



The criticality of tourism development, economic complexity, and country security on ecological footprint

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Received: 18 September 2021 / Accepted: 30 December 2021 / Published online: 15 January 2022
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Abstract

What kinds of countries are likely to be prosperous and have a sustainable environment at the same time? How might countries reorient their policy setting to be more capable of suppressing environmental degradation? To explore these questions, this research examines data from 99 countries for 2006–2017, takes the six major forms of ecological footprint (EF) as indicators of environmental quality, and probes the environmental Kuznets curve (EKC) hypothesis via quantile regression approach. We find that tourism development leads to greater environmental degradation, with tourism development particularly corresponding to more usage of carbon absorption land and cropland. The lower the country security is, the better is the environmental quality. Economic complexity also worsens environmental quality. However, country security weakens the negative influence of tourism development and economic complexity on environmental quality, specifying that better country security stalls the negative impact of tourism and economic complexity on environmental quality. Results mostly support the tourism- and country security-induced EKC hypotheses in fishing footprint, whereas economic complexity-induced EKC is generally validated in cropland footprint. Finally, we present that tourism arrivals, economic complexity, and country security have varying impacts across diverse ecological footprint quantiles.

Keywords Ecological footprint · Tourism development · Economic complexity · Country security · Environmental Kuznets curve (EKC)

Introduction

Pollution, exhaustion of natural resources, higher carbon emissions, global warming, and accumulation of non-recyclable wastes through economic growth are essential issues in the real world and academia when targeting sustainable environment and economic development. The ecological footprint (EF) introduced by Rees (1992) and Wackernagel and Rees (1994) reflects the pressure of human activities on the land (Destek et al., 2018) and denotes environmental degradation in recent studies, because it is an extensive measure of the area of biologically productive land and water that the population consume (Danish et al., 2019; Ulucak and Bilgili, 2018). It is also a far-reaching indicator that depicts anthropogenic pressure on the environment (Ulucak and Khan, 2020) and is also a resource measurement that aids nations in assessing their ecological resources (Solarin et al., 2019). However, human demand on nature in recent years has already surpassed the planet's carrying capacity, leading to an ecological deficit (Ulucak and Khan, 2020) and specifying the importance of further EF exploration.

Responsible Editor: Ilhan Ozturk

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Environmental degradation used to cover the inevitable costs of economic development, but can a country have a secure environment along with benefits to its economy and tourism? How might countries reorient their tourism industry, economic complexity, and country security to become more competitive in both economic development and environmental sustainability? To explore these questions, this study implements EF as a proxy of environmental degradation. Although numerous studies use EF as an environmental degradation indicator, most take the aggregate score of EF or EF per capita rather than the six sub-forms of EF (i.e., built-up land (BUI), carbon absorption land (CAR), cropland (CORP), grazing land (GRAZ), fishing grounds (FISH), and forest area (FOR)) (see Table 9 in Appendix for related studies). Aydin et al. (2019) specify that amongst these EF sub-forms, only fishing grounds validate the income-induced environmental Kuznets curve (EKC) hypothesis. Thus, applying the sub-forms of EF, this research employs a quantile regression (QR) to inspect the basic EKC hypotheses by considering countries' economic complexity (COM), tourism development (TD), and country security (CS) as possible determinants of environmental quality. Figure A1 of the "Appendix" summarizes the research concepts.

EKC essentially discloses how a technically definite quantity of environmental quality varies along with the trend of a nation's prosperity (Dinda, 2004). A considerable number of works on EKC have appeared in recent decades, sharing the fact that environmental degradation happens in the early stages of economic development and then improves in the later stages (Dinda, 2004). The EKC hypothesis literature evolves under the background of various samples, such as China (Sharif et al., 2020b; Yilanci and Pata, 2020), the USA (Dogan and Turkekul, 2016; Pata, 2020), Turkey (Ozatac et al., 2017; Pata, 2018), France (Iwata et al., 2010), Middle East and North African nations (Charfeddine and Mrabet, 2017), Africa (Sarkodie, 2018), BRICS (Haseeb et al., 2018), and countries categorized by income (Al-Mulali et al., 2015b; Ulucak and Bilgili, 2018). Agras and Chapman (1999), Harbaugh et al. (2002), Özokcu and Özdemir (2017), and Liu et al. (2017) find either no evidence or weak evidence in support of an inverted U-shaped curve. The findings are inconclusive even for the same sample country. For example, Pata (2020) presents evidence to support an inverted U-shaped EKC association between COM and environmental degradation for the USA. By contrast, taking CO₂ emissions, Dogan and Turkekul (2016) do not validate the EKC hypothesis for the USA. Thus, EKC findings are still inconclusive.

The tourism field has experienced unceasing development over the past two decades or longer. The World Travel and Tourism Council (WTTC) (2020) notes tourism is one of the world's major economic industries, contributing US\$8.9 trillion to the world's GDP in 2019, generating 330 million

jobs, and improving worldwide GDP by 10.3%. Nevertheless, under tourism industry prosperity, its relevant events have also impacted environment quality, i.e., traffic congestion, overexploitation of natural resources, and problems produced by travelers' incorrect conducts (Chen and Hsieh, 2011; Lee et al., 2020). Moreover, tourism development needs enormous investments in infrastructure such as roads, airports, and various tourism services (shops, resorts, restaurants, and hotels). Hence, it is not unexpected that tourism may negatively impact the environment (Ozturk et al., 2016). Additionally, two of its top priorities are ensuring that its industry's growth is sustainable and contributing positively to ecosystems. Lee and Chen (2021) employ international data pinpointing that tourism notably reduces forest land and grazing land and increases (decreases) fishing ground at lower (higher) fishing quantiles, signifying asymmetric and non-linear influences of tourism across diverse quantiles as well as diverse features of EF kinds. Godil et al. (2020) show that tourism positively and considerably relates to EF and that the U-shaped EKC curve is supported in Turkey and represents a non-linear and asymmetric linkage among the factors. Kongbuamai et al. (2020) display an unlikely negative linkage between tourism and EF, implying that tourism helps develop environmental quality. Moreover, WTTC (2020) states that the tourism industry must have net zero emissions by 2050 to bring about sustainability and fight global warming, pinpointing the important correlations between environmental quality and the tourism industry.

Countries' economic complexity index (COM) in the last decade has become a vital issue when researching economic growth, which covers knowledge, skills, and ubiquity (Ferrarini and Scaramozzino, 2016). The importance of COM is a symbol for the greatly refined industrial competencies of a nation's production structure (Sweet and Maggio, 2015). Some researchers also set up measures of COM concerning ecological footprint, since COM and environmental degradation correlate with a nation's economic development. For instance, Foxon et al. (2013) pinpoint that the property of COM highly relates to the work of environmental sustainability. Can and Gozgor (2017) find that strong COM conquers long-run CO₂ emissions. Doğan et al. (2019) examine the link between COM and carbon emissions, underlining the conquering ability of COM on environmental degradation. Contrarily, Neagu and Teodoru (2019) find that a surge in COM infers extreme environmental degradation. Most COM- and EF-related studies use aggregate EF, such as Liu et al. (2018), Pata (2020), Yilanci and Pata (2020), Shahzad et al. (2021), and Neagu (2020), rather than the six sub-forms of EF, to identify the differing impacts of COM.

Considering that COVID-19's impacts, new travel experiences, and the pressure to have safe and secure tourism will continue to appear in the coming years (WTTC, 2020), one vital element of a country's tourism industry is security

(Ghaderi et al., 2017). Thus, a flourishing traveler's destination should guarantee security for both holiday and business trips (Terrah et al., 2020). Fourie et al. (2020) present that travelers prefer traveling to nations with comparable ranks of security that exist in their own country, but this relation shows an asymmetric pattern. Some researchers examine the relationship between security and climate change. Wenya et al. (2020) explore the influence of climate change on country security. Zhou et al. (2020) study how climate change affects country security using the Fragile States Index (FSI). Therefore, we postulate that country security relates to tourism, the economy, and the environment. There also exists a likely asymmetric association between security and tourism, but scant literature focuses on the security-induced EKC hypothesis and the sub-forms of EF. Thus, this paper creatively investigates the impacts of country security on dissimilar quantiles of EF and dissimilar EF types as well as the security-induced EKC hypothesis.

This research is inspired by the above-mentioned works that have tried to inspect the impacts of tourism development, economic complexity, and country security on environmental degradation phenomenon by looking only at a nation or a group (region) of nations. We investigate the following issues. First, we investigate whether tourism development (i.e., traveler arrivals (TA)), COM, and/or CS (economic (ECO), political (POL), and social securities (SOC)) saliently relates to environmental degradation (EF). Second, because tourism development and economic complexity are dependent on nations' security, this study further examines whether changes in tourism and economic complexity correlations with EF are conditional on the evolution of national security issues. Third, this research further explores whether the connections of inverted U-shaped tourism development-, economic complexity-, and country security-induced EKC hypotheses are validated at diverse EF quantiles and different EF sub-categories. To consider possible asymmetric and non-linear relationships among variables, this paper uses the quantile regression approaches by employing country-level panel data from 99 nations spanning 2006–2017. Specifically, this proposal to study examines the following questions.

1. Does higher tourism development relate to a higher ecological footprint?
2. Does higher economic complexity relate to a lower ecological footprint?
3. Does higher country security relate to a lower ecological footprint?
4. Does higher country security enhance the positive influence of tourism development on ecological footprint?
5. Does higher country security enhance the negative influence of economic complexity on ecological footprint?
6. Does tourism development have an inverted U-shaped correlation with an ecological footprint?

7. Does economic complexity have an inverted U-shaped correlation with an ecological footprint?
8. Does country security have an inverted U-shaped correlation with an ecological footprint?

Despite having solid theoretical foundations, there are considerable gaps between the theoretical understandings regarding TD, COM, and CS across different EF distributions. This paper contributes to the existing literature as follows. First, to the best of our knowledge, this is an original research that uses economic, political, and social country securities to examine the tourism development-, economic complexity-, and country security-induced EKC hypotheses. Second, most existing studies investigate different income group countries, such as Gill et al. (2017) who explored EKC for emerging countries. However, this present paper explores international evidence in order to better generalize the findings. Third, as safety and security have consistently been requisite factors for tourism (Kővári and Zimányi, 2010) and the economy, this study takes country security as the interaction term that influences the links between tourism development and COM with EF. To the best of our knowledge, there are scant studies considering country security as the interaction term of tourism development and COM-induced EKC. Fourth, Lee and Chen (2021) suggest that diverse EF sub-types possess different characteristics and might have dissimilar determinants. Thus, this research employs the six sub-forms of EF as the dependent variables. Finally, this study examines the probable non-linear and/or asymmetric influences of independent variables on EF at diverse quantiles and controls for different econometric issues such as endogeneity and heterogeneity. Hence, we present more reliable and more comprehensive findings than those of prior works for policymakers to comprehend what occurs under extreme circumstances.

The rest of this research runs as follows. The “[Literature review and development of hypotheses](#)” section reviews the literature (i.e., ecological footprint, EKC hypothesis, tourism development, economic complexity, and country security) and formulates the hypotheses. The “[Methodology](#)” section offers the data and methodology used herein. The “[Empirical results and implication](#)” section presents empirical results and their implications. The “[Conclusion](#)” section concludes.

Literature review and development of hypotheses

Environmental problems such as desertification, deforestation, global warming, and climate change have adverse social and economic effects on societies (Pata and Yilanci,

2020; Liu and Lee, 2021). To achieve sustainable development, countries must identify factors that reduce environmental pollution and initiate essential measures before it is too late (Pata and Caglar, 2021). Accordingly, this section is split into six sub-sections. The sequences are ecological footprint (EF), EKC hypothesis, tourism development (TD) and TD-induced EKC hypothesis, economic complexity (COM) and COM-induced EKC hypothesis, country security, and development of hypotheses, respectively.

Ecological footprint

There are six sub-categories of EF (Global Footprint Network (GFN), 2019): BUI, CAR, CROP, FISH, FOR, and GRAZ. The development of EF reveals a mutually exclusive usage of the above territories, in the sense that each territory relates to merely one activity (GFN, 2019). The EF sub-forms depict the multi-dimensional influences on environmental degradation and nowadays are essential and influential when evaluating sustainability and environmental quality (Tietenberg and Folmer, 2005). EF means the natural resource of any given population in a requested biological manufacturing region for consumption by the given population (city or nation) and for absorbing all the waste generated by the same given population (including land and water area) (Kitzes et al., 2007). Al-Mulali et al. (2015a) as well as Ulucak and Lin (2017) identify that EF gives a more comprehensive and straightforward estimate than CO₂ emissions for pointing out and tracing the impact of a climate change strategy. Therefore, EF research has made significant contributions to drawing up the resources of the earth.

Sharif et al. (2020a) find that economic growth positively impacts ecological footprint in the long- and short-run periods at all quantiles. However, Aydin et al. (2019) probe the non-linear influences of economic growth on EF and specify that among the EF sub-types, only fishing grounds support the income-induced EKC hypothesis. Lee and Chen (2021) show that diverse EF sub-types possess various characteristics and might have dissimilar determinants. Lantz and Feng (2006) discover that prior research applying linear relations between environmental degradation and GDP factors might be wrong, because distributional heterogeneities may occur across diverse quantiles of EF. Aşıcı and Acar (2018) disclose that no EKC association exists between income and non-carbon footprints. The related empirical results propose that a non-linear connection occurs between EF and economic development. Additionally, diverse EF sub-forms possess different characteristics and might have diverse determinants. Therefore, this paper examines the determinants of six EF sub-types.

Environmental Kuznets curve (EKC) hypothesis

The insight behind the EKC hypothesis established by Kuznets (1955) is that environmental degradation increases with the per capita income level and declines when per capita income is adequately large. Ever since then, a strand of empirical studies has emerged and focused on the connection between carbon emissions and income regarding the EKC hypothesis. Following Grossman and Krueger (1991, 1995), Holtz-Eakin and Selden (1995) are among the initial researchers to identify an inverted U-shaped connection between economic development and environmental degradation.

The EKC hypothesis and its policy inferences have not been without some challenges. The initial one is that the form of a typical EKC curve is established on the assumption that environmental degradation is not accumulative, or its impacts can be reversed (Aydin et al., 2019). However, Tisdell (1993) and Fodha and Zaghoud (2010) reveal that the pollution produced by CO₂ emissions is accumulative, and the devastation of biodiversity is permanent. The second one is that the outcomes of EKC may not be possible at the global level and for emerging countries, because numerous developed nations can better control environmental problems (Gill et al., 2017), as well as dirty industries that cannot stay in developed countries move to emerging nations (Aydin et al., 2019).

There is also some contrary empirical evidence. For example, Martinez-Alier (1995) pinpoints that emerging countries are too poor to be green. More specifically, the shape of EKC is a consequence of developed nations exporting pollutants to emerging nations that have fairly weaker environmental regulations (Kearsley and Riddell, 2010). Martinez-Zarzoso and Bengochea-Morancho (2003) explore the connection between economic growth and CO₂ emissions and discover inconsistent results for the EKC hypothesis. Lantz and Feng (2006) find that GDP is not linked to CO₂. Al-Mulali et al. (2015a) show that the EKC hypothesis is not supported, since the relation between GDP and pollution is positive in both the short term and long term. Gozgor (2017) discovers that the EKC hypothesis is validated for the case of COM and that energy consumption adds to more pollution. Aydin et al. (2019) specify that the connection between EF (except fishing grounds) and economic development does not show an inverted U-shaped form related to the EKC hypothesis. Additionally, Destek and Sinha (2020) confirm that income-EF EKC is not supported. In sum, the results of the GDP-induced EKC hypothesis are mixed. As there are diverse features among the six EF sub-components, this study further examines the EKC hypothesis with a focus on the six major kinds of EF by addressing the probable non-linear and/or asymmetric relationship among

economic complexity, tourism development, country security, and EF.

Tourism development–induced EKC hypothesis

The tourism industry is currently confronting extraordinary challenges and an existential warning from the effects of COVID-19 worldwide (WTTC, 2020). Governments should recognize how tourism can be persistent through the health crisis so that it can achieve its essential role as a considerable catalyst of worldwide economic revival (WTTC, 2020). It is broadly recognized that the most imperative industry in the trail of a nation's economic development is tourism. Ecological security began when the popularity of tourism gathered more attention (Liu et al. 2016). Most tourism-relevant activities include energy straight from the usage of fossil fuels or circuitously in the usage of electricity often manufactured from petroleum, coal, or gas, from which their depletion affects environmental pollution (Raza et al., 2017; Lee et al., 2022).

TD-induced EKC is a hotly debated theme in the last decade. For instance, using carbon emissions as dependent variables, Katircioğlu (2014) supports the tourism-induced EKC hypothesis for Singapore. Taking total EF as the dependent variable, Ozturk et al. (2016) discover that global tourism is a vital element of the environment and displays an inverted U-shaped EKC hypothesis that occurs more so in higher-middle and high-income countries. De Vita et al. (2015) confirm the EKC hypothesis in the case of Turkey, as traveler arrivals and economic development profoundly affect CO₂ emissions. Using CO₂ emissions, Shakouri et al. (2017) validate the tourism-induced EKC hypothesis in Asia–Pacific nations. Using carbon emissions as the dependent variable, Katircioğlu et al. (2020) display that tourism-induced EKC is supported for those traveler nations that have an inverted U-shaped trend and conclude that tourism development in top traveler nations exerts an educating influence on the ranks of environmental quality. However, Mikayilov et al. (2019) find that the tourism-induced EKC hypothesis is not present for Azerbaijan. Khan and Hou (2021) note that tourism growth improves environmental quality. As tourism is a chief determinant of climate change, EF is a valued measure to examine the sustainability of travel activities (Liu et al., 2016). Although carbon footprint is a major portion of EF, the other five portions of EF are also important to the global environment and have their distinct features. Therefore, this study explores the asymmetric and/or non-linear impacts of tourism development on the six EF sub-types.

Economic complexity (COM) and COM-induced EKC hypothesis

Hidalgo and Hausmann (2009) suggest the notion of economic complexity to identify the stock of knowledge

gathered in a population—also known as production knowledge or production complexity. Thus, the economic complexity index assesses such complexity by measuring the competitiveness of nations and the quality of their exported goods and services. Hidalgo and Hausmann (2009) state two concepts related to COM—that is, diversity and ubiquity—which signify the number of goods a nation can export with a revealed comparative advantage and the number of benefits a nation gets from exporting a specified product, respectively. Thus, an economy is more complicated if it can export a broader base of goods that have comparatively great ubiquity (such as those exported by few other nations) (Chu and Hoang, 2020). Neagu and Teodoru (2019) pinpoint that COM is an element that must be considered when a country's economic and energy policies are formed. There is nothing to help make a nation competitive, just because it produces a huge amount of goods and services (Erkan and Yildirimci, 2015). Economic complexity has also been explored regarding ecological networks (Domínguez-García and Munoz, 2015; Wang et al., 2022).

Can and Gozgor (2017) state that higher COM overwhelms the level of CO₂ emissions in the long term. Lapatinas et al. (2019) study the link between COM and environmental performance (environmental performance index) through yearly data on 88 developed and emerging nations and find that moving to the upper ranks of economic complexity leads to better environmental quality. In contrast, Dogan and Inglesi-Lotz (2020) show that economic complexity enlarges environmental pollution in lower- and upper-middle-income nations and helps control CO₂ emissions in high-income nations. Depending on economic complexity, Neagu (2019) finds that CO₂ emissions display an inverted U-shaped curve. However, Yilanci and Pata (2020) present that COM has a growing influence on the total score of ecological footprints and does not effectively resolve environmental degradation in China. This signifies that the existing findings are inconsistent. Empirical research studies on the effects of COM on the sub-kinds of EF, to our knowledge, are quite limited. Most use carbon emissions or the total score of EF (Shahzad et al., 2021), which cannot depict the whole picture of the environment. However, COM might have varying impacts on diverse EF kinds and across diverse EF quantiles. Such a method to focus on the specific footprints of the environment and COM has rarely been employed in research, and therein lies the policy setting support of this paper.

Country security

The previous research generally has concluded that environmental stress closely relates to instability and conflict, acting in combination with other economic, political, and social contextual issues to exert its impacts (Homer-Dixon 1999).

Many methods have been suggested to deliver a first warning of national failure, but to date the criticality of environmental and natural resources has not received suitable consideration (Hearne and Alcorn, 2012). Travel and security are inevitably interwoven atmospheres, and security is typically the most vital element of a traveler's destination attraction (Boakye-Achampong et al., 2012). Security worries such as terrorism, war, crime, and political unrest are tourism obstacles and sway travelers' decision-making when choosing a specific place (Hall et al., 2004). The vulnerability of global tourism to security worries, particularly after the outbreaks of the 9/11 attacks, the Bali bombings, severe acute respiratory syndrome (SARS), COVID-19, etc., confirms claims that "tourism is irrevocably bound up with the concept of security" (Hall et al., 2004). Fowler et al. (2012) present that travelers' safety and security are absolute criteria for a prosperous traveler process. When travelers sense being unsafe in a destination, they may cultivate a negative image of that destination, which leads to cancellations as future travelers (George, 2010). Because safety and security have consistently been requisite factors for tourism (Kővári and Zimányi, 2010) and the economy, this study considers using country security as the interaction term that influences the links of tourism development and COM with EF. Using the country security of FSI as a yearly measure of nation-level resilience and capability to react to infectious disease outbreaks, Tuite et al. (2020) find that a higher total security index relates to a reduction in tourism volumes. Zhou et al. (2020) use the twelve kinds of FSI to govern a nation's instability and assess the influence of climate change. To the best of our knowledge, there are scant studies considering country security as the interaction term of tourism development as well as COM- and country security-induced EKC.

Hypotheses' development

Based on the above discussions, this paper hypothesizes that COM, country security, and tourism development might have inverted U-shaped links with environmental degradation (i.e., six sub-kinds of EF), no matter whether one considers the interaction effect of country security. Specifically, COM can be specified by economic complexity, and tourism development is proxied by worldwide traveler arrivals (TA). Thus, this paper forms the following hypotheses to generalize the respective links of COM, country security, and TD on EF.

1. *Tourism development relates to a higher ecological footprint.*
2. *Economic complexity relates to a lower ecological footprint.*
3. *Country security relates to a lower ecological footprint.*
4. *Country security enhances the positive influence of tourism development on ecological footprint.*

5. *Country security enhances the negative influence of economic complexity on ecological footprint.*

Using non-linear cointegration analysis and CO₂ as well as SO₂ as dependent variables, Hong and Wagner (2008) find EKC in roughly half of their 19 countries studied. Wagner (2015) explains the shortcomings of linear methods in the empirical EKC literature. Bi and Zeng (2019) inspect the non-linear impacts of tourism on CO₂ emissions in China and find a salient inverse U-shaped relation between tourism development and carbon emissions. Neagu (2019) uses a non-linear model to find that COM-EKC is validated for six of the 25 sample countries. Executing the non-linear smooth transition regression, Aydin et al. (2019) examine the relation between EF and economic growth. Therefore, this paper develops non-linear hypotheses as follows.

6. *Tourism development has an inverted U-shaped relation with ecological footprint, supporting the tourism development-induced EKC hypothesis.*
7. *Economic complexity has an inverted U-shaped relation with ecological footprint, supporting the economic complexity-induced EKC hypothesis.*
8. *Country security has an inverted U-shaped relation with ecological footprint, supporting the country security-induced EKC hypothesis.*

This paper reveals mixed findings and an absence of any precise concern to the economic complexity index, country security, tourism development, various EF sub-forms, and dissimilar EF distribution quantiles. Consequently, this research improves previous works by associating the influences of diverse individual characteristics on EF sub-forms via dissimilar quantiles. By doing so, this study targets to discover that the influences of the independent variables are not all the same on dissimilar EF sub-forms as well as diverse quantiles of EF. Furthermore, this study examines the existence of asymmetric and/or non-linear relationships among variables.

Methodology and data

Data

This paper performs an empirical examination primarily with four types of data (i.e., ecological footprint, tourism development, economic complexity, and country security) taken from four datasets (Global Footprint Network's 2019 Dataset, World Bank databank, MIT's Observatory of Economic Complexity Atlas Media database, and Fund for Peace). The frequency of the data is all annual. For dependent variables, this study applies six sub-types of EF

measured in global sectors, which cover data from 2006 to 2018, i.e., BUI, CAR, CROP, FISH, FOR, and GRAZ. Many studies apply EF, which has been measured for 152 countries (by UN Environment Program World Conservation Monitoring Center, Living Planet Report, World Wide Fund for Nature, Switzerland, 2002), to assess the environmental sustainability of areas and states (Wackernagel et al., 1999). The higher a state's EF is, the bigger is the environmental degradation that the state is generating (Ozturk et al., 2016).

Eugenio-Martin et al. (2004) utilize the number of traveler arrivals (TA) to explore its association with economic growth. Thus, this study employs the log difference of global traveler arrivals (TA). This study collects COM data from MIT's Observatory of Economic Complexity (https://oec.world/en/rankings/legacy_eci). The perception of COM is that complex economies involve different exported goods that have low ubiquity, because only a few diverse nations can make complex products (Hartmann et al., 2017). By contrast, less complicated economies are expected to yield a few ubiquitous products. This study uses COM in the present-level form, because COM can be negative in low-income and some emerging countries, and thus, one cannot take the natural logarithm of negative COM values. It is vital to specify that COM is defined in annual relevant terms utilizing a unit variance. Thus, if a nation has a COM of zero, then its COM equals the world mean in that year. Moreover, a value of one for COM discloses that a nation is one standard deviation above the world average (Can and Gozgor, 2017).

We obtain data on the country security index (CS) containing 178 countries from FSI in Fund for Peace (FFP) (<https://fragilestatesindex.org>). Because the earliest data period of CS is 2006, this study arranges the other dataset for 2006–2017 and uses those countries when the models contain the CS variable. The twelve indicators of FSI are associated with different facets of state stability and strength (Jiao, 2019). Each point is scored between 0 and 10, in which a higher number represents a higher level of fragility. Following Zhou et al. (2020), this study divides twelve indicators of FSI into three sub-categories: economic (economic decline, uneven economic development); political (state legitimacy, public services, human rights and rule of law, security apparatus, factionalized elites, external intervention); and social securities (demographic pressures, refugees and internally displaced persons (IDPs), group grievance, human flight, and brain drain).

The choice of the sample nations is based on data obtainability. The year 2018 provides up-to-date data of EF and COM, while the earliest year for country security is 2006. Therefore, this paper matches nations having EF data with those nations that have TD, COM, and CS data. It then uses 99 nations' yearly panel data over the period 2006–2017 to examine the effect of tourism development (TA), economic complexity (COM), and security (ECO, POL, and SOC) on

EF within the context of EKC. Table 10 (see Appendix) provides the sample countries.

Chiu and Yeh (2017) indicate that tourism development has a considerable correlation with inflation and exchange rate variation. Dogan and Inglesi-Lotz (2020) include industry value as a control variable to study the role of European nations' economic structure when analyzing the EKC hypothesis. Ahmed and Long (2013) find that EKC is not supported in the short run, while in the long run, an inverted U-shaped hypothesis is validated with population density. Khan et al. (2021b; 2021c; 2021d) and Zhang et al. (2017) show that renewable energy consumption reduces environmental degradations. Khan et al. (2022a) and Ang (2009) present that more GDP leads to more environmental degradations. Castro-Nuño et al. (2013) offer that a positive association exists between GDP and tourism. Perles-Ribes et al. (2016) note the unemployment influence of economic crises on hotel and residential tourism destinations. We thus consider the impact of economic elements by comprising EXG (log of the real exchange rate, real exchange rate estimates by the destination country's official exchange rate*US CPI/destination country's CPI), GDP (GDP per capita growth, annual %), IND (industry value added), INF (inflation, consumer prices, annual %), POD (population density), REW (renewable energy consumption), and UMP (log difference of unemployment, total % of total labor force). All annual data are collected in US dollars. All control factors are from the World Bank database. Following Divino and McAleer (2010) that a log difference has sensible interpretations, we use the log difference forms of all variables, except for the variables that have negative values (i.e., COM, GDP, and INF). Table 11 (see Appendix) lists the main variables used.

Models

To analyze the effects of TD, COM, and CS on EF, this study develops the following regression models to examine H1–H3 regarding the influences of tourism development, economic complexity, and country security on ecological footprint.

$$EF_{i,t} = \alpha_0 + \alpha_1 TD_{i,t} + \alpha_2 COM_{i,t} + \alpha_3 CS_{i,t} + \alpha_4 CV_{i,t} + \varepsilon_{i,t} \quad (1)$$

where the dependent variables $EF_{i,t}$ are the six sub-kinds of ecological footprint, α is the vector of estimated coefficients, $\varepsilon_{i,t}$ is the error term, and i and t are the country and time, respectively. The explanatory variables are the economic complexity index ($COM_{i,t}$), tourism development ($TA_{i,t}$), and country security (ECO, POL, and SOC), while $CV_{i,t}$ is the vector of other control variables that might influence the relationships among TD, COM, CS, and EF, such as real exchange rate (EXG), GDP per capita growth (GDP), industry value added (IND), inflation (INF), population density

(POD), renewable energy consumption (REW), and unemployment (UMP).

To see whether the natures of the EF-TD and EF-COM relationships are conditional on the evolution of national security issues, Eq. (2) examines H4 and H5 as follows.

$$EF_{i,t} = \alpha_0 + \alpha_1 TD_{i,t} + \alpha_2 COM_{i,t} + \alpha_3 CS_{i,t} + \alpha_4 TD_{i,t} * CS_{i,t} + \alpha_5 COM_{i,t} * CS_{i,t} + \alpha_6 CV_{i,t} + \varepsilon_{i,t} \tag{2}$$

Here, $COM_{i,t} * CS_{i,t}$ ($TD_{i,t} * CS_{i,t}$) represents the interaction term of COM (TD) and security.

Utilizing the EKC structure as suggested by Grossman and Krueger (1991), this paper adds the square of $TD_{i,t}$ ($TD_{i,t}^2$), the square of $COM_{i,t}$ ($COM_{i,t}^2$), and the square of $CS_{i,t}$ ($CS_{i,t}^2$) to explore the presence of non-linear associations between them and EF. Specifically, this paper forms Eq. (1) regarding the “reduced form of EKC” in which diverse variables enter the fields of COM, TD, and CS to specify the model as Eqs. (3)–(5), which examine H6–H8 in that COM, TD, and CS have an inverted U-shaped correlation with EF, respectively.

$$EF_{i,t} = \alpha_0 + \alpha_1 COM_{i,t} + \alpha_2 TD_{i,t} + \alpha_3 TD_{i,t}^2 + \alpha_4 CS_{i,t} + \alpha_5 CV_{i,t} + \varepsilon_{i,t} \tag{3}$$

$$EF_{i,t} = \alpha_0 + \alpha_1 TD_{i,t} + \alpha_2 COM_{i,t} + \alpha_3 COM_{i,t}^2 + \alpha_4 CS_{i,t} + \alpha_5 CV_{i,t} + \varepsilon_{i,t} \tag{4}$$

$$EF_{i,t} = \alpha_0 + \alpha_1 TD_{i,t} + \alpha_2 CS_{i,t} + \alpha_3 CS_{i,t}^2 + \alpha_4 COM_{i,t} + \alpha_5 CV_{i,t} + \varepsilon_{i,t} \tag{5}$$

Here, compared to Eq. (1), the incremental explanatory variables are $TD_{i,t}^2$, $COM_{i,t}^2$, and $CS_{i,t}^2$ in Eqs. (3)–(5), respectively. Specifically, $TD_{i,t}$ and $TD_{i,t}^2$ ($COM_{i,t}$ and $COM_{i,t}^2$; $CS_{i,t}$ and $CS_{i,t}^2$) are gauged into the following five likelihoods (Zaman et al., 2016); $\alpha_2 = \alpha_3 = 0$, displaying flat/no relation between TD (COM; CS) and EF.

- i) $\alpha_2 > 0, \alpha_3 = 0$, showing TD (COM; CS) has a salient positive value, while the square of TD (COM; CS) has an immaterial value, identifying that there is a monotonically increasing relation between EF and TD (COM; CS).
- ii) $\alpha_2 < 0, \alpha_3 = 0$, showing TD (COM; CS) has a salient negative value, while the square of TD (COM; CS) has an immaterial value, identifying that there is a monotonically decreasing relation between EF and TD (COM; CS).
- iii) $\alpha_2 > 0, \alpha_3 < 0$, showing TD (COM; CS) has a salient positive value, while the square of TD (COM; CS) has a salient negative value, validating the inverted U-shaped link between EF and TD (COM; CS); thus, the EKC hypothesis is confirmed.
- iv) $\alpha_2 < 0, \alpha_3 > 0$, showing TD (COM; CS) has a noticeable negative value, while the square of TD (COM; CS) has

a salient positive value, thus validating the U-shaped relation between EF and TD (COM; CS).

An ordinary least square regression (OLS) can help answer the question of “whether TD and COM symmetrically affect EF.” However, it does not resolve the problem if “TD, COM, and CS can affect EF differently for countries with different levels of EF.” As a robust sign of violation for the assumption of homoscedastic variance in the linear regression approach, Du and Ng (2018) utilize quantile regression to analyze the presence of a negative economic influence of climate change on travel. Employing a quantile regression model, Mills and Waite (2009) investigate the EKC hypothesis and find that traditional regression approaches fail to provide any support for the parabolic link forecasted by the EKC hypothesis. Hence, Khan et al. (2021d) and Mills and Waite (2009) suggest the use of quantile regression in related studies, because it delivers a more inclusive depiction of the link than traditional regression does. Additionally, this method is robust to outliers, heteroskedasticity, and skewness (Koenker and Hallock, 2001). From the perspective of policymaking, it is more motivating to realize what occurs in extreme circumstances. It is also a general form based on the conventional regression and can afford a whole description of a conditional distribution. The equation is inscribed as:

$$N_{y_t}(\varnothing|x_t) = \alpha_\varnothing + x_t^T \beta_\varnothing, \tag{6}$$

where $0 < \varnothing < 1$, $N_{y_t}(\varnothing|x_t)$ means the \varnothing^{th} conditional quantile of y_t , x_t stands for all the elements, and β_\varnothing and α_\varnothing are the estimated parameters and unobserved impact at the \varnothing^{th} quantile. The above equation does not account for unobserved individual heterogeneity. Matched with time-series data, the benefits of panel data contain an enlarged extent of observations and corresponding disparity, as well as a decrease in noise triggered by individual time series regression (Westerlund et al., 2015). Thus, we establish the following quantile regression model:

$$N_{y_{it}}(\varnothing|\alpha_i, x_{it}) = x_{it}^T \beta_\varnothing + \alpha_i \tag{7}$$

Empirical results and implication

Summary statistics and correlations of variables

Tables 1 and 2 provide the summary statistics and correlation matrix for the variables used in the analysis. Among the six kinds of EF, CAR is the highest in mean and standard deviation, which is consistent with Lee and Chen (2021) in that among the six EF sub-kinds the largest portion is the

carbon-absorption land, which has more importance. Likewise, Ulucak and Lin (2017) also state that carbon footprint is the greatest of the EF kinds for the USA. Compared with the other main independent variables, TA and COM data are more volatile. TA has the highest volatility, while ECO has the lowest. While TA, ECO, SOC, and POL display a left tail feature, COM has a right tail. The relatively small gap between minimum and maximum values of BUI implies there are no huge differences among the examined countries in terms of BUI, while INF and GDP have a relatively high standard deviation for all the variables, indicating large differences that exist among sample countries.

Jarque–Bera normality tests (Jarque and Bera, 1980) reject the null hypothesis of normality for each one of the series at the 1% significance level, demonstrating that the usage of the quantile regression model is robust to non-normal skewness in assessment (Troster et al., 2018). To decrease the association between the country security variables, we individually analyze the variables ECO, SOC, and POL in different models. The EF sub-kinds highly correlate with the independent variables. In sum, CAR saliently positively relates to both TA and COM, indicating that tourism development and economic complexity both increase CAR.

In contrast, CAR highly negatively correlates with country security (ECO, SOC, and POL). The higher the CS is, the more the country is fragile. Therefore, this suggests that lower country security denotes higher environmental quality.

Tourism development, economic complexity, and country security on ecological footprint

The influence of tourism development on ecological footprint

We implement the QR method to estimate the impacts of TA, COM, and CS across different levels of EF with the seven control variables. Following the QR works, we present numerical findings for five quantiles from 0.1 to 0.9 with a reflection of the extreme value of EF. Table 3 reports quantile regression results. Regarding the impact of TA, our results indicate that there are salient positive impacts for every CAR and CORP distribution quantiles, suggesting TA increase both CAR and CORP. Additionally, TA have a negative effect on the intermediate-higher quantiles of FISH, FOR, and GRAZ and a positive effect on the lower quantiles of FISH and FOR conditional distributions. Likewise, we

Table 1 Summary statistics

Variable	Mean	Max	Min	S.D	Skewness	Kurtosis	Jarque–Bera	N
BUI	0.06	0.25	0.00	0.03	1.93	8.54	2282	1200
CAR	0.74	2.14	0.02	0.56	0.46	1.99	93.98	1200
CROP	0.41	0.97	0.12	0.14	0.45	2.87	40.76	1200
FOR	0.33	1.47	0.02	0.25	1.94	7.68	8869	1200
FISH	0.10	1.01	0.00	0.13	3.00	14.89	1844	1200
GRAZ	0.21	1.87	0.00	0.22	3.23	18.94	15,000	1200
TA	14.25	18.17	9.31	1.80	−0.12	2.49	11,000	1167
COM	−0.01	2.49	−2.79	1.01	0.33	2.41	32.76	996
ECO	2.84	3.33	1.55	0.37	−1.51	4.70	599.4	1192
SOC	2.80	3.39	1.50	0.41	−1.17	3.81	304.9	1192
POL	2.81	3.38	1.06	0.50	−1.63	4.95	717.1	1192
EXG	3.89	10.04	0.32	2.54	0.36	1.99	73.9	1157
GDP	2.64	121.78	−62.38	5.65	6.33	183.72	1,600,000	1197
IND	3.25	4.48	1.52	0.39	−0.20	3.98	54.61	1169
INF	5.86	254.95	−60.50	10.11	14.28	331.93	5,400,000	1179
POD	4.14	8.98	0.50	1.41	−0.08	3.67	23.28	1200
REW	3.30	4.59	0.01	1.11	−0.93	3.12	145.4	1000
UMP	2.01	3.61	0.22	0.61	0.13	3.28	5.003	802

Yearly data are used for the period 2006–2017 for 99 countries. The dependent variables are the six sub-kinds of ecological footprint: BUI (built-up land), CAR (carbon absorption land), CROP (cropland), GRAZ (grazing land), FISH (fishing grounds), and FOR (forest area). The independent variables are TA (log number of international inbound tourists), COM (economic complexity), three country safety variables (ECO, economic safety; SOC, social safety; POL, political safety). The control variables are the seven variables that might influence EF: EXG, GDP, IND, INF, POD, REW, and UMP. EXG, real exchange rate = (destination country's official exchange rate*U.S. CPI)/destination country's CPI; GDP, GDP per capita growth, annual %; IND, log of industrial production in constant US\$; INF, inflation of consumer prices in annual %; POD, log of population density; REW, renewable energy consumption; UMP, unemployment as % of the total labor force

Table 2 Correlation coefficient of the variables

	BUI	CAR	CROP	FOR	FISH	GRAZ	TA	ECO	SOC	POL	COM	EXG	GDP	IND	INF	POD	REW	UMP
BUI	1																	
CAR	0.15***	1																
CROP	0.36***	0.64***	1															
FOR	0.48***	0.33***	0.38***	1														
FISH	0.08***	0.33***	0.27***	0.17***	1													
GRAZ	0.06**	0.15***	0.01	0.07**	-0.03	1												
TA	0.21***	0.67***	0.47***	0.09***	0.26***	-0.10***	1											
ECO	-0.31***	-0.81***	-0.58***	-0.42***	-0.47***	-0.16***	-0.61***	1										
SOC	-0.31***	-0.78***	-0.58***	-0.47***	-0.45***	-0.19***	-0.57***	0.89***	1									
POL	-0.33***	-0.75***	-0.54***	-0.49***	-0.46***	-0.14***	-0.51***	0.92***	0.91***	1								
COM	0.36***	0.69***	0.47***	0.37***	0.33***	-0.09***	0.67***	-0.69***	-0.66***	-0.69***	1							
EXG	0.03	-0.53***	-0.34***	-0.19***	-0.22***	0.00	-0.41***	0.39***	0.46***	0.41***	-0.37***	1						
GDP	0.06**	-0.04	0.01	0.02	-0.03	-0.00	0.01	0.07**	0.06**	0.09***	-0.07**	0.01	1					
IND	0.09***	0.23***	0.05*	-0.06**	0.09***	0.02	0.28***	-0.11***	-0.07**	0.00	-0.10***	-0.10***	0.12***	1				
INF	-0.10***	-0.14***	-0.19***	-0.12***	-0.11***	0.03	-0.14***	0.20***	0.16***	0.21***	-0.27***	0.01	0.02	-0.01	1			
POD	-0.01	-0.10***	-0.12***	-0.23***	0.05*	-0.48***	0.15***	0.04	0.05*	0.02	0.36***	0.04	0.02	-0.20***	-0.03	1		
REW	0.08**	-0.72***	-0.37***	0.13***	-0.15***	-0.14***	-0.52***	0.41***	0.37***	0.29***	-0.36***	0.38***	0.04	-0.36***	0.08**	0.08**	1	
UMP	-0.24***	0.13***	0.10***	0.06*	-0.22***	-0.01	-0.12***	0.06*	0.02	-0.03	-0.04	-0.20***	-0.04	-0.18***	-0.05	-0.10***	-0.11***	1

The same as the notes in Table 1. Asterisks (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively

only find a positive TA impact for BUI at the 10% lower quantile. This suggests TA have different impacts on different EF sub-kinds and across different quantiles. TA grow with CAR and CORP, which is consistent with those findings reported in De Vita et al. (2015) regarding TA and economic development profoundly affecting CO₂ emissions. TA have a positive impact on the change in the lower quantiles for FISH and FOR conditional distributions, with significantly negative influences at the upper quantiles. This shows that TA increase (decrease) to consume FISH and FOR in low (high) FISH and FOR countries, showing asymmetric relationships between TA and EF (FOR and FISH) variables. This is consistent with Lee and Chen (2021) in that diverse EF sub-kinds possess different characteristics and might have dissimilar determinates. These two kinds of land are sacrificed (enlarged) and then shift toward enhancing more environmental protection lifestyles as TA further rise. Our findings support H1 that tourism development relates to a higher EF of CAR and CORP for all quantiles and to BUI, FISH, and FOR at lower quantiles. Likewise, using EF per capita, Godil et al. (2020) show that tourism positively and considerably relates to EF and that the U-shaped EKC curve is supported and represents a non-linear and asymmetric linkage among the factors.

The influence of economic complexity on ecological footprint

As for the impact of COM, our results show that it is substantial and positive for all quantiles of CAR; most of the quantiles of BUI, CROP, and FOR; and saliently negative for GRAZ from the lowest to intermediate quantiles. We also consistently find different features among different EF sub-kinds. The CAR results are consistent with those reported in Yilanci and Pata (2020) and Sharif et al. (2020a, b) that COM has a growing influence on the total score of ecological footprints, and COM does not effectively resolve environmental degradation. Our findings support H2 that economic complexity relates to a lower ecological footprint only for GRAZ.

The influence of country security on ecological footprint

Regarding the impact of CS on different EF, it is significantly negative from the lowest to highest quantiles for all EF sub-kinds for three kinds of securities (ECO, SOC, and POL). The greater the CS value (i.e., higher risk) is, the lesser secure the nation is; this means that as the economic, social, and political risks increase, the six sub-kinds of EF decrease (i.e., environmental quality increases), implying that the higher (lower) the nation's risk is, the better (worse) the environmental quality is. This is inconsistent with the results of Levy (1995) when these environmental values are

threatened that security is also threatened and confirms that advocates of the direct physical connection between environment and US security have serious arguments worth considering. Thus, our findings do not support H3 that country security relates to a lower ecological footprint.

Regarding the control variables, as shown by Table 3, EXG has a significant and positive effect on BUI at most of the quantiles, while it has a significantly negative influence on CAR, CORP, FISH, and FOR at several quantiles. The UMP effect is negative (positive) on BUI, FISH, FOR, and GRAZ (CAR, CROP), implying UMP plays a vital role in reducing (growing) EF. REW has a saliently positive (negative) influence on BUI, FOR, FISH, and FOR (CAR and GRAZ), indicating that increasing the usage of REW decreases the usage of CAR and GRAZ, while it might also harm BUI, FOR, FISH, and FOR. GDP shows positive and negative influences across dissimilar EF types and EF quantiles, respectively. IND displays a positive influence on BUI and FISH, but a negative effect on CAR, FOR, and GRAZ. INF has mostly no salient impact on EF. POD negatively (positively) influences CAR, CORP, FOR, and GRAZ (FISH) in most of the quantiles of EF, showing the reality that the larger the population density is, the lesser EF that can be consumed. REW has a positive (negative) impact on BUI, FISH, and FOR (CAR and GRAZ). The findings indicate it is unsuitable to probe EF via its total sum due to its diverse features among the six kinds of EFs.

Interaction of country security with tourism development and economic complexity

To determine whether CS affects the relationship between TA (COM) and EF, as well as whether CS enhances or weakens this correlation, we utilize the extended models in Eqs. (4) and (5) to estimate the interaction effects of ECO, POL, and SOC with TA (COM) on EF. Our purpose is to further inspect the indirect effects of CS with diverse levels of EF. Table 4 indicates the empirical findings for the interaction terms between TA, COM, and EF. The direct effect of TA and the indirect effect of TAECO, TASOC, and TAPOL are meaningfully positive and negative in five of the lands except for GRAZ, showing that the factor of CS weakens this positive relationship between TA and EF. Similarly, most of the direct effects of COM in five of the lands except GRAZ are negative, and the indirect effect of COMECO, COMSOC, and COMPOL is significantly positive on EF except GRAZ, suggesting CS weakens this negative association between COM and EF—that is, the riskier a nation is, the more a positive COM impact on environmental quality will decrease. For GRAZ, the negative TA (positive COM) direct effect and the positive (negative) indirect of CS indicate that a higher level of country risk decreases the negative TA (positive

Table 3 Quantile regression estimates

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90
Built															
TA	0.003***	0.001	0.001	0.000	0.000	0.003***	0.000	0.000	0.001	0.004*	0.003***	0.001	0.001	0.001	0.002
COM	0.002	0.003*	0.004	0.012**	0.016***	0.016***	0.002	0.005***	0.010**	0.009**	0.000	0.003	0.003	0.008*	0.014***
ECO	-0.007***	-0.011***	-0.022***	-0.024**	-0.068***	-0.005*	-0.010***	-0.028***	-0.032***	-0.047***	-0.007***	-0.010***	-0.023***	-0.032***	-0.047***
SOC															
POL	0.002***	0.001***	0.001	0.002**	0.002**	0.002***	0.001***	0.002***	0.003***	0.002*	0.002***	0.001***	0.002**	0.003***	0.001
GDP	-0.000	-0.000	0.000	0.000	-0.000	-0.000	-0.000	0.000	0.000	-0.000	-0.000	-0.000	0.000	-0.000	-0.000
IND	0.009***	0.011***	0.009	0.026**	0.017**	0.009***	0.016***	0.018***	0.025**	0.004	0.009***	0.015***	0.012*	0.023**	0.025***
INF	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.001	-0.001	-0.000	-0.000	-0.000	-0.001	-0.000
POD	0.001	0.000	-0.002	-0.000	0.000	0.000	-0.001	-0.000	0.001	0.002	0.001*	0.000	-0.000	0.002	-0.002
REW	0.004***	0.004***	0.008***	0.011***	0.012***	0.004***	0.005***	0.007***	0.009***	0.008***	0.003***	0.004***	0.006***	0.007***	0.012***
UMP	-0.004***	-0.007***	-0.001	-0.005	-0.006*	-0.005***	-0.007***	-0.004	-0.008*	-0.000	-0.004***	-0.008***	-0.005*	-0.013***	-0.012***
C	-0.035**	0.020	0.053	0.018	0.204***	-0.036**	0.009	0.048	0.038	0.118**	-0.037**	0.002	0.048	0.057	0.101**
Pseudo R ²	0.166	0.152	0.127	0.203	0.320	0.164	0.152	0.138	0.207	0.294	0.176	0.159	0.137	0.215	0.321
Carbon															
TA	0.074***	0.063***	0.052***	0.069***	0.036***	0.043***	0.060***	0.051***	0.050***	0.043***	0.086***	0.047***	0.058***	0.074***	0.060***
COM	0.093***	0.075**	0.128***	0.088***	0.132***	0.178***	0.141***	0.155***	0.144***	0.158***	0.088***	0.097***	0.138***	0.101***	0.108***
ECO	-0.678***	-0.648***	-0.608***	-0.626***	-0.583***	-0.535***	-0.555***	-0.505***	-0.467***	-0.448***	-0.499***	-0.499***	-0.422***	-0.415***	-0.404***
SOC															
POL	0.004	-0.006	-0.010**	-0.007	-0.014**	0.005	0.003	-0.009*	-0.007	-0.007**	0.005	-0.001	-0.007	-0.006	-0.006
EXG	0.015***	0.010**	0.005**	0.005	0.004	0.002	0.010**	0.002	0.002	0.000	0.010***	0.006**	0.004	0.003	0.002
GDP	-0.110***	-0.070	-0.052	-0.141***	-0.115**	-0.108*	-0.058	0.020	-0.089*	-0.160***	-0.051	0.007	0.018	-0.086**	-0.069
IND	-0.002	-0.000	0.002	0.004*	0.006**	-0.002	0.002	0.001	0.003	0.003**	-0.002	0.001	0.001	0.004*	0.004
INF	-0.061***	-0.049***	-0.067***	-0.060***	-0.086***	-0.060***	-0.060***	-0.090***	-0.084***	-0.095***	-0.072***	-0.057***	-0.091***	-0.063***	-0.068***
POD	-0.140***	-0.169***	-0.189***	-0.215***	-0.226***	-0.191***	-0.196***	-0.211***	-0.219***	-0.228***	-0.147***	-0.218***	-0.223***	-0.244***	-0.267***
REW	0.017	0.050*	0.127***	0.156***	0.143***	-0.047*	0.046*	0.077***	0.109***	0.102***	-0.004	0.013	0.066***	0.103***	0.117***
UMP	2.362***	2.437***	2.565***	2.769***	3.339***	2.640***	2.244***	2.280***	2.650***	3.108***	1.586***	2.207***	2.019***	2.137***	2.409***
C	0.592	0.607	0.658	0.663	0.647	0.555	0.589	0.637	0.650	0.647	0.593	0.614	0.645	0.660	0.650
Pseudo R ²															
Cropland															
TA	0.027***	0.030***	0.016***	0.017***	0.017***	0.029***	0.023***	0.011**	0.015***	0.022***	0.028***	0.028***	0.016***	0.019***	0.022***
COM	-0.006	-0.006	0.037***	0.020*	0.020	-0.004	0.020*	0.060***	0.035***	0.018	-0.011	0.009	0.047***	0.020*	0.012
ECO	-0.085***	-0.131***	-0.100***	-0.107***	-0.167***	-0.098***	-0.087***	-0.054***	-0.073***	-0.097***	-0.080***	-0.075***	-0.053***	-0.073***	-0.136***
SOC															
POL															

Table 3 (continued)

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	
EXG	-0.010***	-0.013***	-0.007***	-0.002	-0.003	-0.007***	-0.010***	-0.005**	-0.001	-0.005*	-0.010***	-0.011***	-0.008***	-0.002	0.003	-0.010***	-0.011***	-0.008***	-0.002	0.003	
GDP	-0.002	-0.000	0.002*	0.004**	0.005***	-0.002*	-0.000	0.002	0.003*	0.003*	-0.001	-0.001	0.001	0.003**	0.004**	-0.001	-0.001	0.008	0.003**	0.004**	
IND	0.027	-0.008	-0.003	-0.048**	-0.036	0.043**	-0.000	-0.009	-0.010	-0.064**	0.053***	0.009	0.008	-0.034	-0.026	0.053***	0.009	0.008	-0.034	-0.026	
INF	-0.001	0.000	0.001	0.002*	0.003**	-0.001	-0.000	0.000	0.002*	0.001	-0.001	-0.000	0.001	0.002*	0.003**	-0.001	-0.000	0.001	0.002*	0.003**	
POD	-0.002	-0.005	-0.024***	-0.032***	-0.042***	-0.002	-0.012**	-0.035***	-0.037***	-0.040***	0.000	-0.011**	-0.026***	-0.033***	-0.038***	0.000	-0.011**	-0.026***	-0.033***	-0.038***	-0.038***
REW	0.005	0.015**	-0.003	-0.004	0.003	0.005	0.013*	-0.010	-0.008	-0.006	0.001	0.011*	-0.007	-0.010	-0.016**	0.001	0.011*	-0.007	-0.010	-0.016**	
UMP	-0.028**	0.028***	0.054***	0.046***	0.054***	-0.030***	0.022**	0.037***	0.045***	0.035***	-0.036***	0.013	0.045***	0.040***	0.042***	-0.036***	0.013	0.045***	0.040***	0.042***	
C	0.139	0.271**	0.491***	0.747***	0.915***	0.090	0.245*	0.553***	0.577***	0.820***	0.037	0.145	0.362***	0.609***	0.775***	0.037	0.145	0.362***	0.609***	0.775***	
Pseudo R ²	0.236	0.273	0.310	0.309	0.289	0.254	0.265	0.294	0.300	0.280	0.243	0.258	0.298	0.307	0.310	0.243	0.258	0.298	0.307	0.310	
Fishing																					
TA	0.006***	0.006***	-0.003	-0.019*	-0.024***	0.005***	0.008***	-0.002	-0.013	-0.015*	0.005***	0.008***	-0.001	-0.010	-0.019***	0.005***	0.008***	-0.001	-0.010	-0.019***	
COM	-0.001	-0.001	0.000	0.006	0.012	0.002	0.006	0.006	0.035	0.041**	-0.002	0.005	-0.003	-0.001	0.013	-0.002	0.005	-0.003	-0.001	0.013	
ECO	-0.037***	-0.058***	-0.127***	-0.297***	-0.329***	-0.022***	-0.015**	-0.082***	-0.208***	-0.284***	-0.022***	-0.015**	-0.082***	-0.208***	-0.284***	-0.022***	-0.015**	-0.082***	-0.208***	-0.284***	
SOC																					
POL	-0.001*	-0.001	-0.001	-0.003	-0.008**	-0.000	0.000	-0.000	-0.001	-0.006	-0.000	0.000	-0.001	-0.001	-0.008***	-0.000	0.000	-0.001	-0.001	-0.008***	
EXG	-0.000	-0.000	-0.002	-0.000	-0.001	-0.000	-0.000	-0.002*	-0.000	0.000	-0.000	-0.000	-0.002	-0.000	-0.001	-0.000	-0.000	-0.002	-0.001	-0.008***	
GDP	-0.017***	0.001	0.051**	0.178***	0.129***	-0.020***	-0.008	0.054***	0.150***	0.175***	-0.012***	-0.002	0.056***	0.145***	0.116***	-0.012***	-0.002	0.056***	0.145***	0.116***	
IND	-0.000	-0.001	-0.000	0.002	-0.001	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000**	-0.000	-0.000	-0.000	0.001	-0.000**	-0.000	-0.000	-0.000	0.001	
INF	0.002**	0.005**	0.017***	0.021*	-0.013**	0.003***	0.002	0.012***	0.010	0.001	0.002***	0.002	0.017***	0.025***	-0.016**	0.002***	0.002	0.017***	0.025***	-0.016**	
POD	0.003***	0.005**	0.009	0.032**	0.032***	-0.002	-0.000	0.007	0.025*	0.032***	0.000	0.002	0.001	0.018**	0.018**	0.000	0.002	0.001	0.018**	0.018**	
REW	-0.001	-0.003	-0.022**	-0.041*	-0.098***	-0.001	-0.002	-0.025***	-0.061***	-0.100***	-0.000	-0.004	-0.029***	-0.055***	-0.130***	-0.000	-0.004	-0.029***	-0.055***	-0.130***	
UMP	0.088***	0.080*	0.269**	0.578**	1.296***	0.071***	-0.018	0.142	0.438*	0.792***	0.057***	-0.002	0.128	0.415*	1.115***	0.057***	-0.002	0.128	0.415*	1.115***	
C																					
Pseudo R ²	0.131	0.116	0.149	0.240	0.394	0.121	0.102	0.130	0.213	0.372	0.137	0.111	0.153	0.261	0.413	0.137	0.111	0.153	0.261	0.413	
Forest																					
TA	0.018***	0.013***	0.011	-0.013	-0.042***	0.019***	0.014**	0.009	-0.017	-0.024*	0.024***	0.019***	0.009	-0.007	-0.039**	0.024***	0.019***	0.009	-0.007	-0.039**	
COM	-0.002	0.009	0.034**	0.080***	0.149***	0.027***	0.028**	0.026	0.069***	0.077***	-0.011	0.010	0.021	0.064**	0.134***	-0.011	0.010	0.021	0.064**	0.134***	
ECO	-0.178***	-0.235***	-0.300***	-0.349***	-0.304***	-0.135***	-0.185***	-0.312***	-0.374***	-0.442***	-0.135***	-0.185***	-0.312***	-0.374***	-0.442***	-0.135***	-0.185***	-0.312***	-0.374***	-0.442***	
SOC																					
POL	-0.006***	-0.009***	-0.006**	-0.007	-0.007	-0.001	-0.003	-0.007*	-0.007	-0.016**	-0.003	-0.006**	-0.011***	-0.007	-0.001	-0.003	-0.006**	-0.011***	-0.007	-0.001	
EXG	0.001	0.002	0.001	-0.002	0.005	-0.002**	-0.002	-0.000	-0.001	0.002	0.000	0.001	-0.001	0.003	0.002	0.000	0.001	-0.001	0.003	0.002	
GDP	-0.094***	-0.085***	-0.066**	-0.057	-0.045	-0.049***	-0.050*	-0.008	0.022	-0.072	-0.056***	-0.052**	-0.019	0.016	-0.055	-0.056***	-0.052**	-0.019	0.016	-0.055	
IND	0.001	0.001	0.000	0.003	0.005*	0.002**	0.001	0.000	0.002	0.004	0.000	0.001	-0.000	0.002	0.004	0.000	0.001	-0.000	0.002	0.004	
INF	-0.013***	-0.018***	-0.034***	-0.051***	-0.072***	-0.022***	-0.021***	-0.034***	-0.046***	-0.081***	-0.018***	-0.022***	-0.032***	-0.034***	-0.080***	-0.018***	-0.022***	-0.032***	-0.034***	-0.080***	
POD	0.040***	0.057***	0.062***	0.074***	0.084***	0.050***	0.057***	0.058***	0.070***	0.059***	0.036***	0.048***	0.060***	0.057***	0.050**	0.036***	0.048***	0.060***	0.057***	0.050**	
REW																					

Table 3 (continued)

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	
UMP	0.034***	0.039***	0.048***	-0.001	0.034	0.024***	0.025**	0.021	0.032	-0.020	0.024**	0.027**	0.029**	-0.004	-0.040						
C	0.593***	0.797***	1.060***	1.750***	2.112***	0.306***	0.552***	0.988***	1.534***	2.523***	0.369***	0.472***	0.857***	1.158***	2.209***						
Pseudo R ²	0.270	0.279	0.326	0.338	0.331	0.245	0.260	0.343	0.406	0.389	0.270	0.281	0.338	0.363	0.331						
Grazing																					
TA	0.004	-0.001	-0.019***	-0.039**	-0.092***	-0.004	0.001	-0.016**	-0.046***	-0.079***	0.006*	0.004	-0.015**	-0.038**	-0.090***						
COM	-0.036***	-0.035***	-0.031**	0.005	-0.004	-0.024***	-0.034***	-0.022*	-0.012	-0.019	-0.041***	-0.044***	-0.036**	0.001	0.034						
ECO	-0.166***	-0.156***	-0.147***	-0.056	-0.154***																
SOC						-0.143***	-0.141***	-0.142***	-0.211***	-0.220***											
POL											-0.124***	-0.124***	-0.115***	-0.042	0.035						
EXG	-0.003**	-0.002	-0.002	-0.004	0.012*	-0.002	-0.003	0.001	-0.004	0.008	-0.002	-0.002	-0.002	-0.004	0.020***						
GDP	0.001	0.002*	0.003	0.006	0.009**	-0.001	0.001	0.004**	0.005	0.009**	0.001	0.001	0.003	0.007	0.008**						
IND	-0.060***	-0.063***	-0.121***	-0.155**	-0.247***	-0.013	-0.048**	-0.124***	-0.095	-0.195***	-0.022	-0.046***	-0.115***	-0.156*	-0.384***						
INF	0.000	-0.001	-0.003*	-0.000	0.001	-0.000	-0.003***	-0.002	0.003	0.000	-0.001	-0.001*	-0.003	-0.000	0.003						
POD	-0.019***	-0.025***	-0.056***	-0.100***	-0.149***	-0.020***	-0.024***	-0.058***	-0.092***	-0.162***	-0.021***	-0.021***	-0.061***	-0.099***	-0.149***						
REW	-0.006*	-0.010**	-0.025***	-0.052**	-0.135***	-0.010***	-0.014**	-0.031***	-0.039**	-0.140***	-0.015***	-0.022***	-0.031***	-0.056***	-0.163***						
UMP	0.014**	0.015*	-0.022	-0.098***	-0.179***	-0.010	0.005	-0.019	-0.073**	-0.148***	-0.001	0.007	-0.037***	-0.095***	-0.191***						
C	0.769***	0.897***	1.658***	2.303***	4.428***	0.713***	0.799***	1.605***	2.497***	4.246***	0.557***	0.698***	1.537***	2.246***	4.405***						
Pseudo R ²	0.210	0.202	0.197	0.237	0.447	0.203	0.208	0.216	0.275	0.467	0.220	0.226	0.208	0.236	0.441						

This table presents the quantile regression estimates according to the empirical model defined by Eq. (1). The others are the same as the notes in Tables 1 and 2

Table 4 Quantile regression for country security interaction results

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90
Built															
TA	0.045***	0.041***	0.035***	0.065***	0.044***	0.025***	0.019***	0.018	0.031*	0.021	0.021***	0.029***	0.023**	0.045***	0.052***
COM	-0.013	0.003	-0.030**	-0.019	0.042***	-0.013**	-0.002	-0.018	0.019	0.059***	-0.005	0.003	-0.011	-0.016	0.035***
ECO	0.218***	0.200***	0.156**	0.281**	0.166**										
TAECO	-0.015***	-0.013***	-0.012***	-0.021**	-0.014***										
COMECO	0.005*	0.000	0.011**	0.009	-0.010*										
SOC				0.105***	0.087**	0.105***	0.087**	0.068	0.127	0.053					
TASOC				-0.007***	-0.006**	-0.007***	-0.006**	-0.006	-0.010	-0.006					
COMSOC				0.006**	0.002	0.006**	0.002	0.008	-0.003	-0.016**					
POL						0.083***	0.140***	0.101*	0.189**	0.189**	0.083***	0.140***	0.101*	0.189**	0.225***
TAPOL						-0.006***	-0.009***	-0.008**	-0.015**	-0.017***	-0.006***	-0.009***	-0.008**	-0.015**	-0.017***
COMPOL						0.002	-0.000	0.005	0.008	0.006	0.002	-0.000	0.005	0.008	-0.006
Pseudo R ²	0.182	0.172	0.142	0.213	0.345	0.171	0.156	0.143	0.216	0.321	0.183	0.173	0.144	0.222	0.348
Carbon															
TA	0.411***	0.323**	0.400***	0.345***	0.230*	0.183	0.281***	0.306***	0.287***	0.157**	0.078	0.078	0.200***	0.189***	0.077
COM	-0.108	-0.270*	-0.304***	-0.236**	-0.114	0.420***	0.066	-0.023	-0.015	-0.053	0.061	-0.123	-0.062	-0.038	0.000
ECO	1.164**	0.789	1.209***	0.762	0.359										
TAECO	-0.124***	-0.101**	-0.126***	-0.096***	-0.066										
COMECO	0.083**	0.147***	0.1159***	0.119***	0.074										
SOC				0.109	0.610	0.109	0.610	0.839*	0.828*	0.113					
TASOC				-0.037	-0.079**	-0.037	-0.079**	-0.091***	-0.087***	-0.040*					
COMSOC				-0.106*	0.025	-0.106*	0.025	0.068*	0.066	0.074**					
POL						-0.557	-0.380	0.323	0.200	-0.338	-0.557	-0.380	0.323	0.200	-0.338
TAPOL						0.004	-0.014	-0.052**	-0.040*	-0.005	0.004	-0.014	-0.052**	-0.040*	-0.005
COMPOL						0.012	0.083***	0.075***	0.054**	0.036	0.012	0.083***	0.075***	0.054**	0.036
Pseudo R ²	0.605	0.620	0.668	0.670	0.648	0.561	0.595	0.644	0.655	0.649	0.594	0.619	0.650	0.663	0.650
Cropland															
TA	0.312***	0.275***	0.142***	0.093*	0.035	0.224***	0.203***	0.090*	0.006	0.079	0.164***	0.135***	0.017	0.022	-0.002
COM	-0.210***	-0.222***	-0.187***	-0.163***	-0.246***	-0.199***	-0.194***	-0.049	-0.006	-0.126*	-0.121***	-0.059	0.015	-0.024	0.034
ECO	1.422***	1.207***	0.534**	0.244	-0.177										
TAECO	-0.100***	-0.090***	-0.047***	-0.027	-0.006										
COMECO	0.080***	0.086***	0.083***	0.068**	0.088***										
SOC				0.967***	0.902***	0.967***	0.902***	0.378	-0.132	0.148					
TASOC				-0.072***	-0.069***	-0.072***	-0.069***	-0.030*	0.003	-0.020					
COMSOC				0.077***	0.082***	0.077***	0.082***	0.043*	0.015	0.049*					
POL						0.632***	0.530***	-0.045	-0.064	-0.255	0.632***	0.530***	-0.045	-0.064	-0.255
TAPOL						-0.048***	-0.040***	-0.001	-0.001	0.008	-0.048***	-0.040***	-0.001	-0.001	0.008

Table 4 (continued)

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	
COMPOL	0.277	0.315	0.333	0.320	0.299	0.280	0.297	0.299	0.301	0.283	0.044***	0.030**	0.013	0.016	0.007	0.255	0.273	0.299	0.308	0.310	
Pseudo R ²																					
Fishing																					
TA	0.079***	0.079***	0.071	-0.118	-0.350***	0.069***	0.064***	0.023	-0.138	-0.041	0.029***	0.013	0.014	-0.114*	-0.299***						
COM	-0.048***	-0.072***	-0.083*	-0.112	0.051	-0.065***	-0.061***	-0.053	-0.032	0.078	-0.054***	-0.066***	-0.036	-0.111	0.022						
ECO	0.341***	0.330***	0.252	-0.868	-2.063***																
TAECO	-0.026***	-0.026***	-0.025	0.034	0.112***																
COMECO	0.016***	0.027***	0.027	0.038	-0.020																
SOC						0.305***	0.279***	0.035	-0.871*	-0.415											
TASOC						-0.022***	-0.021***	-0.009	0.044	0.009											
COMSOC						0.024***	0.025***	0.021	0.028	-0.013											
POL											0.084**	-0.010	-0.014	-0.824**	-1.786***						
TAPOL											-0.009***	-0.003	-0.005	0.036	0.098***						
COMPOL											0.018***	0.026***	0.011	0.036	-0.013						
Pseudo R ²	0.153	0.130	0.154	0.250	0.422	0.137	0.115	0.134	0.223	0.372	0.147	0.124	0.154	0.287	0.448						
Forest																					
TA	0.287***	0.304***	0.221***	-0.162	-0.491***	0.231***	0.266***	0.098	-0.256***	-0.331**	0.209***	0.177***	0.097*	-0.135	-0.397**						
COM	-0.308***	-0.240***	-0.283***	-0.003	0.292*	-0.207***	-0.232***	-0.121	0.140	0.388*	-0.271***	-0.289***	-0.165***	0.035	0.362**						
ECO	1.105***	1.230***	0.736**	-1.157	-2.690***																
TAECO	-0.093***	-0.100***	-0.074***	0.053	0.155***																
COMECO	0.107***	0.089***	0.112***	0.029	-0.048																
SOC						0.971***	1.119***	0.128	-1.654***	-1.912**											
TASOC						-0.078***	-0.089***	-0.031	0.085***	0.104*											
COMSOC						0.086***	0.095***	0.050	-0.026	-0.097											
POL											0.804***	0.594***	0.155	-1.010**	-2.163**						
TAPOL											-0.068***	-0.056***	-0.030	0.048	0.126**						
COMPOL											0.098***	0.108***	0.066***	0.010	-0.072						
Pseudo R ²	0.322	0.318	0.342	0.344	0.355	0.269	0.284	0.344	0.422	0.402	0.320	0.322	0.348	0.374	0.362						
Grazing																					
TA	-0.028	0.049	-0.095	-0.394**	-0.836***	-0.130***	-0.015	-0.119**	-0.265**	-0.608***	0.015	-0.002	-0.009	0.077	-0.441***						
COM	0.023	-0.000	-0.007	0.414**	0.871***	0.126***	0.017	-0.037	0.057	0.525***	-0.020	-0.026	-0.049	0.018	0.486***						
ECO	-0.302	0.093	-0.552	-1.926**	-3.987***																
TAECO	0.011	-0.016	0.027	0.124**	0.265***																
COMECO	-0.020	-0.013	-0.008	-0.152**	-0.301***																
SOC						-0.775***	-0.212	-0.731***	-1.351**	-2.920***											
TASOC						0.045***	0.006	0.035**	0.074*	0.184***											

Table 4 (continued)

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90
COMSOC															
POL															
TAPOL															
COMPOL															
Pseudo R ²	0.211	0.204	0.200	0.243	0.468	0.221	0.211	0.224	0.286	0.490	0.221	0.226	0.209	0.240	0.447

This table presents the quantile regression estimates according to the empirical model defined by Eq. (2). Due to space limitation, this table omits the results of control variables (real exchange rate, GDP per capita growth, industry value added, inflation, log of population density, renewable energy consumption, unemployment rate). The others are the same as the notes in Tables 1 and 2

COM) effect on GRAZ. Generally, ECO, POL, and SOC may mitigate the negative (positive) impact between COM (TA) and EF, although CS seems very bad to the tourism environment. Our finding does not support H4 that country security enhances the positive influence of tourism development on ecological footprint. Additionally, H5, in which country security enhances the negative influence of economic complexity on EF, is not supported. The three kinds of country securities (i.e., ECO, POL, and SOC) decrease the positive (negative) impact of TA (COM) on EF. Our results highlight the fact that average results do not hold for all quantiles of the EF distribution, as the significance and intensity of the TA, CS, and COM effects vary across quantiles. To save space, we display only the estimations for the main independent variables. Our findings are therefore constant with the fact of Tuite et al. (2020) that a higher total security index (FSI) relates to a reduction in tourism volumes. Moreover, we extend their findings to when a nation is insecure, its TA decrease, and then its environmental quality becomes better.

EKC hypotheses

Tourism development–induced EKC hypothesis

The quantile analyses in Table 5 generally expose a negative influence of TA and a positive impact of TA² on EF (i.e., a U-shaped relation) at most of the quantiles, indicating that when TA are large enough, then EF increases. TA have a positive impact on EF especially under the linear quantile regression, while as TA reach a specific threshold, environmental quality worsens. However, FOR at the 75th–90th quantiles, FISH at the 75th and 90th quantiles, and GRAZ at the 50th quantile show an inverted U-shaped link with TA, confirming the EKC hypothesis. The findings confirm Godil et al. (2020) and De Vita et al. (2015) who support the tourism-induced EKC. The findings of this study support the tourism development–induced ECK hypothesis only for FOR at the 75th–90th quantiles, FISH at the 75th and 90th quantiles, and GRAZ at the 50th quantile. However, most of the relationships between TA and EF show a U shape. This could be explained by more TA reach a specific level that then increases EF. Increasing TA might raise EF and the demand for environmental sacrifice, thereby increasing environmental degradation.

Economic complexity–induced EKC hypothesis

As for economic complexity, the quantile regression stated in Table 6 discloses its heterogeneous impacts on EF across quantiles. COM exerts an important positive effect in several quantiles of BUI, CAR, CROP, and FOR, indicating

Table 5 Quantile regression for tourism development–induced EKC hypothesis

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90
Built															
TA	0.006	-0.006	-0.030*	-0.022	-0.013	0.006	-0.011	-0.013	-0.029	-0.016	0.001	-0.016*	-0.032*	-0.039*	-0.007
TA ²	-0.000	0.000	0.001*	0.001	0.001	-0.000	0.000	0.000	0.001	0.001	0.000	0.001*	0.001*	0.001*	0.000
COM	0.001	0.003*	0.002	0.008*	0.011***	0.002	0.005***	0.005*	0.008*	0.008*	0.000	0.002	0.002	0.005	0.012***
ECO	-0.007**	-0.012***	-0.025***	-0.030***	-0.071***										
SOC						-0.005	-0.012***	-0.027***	-0.039***	-0.045***					
POL											-0.007***	-0.012***	-0.022***	-0.037***	-0.047***
Pseudo R ²	0.167	0.153	0.133	0.206	0.323	0.164	0.152	0.140	0.209	0.296	0.176	0.161	0.144	0.222	0.322
Carbon															
TA	-0.421***	-0.465***	-0.189*	-0.106	0.070	-0.388**	-0.252*	-0.063	-0.110	0.059	-0.192	-0.513***	-0.394***	-0.265**	-0.159
TA ²	0.017***	0.018***	0.008**	0.006	-0.001	0.016***	0.011**	0.004	0.005	-0.000	0.010**	0.020***	0.016***	0.012***	0.007*
COM	0.076***	0.062**	0.108***	0.081***	0.133***	0.127***	0.111***	0.132***	0.144***	0.158***	0.085***	0.043**	0.118***	0.081***	0.098***
ECO	-0.729***	-0.697***	-0.624***	-0.648***	-0.581***										
SOC						-0.531***	-0.641***	-0.550***	-0.482***	-0.449***					
POL											-0.496***	-0.557***	-0.451***	-0.462***	-0.425***
Pseudo R ²	0.608	0.620	0.659	0.664	0.647	0.563	0.596	0.639	0.650	0.647	0.602	0.629	0.650	0.663	0.653
Cropland															
TA	-0.154***	-0.209***	-0.188***	-0.112**	0.054	-0.110**	-0.194***	-0.196***	-0.062	0.038	-0.200***	-0.215***	-0.175***	-0.123**	0.007
TA ²	0.006***	0.008***	0.007***	0.004**	-0.001	0.005***	0.007***	0.007***	0.003	-0.001	0.008***	0.008***	0.006***	0.005**	0.001
COM	-0.013	-0.012	0.028***	0.016	0.021	-0.013	0.011	0.048***	0.033***	0.021	-0.022***	0.001	0.041***	0.015	0.011
ECO	-0.126***	-0.127***	-0.122***	-0.124***	-0.166***										
SOC						-0.115***	-0.099***	-0.065***	-0.080***	-0.101***					
POL											-0.099***	-0.081***	-0.063***	-0.090***	-0.139***
Pseudo R ²	0.247	0.292	0.328	0.318	0.289	0.263	0.280	0.306	0.304	0.281	0.263	0.277	0.312	0.317	0.310
Fishing															
TA	-0.039***	-0.065***	-0.020	0.085	0.211***	-0.026*	-0.057***	0.026	0.206*	0.155	-0.022	-0.067***	-0.006	0.111	0.122
TA ²	0.002***	0.002***	0.001	-0.004	-0.008***	0.001**	0.002***	-0.001	-0.008*	-0.006*	0.001*	0.003***	0.000	-0.004	-0.005
COM	-0.002	-0.003	-0.001	0.019	0.019	-0.001	0.005	0.007	0.047**	0.053***	-0.002	0.000	-0.003	0.007	0.012
ECO	-0.038***	-0.054***	-0.131***	-0.272***	-0.316***										
SOC						-0.024***	-0.018***	-0.081***	-0.177***	-0.264***					
POL											-0.028***	-0.029***	-0.085***	-0.223***	-0.239***
Pseudo R ²	0.135	0.124	0.149	0.245	0.414	0.122	0.110	0.131	0.221	0.379	0.139	0.121	0.153	0.267	0.415
Forest															
TA	-0.098**	-0.108*	-0.022	0.378***	0.567***	-0.117***	-0.051	0.108	0.277***	0.398**	-0.102*	-0.152***	0.046	0.279**	0.616**
TA ²	0.004***	0.004**	0.001	-0.013***	-0.020***	0.005***	0.002	-0.003	-0.010***	-0.014**	0.004**	0.006***	-0.001	-0.010**	-0.022***
COM	-0.011	0.002	0.029*	0.093***	0.165***	0.021***	0.022*	0.032*	0.074***	0.104***	-0.011	-0.008	0.021	0.091***	0.165***

Table 5 (continued)

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90
ECO	-0.199***	-0.241***	-0.300***	-0.313***	-0.260***										
SOC						-0.150***	-0.198***	-0.316***	-0.368***	-0.356***					
POL											-0.150***	-0.179***	-0.245***	-0.222***	-0.159***
Pseudo R ²	0.286	0.284	0.326	0.357	0.353	0.261	0.262	0.345	0.415	0.402	0.288	0.293	0.338	0.369	0.347
Grazing															
TA	0.008	0.047	0.117	0.155	-0.083	0.030	0.019	0.146*	-0.125	-0.041	-0.030	0.017	0.023	0.165	0.131
TA ²	-0.000	-0.002	-0.005*	-0.006	-0.000	-0.001	-0.001	-0.005**	0.003	-0.001	0.001	-0.000	-0.001	-0.007	-0.007
COM	-0.036***	-0.033***	-0.024	0.008	-0.003	-0.022***	-0.031***	-0.023*	-0.015	-0.015	-0.042***	-0.043***	-0.034**	0.008	0.049*
ECO	-0.165***	-0.151***	-0.125***	-0.040	-0.154***										
SOC						-0.144***	-0.137***	-0.148***	-0.227***	-0.217***					
POL											-0.124***	-0.124***	-0.111***	-0.024	0.060
Pseudo R ²	0.210	0.203	0.200	0.239	0.447	0.204	0.208	0.221	0.275	0.467	0.222	0.226	0.208	0.239	0.442

This table presents the quantile regression estimates according to the empirical model defined by Eq. (3). The others are the same as the notes in Tables 1, 2, and 4. The shaded area presents support of the EKC hypothesis

Table 6 Quantile regression for economic complexity–induced EKC hypothesis

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90
Built															
TA	0.004***	0.001*	0.002	0.000	0.004***	0.002**	-0.000	0.000	0.004**	0.004*	0.004***	0.001*	0.001	0.001	0.002
COM	0.002	0.002	0.013***	0.014***	0.001	0.003*	0.005*	0.011**	0.009**	-0.001	0.002	0.002	0.002	0.008*	0.014***
COM ²	0.002*	0.001	-0.002	0.001	0.003	0.002*	-0.001	0.002	0.002	0.002	0.001	0.001	-0.002	-0.000	-0.001
ECO	-0.006*	-0.010***	-0.029***	-0.022**	-0.069***										
SOC						-0.006**	-0.007**	-0.029***	-0.032***	-0.043***	-0.007***	-0.008***	-0.024***	-0.032***	-0.048***
POL											0.178	0.160	0.139	0.215	0.321
Pseudo R ²	0.169	0.154	0.129	0.203	0.325	0.168	0.154	0.139	0.209	0.296	0.183***	0.160	0.139	0.215	0.321
Carbon															
TA	0.084***	0.043***	0.053***	0.070***	0.025**	0.066***	0.066***	0.055***	0.047***	0.044***	0.083***	0.043***	0.058***	0.072***	0.053***
COM	0.079***	0.114***	0.123***	0.091***	0.148***	0.111***	0.128***	0.151***	0.142***	0.153***	0.069***	0.097***	0.140***	0.103***	0.116***
COM ²	0.008	-0.027	-0.010	-0.011	0.024*	0.052***	0.014	0.007	0.013	0.005	0.010	-0.014	-0.001	0.004	0.015
ECO	-0.660***	-0.674***	-0.624***	-0.616***	-0.562***										
SOC						-0.458***	-0.541***	-0.506***	-0.469***	-0.451***	-0.511***	-0.525***	-0.422***	-0.410***	-0.400***
POL											0.594	0.614	0.645	0.660	0.652
Pseudo R ²	0.593	0.609	0.658	0.663	0.648	0.560	0.590	0.638	0.651	0.647	0.594	0.614	0.645	0.660	0.652
Cropland															
TA	0.018***	0.017***	0.010**	0.016***	0.019***	0.023***	0.011**	0.007	0.014***	0.020***	0.019***	0.018***	0.013**	0.020***	0.021***
COM	0.016	0.019*	0.041***	0.024**	0.014	0.016*	0.048***	0.069***	0.037***	0.010	0.017**	0.037***	0.054***	0.019	0.008
COM ²	-0.021***	-0.026***	-0.020***	-0.011	-0.009	-0.016***	-0.026***	-0.016**	-0.002	-0.014*	-0.020***	-0.028***	-0.016**	-0.011	-0.010
ECO	-0.109***	-0.161***	-0.136***	-0.117***	-0.194***										
SOC						-0.104***	-0.111***	-0.066***	-0.072***	-0.131***	-0.088***	-0.096***	-0.070***	-0.083***	-0.140***
POL											0.265	0.276	0.304	0.310	0.314
Pseudo R ²	0.262	0.293	0.323	0.310	0.292	0.267	0.284	0.297	0.300	0.285	0.265	0.276	0.304	0.310	0.314
Fishing															
TA	0.003***	0.002	-0.002	-0.015	-0.019**	0.003***	0.007***	-0.002	-0.017	-0.016*	0.004***	0.003	-0.000	-0.013	-0.016**
COM	0.002	0.004	-0.006	-0.004	-0.017	0.002	0.007	0.005	0.039	0.022	0.001	0.002	-0.004	-0.014	-0.007
COM ²	-0.011***	-0.014***	-0.012*	-0.029**	-0.035***	-0.005***	-0.001	-0.005	-0.014	-0.027***	-0.009***	-0.015***	-0.007	-0.026**	-0.034***
ECO	-0.070***	-0.084***	-0.143***	-0.330***	-0.404***										
SOC						-0.037***	-0.016**	-0.090***	-0.232***	-0.333***	-0.044***	-0.058***	-0.090***	-0.280***	-0.266***
POL											0.148	0.122	0.156	0.289	0.439
Pseudo R ²	0.141	0.129	0.154	0.265	0.419	0.124	0.102	0.132	0.218	0.382	0.148	0.122	0.156	0.289	0.439
Forest															
TA	0.014***	0.013***	0.012	-0.008	-0.045***	0.021***	0.012*	0.011	-0.006	-0.025*	0.017***	0.015***	0.010	-0.004	-0.050***
COM	-0.003	0.008	0.035**	0.062**	0.151***	0.022**	0.035***	0.019	0.052**	0.077***	-0.006	0.012	0.022	0.062**	0.143***
COM ²	-0.010*	-0.016***	-0.011	-0.011	0.007	0.005	-0.011	-0.010	-0.018	-0.001	-0.007	-0.017***	-0.019**	-0.006	0.018
ECO	-0.233***	-0.275***	-0.313***	-0.372***	-0.307***										

Table 6 (continued)

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	
SOC																					
POL																					
Pseudo R ²	0.275	0.287	0.327	0.339	0.332	0.247	0.263	0.344	0.407	0.389	0.273	0.288	0.342	0.364	0.334	-0.178***	-0.203***	-0.263***	-0.276***	-0.229***	
Grazing																					
TA	0.003	0.000	-0.017**	-0.028*	-0.089***	-0.003	0.001	-0.017**	-0.037**	-0.088***	0.006	0.004	-0.017**	-0.028*	-0.087***						
COM	-0.034***	-0.034***	-0.022	-0.066**	0.001	-0.025***	-0.030***	-0.023	-0.048	0.002	-0.041***	-0.044***	-0.021	-0.063**	0.052						
COM ²	-0.001	0.004	0.025***	0.085***	0.036*	0.007*	0.009*	0.013	0.036**	0.015	0.000	0.003	0.017*	0.087***	0.091***						
ECO	-0.165***	-0.154***	-0.064**	0.020	-0.091																
SOC																					
POL																					
Pseudo R ²	0.210	0.202	0.207	0.263	0.448	0.209	0.213	0.221	0.279	0.468	0.220	0.227	0.211	0.264	0.451	-0.124***	-0.120***	-0.066***	0.031	0.108**	

This table presents the quantile regression estimates according to the empirical model defined by Eq. (4). The others are the same as the notes in Tables 1, 2, and 4. The shaded area presents support of the EKC hypothesis

COM does not upgrade environmental quality, while there is no salient impact on COM². As shown in CROP, the inverted U shapes exist in the 10th–50th quantiles, supporting H6 that economic complexity has an inverted U-shaped relation with EF (i.e., supporting economic complexity-induced EKC hypothesis in CROP). The results therefore indicate that economic complexity worsens environmental quality, and this is in line with preceding studies of Yilanci and Pata (2020) that COM has a growing influence on the total score of ecological footprints, and COM does not effectively resolve environmental degradation, while economic complexity-induced EKC hypothesis is not supported in Yilanci and Pata (2020) who use EF per capita. In contrast, we find a U-shaped link between GRAZ and COM, signifying that a negative relationship existing between GRAZ and COM will change to a positive relationship as COM reaches a specific level. Therefore, our findings emphasize that the existing empirical research studies on CO₂ or integrated EF effects of COM might have a bias that cannot depict the whole picture of the environment. Additionally, we show that COM has varying impacts on diverse EF lands and across diverse EF quantiles. The impact of COM is heterogeneous across the quantiles.

Country security-induced EKC hypothesis

As for country security, the quantile regression stated in Table 7 discloses its heterogeneous impacts on EF across quantiles. CS exerts a U-shaped relationship with CAR, FISH, and GRAZ, indicating that as country insecurity increases to a specific level, CAR, FISH, and GRAZ lands are exhausted. However, CS shows an inverted U-shaped link with FOR at the 50th–90th quantiles, BUI at the 25th–50th quantiles, and CROP at the 50th–75th quantiles, supporting the country security-induced EKC hypothesis. The results therefore indicate that country insecurity increases usages of BUI, CROP, and FOR. The effect of CS is heterogeneous across the quantiles as well as across different sub-kinds of EF. Overall, this study initially finds that CS has an inverted U shape with EF and partially supports H7 for the country security-induced EKC hypothesis. However, Lee and Chen (2021) find that country risk ratings have shifted from enhancing more environmentally protective policies to encouraging EF-consuming lifestyles for these EF components.

Robustness checks

Wald F statistics are employed to assess the equality of coefficients across the quantile regression results. Non-linearity is also examined by the Wald F-test across quantiles with the six sub-types of EF as the dependent

Table 7 Quantile regression for country security–induced EKC hypothesis

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90
Built															
TA	0.003***	0.000	0.001	-0.000	-0.000	0.003***	0.000	0.001	0.001	0.002	0.003***	0.001	0.001	0.001	0.001
COM	0.002	0.003**	0.003	0.012**	0.018***	0.002	0.005***	0.006**	0.010**	0.014***	0.000	0.002	0.001	0.008	0.017***
ECO	0.030	0.092***	0.234***	0.084	-0.194***										
ECO ²	-0.007	-0.021***	-0.051***	-0.022	0.026**										
SOC					0.040	0.072***	0.079**	-0.020	-0.020	-0.327***					
SOC ²					-0.009*	-0.017***	-0.020***	-0.002	-0.002	0.054***					
POL											0.000	0.033**	0.041	-0.030	-0.158***
POL ²											-0.002	-0.009**	-0.014**	-0.000	0.025***
Pseudo R ²	0.169	0.161	0.145	0.209	0.325	0.167	0.167	0.147	0.207	0.317	0.176	0.165	0.142	0.215	0.341
Carbon															
TA	0.065***	0.038**	0.048***	0.066***	0.032***	0.082***	0.065***	0.060***	0.067***	0.043***	0.073***	0.046***	0.062***	0.074***	0.060***
COM	0.068***	0.098***	0.126***	0.058**	0.063***	0.159***	0.149***	0.163***	0.153***	0.158***	0.104***	0.096***	0.137***	0.101***	0.105***
ECO	0.115	0.479	0.214	0.941**	1.755***										
ECO ²	-0.174**	-0.232*	-0.169**	-0.324***	-0.483***										
SOC					-1.687***	-1.312***	-1.480***	-1.671***	-0.402	-0.402					
SOC ²					0.238***	0.157*	0.204***	0.248***	-0.010	-0.010					
POL											-0.094	-0.355	-0.568**	-0.469**	-0.349
POL ²											-0.091*	-0.033	0.033	0.012	-0.012
Pseudo R ²	0.597	0.610	0.661	0.669	0.658	0.563	0.594	0.642	0.654	0.647	0.5965	0.614	0.645	0.660	0.650
Cropland															
TA	0.028***	0.024***	0.006	0.014***	0.015**	0.027***	0.026***	0.010**	0.015***	0.023***	0.028***	0.029***	0.018***	0.018***	0.022***
COM	-0.008	-0.001	0.039***	0.012	0.002	-0.003	0.014	0.060***	0.034***	0.019	-0.003	0.008	0.046***	0.017	0.015
ECO	-0.063	0.220	0.425**	0.458**	0.430										
ECO ²	-0.005	-0.070	-0.111***	-0.120***	-0.129***										
SOC					-0.085	-0.194	0.017	-0.048	-0.048	-0.350*					
SOC ²					-0.003	0.021	-0.015	-0.005	-0.005	0.046					
POL											-0.345***	-0.291***	-0.131	-0.011	-0.170
POL ²											0.059***	0.046*	0.018	-0.014	0.008
Pseudo R ²	0.236	0.277	0.322	0.319	0.295	0.254	0.266	0.294	0.300	0.282	0.250	0.262	0.298	0.308	0.310
Fishing															
TA	0.008***	0.010***	-0.002	-0.010	-0.019**	0.006***	0.008***	-0.002	-0.012	-0.012*	0.007***	0.009***	-0.001	-0.006	-0.018***
COM	0.003	0.002	0.007	0.007	0.031*	0.001	0.007*	0.007	0.038	0.042***	-0.000	0.003	-0.002	-0.001	0.011
ECO	-0.353***	-0.351***	-0.803***	-1.302***	-1.296***										
ECO ²	0.065***	0.061***	0.130***	0.195**	0.195***										
SOC					-0.144***	-0.244***	-0.228*	-0.783**	-0.783**	-1.151***					
SOC ²					0.024***	0.043***	0.030	0.110	0.110	0.170***					

Table 7 (continued)

	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	Q10	Q25	Q50	Q75	Q90	
POL						-0.141***	-0.207***	-0.103	-0.581***	-0.495***						
POL ²						0.025***	0.037***	0.004	0.072*	0.054*						
Pseudo R ²	0.150	0.134	0.165	0.255	0.409	0.126	0.105	0.132	0.216	0.393	0.143	0.124	0.153	0.269	0.415	
Forest																
TA	0.021***	0.011**	0.007	-0.019	-0.066***	0.017***	0.015**	0.008	-0.025***	-0.049***	0.024***	0.018***	0.009	-0.026***	-0.028	
COM	-0.004	0.006	0.015	0.057**	0.084***	0.014*	0.028**	0.032*	0.047***	0.076***	-0.010	0.014	0.010	0.056***	0.086**	
ECO	-0.405***	0.151	0.716**	1.628***	2.425***											
ECO ²	0.044	-0.081*	-0.211***	-0.402***	-0.551***											
SOC						-0.498***	-0.663***	-0.538*	0.946***	1.171***						
SOC ²						0.073***	0.096**	0.046	-0.267***	-0.305***						
POL											-0.176	0.098	0.494***	0.688***	0.854**	
POL ²											0.004	-0.059**	-0.161***	-0.209***	-0.230***	
Pseudo R ²	0.270	0.281	0.335	0.377	0.390	0.254	0.267	0.344	0.432	0.411	0.270	0.284	0.350	0.405	0.380	
Grazing																
TA	0.004	0.001	-0.022***	-0.043**	-0.095***	-0.001	0.003	-0.022***	-0.051***	-0.081***	0.005	0.004	-0.016**	-0.037**	-0.093***	
COM	-0.031***	-0.033***	-0.033***	0.007	-0.009	-0.020***	-0.033***	-0.030**	-0.017	-0.015	-0.032***	-0.046***	-0.039***	-0.000	0.042*	
ECO	-0.382***	-0.306**	0.008	0.317	0.687											
ECO ²	0.049*	0.031	-0.035	-0.077	-0.181*											
SOC						-0.417***	-0.299**	0.259	0.540	-0.249						
SOC ²						0.058***	0.034	-0.085**	-0.147*	0.006						
POL											-0.234***	-0.091	0.021	0.012	-0.432*	
POL ²											0.027*	-0.008	-0.031	-0.012	0.095*	
Pseudo R ²	0.211	0.202	0.198	0.238	0.450	0.213	0.210	0.221	0.280	0.467	0.223	0.226	0.210	0.236	0.444	

This table presents the quantile regression estimates according to the empirical model defined by Eq. (5). The others are the same as the notes in Tables 1, 2, and 4. The shaded area presents support of the EKC hypothesis

Table 8 Test for heterogeneity of the quantile regression estimates

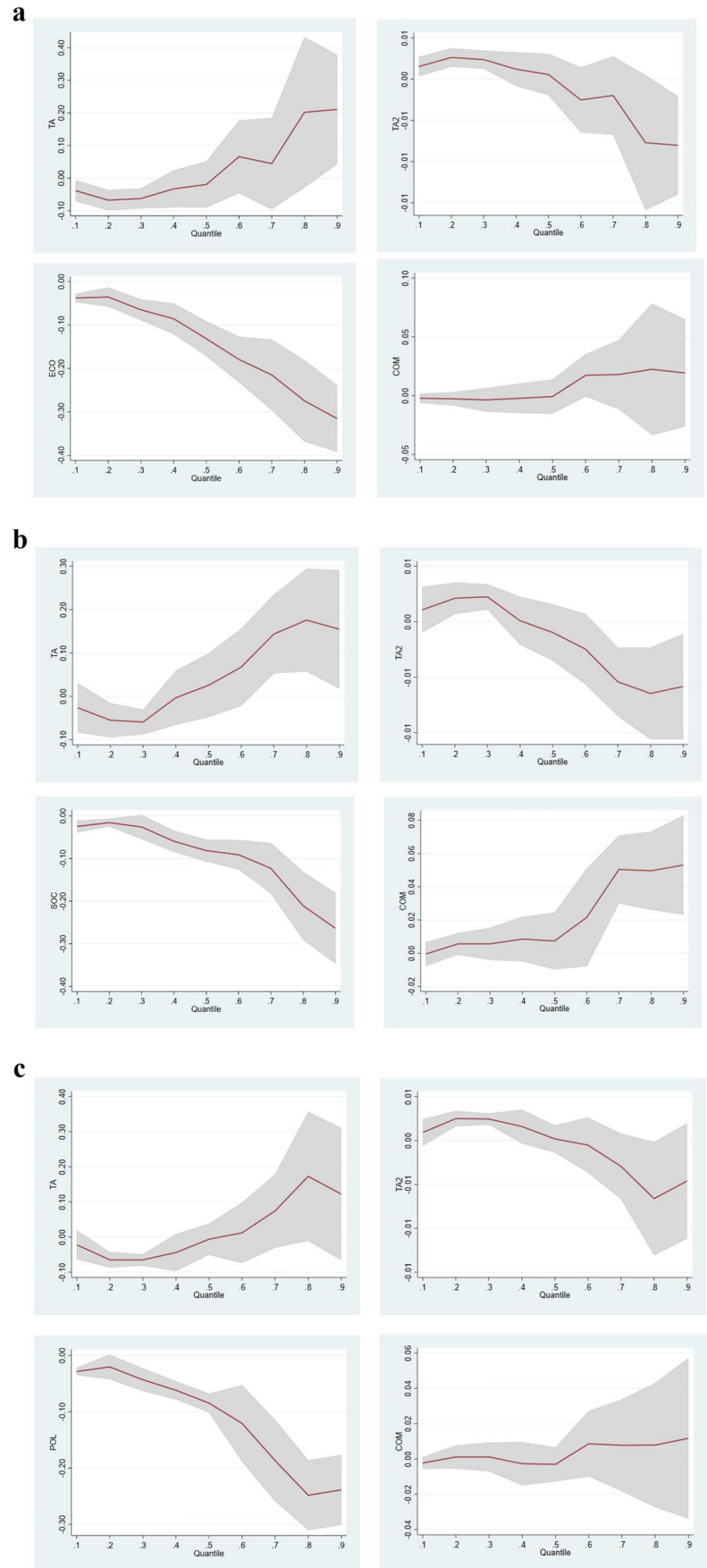
Built	TA	ECO	COM	TA	SOC	COM	TA	POL	COM
<i>P</i> value									
Q10-Q25	0.000***	0.257	0.391	0.000***	0.089*	0.055*	0.001***	0.334	0.164
Q10-Q50	0.137	0.183	0.384	0.056*	0.007***	0.154	0.098*	0.067*	0.342
Q10-Q75	0.214	0.194	0.007***	0.371	0.043**	0.049**	0.179	0.034**	0.035**
Q10-Q90	0.060*	0.000***	0.000***	0.768	0.000***	0.150	0.500	0.000***	0.000***
Q25-Q50	0.869	0.282	0.566	0.901	0.024**	0.893	0.829	0.096*	0.836
Q25-Q75	0.941	0.282	0.013**	0.725	0.092*	0.225	0.922	0.049**	0.130
Q25-Q90	0.582	0.282	0.000***	0.205	0.001***	0.395	0.538	0.000***	0.001***
Q50-Q75	0.831	0.282	0.036**	0.684	0.699	0.187	0.786	0.349	0.133
Q50-Q90	0.527	0.282	0.008***	0.205	0.090*	0.409	0.653	0.010**	0.009***
Q75-Q90	0.669	0.282	0.268	0.254	0.140	0.837	0.511	0.173	0.136
Carbon									
Q10-Q25	0.497	0.584	0.544	0.454	0.733	0.292	0.008***	1.000	0.707
Q10-Q50	0.177	0.104	0.190	0.718	0.671	0.584	0.110	0.027**	0.066*
Q10-Q75	0.784	0.341	0.862	0.807	0.280	0.382	0.465	0.027**	0.642
Q10-Q90	0.034**	0.212	0.200	0.984	0.158	0.577	0.121	0.030**	0.513
Q25-Q50	0.505	0.427	0.072*	0.567	0.295	0.597	0.500	0.022**	0.141
Q25-Q75	0.760	0.744	0.709	0.596	0.054*	0.917	0.121	0.036**	0.903
Q25-Q90	0.161	0.449	0.101	0.336	0.030**	0.542	0.507	0.026**	0.731
Q50-Q75	0.118	0.653	0.059*	0.900	0.297	0.666	0.165	0.847	0.051*
Q50-Q90	0.200	0.721	0.874	0.503	0.203	0.922	0.927	0.624	0.264
Q75-Q90	0.001***	0.470	0.044**	0.571	0.529	0.438	0.127	0.724	0.696
Cropland									
Q10-Q25	0.720	0.081*	0.993	0.436	0.497	0.042**	0.970	0.822	0.206
Q10-Q50	0.091*	0.645	0.008***	0.012**	0.048**	0.000***	0.091*	0.183	0.000***
Q10-Q75	0.145	0.551	0.099*	0.065*	0.216	0.002***	0.198	0.781	0.055*
Q10-Q90	0.219	0.103	0.107	0.443	0.969	0.130	0.442	0.045**	0.112
Q25-Q50	0.044**	0.230	0.005***	0.116	0.069*	0.005***	0.128	0.242	0.015**
Q25-Q75	0.124	0.439	0.083*	0.366	0.453	0.340	0.312	0.928	0.531
Q25-Q90	0.175	0.443	0.132	0.914	0.726	0.895	0.553	0.043**	0.874
Q50-Q75	0.905	0.795	0.107	0.440	0.241	0.012**	0.676	0.223	0.028**
Q50-Q90	0.813	0.100	0.195	0.107	0.127	0.001***	0.440	0.001***	0.021**
Q75-Q90	0.874	0.100	0.971	0.226	0.306	0.132	0.503	0.003***	0.440
Fishing									
Q10-Q25	0.708	0.072	0.982	0.299	0.463	0.210	0.246	0.816	0.042**

Table 8 (continued)

Built	TA	ECO	COM	TA	SOC	COM	TA	POL	COM
Q10-Q50	0.011**	0.000***	0.823	0.000*	0.000***	0.426	0.013**	0.000***	0.901
Q10-Q75	0.002***	0.000***	0.586	0.017**	0.000***	0.005***	0.009***	0.000***	0.911
Q10-Q90	0.001***	0.000***	0.495	0.002***	0.000***	0.020**	0.002***	0.000***	0.420
Q25-Q50	0.001***	0.002***	0.846	0.000***	0.000***	0.903	0.000***	0.000***	0.064*
Q25-Q75	0.001***	0.000***	0.605	0.009***	0.000***	0.013**	0.003***	0.000***	0.678
Q25-Q90	0.000***	0.000***	0.513	0.001***	0.000***	0.034**	0.001***	0.000***	0.684
Q50-Q75	0.019**	0.000***	0.657	0.123	0.004***	0.008***	0.066*	0.001***	0.881
Q50-Q90	0.008***	0.000***	0.526	0.044**	0.000***	0.027**	0.017**	0.000***	0.401
Q75-Q90	0.601	0.513	0.719	0.860	0.068*	0.721	0.214	0.701	0.438
Forest									
Q10-Q25	0.490	0.031**	0.283	0.504	0.096	0.953	0.372	0.684	0.078*
Q10-Q50	0.440	0.004***	0.006***	0.343	0.000***	0.893	0.107	0.004***	0.020**
Q10-Q75	0.101	0.001***	0.002***	0.004***	0.000***	0.003***	0.039**	0.015**	0.003***
Q10-Q90	0.001***	0.113	0.000***	0.013**	0.000***	0.028**	0.001***	0.171	0.000***
Q25-Q50	0.665	0.076*	0.026**	0.476	0.000***	0.852	0.175	0.001***	0.388
Q25-Q75	0.116	0.052*	0.006***	0.001***	0.000***	0.009***	0.053*	0.005***	0.040**
Q25-Q90	0.000***	0.366	0.000***	0.017**	0.000***	0.037**	0.001***	0.173	0.000***
Q50-Q75	0.100	0.321	0.040**	0.002***	0.071*	0.008***	0.129	0.761	0.043**
Q50-Q90	0.001***	0.960	0.000***	0.031**	0.013**	0.032**	0.007***	0.902	0.000***
Q75-Q90	0.093*	0.464	0.012**	0.637	0.122	0.672	0.066*	0.752	0.013**
Grazing									
Q10-Q25	0.199	0.694	0.876	0.101	0.926	0.319	0.523	0.958	0.709
Q10-Q50	0.000***	0.562	0.707	0.089*	0.995	0.868	0.002***	0.649	0.699
Q10-Q75	0.000***	0.015**	0.031**	0.000***	0.124	0.344	0.002***	0.039**	0.026**
Q10-Q90	0.000***	0.872	0.354	0.000***	0.134	0.888	0.000***	0.025**	0.027**
Q25-Q50	0.001***	0.704	0.741	0.009***	0.947	0.300	0.001***	0.585	0.500
Q25-Q75	0.001***	0.010**	0.032**	0.000***	0.095*	0.167	0.003***	0.035**	0.018**
Q25-Q90	0.000***	0.970	0.383	0.000***	0.114	0.672	0.000***	0.025**	0.024**
Q50-Q75	0.045**	0.025**	0.042**	0.000***	0.039**	0.459	0.053*	0.045**	0.042**
Q50-Q90	0.000***	0.924	0.439	0.000***	0.125	0.929	0.000***	0.027**	0.037**
Q75-Q90	0.000***	0.175	0.777	0.016	0.856	0.819	0.002***	0.204	0.246

This table presents the quantile regression estimates according to the empirical model defined by Eq. (1). The others are the same as the notes in Tables 1, 2, and 4

Fig. 1 (1a to 1c). Quantile regression estimates for the result offishing for Eq. (3). **a** The impacts of TA, TA²,ECO, and COM on Fishing. **b** The impacts of TA, TA²,SOC, and COM on Fishing. **c** The impacts of TA, TA²,POL, and COM on Fishing. Notes: Vertical-axes represent estimates of the named independent variable, while horizontalaxes show the quantiles of the fishing dependent variable. Quantile regressionestimates are with 95% confidence intervals shaded



variable in Eq. (1). Table 8 gathers the results that reject the null hypothesis of equal coefficient estimations at the usual significance levels for specific explanatory variables and quantile pairs. The impacts of COM, SOC, and POL on BUI are saliently different across quantiles, identifying that these three factors non-linearly influence BUI. POL non-linearly affects CAR, while COM non-linearly affects CROP. TA, ECO, SOC, and POL (ECO, SOC, and COM) non-linearly influence FISH (FOR), while TA, POL, and COM non-linearly affect GRAZ. These findings validate heterogeneity in the response of EF to variations in the explanatory variables.

To save space, Fig. 1c depicts only the QR results of Eq. (3) regarding the TA-induced EKC hypothesis of FISH. The results confirm that the sensitivity of TA to variations in FISH may be dissimilar across quantiles during the entire sample period. Additionally, the slope equality of the coefficients across dissimilar quantiles is considered for examining the heterogeneity of the sensitivity of EF at diverse phases of the economy by considering the following elements: EXG, GDP, IND, INF, POD, REW, and UMP.

Implications

The results of this study present the different impacts of variables on ecological footprints and offer some imperative implications as follows.

First, analyzing Turkey, Godil et al. (2020) find TA increase EF, whereas Kongbuamai et al. (2020) probing Thailand and Khan and Hou (2021) inspecting 38 nations find tourism growth improves environmental quality. These three studies utilize EF per capita as the dependent variable. Our study uses the six sub-kinds of EF as proxies of environmental degradation, noting that TA increase (decrease) to consume FISH and FOR in low (high) FISH and FOR countries and showing asymmetric relationships between TA and EF (FOR and FISH). These two kinds of land are sacrificed and then change toward focusing more environmental protection lifestyles as TA further rise. Tourism development relates to a higher EF of CAR and CORP for all quantiles. Tourism development presents a U-shaped relationship with most EFs, showing when TA is large enough that EF increases. However, country security can mitigate the positive effects of TA on EF. Thus, policymakers whose countries focus on tourism development to bring economic growth should take cognizance of their precaution especially for carbon-absorption land and cropland resources, provide environmental education for the citizenry, develop sustainable tourism programs, and respect nature when initiating policies relating to environmental sustainability and tourism development.

Second, we find economic complexity does not effectively resolve environmental degradation, except for grazing land. However, our findings reveal that country security can alleviate the negative influence of economic complexity on environmental quality. Prior studies report that economic complexity has a great influence on GDP and national competitiveness (Dogan et al., 2020; Hidalgo and Hausmann, 2009). Thus, a policymaker can try to have certain levels of country securities to decrease the negative influence on the environment generated from economic complexity. Moreover, as countries focus on growing economic complexity, we suggest that policymakers should place emphasis on long-run policies and strategies to increase their capability to conduct sustainable economic systems and decrease environmental pressure (especially carbon-absorption land at all quantiles and most of the quantiles of BUI, CROP, and FOR).

Third, Khan et al. (2021d) suggest using quantile regression to consider the effects of location and scale in the conditional distribution of carbon emissions. Likewise, our findings display heterogeneity in the response of diverse ecological footprint elements and across different quantiles to variations in the explanatory variables. This emphasizes that the existing empirical research studies on CO₂ or integrated EF effects of the independent variables might have a bias that cannot depict the whole picture of the environment. For academic research, the main implication of the estimation results of the QR model is that there is significant heterogeneity across the EF distribution quantiles for the effects of tourism development, economic complexity, and country security on the environmental sustainability process. Additionally, policymakers should consider their countries' ecological footprint conditions and provide strategies concerned with sustainable environment and economic growth. Furthermore, the key findings of this research are to identify the existence of tourism development, economic complexity, and country security-induced EKC hypotheses in the six sub-groups of ecological footprint to achieve better environmental quality control in each EF perspective. Most recommended policies should have a nation-specific orientation. A valuable policy can only be implemented once, whereas empirical examinations can consider the outcome of variables' sensitivity as is done herein.

Fourth, different from other EKC research, this paper denotes the country security-induced EKC hypothesis based on economic, political, and social securities, since country security has a critical role within environmental concerns (Wenya et al., 2020; Zhou et al., 2020; Lee and Chen, 2021). We discover that country security leads to a safe environment that attracts tourists and investments; however, environmental quality might be sacrificed at

the same time. Moreover, economic, political, and social securities are all important determinants of ecological footprint, and thus, this study provides implications of important country security elements on environmental quality, which might be an effective device when a country is harassed by environmental threats.

Fifth, the policy-level initiatives of this paper can aid countries in ways such as sustainable environment, job creation, and economic progress. More specifically, a country's policymakers should consider the negative influence of the independent variables on ecological footprint. For example, economic complexity has a negative effect on EF, and hence, the construction of production and services should be reassessed toward using alternative energy sources or setting up a relevant control mechanism. The empirical results herein allow us to draw new conclusions, as a nation's policies and environmental regulations can impact economic progress.

Finally, one of the EKC criticisms is that it may not exist at the global level (Gill et al., 2017). Utilizing the sub-types of an ecological footprint as dependent variables, this study examines whether tourism development, economic complexity, and country security-induced EKC hypotheses are supported via international evidence. Among the three EKC, we find that country security-induced EKC is the most notable. Specifically, this specific EKC exists at lower (highest) to intermediate quantiles of built-up land (forest area) and the 50th–75th quantiles of cropland, which highlight the importance of promoting greener energy to combat environmental degradation. Our findings are consistent with Lee and Chen (2021) that tourism, CR, and GDP influence EF inversely under diverse sub-footprints and that there are noticeably different links across varying EF quantiles.

Conclusion

In the new wave of environmental sustainability, people are placing the environment high up in importance. The speed of climate change also is spurring global actions to be linked to growing environmental degradation. Thus, some facets of environmental quality have been inspected in recent economic, tourism, and institutional research. Employing QR, this research addresses heterogeneity in terms of tourism development, economic complexity, country security, and environmental degradation as well as analyzes the EKC approach from not only different sub-kinds of ecological footprints, but also different quantiles of ecological footprint.

Tourism development is notably connected to higher usage of carbon absorption land and cropland for all quantiles. The lower (higher) the nation's security is, the better (worse) the environmental quality is. Economic complexity worsens environmental quality, and this is consistent with prior studies of Yilanci and Pata (2020) that economic complexity has a growing impact on the total score of ecological footprints, and economic complexity does not effectively resolve environmental degradation. Country security alleviates the saliently negative influence of tourism development (economic complexity) on environmental quality. As tourist arrivals increase to a specific level, ecological footprint then increases, which leads to more environmental sacrifice. The economic complexity-induced EKC hypothesis is supported in the 10th–50th cropland quantiles, while country security-induced EKC hypotheses are supported in some specific EF quantiles. Therefore, our findings pinpoint that the existing empirical research studies on CO₂ emissions or integrated ecological footprint effects of economic complexity might not depict the whole picture of the environment. Additionally, we show that tourism arrivals, economic complexity, and country security have varying impacts across diverse ecological footprint quantiles.

The limitations of the research are as follows. First, it does not comprise any institutional and bureaucratic elements that may impact environmental strategies and policies, as institutional issues play a salient role in a nation's environmental laws, energy usage, and economic growth. Future research can investigate the pros and cons of such issues regarding the environment, tourism, country security, and economic complexity. Second, the Granger causality test estimates the cause-effect relationship between the exogenous and endogenous variables (Khan et al., 2021e). Third, Işık et al. (2020) suggest that a rise in renewable energy consumption has a negative (reduction) impact on CO₂ emissions; thus, follow-up research can include the renewable energy variable. Fourth, a future study can explore the issue via dynamic autoregressive-distributed lag (ARDL) to look into the long- and short-run relationships between economy and environment (Pata and Balsalobre-Lorente, 2021). Fifth, a future study may examine the industry or enterprise level to gain more knowledge in sustainable goals (Yu et al., 2021; Khan et al., 2021a, 2022b). Finally, future research may expand the topic herein by including threshold points and/or a conventional cubic specification of EKC hypotheses for more detailed conclusions and theoretical implications.

Appendix

Table 9 Previous literature on EKC by using EF as a dependent variable

Author(s)	Research purpose	Method	Sample	Results
Godil et al. (2020)※	Asymmetric impact of tourism, financial development, and globalization on EF	QARDL	Turkey	Tourism, globalization, and financial development are positively and saliently associated with EF; the U-shaped EKC curve is found to be valid; the results depict a non-linear and asymmetric linkage among the variables
Khan and Hou (2021)※	Impact of energy consumption and tourism growth on EFs and economic growth	fully modified least square	38 IEA countries	Energy consumption promotes economic growth and degrades environmental quality in the long run, and tourism growth improves environmental quality and stimulates economic growth in the long run
Kongbuamai et al. (2020)※	Impact of economic growth, energy consumption, tourism, trade openness, and population density on EFs	VECM	Thailand	Economic growth, energy consumption, and trade openness have positive relationships with EF, while tourism and population density are negatively associated with EF
Lee and Chen (2021)	Examine economic-, tourism-, and country risk rating-induced EKC hypotheses	MMQR	123 countries	EKC hypothesis in European countries; tourism increases (reduces) fishing ground at lower (higher) fishing quantiles, suggesting asymmetric impacts of tourism across different quantiles
Majeed (2020)※	EKC hypothesis for upper-income countries, middle-income countries, and low-income countries	fixed effects quantile regression	76 countries	The roles of biocapacity, human capital, and trade are conducive to managing global EF
Pata and Yilanci (2020)※	The dynamic relationships among financial development, globalization, energy consumption, economic growth, and EF	threshold cointegration test	G7 countries	Globalization is a more effective tool than financial development in regulating EF for G7 countries
Saqib and Benhmad (2020)※	Look at EKC hypotheses by investigating the relationships between EF, economic growth, energy consumption, and population growth	DOLS and FMOLS	22 European countries	There is unidirectional causality running from GDP to EF and bidirectional causality running between energy consumption and EF
Sharif et al. (2020a, b)※	The impact of renewable and non-renewable energy consumption on EF	QARDL	Turkey	There is a bidirectional causal relationship between renewable energy consumption, energy consumption, and economic growth with EF
Shahzad et al. (2021)※	The nexus between economic complexity, fossil fuel energy, and EF	QARDL	U.S	economic complexity and fossil fuel energy consumption significantly enhance EF in the United States
Ulucaak and Khan (2020)※	The drivers that reduce EF	FMOLS and DOLS	BRICS	EKC is validated in individual BRICS economies; natural resource rent, renewable energy, and urbanization are found to reduce EF
Wang et al. (2020)※	Impact of biomass energy production on EF	dynamic seemingly unrelated regression	G7 countries	Unidirectional causality runs from biomass energy production to EF

Table 9 (continued)

Author(s)	Research purpose	Method	Sample	Results
Yilanci and Pata (2020)*	The short- and long-term relationships among economic growth, economic complexity index, energy consumption, and EF	Fourier ARDL	China	The EKC hypothesis is not valid for China; economic complexity has an increasing impact on EF; and economic growth does not effectively solve environmental problems in China

Due to space limitations, this table lists only related works in 2020, using ecological footprints as dependent variables. * represents a study using aggregate EF or EF per capita as the dependent variable, rather than the six sub-kinds of EF

Table 10 List of the 99 countries in the sample

Albania	Canada	Gambia	Libya	North Macedonia	Sweden
Angola	Chad	Ghana	Lithuania	Norway	Switzerland
Armenia	Chile	Guinea	Madagascar	Pakistan	Tanzania
Australia	China	Guyana	Malawi	Panama	Thailand
Austria	Colombia	Guinea-Bissau	Malaysia	Paraguay	Togo
Azerbaijan	Congo, Dem. Rep	Haiti	Mali	Peru	Tunisia
Bangladesh	Congo, Rep	India	Lesotho	Philippines	Turkey
Barbados	Costa Rica	Indonesia	Mexico	Poland	Uganda
Benin	Cote D'Ivoire	Japan	Moldova	Romania	UK
Bhutan	Croatia	Jamaica	Montenegro	Russia	USA
Bolivia	Czech	Jordan	Mongolia	Rwanda	Venezuela
Bosnia and Herzegovina	Denmark	Kazakhstan	Mozambique	Saudi Arabia	Vietnam
Botswana	Dominican	Kenya	Myanmar	Serbia	Yemen
Brazil	El Salvador	Korea, Rep	Nepal	Sierra Leone	Zambia
Burkina Faso	Estonia	Lao PDR	Nicaragua	Singapore	
Burundi	Ethiopia	Latvia	Niger	South Africa	
Cameroon	Fiji	Lebanon	Nigeria	Suriname	

This study gathers the countries that have tourism relevant, economic complexity, country security, and ecological footprint data in the World Bank database. The above 99 countries are utilized in this study

Table 11 Main variable list

Variable	Definition and source
<i>Dependent variables</i>	
Six ecological footprints (EF) sub-kinds (yearly data from Global Footprint Network, https://www.footprintnetwork.org/)	
Built	Built-up land
Carbon	Carbon-absorption land
Crop	Cropland
Fish	Fishing grounds
Forest	Forest area
Graze	Grazing land
<i>Independent variables</i>	
<i>Tourism development (TD) sub-kinds are from the World Bank database (World Tourism Organization, Yearbook of Tourism Statistics, and IMF and World Bank import estimates, WTO)</i>	
TA	Log difference of international inbound travelers is the yearly number of arrivals who travel to a nation other than that in which they have their usual residence
<i>Economic complexity index (ECI) MIT's Observatory of Economic Complexity Atlas Media database</i>	
EC	Economic Complexity Index
<i>Country security (CS) variables of the Fragile State Index are obtained from the Fund for Peace (FFP)</i>	
ECO	Economic security
POL	Political security
SOC	Social Security
<i>Control variables (CV)</i>	
<i>Macroeconomic factors are from the World Bank database (World Development Indicators)</i>	
EXG	Real exchange rate = (destination country's official exchange rate*U.S. CPI)/destination country's CPI
GDP	GDP per capita growth, annual %
IND	Industry value-added, % GDP
INF	Inflation, consumer prices, annual %
POD	Population density (people per square km of land area)
REW	Renewable energy consumption, % of total final energy consumption
UMP	Unemployment, total % of total labor force
DEV	A developing country equals 1 if the country is developing and 0 otherwise
EUR	European country equals 1 if the country is in Europe and 0 otherwise
CRS	Financial crisis, equals 1 if the period is during the financial crisis (2008–2009) and 0 otherwise

All the variables are in log difference form, except for variables that have negative values (COM, GDP, and INF)

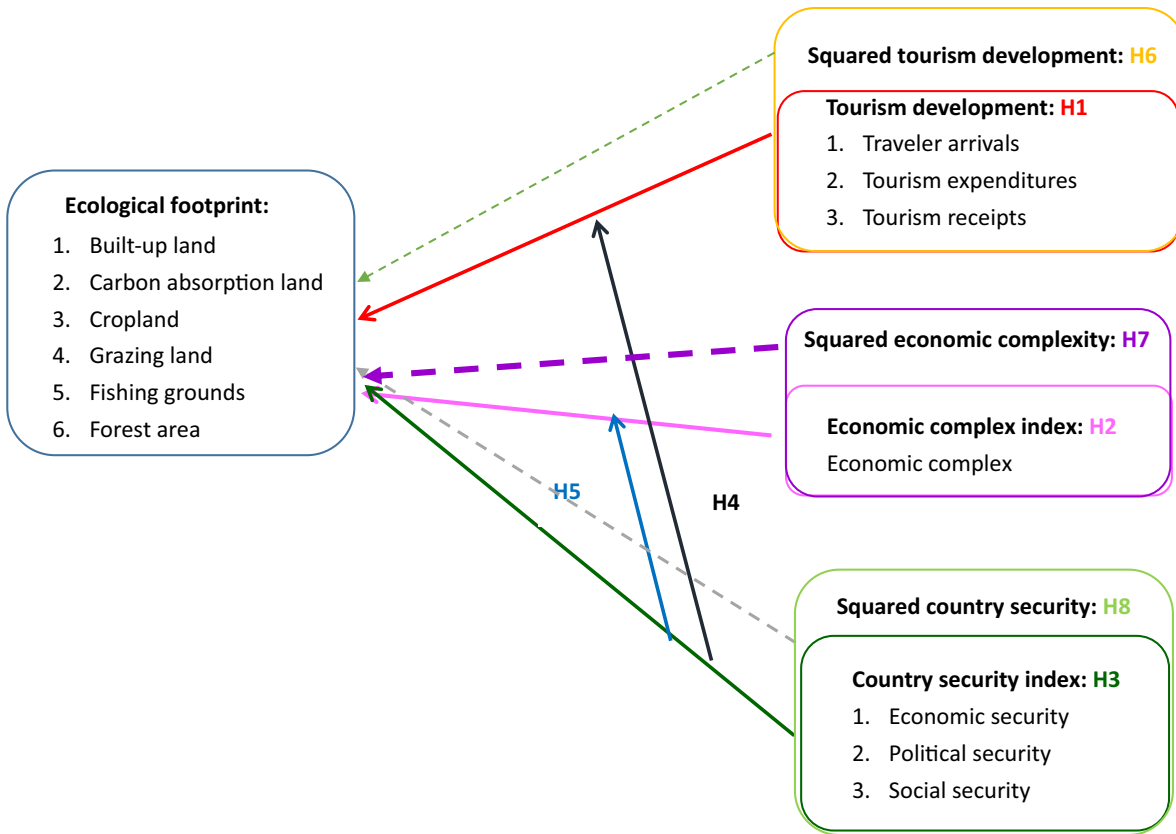


Fig. A1 Research concepts. Note: The dotted line presents the EKC hypotheses

Acknowledgements We acknowledge the financial support from the Social Science Foundation of Jiangxi Province of China for financial support through Grant No: 21JL02. The authors are also very grateful to Professor & Editor Ilhan Ozturk and two anonymous reviewers for their insightful comments that helped us sufficiently improve the quality of this paper.

Author contribution Conceptualization, Chien-Chiang Lee; methodology, Chien-Chiang Lee; formal analysis and investigation, Wenmin Wu; writing (original draft preparation), Mei-Ping Chen; writing (review and editing), Mei-Ping Chen; funding acquisition, Chien-Chiang Lee; resources, Mei-Ping Chen; and supervision, Chien-Chiang Lee.

Data Availability The data that support the findings of this study are available upon request from the corresponding author.

Declarations

Ethical approval and consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

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