and transportation activities that drive up energy consumption, the significance of energy for the tourism sector is beyond debate (Katircioglu, 2014). In this context, examinations of the nature of the linkage of economic growth (especially gross domestic product [GDP]), tourism (mainly the number of tourists and amount of tourism income), energy consumption, population and climate change are of interest to both policy makers and practitioners (Koçak et al., 2020). The results of related works indicate that tourism growth effects increases in energy use (Katircioglu, 2014). Furthermore, not only economic, tourism and population growth but also increasing energy consumption may affect environmental quality or climate change. However, very few studies have explored the econometric linkage among economic growth (GDP), tourism (number of tourists and tourism income), energy consumption, population and climate change (carbon emissions) (Koçak et al., 2020; Shaheen et al., 2019). One work examines top tourist destination countries, namely, China, France, Italy, the UK, Mexico, Germany, Turkey, Spain, the USA, and Russia, over the period of 1995–2016 (Shaheen et al., 2019), and (Koçak et al., 2020) examine data from 1995 to 2014 for the 10 most visited countries in 2017: France, Spain, the USA, China, Italy, Mexico, the UK, Turkey, Germany, and Thailand. The most widely used econometric methods fall into three groups as follows: (1) the autoregressive distributed lag (ARDL) method (Katircioglu, 2014; Sherafatian-Jahromi et al., 2017; Zhang et al., 2019) and generalized method of moments (GMM) (Bi and Zeng, 2019; Ozturk et al., 2016); (2) ARDL combined with the error correction model (ECM) (Akadiri et al., 2019; Işik et al., 2017; Katircioglu et al., 2014) and (3) fully modified ordinary least squares (FMOLS) and panel dynamic ordinary least squares (DOLS) in combination with ARDL (Gövdeli, 2019a; Lee and Brahmasrene, 2013).

Thailand is a world-class destination for international tourists and in 2018 ranked third in the world in tourism earnings, at approximately 63 USD billion (World Tourism Organization., 2019), representing approximately 27% of its GDP (Ministry of Tourism and Sports, 2019). (Jermsittiparsert and Chankoson, 2019) investigate the environmental trends of the tourism industry, concentrating in six dimensions for tourism and five dimensions for carbon emissions as environmental factors for the period of 2000–2014. Currently, the Thai government is promoting second-tier cities across 55 provinces that are not famous among tourists but still have strong tourism resources (Ministry of Tourism and Sports, 2019). Due to this campaign, these cities contributed a total income of 4.63 USD billion—approximately 11.15% of total tourism income—in 2019 (In-Touch Research and Consultancy, 2020). In this context, we investigate the econometric linkage among economic growth (GDP, GDP per capita and the square of GDP per capita), tourism (number of tourists and tourism income), energy consumption, population, and climate change (carbon emissions) in these 55 provinces by collecting annual data for 2009–2017. This study conducts a panel analysis with four widely used econometric methods, namely, panel dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), the autoregressive distributed lag (ARDL) method and the generalized method of moments (GMM), as well as Granger causality testing to examine the presence of any bidirectional causal link across the variables.

The rest of the article is structured as follows: Section 2 reviews the literature. Section 3 presents the empirical methodology. The empirical results and discussion are reported in Section 4. Last, we provided conclusions and policy implications.

2. LITERATURE REVIEW

This section investigates tourism factors that affected carbon emissions through a literature review of 44 works from the period 2013–2020, identifying 37 factors used to analyze this relationship that can be classified into 6 groups: (1) economic factors, (2) energy factors, (3) tourism factors, (4) environmental factors, (5) welfare factors, and (6) other factors (Table 1).

The first group of indicators analyzed in relation to carbon emissions is economic factors. Nine economic factors affect carbon emissions: real GDP, per capita GDP, square of per capita GDP, trade openness, gross fixed capital formation, net flows of foreign direct investment (FDI), financial development, economic growth, and trade per capita. GDP per capita, real GDP and the square of GDP per capita are used in 17, 11 and 11 studies, respectively, and the results illustrated a significant positive relationship with carbon emissions.

Energy indicators are the second set of factors that are widely used to analyze carbon emissions. Previous studies have identified 6 energy factors that are significantly related to carbon emissions, namely, (1) energy use/energy consumption, (2) per capita energy use, (3) renewable energy consumption/renewable energy production, (4) energy mix/energy intensity, (5) nonrenewable energy consumption, and (6) total primary energy consumption. Only energy use/energy consumption and renewable energy consumption/renewable energy production are commonly used, appearing in 18 previous studies and 7 previous studies, respectively, with the results revealing that energy factors are significantly positively correlated with carbon emissions.

The third group is the tourism group, with 9 factors identified as affecting carbon emissions: tourism index, number of international tourists/inbound tourism, outbound tourism, international expenditure/international tourism receipts, square of international tourism receipts, total tourism investment, total tourism income, tourist occupancy per night and tourism efficiency. The number of international tourists/amounts of inbound tourism is a favored variable for analyzing the correlation with carbon emissions, appearing in 32 previous

Table 1: Literature review on factors affecting carbon emissions, with a focus on economic indicators, energy consumption and tourism indicators

Author	Area of Study	Period	Estimation Technique	Real GDP	GDP per capita	Tourism Index	Energy use/ Energy consumption	Gross fixed capital formation	Health expenditure per capita	Square of GDP per capita	Number of International Tourists/ Inbound Tourism	Trade Openness (merchandise trade/GDP)	Net Flows of Foreign Direct Investment or FDI inflows	GHG emission	Water resources	Outbound tourism/ Number of tourist departures	Sanitation facilities	International Tourism Expenditure/ International tourism receipts	Square of international tourism receipts	Globalization index	Financial development of the countries	Population	Total Tourism Investment	Financial development index	Renewable Energy Consumption/ Renewable Electricity Production	Technology	Trade Per Capita	Total Tourism Income	Tourist occupancy per night	Energy Mix/ Energy Intensity	Carbon reduction policy	Sustainable education	Tourism efficiency	Transportation Infrastructure	Nonrenewable Energy Consumption	Natural Resource Depletion	Net forest depletion	Economic Growth	Urbanization	Total Primary Energy Consumption
Zamanet al., (2016)	Thirty-four countries	2005-2013	Panel 2SLS		•	•	•	•	○	○																														
Zhang et al., (2019)	Thailand	2001-2017	ARDL								•																													
Dogan et al., (2017)	OECD countries	1995-2010	Panel Time Series	•			•			•	•	•																												
Qureshi et al., (2017)	Top 80 International Destinations	1995-2015	Panel Time Series		•		•		○		○	○	○	○	○	○	○	○																						
Katircioglu, (2014)	Turkey	1970-2014	ARDL		•						•									○																				
Basarir and Cakir, (2015)	Turkey, France, Spain, Italy and Greece	1995-2010	DOLS				•														•																			
Alam and Paramati, (2017)	Ten Major Tourism Countries	1995-2013	FMOLS		•							•										•	•																	
Khan et al., (2019)	34 high-income countries	1995-2017	Panel causality test, FMOLS, DOLS, FGLS, AMG, ECM								•	•									•			•	•															
Doğan, (2017)	Top 10 Tourism Countries	1995-2011	FMOLS and DOLS								•														•															
Katircioglu et al., (2014)	Turkey	1960-2010	ARDL	•			•				•																													
Sharif et al., (2017)	Pakistan	1972-2013	Cointegration, FMOLS and DOLS				•				•																													
Dogan and Aslan, (2017)	EU	1995-2011	OLS, DOLS and FMOLS				•																																	
Omri et al., (2015)	18 MENA Countries	1995-2011	POLS and GMM								•																													
Azam, (2018)	Malaysia, Singapore and Thailand	1990-2014	FM OLS		•		•			•	•																													
Paramati et al., (2018)	EU28 Countries	1990-2013	Panel cointegration and ARDL		•							•										•	•			•														
Jebli et al., (2014)	22 Central and South American Countries	1995-2010	Panel Granger causality test, FMOLS and DOLS	•							•	•													•															
Wakimin et al., (2018)	Malaysia, Indonesia, Singapore, Thailand and Philippines	1970-2014	Panel data estimator and ARDL								•																													
Jermsittiparsert and Chankoson, (2019)	Thailand	2000-2014	Linear Regression															•																						
Nepal et al., (2019)	Nepal	1975-2014	ARDL		○		○	○			•																													
Katircioglu, (2014)	Singapore	1971-2010	DOLS and Granger causality tests				•			•	•																													
Lee and Brahmasrene, (2013)	27 EU Countries	1988-2009	Panel cointegration and panel unit root test	•							•		•																											
Ahmad et al., (2019)	Indonesia, Philippines and Vietnam	1995-2014	FMOLS		•		•			•	•																													
Ubaidillah, (2012)	Malaysia	1980-2010	Unit root tests and VECM								•																													
Yazdi et al., (2014)	Iran	1975-2011	Unit root tests and ARDL	•			•				•	•																												
ben Jebli et al., (2019)	22 Central and South American countries	1995-2010	FMOLS and DOLS	•							•	•													•															
Amzath and Laijun, (2014)	Maldives	1984-2010	Unit root tests and OLS																									•	•											
Sekrafi and Sghaier, (2018)	Tunisia	1972-2011	ARDL				•				•																													
Bi and Zeng, (2019)	China	2003-2016	GNSM		•		•																							•	•	•	•	•						
Koçak et al., (2020)	Top 10 most visited countries in 2017	1995-2014	CUP-BC		•						•											•								•										
Akadiri et al., (2019)	Turkey	1970-2014	ARDL and VECM		•															•																				
Zhang and Gao, (2016)	China	1995–2011	FMOLS		•		•				•																													
Zhang and Liu, (2019)	Northeast and Southeast Asian (NSEA-10) countries	1995-2014	FMOLS and AMG		•					•															•										•					
Işik et al., (2017)	Greece	1970-2014	ARDL and VECM		•													•			•						•													
Sajjad (2014)	South Asia, Middle East and North Africa, sub-Saharan Africa, and East Asian and Pacific regions	1975-2012	ARDL and VECM															•																		•	•			
Gövdeli, (2019a)	Turkey	1970-2014	ARDL, FMOLS and DOLS								•	•																										•		
Sherafatian-Jahromi et al., (2017)	Malaysia, Indonesia, Singapore, Thailand and Philippines	1979-2010	ARDL	•			•				•																												•	
ben Jebli et al., (2015)	Tunisia	1990-2010	VECM		•						•														•															
Shaheen et al., (2019)	Top 10 tourism countries	1995-2016	Panel FMOLS and panel multivariate Granger causality	•			•			•	•	○				•						○						○												
Ozturk et al., (2016)	144 Countries	1988-2008	Panel GMM									•										•						•												•

1. Nonsignificant/no causal relationship; •significant; causal relationship, 2. SLS: Two-stage least squares method; 2. ARDL = autoregressive distributed lag method, 3. DOLS: Panel dynamic ordinary least squares, 4. FMOLS: Fully modified ordinary least squares, 5. FGLS: Parks' feasible generalized least squares, 6. AMG: Augmented mean group estimator, 7. VECM: Vector error correction model, 8 CUP-BC: Continuously updated bias-corrected estimators, 9. GMM: Generalized method of moments, Data frequencies in the literature review are yearly, For each of the following factors, only 1 previous study includes the factor in the correlation analysis with carbon emission and finds a significant effect: tourism index, square of international tourism receipts, per capita energy use, technology, tourist occupancy per night, carbon reduction policy, sustainable education, tourism efficiency, transportation infrastructure, nonrenewable energy consumption, natural resource depletion, net forest depletion, economic growth, urbanization and total primary energy consumption, For each of the following factors, only 1 previous study includes the factor in the correlation analysis with carbon emission and finds a nonsignificant effect: health expenditure per capita, GHG emissions, water resources and sanitation facilities

studies, while the other factors are not as popular in assessments of the relationship with carbon emissions.

The fourth group is the environmental group. Previous studies have shown that 6 environmental factors, namely, GHG emissions, water resources, carbon reduction policies, sustainable education, natural resource depletion and net forest depletion, have a relationship with tourism, with each environmental variable, excluding GHG emission and water resources, appearing and identified as significant in only a few previous studies.

The fifth set of indicators is the welfare group, with 3 factors used to analyze the correlation with carbon emissions, including health expenditure per capita, sanitation facilities and transportation infrastructure. However, only transportation infrastructure, used in just a few previous studies, is found to have a significant relationship with carbon emissions.

The last group includes studies that do not develop proper models to determine the focal variables' relationship with the carbon emission, among them, globalization, technology, population, and urbanization. Population is a favorite variable used for analysis, identified in 4 previous studies as having a significant effect and in 1 study a nonsignificant effect.

In terms of model estimators, a variety of different econometric models are commonly used for analysis. They can be divided into 3 groups, namely, freestanding methods, comparisons of results from 2 methods and comparisons of results of 3 methods.

The first group, which includes 18 previous studies, analyzes the focal variables' relationship with carbon emissions with panel two-stage least squares (2SLS), autoregressive distributed lag (ARDL), panel dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), ordinary least squares (OLS) and the generalized method of moments (GMM). Meanwhile, the autoregressive distributed lag (ARDL) model is applied in 7 previous studies, followed by ordinary least squares (OLS) and fully modified ordinary least squares (FMOLS) analyses in 3 studies each.

The second group of studies each deploy 2 different methods to compare the accuracy of the results. Commonly used models include panel cointegration and autoregressive distributed lag (ARDL), panel cointegration and panel dynamic ordinary least squares (DOLS), panel cointegration with fully modified ordinary least squares (FMOLS) and autoregressive distributed lag (ARDL) with an error correction model (ECM) for causality tests. The autoregressive distributed lag (ARDL) and error correction model (ECM) are used for causality tests in 3 studies followed by panel cointegration in combination with fully modified ordinary least squares (FMOLS) and panel cointegration in combination with an autoregressive distributed lag (ARDL) model in 2 previous studies each.

The last group of studies compare the results of 3 methods such as fully modified ordinary least squares (FMOLS), panel dynamic ordinary least squares (DOLS), the autoregressive distributed lag (ARDL) method, panel dynamic ordinary least squares (DOLS), ordinary least squares (OLS) or panel cointegration.

In addition, the literature review reveals that yearly data are commonly used and that samples usually encompass 9–50 units of analysis, depending on the method's assumptions. A popular method of analysis is to compare outcomes across countries in the same period.

According to the literature review, only 3 previous studies that analyze the relationship of tourism with carbon emissions focused on Thailand, comparing ASEAN countries based on yearly data collected from 1990 to 2014, 1970 to 2014 and 1979 to 2010, and only 1 previous study concentrated on Thailand during 2000–2014. The results reveal that the variables with positive significance for carbon emissions are GDP per capita, energy consumption, GDP per capita squared and the number of international tourists.

Based on the literature review, this study develops a model with common variables used to analyze the relationship of tourism with carbon emissions as follows: (1) 3 economic variables (GDP per capita, real GDP, and GDP per capita squared); (2) 2 energy variables (energy use/energy consumption and renewable energy consumption); (3) 1 tourism variable (international tourists/inbound tourism); and (4) 1 variable from the other group (population). Variables in the environmental and welfare groups are not widely used to analyze carbon emissions.

This study focuses on second-tier cities in Thailand, and thus some variables—such as GDP per capita, real GDP, the square of GDP per capita, energy consumption, the number of international tourists and population—must be changed to the city level. There are an increasing number of total tourists and amount of tourism income in the model because 90% of tourists in the sample period were domestic tourists. Because of data limitations, renewable energy consumption cannot be included in the model.

3. EMPIRICAL METHODOLOGY

In this section, the data sources and methodology are discussed in terms of the main methods for analysis and model estimation in this research.

3.1. Theoretical framework, Model Specification and Data

This research aims to explore the nexus among carbon emissions, economic factors, energy consumption, tourism indicators and population. After a detailed investigation (Table 1), it was found that gross provincial product (GPP), gross provincial product per capita (GPP per capita) and the square of gross provincial product per capita are the major economic factors considered in the literature, whereas the tourism-related factors mainly focus on the number of tourists (total number and number of international tourist arrivals) and tourism income (total tourism income and international tourism income). The literature (Table 1) highlights that energy consumption (captured by energy sector variables and population) directly affects carbon emissions. Therefore, the present study uses four group indicators mentioned above as explanatory variables. In general, the carbon emission demand function is expressed as:

$$CO_{2it} = \int(GPP_{it}, GPPcap_{it}\ , (GPPcap_{it})^2, EN_{it}, TU_{it}, ITU_{it}, TUI_{it}, ITUI_{it}, POP_{it}\ ) \quad (1)$$

The function in Eq. (1) can be transformed into an econometric model by including a constant term and an error term, as given in Eq. (2).

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln GPP_{it} + \beta_2 \ln GPPcap_{it} + \beta_3 \ln GPPcap_{it}{}^2 + \beta_4 \ln EN_{it} + \beta_5 \ln TU_{it} \beta_6 \ln ITU_{it} + \beta_7 \ln TUI_{it} + \beta_8 \ln ITUI_{it} + \beta_9 \ln POP_{it} + \varepsilon_{it} \quad (2)$$

where is the constant term; the symbols $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8$ and β_9 represent the coefficients of the explanatory variables; and ε is the error term. The data used in this study are as follows: CO_2 is carbon emissions in a second-tier tourism province (tons of CO_2 eq.); GPP is the gross provincial product (million baht); GPP cap is gross provincial product per capita (baht); (GPP cap)^2 is the square of gross provincial product per capita (baht); EN is energy consumption (Ktoe); TU is the total number of tourists, both domestic and international (persons); ITU is the total number of international tourists (persons); TUI is total tourism income (million baht); ITUI is total international tourism income (million baht); and POP is the population (person). The subscript shows the time (e.g. 2009) and province. This study conducts a panel analysis by comparing the results of four widely used econometric methods, namely, dynamic ordinary least squares (DOLS), panel fully modified ordinary least squares (FMOLS), the autoregressive distributed lag (ARDL) model and the generalized method of moments (GMM), to determine panel cointegration. In the final stage, the Emirmahmutoglu-Kose Granger causality test is used to examine the presence of any causal links across the variables under study.

3.2. Data and Sources

In line with the research objective, the following variables from the literature review were used to determine the dynamic linkage of carbon emissions, economic growth, energy consumption, tourism and population in 55 provinces with second-tier cities: (1) to capture economic factors, real gross provincial product (GPP), real GPP per capita and the square of real gross provincial product per capita; (2) to capture energy factors, energy consumption; (3) to capture tourism factors, the numbers of total tourists and international tourists and the amounts of total tourism income and international tourism income; and (4) to capture other factors, population. This study uses annual data for the period 2009–2017 for Thailand. The 55 provinces consist of 16 provinces in the north, 18 provinces in the northeast, 5 provinces in the east, 7 provinces in the central region and 9 provinces in the south (Ministry of Tourism and Sports, 2019). The names of the variables, abbreviations, measurement scales and data source are shown in Table 2. Table 3 compares the descriptive statistics of the variables in this study.

3.3. Econometric Procedure

This study has six econometric steps: (1) The cross-sectional dependence (CD) test is the opening step in panel data analysis and

Table 2: Data description and measurement units

Variable Name	Abbreviation	Measurement Scale	Source
Carbon emissions	CO_2	Tons of CO_2 eq	NSO^2 TGO
Economic growth factors			
Gross provincial product	GPP	Million baht	NESDC
Gross provincial product per capita	GPP cap	Baht per person	NESDC
Square of gross provincial product per capita	(GPP cap)^2	Baht per person	NESDC
Energy factors			
Energy consumption	EN	ktoe	NSO^1
Tourism factors			
Number of total tourists	TU	Persons	NSO^2
Number of international tourists	ITU	Persons	NSO^2
Total tourism income	TUI	Million baht	NSO^2
International tourism income	ITUI	Million baht	NSO^2
Other factors			
Population	POP	Persons	NSO^3

Source: Authors' compilation, Notes: NESDC. (National Statistical Office, 2020a), NSO^1. (National Statistical Office, 2020c), NSO^2. National Statistical Office, 2020d, NSO^3. National Statistical Office, 2020b, TGO. (Thailand Greenhouse Gas Management Organization (Public Organization), 2017, CO^2 calculated from NSO^2 and TGO

Table 3: Descriptive statistics of the main variables

Variable name	Mean	SD	Min	Max	Skewness	Kurtosis
CO_2	466,649.1	324,165.2	0	1,758,009	1.6006	5.7885
GPP	55,392.85	39,428.31	0	297,249.7	2.015	8.945
GPPcap	89,387.42	54,712.65	0	486,600.6	3.356	18.835
(GPPcap)^2	1.10 E+10	2.12 E+10	0	2.37 E+11	6.423	52.007
EN	169.6767	116.9065	0	602.5432	1.253	4.183
TU	1,149,138	790,413.6	0	3,704,823	1.107	3.550
ITU	80,869.89	124,879.2	0	593,251	2.291	7.818
TUI	2,929.082	3,482.857	0	26,053.86	3.104	15.646
ITUI	395.6895	963.0724	0	7321.050	4.329	23.554
POP	704,051.9	407,035.1	0	1,869,633	0.9399	3.101

The number of observations is 485, and all numbers in this table are in levels eliminates the means in the calculation of the correlations. Under the null hypothesis of cross-sectional independence, the CD test statistic indicates the presence of an asymptotic two-tailed standard normal distribution (Breitung and Pesaran, 2005; Pesaran, 2021; Rafael and Vasilis, 2006). (2) The panel unit root test calculates the order of integration and stationarity at diverse level and first differences. (Zhang and Liu, 2019) and (Breitung and Pesaran, 2005) suggest four techniques to explore the correct cointegration order, namely, the Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), Fisher augmented Dickey-Fuller (ADF), and Fisher Phillips-Perron (PP) tests. The LLC t-statistic test is used to evaluate the presence of a common unit root process in the cross-section, whereas the IPS W-statistic, Fisher-ADF $\chi 2$, and Fisher-PP $\chi 2$ are used to evaluate an individual unit root process in the cross-section (Hsiao et al., 2012; Zhang and Liu, 2019). Furthermore, a second-generation unit root test is the cross-sectional augmented IPS (CIPS), which has the ability to detect heterogeneity and cross-sectional dependence (Breitung and Pesaran, 2005; Hsiao et al., 2012; Pesaran, 2021). (3) Four panel cointegration tests are used to explore the possible presence of cointegration within a heterogeneous panel context: (a) The Pedroni panel cointegration test (Pedroni, 2004) is applicable for heterogeneous panels with seven test statistics. (b) The Pesaran bounds test and FMOLS-based Engle-Granger test are also used to evaluate cointegration (Breitung and Pesaran, 2005; Pesaran, 2015, 2021). (c) The Kao panel cointegration test (Kao, 1999) is a procedure similar to the Pedroni test but includes cross-homogeneous coefficients on the first-stage regressors. Finally, (d) the LM bootstrap panel cointegration test is a second-generation cointegration test used to check the verdicts of earlier tests (Westerlund and Edgerton, 2007). These tests account for issues of both cross-sectional dependence and heterogeneity in identifying the cointegration relation among the variables and are superior to first-generation cointegration tests (Doğan, 2017). (4) We examine the long-run linkage among variables with economically and statistically meaningful, reliable, and accurate coefficients on GPP, GPP per capita, squared GPP per capita, energy consumption, number of tourists, number of international tourists, total tourism income, international tourism income and population for CO_2 emissions since this study confirms in the preceding sections that the variables are cointegrated and move together in the long run. This study deploys four widely used estimator approaches: (a) Panel fully modified ordinary least squares (FMOLS) uses a nonparametric approach, has the ability to correct problems of endogeneity and serial correlation in panel data due to second-order asymptotic bias and shows reliable parameters in small samples (ben Jebli et al., 2019; Jebli et al., 2014; Khan et al., 2019; Pedroni, 2004); (b) Panel dynamic ordinary least squares (DOLS), a parametric approach of panel estimates recommended by (Kao and Chiang, 2000), produces consistent coefficient estimates of explanatory variables in small samples and is better able to counter the issues of endogeneity and serial correlation than OLS and FMOLS (Doğan, 2017; Dogan et al., 2017; Khan et al., 2019). (c) Panel autoregressive distributed lags (ARDL) bounds testing is able to assume cross-sectional independence, implying that disturbances are independently distributed across units and over time with zero mean and constant variances. This approach can incorporate constant and trend variables and select the appropriate lag length by using the Schwarz information criterion (SIC), even when applied to small samples (Breitung and Pesaran, 2005; Paramati et al., 2018; Rafael and Vasilis, 2006). Finally, (d) the panel generalized method of moments (GMM) approach is able to reduce the problem of possible endogeneity in a set of given equations by using an appropriate list of instrumental variables confirmed by Sargan-Hansen J-statistics (Breitung and Pesaran, 2005; Pedroni, 2004; Qureshi et al., 2017). In the final stage, the panel Granger causality tests of (Emirmahmutoglu and Kose, 2011) are conducted to reveal causal relationships among variables. These tests account for issues of both cross-sectional dependence (CD) and heterogeneity (HTR), thus allowing the identification of reliable and robust causal linkages among the analyzed variables.

4. RESULTS AND DISCUSSION

This section presents the results of the tests described in Section 3.3, namely, (a) the cross-sectional dependence (CD) test, (b) panel unit root tests, (c) panel cointegration tests, (d) long-run estimates, and (e) short-run and long-run causality tests.

4.1. Cross-Sectional Dependence (CD) Test Results

The results of the CD test for each variable are reported in Table 4. The results show offer strong evidence to reject the null hypothesis of cross-sectional independence for all of the analyzed variables.

4.2. Panel Unit Root Test Results

Table 5 presents the estimated results of the unit root tests at various levels and first differences for all ten variables in our data set. The results are computed by employing four panel unit root tests—Fisher ADF, Fisher PP, IPS and LLC—on each time series. The results show that for each variable in levels, the null hypothesis of a unit root can be rejected at the 1% level. Thus, they are stationary processes with 99% significance and integrated in levels. The results of the second-generation tests for panel unit root processes in the cross-section show that all of the variables are stationary processes in levels since we have enough evidence to reject the null hypothesis of the presence of a unit root at the 99% level of significance.

4.3. Panel Cointegration Tests Results

According to the ADF statistic in Table 6, all seven tests imply the validity of a long-run relationship among CO_2 emissions, GPP, GPP per capita, squared GPP per capita, energy consumption,

Table 4: Results of the cross-sectional dependence test for panel time series data

	CO_2	GPP	GPPcap	qGPPcap	EN	TU	ITU	TUI	ITUI	POP
CD tests										
Statistic	104.22***	79.83***	79.89***	79.98***	99.06***	102.11***	74.86***	106.68***	80.39***	33.95***
P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

***denotes statistical significance at the 1% level. This test is of the null hypothesis of cross-sectional independence

Table 5: Results of panel unit root tests

Variable	Fisher ADF		Fisher PP		Im, Pesaran and Shin		Levin, Lin and Chou		CIPS	
	Level	First difference	Level	First difference	Level	First difference	Level	First difference	Level	First difference
CO_2	113.53***	442.79***	256.30***	607.34***	–3.43***	–15.42***	–10.51***	–34.19***	–2.87***	–10.77***
GPP	167.69***	228.96***	324.84***	287.03***	–3.08***	–5.83***	–3.08***	–16.14***	–3.37***	–10.98***
GPPcap	178.74***	228.06***	334.23***	290.80***	–3.56***	–5.81***	–12.38***	–16.08***	–3.03***	–74.63***
Sqr GPPcap	178.82***	228.08***	334.54***	290.84***	–3.56***	–5.81***	–12.38***	–16.08***	–3.03***	–372.46***
EN	266.24***	266.49***	359.07***	359.07***	–7.32***	–5.68***	–16.46***	–13.95***	–2.48***	–3.20***
TU	167.72***	410.16***	257.08***	503.89***	–2.39***	–13.89***	–17.51***	–28.53***	–3.29***	–41.40***
ITU	245.17***	387.29***	300.98***	503.89***	–7.82***	–14.97***	–26.24***	–40.70***	–2.24***	–4.79***
TUI	193.37***	360.53***	294.26***	454.47***	–3.25***	–12.06***	–15.41***	–28.27***	–2.95***	–12.05***
ITUI	233.14***	442.27***	294.81***	554.79***	–5.60***	–16.25***	–20.32***	–36.91***	–2.27***	–6.23***
POP	97.29***	234.57***	165.61***	275.00***	2.31***	–5.89***	–8.61***	–16.46***	–3.02***	–31.92***

***indicates statistical significance at the 1% level

Table 6: Results of Pedroni cointegration test

Alternative hypothesis: Common AR coefficients (within–dimension)		
	Weighted statistic	Prob
Panel v-statistic	–3.81***	0.00
Panel rho-statistic	–4.97***	0.00
Panel PP statistic	–10.22***	0.00
Panel ADF statistic	–10.91***	0.00
Alternative hypothesis: Individual AR coefficients (within-dimension)		
	Statistic	**prob.**
Group rho-statistic	12.49***	0.00
Group PP statistic	–11.45***	0.00
Group ADF statistic	11.45***	0.00

*** denotes statistical significance at the 1% level

the number of tourists, the number of international tourists, total tourism income, international tourism income and population. Although this test offers good small sample properties and is more reliable, we need to apply more tests to reach a robust conclusion (Doğan, 2017). This study uses a second panel cointegration test, the Kao test, to analyze the variables. Based on this test, all variables are cointegrated and have a long-run relationship since we have enough evidence to reject the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration at the 1% level of significance (Table 7). Although the Pedroni and Kao panel cointegration tests have been frequently used in various studies, this study also employs the LM bootstrap panel cointegration test of (Westerlund and Edgerton, 2007) to check for cross-sectional dependence and heterogeneity in identifying the cointegration relation among variables. The results in Table 8 show no evidence to reject the null hypothesis of cointegration. This study indicates that CO_2 emissions, GPP, GPP per capita, squared GPP per capita, energy consumption, number of tourists, number of international tourists, total tourism income, international tourism income and population are cointegrated and have a long-run relationship. The results imply that the cointegration relationship among the variables for the 55 s-tier cities became more robust and stronger since the second-generation panel cointegration test accounted for cross-sectional dependence and heterogeneity for all variables in this study.

Table 7: Results of Kao panel cointegration test

Kao panel cointegration	Statistic	Prob
ADF	–10.12***	0.00
Residual Variance	0.002	
HAC Variance	0.002	

*** denotes statistical significance at the 1% level

Table 8: Results of LM bootstrap panel cointegration test

Test	LM statistic	Bootstrap p value
LM bootstrap cointegration	11.25	0.99

The LM bootstrap test is calculated using 5000 replications. The LM bootstrap cointegration approach tests the null hypothesis of cointegration against the alternative of no cointegration.

4.4. Long-Run Estimates

The long-run estimators should yield economically and statistically meaningful, reliable, and accurate coefficients on GPP, GPP per capita, squared GPP per capita, energy consumption, the number of tourists, the number of international tourists, total tourism income, international tourism income and population in relation to CO_2 emissions since this study confirmed in the preceding section that these variables are cointegrated and have a long-run relationship. This study further applies the panel GMM, group mean ARDL, group mean DOLS, and group mean panel FMOLS estimator methods. (Pedroni, 2004) suggests that group-mean estimators generate more consistent estimates than weighted and pooled estimators if heterogeneity exists in cointegrated panel data. When the variables are converted into logarithmic values of the panel time series data, the coefficient estimates are all statistically significant at either the 95% or 99% level of significance, referring to the given *P* value and t-statistics, which are shown in Table 9. The findings show that the DOLS, FMOLS, ARDL and GMM estimates are similar in terms of coefficient value, sign, and statistical significance.

Starting with economic growth, the signs of the coefficients on GPP, GPP per capita and square GPP per capita are negative, positive, and positive, respectively. The GPP coefficient ranges from 0.003% to 1.64%, implying that increasing real GPP leads to a lower level of emissions in second-tier cities. The negative coefficient for real income is indirectly connected to the environmental Kuznets curve (EKC) hypothesis, which claims

Table 9: Results from long-run estimates

Methods Regressor	DOLS Coeff. (p-value)			FMOLS Coeff. (p-value)		GMM Coeff. (p-value)		ARDL Coeff. (p-value)	
Trend						0.036	0.123	–1.059	–1.059
EN	0.364***	0.336***	0.387***	1.856***	1.901***	0.235***	0.264***	0.004***	0.004***
GPP	–	–	–0.003***	–	–	–0.82***	–1.639***	–0.13	–0.006**
GPPcap	0.525***	0.266***	0.185***	1.5361***	1.8901***	–	–	–	0.066**
QGPPcap	–	–	–	0.7522***	0.9271***	0.421***	0.76***	0.097***	–
TU	0.493***	0.003***	–	0.26***	0.322***	0.283***	–	0.064***	0.037***
ITU	–	–	–0.07***	–	–	–	–0.21***	–	–0.018***
TUI	–0.273***	–0.117***	–	–	–	–	–	–0.041***	–
ITUI	–	–	–0.121***	–	–	–	–0.33***	–	–
POP	–	0.539***	0.551***	0.09***	–	1.252***	1.42***	0.216***	0.070***
Statistical Tests									
R2	0.995	0.997	0.997	0.966	0.962	–	–	0.535	0.321
Adjusted R2	0.994	0.997	0.997	0.922	0.935	–	–	0.156	0.192
Chi-squared (Wald test)									
J-statistics						42.80***	38.83***		
F-statistic								14.133***	2.49***
Jarque-Bera	251.22***	649.56***	415.68***	41.568***	42.44***	221.64***	177.38***	250.78**	495.59***

***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively

that increases in real income affect environmental improvement in second-tier cities after cities pass a threshold level of income. The prediction of the EKC hypothesis is also supported by many studies focusing on carbon emissions and economic growth and tourism. The EKC has been validated for EU and EU candidate countries (Dogan and Aslan, 2017), OECD countries (Dogan et al., 2017), the top 80 international tourist destination cities in 37 countries (Qureshi et al., 2017), and Chinese cities (Tian and Zhou, 2019). These studies also support the negative impact of economic growth on CO_2 emissions, which suggests that countries or cities beyond the threshold level of income should continue to produce goods and services to yield environmental improvements.

The elasticity of carbon emissions to energy consumption is significantly positive and ranges from 0.004% to 1.901%, implying that increases in energy consumption led to a high level of emissions in the 55 s-tier cities. It should be noted that electricity and oil play an important role in carbon emissions, and second-tier cities are highly dependent on these sources of energy. Meanwhile, the total electricity provided in Thailand in 2019 was approximately 212,050 GWh, with natural gas and coal/lignite being the main source for generated electricity, representing 57% and 17% of total electricity production (The Energy Policy and Planning Office, 2020). Similarly, (Ahmad et al., 2019), (Sherafatian-Jahromi et al., 2017) and (Dogan and Aslan, 2017) also confirm a positive significant relationship between energy consumption and carbon emissions.

In comparison with the coefficient on economic growth, the positive elasticity of carbon emissions to the number of tourists, both domestic and international, ranges from 0.003% to 0.5%, which indicates that increases in the number of tourists had a medium effect on emissions in second-tier cities. Domestic tourists generate considerable tourism income in second-tier cities, with more than 90% of total domestic tourists visiting second-tier cities (National Statistical Office, 2020d) by traveling with their own vehicles, which consume mainly fossil fuels (Panyarien et al., 2020; Wutthigamraksa, 2018). Moreover, tourist arrivals are regularly accompanied by solid waste, including garbage, plastic bags and other tourist litter, implying that domestic tourists are not concerned about environmental pollution in the sample cities (Ahmad et al., 2019). (Ahmad et al., 2019), (Sherafatian-Jahromi et al., 2017), and (Gövdeli, 2019a) also suggest that strict environmental policies are essential to reduce carbon emissions from tourists, especially domestic tourists, in second-tier cities. On the other hand, carbon emissions display a negative elasticity to international tourist arrivals, ranging from 0.07% to 0.21%. This result suggests that increases in the number of international tourists reduce carbon emissions but at a low rate, consistent with the findings of (Azam et al., 2018). (Zhang et al., 2019) also confirm that environmental performance improved and crime decreased in association with increasing international tourist arrivals. (Dogan and Aslan, 2017) suggest that second-tier cities should create regulations regarding environmental protection and encourage renewable energy consumption and sustainable tourism.

Similarly, the long-run relationship between carbon emissions and population is positive, and the coefficient ranges from 0.07 to 1.42, implying that an increase in population directly affects carbon emissions in second-tier cities at a high level but has a lower effect than energy consumption. More explicitly, a one percent increase in the population leads to a rise in carbon emissions of 0.07% to 1.42%. This is consistent with findings in existing studies such as (Alam and Paramati, 2017), (Koçak et al., 2020), (Ozturk et al., 2016), and (Paramati et al., 2018).

In the case of tourism income, total and international tourism income have negative coefficients ranging from 0.0018% to 0.273% and 0.121% to 0.33%, respectively. The results show that a one percent increase in either total or international tourism income leads to a reduction in carbon emissions of 0.0018% to 0.273% and 0.121% to 0.33%, respectively. (Lee and Brahmasrene, 2013) and (Sajjad et al., 2014) also confirm that carbon emissions have a negative elasticity to tourism receipts and coefficient values of less than 1% in the European Union and the Middle East and North Africa (MENA) and South Asia, respectively. Similarly, (Mikayilov et al., 2019) find a negative significant relationship between tourism income and carbon emissions in Azerbaijan.

The long-run estimation clearly indicates that energy consumption is the most significant contributor to carbon emissions in second-tier cities and that the share of energy use and GPP per capita are the main generators of carbon emissions in second-tier cities. However, the contributions of the number of total tourists, both domestic and international, and the population are relatively low but still positive. These findings are similar to those of (Ahmad et al., 2019) for the Philippines and Vietnam. (Sherafatian-Jahromi et al., 2017) also confirms that GDP per capita and energy use directly increase carbon emissions in Southeast Asia.

4.5. Short-Run and Long-Run Causality Test Results

The results from the bootstrap causality test are reported in Table 10. The results show enough evidence to conclude that there is bidirectional Granger causality between carbon emissions and 8 variables, namely, energy consumption, gross provincial product, gross provincial product per capita, squared gross provincial product per capita, the total number of tourists (international and domestic), the number of international tourists, and population. There is unidirectional causality running from the level of carbon emissions to tourism income and the level of carbon emissions to international tourism income. The two-way causality detected between carbon emissions and energy consumption is in line with the findings of (Dogan and Aslan, 2017), (ben Jebli et al., 2019), (Dogan et al., 2017), and (Jebli et al., 2014). The finding of carbon emissions driven by economic growth (GPP, per capita GPP, and squared per capita GPP) is also identified by (Dogan and Aslan, 2017), (Akadiri et al., 2019), (Dogan et al., 2017) and (Qureshi et al., 2017). The bidirectional causality between the number of tourists (domestic and international) and the number of international tourists and carbon emissions is also supported by (Dogan and Aslan, 2017), (ben Jebli et al., 2019), (Akadiri et al., 2019), (Koçak et al., 2020), and (Jebli et al., 2014). The relationship between carbon emissions and tourism income and international tourism income is consistent with the findings in (Sajjad et al., 2014), (Koçak et al., 2020), and (Qureshi et al., 2017). Overall, the empirical findings in this study are consistent with those of many studies. Moreover, it is worth pointing out that the directions of Granger causality found in this study based on Emirmahmutoglu-Kose Granger causality tests are reliable for informing policy recommendations, as they are based on a bootstrap technique that is robust to the presence of both cross-sectional dependence (CD) and heterogeneity (HTR).

Table 10: Results of Emirmahmutoglu-Kose Granger causality tests

Hypothesis	Fisher statistic	p-value	Conclusion
EN→CO_2	248.14***	0.00	Two-way causality between CO_2 and EN
CO_2→EN	142.81***	0.00	
GPP→CO_2	3.01**	0.04	Two-way causality between CO_2 and GPP
CO_2→GPP	24.65***	0.00	
GPPcap→CO_2	87.50***	0.00	Two-way causality between CO_2 and GPPcap
CO_2→GPPcap	6.48***	0.00	
qGPPcap→CO_2	92.34***	0.00	Two-way causality between CO_2 and qGPPcap
CO_2→qGPPcap	4.83***	0.00	
TU→CO_2	27.38***	0.00	Two-way causality between CO_2 and TU
CO_2→TU	22.20***	0.00	
ITU→CO_2	3.86**	0.02	Two-way causality between CO_2 and ITU
CO_2→ITU	86.29***	0.00	
TUI→CO_2	1.04	0.35	One-way causality between CO_2 and TUI
CO_2→TUI	86.29***	0.00	
ITUI→CO_2	0.83	0.43	One-way causality between CO_2 and ITUI
CO_2→ITUI	6.21***	0.00	
POP→CO_2	45.35***	0.00	Two-way causality between CO_2 and POP
CO_2→POP	14.97***	0.00	

***, **, and * indicate statistical significance at the 1%, 5% and 10% levels, respectively

5. CONCLUSION AND POLICY IMPLICATIONS

Using time series data on 55 second-tier cities in Thailand during 2009–2017, this study proffers new insight into the relationship among economic growth, tourism indicators, energy consumption, population, and carbon emissions through a panel analysis comparing the results of four widely used econometric methods, namely, DOLS, FMOLS, ARDL and GMM, and determines the bidirectional causal links across the variables. The empirical results provide significant evidence of a relationship among carbon emissions, energy consumption, gross provincial product per capita, number of tourists (domestic and international), total tourism income and population. The empirical results also confirm that carbon emissions have a bidirectional Granger-causal relationship with 6 variables, namely, energy consumption, gross provincial product, gross provincial product per capita, squared gross provincial product per capita, the number of tourists (international and domestic), the number of international tourists, and population. Only tourism income and international tourism income have a unidirectional causal relationship running from the level of carbon emissions. Based on the empirical results, the following implications are derived:

1. Energy consumption directly affects carbon emissions with a positive sign and high magnitude. The first step toward reducing the level of emissions is to increase energy efficiency. Although scientific research funding is important for developing projects to reach energy sustainability targets, the government should increase the share of renewable sources in the energy mix, especially in the 55 second-tier cities, for example by installing more solar panels and wind turbines, as they do not cause pollution. Loans with special interest rates can help tourism supply chain entrepreneurs provide energy-efficient products and improve the public transportation system to induce tourists and households to use public transportation as much as possible. Public awareness is essential for decreasing energy consumption and focusing on energy efficiency, energy savings and environmental pollution and can be raised by encouraging households to use energy-efficient products, turn off and unplug devices and bulbs while not in use, and use as much renewable energy as possible

2. The positive sign and large magnitude of the coefficient of GPP indicates that growth increases the level of carbon emissions, whereas per capita GPP is negatively correlated with the level of carbon emissions with a large coefficient. These contrasting empirical results show that increasing income per capita brings increasing attention to energy savings and environmental pollution. The study suggests some policy recommendations related to enlarging the tourism industry and maintaining a green and sustainable environment. A sustainable low-carbon economic policy needs to be implemented with budget allocations to renovate or reconstruct the tourism infrastructure with an eye to economic development and energy protection and provide special funding and business tax refunds for tourism entrepreneurs who can reduce carbon emissions
3. The number of international and domestic tourists affects the carbon emission level, with this effect reflecting the increasing numbers of tourists (more than 50 million) who visited second-tier cities during 2009–2017 and the increase in the occupancy rate (of approximately 50%) reported by the National Statistical Office. To facilitate sustainable tourism growth, the government should proactively engage in promotion of low-carbon tourism activity in stakeholders' tourism destinations, create awareness and publicize the merits of green tourism among tourists. Moreover, the government should introduce and enforce environmental taxes on visiting tourists to protect the environment at tourism destinations
4. The population also directly affects the carbon emission level and constrains government provision of alternative energy, energy efficiency and energy savings. Moreover, public awareness is important not only for tourism entrepreneurs and tourists but also for people who live in second-tier cities.

However, dynamic panel data still display limits in terms of measurement of the reaction of the economy to changes in external factors such as policy or technology (Zhang and Liu, 2019). Therefore, future studies should examine the transmission mechanism connecting carbon emissions in second-tier cities with economic growth and capture external effects, such as the impact of human and physical capital, technology, and public services, through tourism satellite accounts (TSAs), computable general equilibrium (CGE) models and dynamic stochastic general equilibrium (DSGE) models (Zhang and Liu, 2019).

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