Time-Frequency Nexus between Tourism Development, Economic Growth, Energy Consumption, and Ecological Footprint in Singapore

Bui Hoang Ngoc[1,*] and Le Mai Hai[2]

[1]Faculty of Business Administration, Ho Chi Minh City University of Food Industry, Ho Chi Minh City, Vietnam

[2]Faculty of Business Administration, Sai Gon University, Ho Chi Minh City, Vietnam

Abstract: Singapore has been listed as one of the top-visited countries and has the highest ecological deficit. Despite the abundance of previous studies, the distinction between short, medium, and long term by decomposing tourism development, economic growth, energy consumption, and ecological footprint has been largely ignored. This study aims to investigate the lead-lag nexus structures between ecological footprint and Singapore's economic activities from 1978 to 2016. By adopting the wavelet analysis and scale-by-scale Granger causality test, the outcomes show that energy consumption positively impacts ecological footprint at high frequencies, while tourism and economic growth positively drive ecological footprint at high and medium frequencies. We also find that the positive impact of macroeconomic variables on ecological footprint has not been evident since 2003. Additionally, the wavelet-based Granger test confirms a bi-directional causal between economic growth and ecological footprint at all frequencies, whilst there is a bi-directional relationship between tourism, energy consumption, and ecological footprint at high frequency. Based on these findings, the research may further strengthen the belief of Singapore's policy-makers on the promotion of tourism and suggests some helpful lessons for emerging countries.

Keywords: Ecological footprint, Tourism development, Economic growth, Energy consumption, Singapore.

1. INTRODUCTION

Achieving economic growth with environmental sustainability is considered an important objective of macro-economic policies issued by governments across the globe. Islam *et al*. (2013) have argued that promoting economic growth without influencing the natural ecosystem is impossible. However, many researchers have debated that the impact of economic activities on environmental quality is different in developed and emerging countries. In recent years, several researchers and policy-makers have recognized that the efficiency of the education system, environmental regulations, and green technologies can reduce environmental pollution and enhance the prospects for growth. Consequently, some scholars have devoted their efforts to investigating the impact of economic activities on environmental pollution in developed nations to suggest successful stories for emerging countries.

Numerous researchers have agreed that tourism development, economic growth, and energy consumption are three key pillars of environmental distortions. However, the practical studies have failed to provide a consistent result. For example, Godil *et al*. (2020) confirmed that tourism development has a significant positive impact on environmental pollution, while the study of Kongbuamai, Zafar, *et al*. (2020) provided a contrary conclusion. Analysis for Singapore, Katircioğlu (2014) used the error correction model to inspect the influence of tourism development on environmental pollution from 1971 to 2010. Their result showed that tourist arrivals negatively affect CO_2 emissions in both the short- and long-run. Likewise, Azam *et al*. (2018) found an inverse relationship between tourism development and environmental pollution in Singapore. More specifically, a 1% increase in tourism arrivals leads to a 0,671% decrease in carbon dioxide emissions. Furthermore, Azam *et al*. (2018) revealed that tourism development reduces pollution is not valid in the Malaysian context, where a 1% increase in total international visitors leads to a 0.098% increase in air pollution.

Many previous studies used carbon dioxide emissions (CO_2) to proxy environmental degradation. However, more recent studies have suggested that ecological footprint (EF) is a superior measurement of environmental degradation than CO_2 and GHG (Solomon Nathaniel & Syed Abdul Rehman Khan, 2020; Shahzad *et al*., 2021; Sharif *et al*., 2020; Usman, Kousar, Yaseen, *et al*., 2020). According to Erdogan and Okumus (2021), EF has emerged as a more holistic and comprehensive measure of environmental degradation because it considers land, forest, and air quality. Contrary to tourism, almost previous studies have found that economic growth and electricity

*Address correspondence to this author at the Faculty of Business Administration, Ho Chi Minh City University of Food Industry, Ho Chi Minh City, Vietnam; E-mail: ngocbh@hufi.edu.vn

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consumption positively contribute to environmental depletion. Nathaniel and Khan (2020) applied the STIRPAT framework to analyze the impact of economic growth, trade, and non-renewable energy on environmental quality. Their findings revealed that the above factors contribute significantly to environmental degradation in ASEAN nations. Likewise, Awan *et al*. (2022) found an inverted U-shape relationship between economic growth and environmental degradation in 10 emerging countries during 1996-2015. The literature review section will discuss the link between economic growth, energy consumption, and ecological footprint.

This topic is essential for Singapore. Despite being a land-scare nation devoid of natural resources, Singapore developed rapidly within a short time to achieve the top high-income country in the world. Tourism can be considered the pillar industry, where it is ranked as one of the largest tourism markets in the Asia Pacific region and contributes to 14.1% of the total employment in Singapore (World Travel & Tourism Council, 2020). Nevertheless, Singapore faces severe CO_2 emissions and an ecological deficit when an ecological footprint has exceeded the biocapacity of 10,300%. All the above evidence implies that the trade-off hypothesis may be valid in the case of Singapore. To cope with the environmental distortions, Singapore has issued many synchronous policies since 1992, such as replacing environmental regulations, encouraging enterprises to apply green technologies, and raising awareness of environmental protection for tourists and residents. Nowadays, Singapore is called a "Clean and Green City", and is an ideal model of successful environmental management. No more debates, Singapore is an interesting research context, which provides a comprehensive knowledge of the relationship between environmental pollution and economic activities.

The studies mentioned above have enriched the literature. However, it is easy to recognize that these are based on the assumption that unknown estimated parameters are valid at all time domains. The distinction between short, medium, and long term by decomposing tourism development, economic growth, energy consumption, and ecological footprint at different time scales has been ignored, which raises doubt about the effectiveness of suggested development policies. So, the contribution of this paper is presented that:

i. In our research, the causal link between variables is examined at different time scales. We use two novel techniques, including: continuous wavelet transform, and wavelet coherence, to provide ecological footprint's intercorrelation with other related variables in time and frequency domains, promoting our understanding of possible relationships. The advantage of wavelet analysis is its ability to unveil latent processes of evolving cycle patterns, trends, and non-stationarity that are typical properties of economic time series (Hung, 2022).

ii. A weakness of studies using a linear framework is that they could not fully explain the direction of causality across various frequencies and through time. To overcome this limitation, we employ a novel scale-by-scale Granger's causality test. It helps a comprehensive understanding of Granger causality, running from the shortest to the longest scale of one indicator to the scale of others.

2. LITERATURE REVIEW

2.1. The Relationship between Tourism Development - Ecological Footprint Nexus

Several previous studies on tourism development (e.g., Sharpley, 2000) have tried to establish a theoretical link between sustainable tourism and the broader framework of sustainable development. Investigating the effect of tourism development on sustainable development, some studies have demonstrated that tourism development improves environmental quality by decreasing EF (Croes *et al*., 2021; Khan & Hou, 2020; Usman, Kousar, & Makhdum, 2020). More specifically, Kongbuamai, Bui, *et al*. (2020) discover the influence of economic growth, energy consumption, tourism, and natural resources on EF in the ASEAN countries from 1995 to 2016. The findings showed that tourism development and natural resources help decrease EF. In the same vein, Usman, Kousar and Makhdum (2020) investigate the long-run impact of tourism development on EF among 20 highest emitting countries from 1995 to 2017. Their outcome from the Augmented Mean Group approach revealed that the development of the tourism industry increases environmental quality (by decreasing EF). Similarly, the critical role of tourism in improving EF was confirmed by the study by Khan and Hou (2020). Some reasons are given to explain the beneficial effect of tourism development on EF. First, tourism development generates a vast tourist inflow and thus, increases income and fosters economic activities for a country (Brida *et al*., 2014). Those actions and economic mobilities contribute to environmental quality by decreasing CO_2 emissions (Dogan & Aslan, 2017), greenhouse gas emissions (Lenzen *et al*., 2018), and EF (Gössling *et al*., 2002). Second, tourism can increase environmental quality by fostering research and development investment, generating more technological innovations, more efficiency in the transportation energy sector, and utilization of lower energy-consuming technology (Ngoc & Awan, 2021). Third, tourism growth boosts cultural and social advancement, and generates jobs as well as fosters socio-economic developments such as environmental awareness (Gokmenoglu & Eren, 2019; Kongbuamai, Bui, *et al*., 2020; Zhang & Gao, 2016) and thus, contributes a blueprint to achieve the Sustainable Development Goals (Dogan & Aslan, 2017).

However, many other studies indicate that this industry accounts for 5% of the greenhouse gas emissions (mainly CO_2 emissions) through tourism activities such as consumption, transportation, and accommodation (Gössling & Peeters, 2015; Peeters & Dubois, 2010). Godil *et al*. (2020) investigated the short-run and long-run relationship between tourism development and EF in Turkey during 1986-2018 using the Quantile ARDL method. They conclude that the more tourism this country develops, the more serious the EF is. Likewise, Koçak *et al*. (2020) investigated the most visited countries between 1995 and 2014, and empirical results validated the negative impact of tourism development on environmental quality. Similarly, Dogan *et al*. (2017) inspected the real GDP and tourism development on carbon dioxide emissions in OECD countries. The obtained result showed that an increase in the number of international tourists arriving leads to increased gas emissions, while the increase in trade openness leads to environmental improvements. Based on the concept of resource use intensities, the empirical outcomes of Gössling and Peeters (2015) indicated that tourism's overall resource consumption might grow by between 92% (demand for water use), and 189% (land use) in the period 2010 - 2050. Likewise, the link between tourism growth and CO_2 emissions was demonstrated by the study of Paramati *et al*. (2016), who concluded that the impact of tourism on CO_2 emissions is reducing much faster in developed economies than in developing economies.

Interestingly, some studies demonstrate contradicted findings for countries in the same area. For example, Paramati *et al*. (2017) show that tourism increases environmental quality in the Eastern European Union (EU) while negatively impacting this variable in the Western EU. Furthermore, Azam *et al*. (2018) investigate how tourism development influences environmental quality in Malaysia, Thailand, and Singapore and show that tourism increases environmental degradation in Malaysia while declining environmental deterioration in the remaining countries.

2.2. The Links between Economic Growth - Ecological Footprint Nexus

Similar to the link between tourism development and EF, the nexus between economic growth and EF is obscure and controversial. This linkage is understandable since the impact of economic growth on EF depends on the macroeconomic policies of each country or area. The literature review reveals that most studies empirically validate the positive impact of economic growth on EF (Khoi *et al*., 2021). A few works demonstrate a negative link between the two variables (Hassan *et al*., 2019; Usman, Kousar, Yaseen, *et al*., 2020) or even insignificant (Baz *et al*., 2020). More specifically, Alola *et al*. (2019) investigated the impact of economic growth on EF among 16 EU countries using the panel ARDL approach from 1997 to 2014. The results indicate a positive relationship between these variables. Ahmed *et al*. (2020) adopted the CUP-FM and CUP-BC techniques to examine the influence of economic growth on EF in G7 countries. They discovered that economic growth contributes to the increase in EF. Similarly, S. Nathaniel and S.A.R. Khan (2020) used the STIRPAT framework on panel data of ASEAN countries from 1990 to 2016 and found that economic growth and EF variate in the same direction. Destek and Sinha (2020) reveal the same results in the MENA countries from 1990 to 2016, and 24 OECD nations from 1980 to 2014.

Notwithstanding, some studies demonstrate the opposite findings. In their study, Usman, Kousar, Yaseen, *et al*. (2020) examine the linkage between economic growth - EF nexus for 33 upper-middle-income countries from 1994 to 2017. The results indicated that economic growth hurts EF in Africa and Europe. Likewise, Hassan *et al*. (2019) applied the ARDL approach to testing the interaction between economic growth and EF in Pakistan. Their findings suggested that in the long term, economic growth harms EF. Another study by Baz *et al*. (2020) employed the NARDL approach to discover the non-linear effect of economic growth on EF in Pakistan from 1971 to 2014. Surprisingly, the findings revealed that an insignificant relationship between economic growth and EF. Thus, it is necessary to re-establish the relationship between economic growth and EF in new contexts (e.g., Singapore) to promote effective macroeconomic policies.

2.3. The Links between Energy Consumption - Ecological Footprint Nexus

There exists extensive literature regarding the relationship between energy consumption and environmental degradation (Shahzad *et al*., 2021; Solarin & Bello, 2020; Usman, Kousar, Yaseen, *et al*., 2020). More specifically, some previous studies have validated the nexus between energy consumption and CO_2 (Bello *et al*., 2018) and greenhouse gas emission (GHG; Andrés & Padilla, 2018; Bölük & Mert, 2014; Khan *et al*., 2019) as proxies for environmental degradation. While previous studies on the energy consumption - EF nexus reveal that the relationship between energy consumption and EF is not the same between countries or areas, especially when considerating the role of non-renewable (NRE) and renewable energy (RE). Therefore, in order to form more comprehensive policies for sustainable development regarding energy consumption, many scholars have investigated the role of both NRE and RE toward EF in a study (e.g., Chen, Wang, *et al*., 2019; Destek & Sinha, 2020; Sharif *et al*., 2020). For example, Alola *et al*. (2019) use panel ARDL on data of 16 European countries and prove that NRE significantly damages EF while RE mitigates this variable. Similarly, Destek and Sinha (2020) adopt the panel fully modified least squares (FMOLS) and dynamic ordinary least squares (DOLS) to investigate the impact of NRE and RE on EF for 24 OECD countries using the annual data from 1980 to 2014. The findings indicate that energy consumption is one of the most important factors affecting ecological footprint, in which NRE and RE have positive and negative impacts on EF, respectively. In the same manner, Sharif *et al*. (2020) investigated renewable, and non-renewable electricity use on EF in Turkey during 1965-2017, and the findings from the QARDL approach suggest that NRE increases EF while RE decreases EF. Last but not least, Nathaniel and Khan (2020) inspected the role of NRE and RE toward EF for ASEAN countries from 1990 to 2016. The findings revealed that economic progress and non-renewable energy significantly damage the environment in ASEAN economies. Generally, these conclusions are consistent and suggest that the usage of carbon-intense energy resources (e.g., crude oil, natural gases, and coal) raises environmental degradation while renewable energy usage (e.g., solar, wind, ocean, hydropower) improves environmental quality (Sharif *et al*., 2020; Ulucak & Lin, 2017; Usman, Kousar, Yaseen, *et al*., 2020).

Nevertherless, there is also empirical evidence demonstrating that RE does not exert a significant influence on EF in some countries, leading to a debate regarding the role of RE toward EF. For instance, Lin and Moubarak (2014) investigate the link between RE and EF in China from 1977 to 2011 by adopting the ARDL approach and the Granger causality test. The results indicate that there is no significant association between RE and EF. These authors argue that the findings are as expected since renewable energy gained only 8.8% of the total energy produced in 2011. In the same vein, Al-Mulali *et al*. (2015) investigated the EKC hypothesis in Vietnam from 1981 to 2011. It is interesting that while NRE (fossil fuel) consumption increases EF, RE consumption has no significant effect on reducing EF. They justify the result because renewable energy plays only 1% of the total energy consumed in Vietnam. Chen, Zhao, *et al*. (2019) test the EKC hypothesis at the regional levels in China based on a balanced provincial panel dataset from 1995 to 2012. The empirical results suggested that the impact of RE on EF does not hold in China’s central region. Surprisely, Bölük and Mert (2014) investigated 16 EU countries from 1990 to 2008 using fixing the multicollinearity problem approach. The results suggest that RE increases environmental degradation in these countries.

Our literature review is certainly not exhaustive. Nevertheless, our review indicates that the impact of tourism development, economic growth, and energy consumption on EF is still mixed and inconclusive. Besides, the differentiation between the short, medium, and long term at different time scales has not been widely examined. So, exploring the impact of macroeconomic variables on EF at different time scales is necessary. To fulfill this gap, we apply the cross wavelet transform, and wavelet coherence techniques. The advantage of two novel approaches is that it provides a more intuitive understanding of the connectedness between examined variables signifying short, medium, and long-run relationships. More specifically, it reveals the lead-lag nexus structures between selected variables. The findings draw a more comprehensive picture regarding how tourism development, economic growth, and energy consumption are related to EF, and suggest some helpful policy implications to Singapore's policy-makers.

3. METHODOLOGY

The study aims to investigate the relationship between environmental pollution (measured by ecological footprint index, unit: gha per capita) and three main economic activities of Singapore, including tourism development (measured by total international visitors, unit: million persons), economic growth (proxy by income per capita at the fixed price 2010, unit: U.S dollar), and energy consumption (calculated by per capita electricity consumption, unit: kWh). Annual data of three variables from 1978 to 2016, including tourism development (labeled, TO), economic growth (GDP), and energy consumption (EC), was collected from the national statistical office of Singapore, while the ecological footprint database was taken from Footprintnetwork.org (2021). The ending year is 2016 because the ecological footprint database after 2016 is not available. To achieve the objectives, the analysis is performed on the following general model:

$$EF_t = f(TO_t, GDP_t, EC_t) \tag{1}$$

This work applied the Wavelet framework for continuous wavelets, and cross-wavelet transforms (CWT), wavelet coherence (XWT), wavelet phase-difference analysis, and wavelet-based Granger causality approach to explore the lead-lag nexus, which previous studies have ignored. Wavelet analysis is applied to decompose time series into several Wavelet scales, which are stretched and translated functions of a given mother Wavelet localized in both time and frequency domains. As a result, both time and frequency variations of the correlation between series can be observed in a time-frequency space. (CWT) to explore how the local variance and covariance of two-time series co-vary and Wavelet coherence and phase analysis capture the interdependence between two series in the time-frequency domain. Applying to this study, the wavelet coherence is well utilized as a much better measure of co-movement between ecological footprint and economic activities compared to the classical correlation analysis. The advantage of Wavelet techniques is that Wavelet filters offer a natural platform to address the time-varying characteristics found in most real-world time series (Hung, 2022). The assumption of stationarity would be avoided.

The continuous wavelet transform

The continuous wavelet transform $W_x(s)$ allows us to investigate the joint behavior of time series for both frequency and time. The Wavelet is defined as:

$$W_x(s) = \int_{-\infty}^{\infty} x(t)\frac{1}{\sqrt{s}}\psi^*\left(\frac{t}{s}\right) \tag{2}$$

where, * denotes the complex conjugate and where the scale parameter s identifies whether the Wavelet can detect higher or lower components of the series *x(t)*, possible when the admissibility condition yields.

Wavelet Coherence

To specify the interdependence between two time series in the time and frequency domains, we apply three different approaches, including the wavelet power spectrum, cross-wavelet power, and cross-Wavelet transform. While the wavelet power spectrum measures the variance of the series at each time scale, cross-wavelet power evaluates covariance contribution in the time-frequency space. The cross-wavelet of two series *x(t)* and *y(t)* can be defined as:

$$W_n^{XY}(u,s) = W_n^X(u,s)W_n^{Y*}(u,s) \tag{3}$$

where *u* denotes the position, s is the scale, and * denotes the complex conjugate.

Torrence and Webster (1999) introduced wavelet coherence as the coefficient of the correlation of time-frequency space based on the wavelet power spectrum, cross-wavelet power, and cross-wavelet transform. The squared wavelet coefficient can be defined as follows:

$$R_n^2(u,s) = \frac{\left|S\left(s^{-1}W_n^{XY}(u,s)\right)\right|^2}{S\left(s^{-1}\,|W_X(u,s)|^2\right)S\left(s^{-1}\,|W_Y(u,s)|^2\right)} \tag{4}$$

where, S presents time, which is a smoothing operator over time. $R^2(u,s)$ denotes intervals between zero and one in a time-frequency window. In a situation, when the $R^2(u,s)$ approaches one, it means that there is the strongest co-movement between *x(t)* and *y(t)* series, while $R^2(u,s)$ approaches zero, it means that the series indicators are not associated or have no causal link (Adebayo & Odugbesan, 2021).

Phase Differences

The Wavelet coherence analysis provides the level of correlation strength. However, it omits the sign of the connection. Hence, the Wavelet phase-difference developed by Torrence and Compo (1998) was employed to solve this omittance. The phase difference is the total cycle of the time series for a function of frequency, which provides us information about a delay in or synchronization between the two-time series. Specifically, it estimates the negative and positive relationships and lead-lag nexus between two time series in time-frequency domains. As a result, we use the phase difference tool to examine the dependency and causality interconnections between time series. The phase difference between x(t) and y(t) is defined as follows:

$$\phi_{XY}(u,s) = \tan^{-1}\left(\frac{\Im\{S(s^{-1}W_{XY}(u,s))\}}{\Re\{S(s^{-1}W_{XY}(u,s))\}}\right) \quad (5)$$

where, $\Im$ and $\Re$ are the imaginary and real parts of the smooth power spectrum, respectively. Phase interrelatedness between two variables is shown in the coherence phase by means of arrows: (i) the correlation is positive (negative) when the arrows point to the right (left); (ii) and the second (first) variable leads the first (second) variable by 90^0 when the arrows point to down (up). Finally, the scale-by-scale Granger causality test was employed to inspect the causality relationship among two selected variables in Eq (1).

4. EMPIRICAL RESULTS

Now, we proceed to the results and their interpretation. Table **1** further divides databases into three holding periods, namely, 2 to 4-year scales based on the wavelet scale D_1, which presents the short-run horizon. The outcomes estimated rely on the wavelet scale D_2, which refers to the medium-run horizon, and the wavelet scale D_3, D_4, which demonstrates the long-run horizon. Finally, S_4 is linked with long-term dynamics corresponding to the period above 32 years. These scales and frequency domains are introduced by Torrence and Compo (1998).

Table 1: Time Interpretation of Wavelet Scales

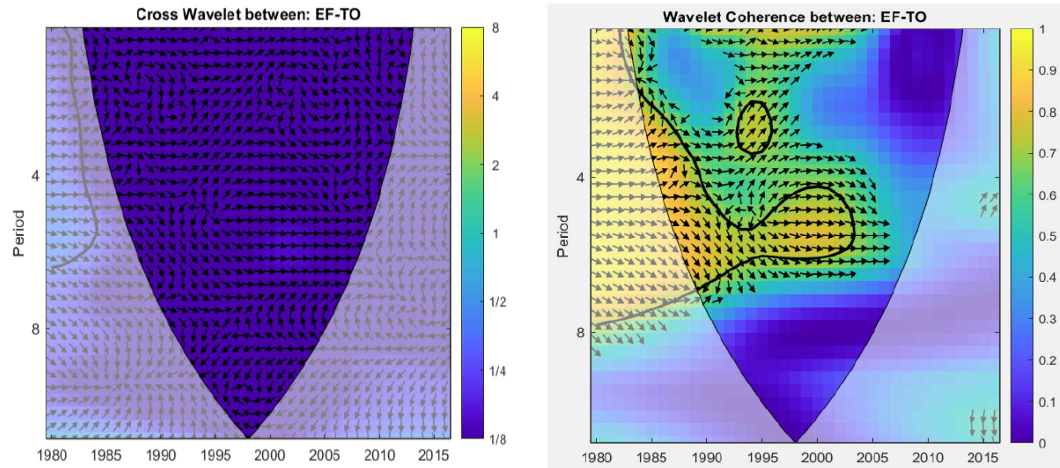
Detail	Wavelet scales	Frequency
D_1	1	2-4 years
D_2	4	4-8 years
D_3	8	8-16 years
D_4	16	16-32 years
S_4	>32	Above 32 years

Next, the study applied the cross wavelet transform, wavelet coherence, and wavelet phase-difference to analyze co-movement, and empirical outcomes are shown in Figures **1a**, **1b**, **1c**, where the yellow (blue) colors indicate high (low) power. Accordingly, the result obtained from CWT (see Figure **1a**) reveals that EF and tourism development are related in the short run, and it also shows the non-existence of co-movement in some scales and times. This conclusion is confirmed by the obtained result of the wavelet coherence approach. The left-Figure **1a** indicates that the arrows are rightward-down, suggesting that EF and TO are in-phase and present a cyclic effect where EF is the leading variable from 1978 to 1997. Since 2003, the co-movement between EF and TO is weak. In general, both CWT and XWT approaches imply that EF and TO are highly volatile at high and medium-frequency bands from 1978 to 2005, and less volatile from 2006 to 2016.

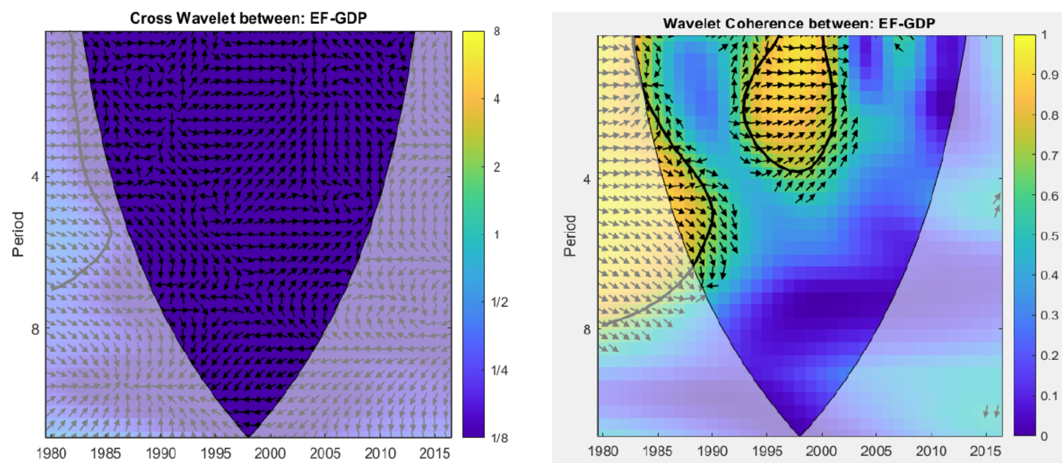
Similarly, Figure **1b** revealed a strong co-movement between EF and GDP at the high-frequency period 1978-2003, with EF as the lagging variable, and a light correlation at the low-frequency domains from 2005 to 2016. Likewise, Figure **1c** showed that the influence of energy consumption on ecological footprint was strong before 1993. After that, this impact is insignificant co-movement over time and frequency domains. These findings imply that the harmful effects of economic activities on EF have been reduced since 2003. The successful lessons in environmental protection in Singapore will discuss in the policy implication section.

Next step, the study has carried out the scale by scale Granger causality test, and the outcomes are reported in Table **2**. The analysis offers us a chance to identify whether ecological footprint causes changes in low, medium, and high frequencies of tourism development, economic growth, and energy consumption variables. The findings show the persistence of bi-directional causal interaction between ecological footprint and tourism development in the medium term. Similarly, Table **2** also indicates bi-directional causal interaction between ecological footprint and tourism development over time scales. At the same time, there is bi-directional causal between ecological footprint and tourism development in the short-run (four to eight quarter scales).

Finally, the quantile regression was employed to check robustness. Table **3** indicates that energy consumption positively influences ecological footprint at low quantiles, while the impact of tourism and economic growth is only determined at high quantiles.



a



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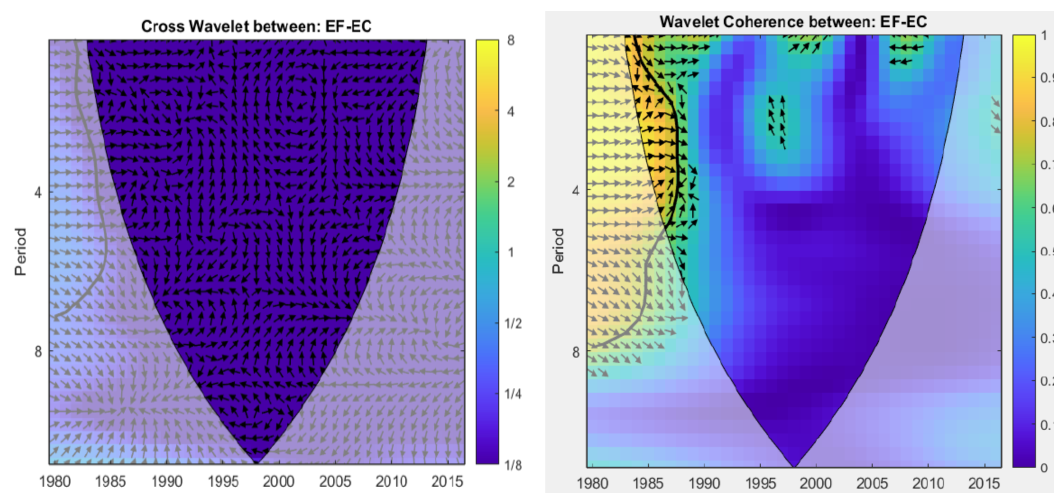

c

Figure 1: a: Cross wavelet and wavelet coherence between ecological footprint and tourism development.

b: Cross wavelet and wavelet coherence between ecological footprint and economic growth.

c: Cross wavelet and wavelet coherence between ecological footprint and energy consumption.

Note: The color bar on the right side suggests the color code for power that ranges from blue (low) to yellow (high). The Y-axis indicates frequencies, while the X-axis presents the study times.

Table 2: Results of Wavelet-Based Granger Causality Test at Different Time Scales

Time-domains	Conclusions	Null hypothesis			
		EF does not cause X		X does not cause EF	
		F-test	Prob	F-test	Prob
Ecological footprint & Tourism development					
D_1	EF => TO	2.512	0.094	1.643	0.206
D_2	EF ⇔ TO	6.074	0.005	4.449	0.018
D_3	EF ⇔ TO	4.477	0.026	2.477	0.097
D_4	No causality	2.068	0.139	1.634	0.201
S_4	TO => EF	1.919	0.157	5.105	0.011
Ecological footprint & Economic growth					
D_1	GDP => EF	0.935	0.158	4.384	0.021
D_2	EF ⇔ GDP	15.72	0.000	12.09	0.000
D_3	EF ⇔ GDP	8.244	0.001	7.287	0.002
D_4	EF ⇔ GDP	25.99	0.000	26.70	0.000
S_4	EF ⇔ GDP	38.60	0.000	39.27	0.000
Ecological footprint & Energy consumption					
D_1	No causality	1.839	0.157	1.309	0.281
D_2	EF ⇔ EC	9.163	0.000	8.090	0.001
D_3	No causality	1.710	0.187	1.726	0.181
D_4	No causality	1.886	0.148	1.700	0.189
S_4	EF ⇔ EC	2.672	0.081	2.535	0.092

Table 3: Robustness Check by Quantile Regression

Quantile (τ)	β(*lnTO*)	β(*lnGDP*)	β(*lnEC*)
Dependence variable: *lnEF*			
Quantile_10	0.412	-1.804	2.129**
Quantile_25	0.416	-1.498	1.797***
Quantile_50	0.209	-0.929	1.341
Quantile_75	0.818**	1.681**	1.399
Quantile_95	0.958*	2.814*	2.298

Note: *,**,*** denotes the significant at the level of 10%, 5% và 1%, respectively.

These results are in line with the findings of Wavelet analysis.

DISCUSSION

The empirical results demonstrate that tourism development significantly impacts EF in Singapore in the short run. More specifically, EF plays the leading variable, implying that an increase in biocapacity leads to an increase in attracting international visitors to Singapore. The findings are in line with some past studies such as Dogan *et al*. (2017) on OECD countries, Dogan and Aslan (2017) on European economies, Adedoyin *et al*. (2020) on top ten earners from international tourism, Koçak *et al*. (2020) on most visited countries. However, the results are inconsistent with some previous studies, which demonstrate that tourism development decreases EF in different areas/groups of countries such as ASEAN (Kongbuamai, Bui, *et al*., 2020), 38 International Energy Agency (IEA) countries (Khan & Hou, 2020), top 10 tourist countries (Katircioglu *et al*., 2018), 20 highest emitting economies (Usman, Kousar, &

Makhdum, 2020). Notably, most previous studies employ linear techniques to examine the link between tourism development and EF in Singapore. Thus, one of the most important contributions of the current study is using the wavelet approaches to investigate the short, medium, and long-term effects at different time scales, to form a more comprehensive picture of how tourism development affects EF. This conclusion is confirmed by the scale-by-scale Granger causality test. As such, promoting tourism development, on the one hand, should also consider adopting greener and more sustainable tourism development to increase biocapacity in Singapore more strongly.

The findings reveal that economic growth is related to EF at high and medium frequencies. The results are consistent with many previous studies investigating the positive link between economic growth and EF (Ahmed *et al*., 2021). They are also incongruent with research that shows a negative relationship between the two variables (Hassan *et al*., 2019; Usman, Kousar, Yaseen, *et al*., 2020). The results suggest that there exists a trade-off between economic growth and EF. The more developed the economy, the more serious the EF is. This is understandable since economic growth requires more natural resources (e.g., soil, forest) and consumes more energy, which in turn creates more pollution, degrades the environment, and increases EF (Alola *et al*., 2019; Zafar *et al*., 2019).

The empirical results show that energy consumption has a positive influence on EF from 1978 to 1993. However, it also reveals a weak interaction between energy consumption and EF in Singapore from 1994 to 2016. This finding is in line with the conclusion of Adedoyin *et al*. (2020) for Malaysia, and Sharif *et al*. (2020) for Turkey. This succession is caused by Singapore's government being very active in fighting environmental degradation by acquiring clean and green technologies in economic activities.

5. CONCLUSION AND POLICY IMPLICATIONS

By applying the wavelet analysis, this study showed that the co-movement between ecological footprint and tourism development, economic growth, and energy consumption is different at the specific time-frequency domains. Specifically, the outcomes show that energy consumption positively impacts ecological footprint at high frequency, while tourism and economic growth positively drive ecological footprint at high and medium frequencies. Moreover, the positive impact of macroeconomic variables on ecological footprint has not been evident since 2003 in Singapore. Additionally, the scale by scale Granger causality test confirms a bi-directional relationship between economic growth and ecological footprint at all different time and frequency domains. At the same time, there is a bi-directional relationship between tourism, energy consumption, and ecological footprint at high frequency.

Based on the lessons of successful environmental management in Singapore, some policy implications for emerging countries are suggested: First, the government should encourage enterprises and households to apply/use green technologies and replace outdated environmental regulations. These can help efficiently use energy, reduce natural resources, and low CO_2 emissions. Second, several green practical guides for all stakeholders, including service providers and international visitors, must be published and communicated. Third, some alternative tourism types, such as eco-tourism or community-based tourism, should be considered in national tourism development strategies. Four, the carbon tax should be considered to reduce emissions and stimulate sustainable development./.

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