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Tourism's impact on energy efficiency: A panel data analysis

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ABSTRACT

Countries have continued to focus on the issues related to the energy crisis, climate change, and the transition to a low-carbon economy. Energy consumption is essential for countries' economic growth as energy provides various services for industrial, residential, and transportation sectors. However, heavy use of fossil fuels may cause many environmental problems and climate change. This dilemma forces countries to implement various policies. Policies implemented for energy efficiency improvement form one avenue to reach climate change mitigation and environmental goals, ensure sustainable economic development and transition to a low-emission regime. This study employs energy and carbon intensity as indicators to evaluate energy efficiency. As economies grow, structural shifts may occur from heavy industry to service sector. This may lead to lower energy consumption. However, the service sector may provide more job opportunities, leading to higher living standards, per capita national income, and energy consumption. Energy intensity may increase as a result of structural economic transformation. As part of the service sector, tourism may contribute to the transition to a low-carbon economy. Therefore, based on panel data techniques, this study aims to analyze the tourism sector's impact on energy and carbon intensities using data on 24 countries over 2013-2020. Findings show the importance of energy efficiency improvements in the tourism sector to reduce economies' energy intensity and carbon intensity. In conclusion, countries should implement various policies to strengthen energy efficiency improvements in all industries while giving special attention to tourism.

1. Introduction

As countries grow and living standards increase, energy consumption increases at a higher rate, and this causes severe environmental problems. The issues related to the energy crisis, climate change, and the transition to a low-carbon economy are on the agenda of countries. Energy consumption is essential for countries' economic growth as energy provides various services for industrial, residential, and transportation sectors. However, heavy use of fossil fuels may cause many environmental problems and climate change. This dilemma forces countries to implement various policies. Policies implemented for energy efficiency improvement form one avenue to reach climate change mitigation and environmental goals, ensure sustainable economic development and transition to a low-emission regime. According to the reports of important organizations, such as The International Energy Agency and the Organization for Economic Cooperation and Development (OECD), energy efficiency improvement serves for mitigation of emissions, ensuring energy affordability and competitiveness, and reduction in energy prices and need for additional investment on energy infrastructure (Bashir et al., 2020). Studies show the importance of energy efficiency improvement for environmental quality, such as those by Chu and Le (2022), Zhu et al. (2021), and Robaina-Alves et al. (2016). Shifting to more efficient technologies can prevent environmental degradation and ensure economic growth (Chu & Le, 2022).

Moreover, as countries reach a higher level of development, economic structure may change, so the share of heavy industry declines, and the share of the service sector may increase. This situation may decrease energy consumption. On the other hand, due to more job opportunities and higher living standards provided by the service sector, energy consumption may increase associated with higher per capita income, leading to higher energy and carbon intensity. Although strict energy-saving measures are put into force, there may not be a significant decline in energy consumption. This is called the Jevons paradox (Coles et al., 2016). Therefore, energy intensity may still increase as a result of the rebound effect in such a way that energy-saving gains from energy efficiency improvements may be offset by increases in energy consumption resulting from higher demand for new products and services that have declining marginal costs

Research Paper

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due to technological innovations (Yu et al., 2022). The tourism sector is part of the service sector as the sector includes many service subsectors, such as restaurants, entertainment services, transportation, and accommodation. All these tourism subsectors have various environmental impacts because they are based on heavy usage of natural resources, such as water and energy. The focus of this study is on energy consumption. These subsectors consume high amounts of energy causing an increase in greenhouse gas emissions. Approximately 8% of global greenhouse gas emissions are due to tourism (Lenzen et al., 2018). Parallel to green transition, the subsectors are in a transformation process due to energy efficiency applications and e-mobility. Also, in tandem with sustainable development, conservation has gained importance also in the tourism sector. Sustainable tourism and ecotourism emerged as a result of increased awareness on biodiversity protection. For more information related to sustainable tourism, ecotourism and other types of tourism focusing on conservation, one can refer to the study performed by Stronza et al. (2019). In addition to employment and revenue generation, ecotourism may lead to behavioral changes of tourists towards a more conservative manner in their consumption after their visits and strengthen institutions responsible for resource management (Stronza et al., 2019). Therefore, the tourism sector may contribute to improving energy efficiency, but this should be examined using various econometric techniques. There are various studies analyzing factors affecting energy efficiency. However, only some studies have investigated the tourism sector's impact, considering the effects of various factors such as economic complexity, uncertainty, and environmental policy stringency. Therefore, the study aims to investigate tourism's impact on energy and carbon intensities by employing panel data on 24 countries over 2013-2020 and panel data techniques. The countries are Australia, Austria, Belgium, China, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Japan, Korea Republic, Mexico, Netherlands, New Zealand, Norway, Portugal, Russian Federation, South Africa, Spain, Sweden, Turkiye, and the United Kingdom.

The improvement in energy efficiency is measured based on indicators such as energy intensity and carbon intensity (Bashir et al., 2020; H. L. Zheng et al., 2021). Although energy efficiency is an important research area, insufficient studies investigate its determinants (Paramati et al., 2022; Saudi et al., 2019). Furthermore, studies have not reached any consensus in literature (Chen et al., 2021). Many more studies should consider and investigate the potential of energy saving. According to projections of Zhong et al. (2021), over 2014-2060, energy savings of residential and commercial buildings are expected to be 28 EJ and 28.9 EJ, respectively, due to the energy efficiency improvements. They also show residential buildings' higher energy-saving potential in lower-middle-income regions. For European Union countries, the decline in energy consumption was targeted at 20% for 2020 and at least 32.5% for 2030 compared to the baseline forecasts. Energy intensity has declined around 33% between 1990 and 2015 in most countries around the world as a result of efficiency gains in buildings, vehicles, and industries because of regulations, efficiency standards, technological advances related to energy, various incentives provided by governments, and market competition (Paramati et al., 2022). Using the Malmquist productivity index, Mavi and Mavi (2019) showed that among OECD countries, Switzerland performed better in terms of energy and environmental efficiency over 2012-2014, and they also indicated continuous efficiency improvements in the USA and Ireland. Due to the various uncertainties related to climate and energy production, energy efficiency improvement contributes to climate change mitigation efforts and adaptation. According to Paramati et al. (2022), Chen et al. (2021), and Bashir et al. (2020), energy efficiency improvement also serves Sustainable Development Goals (SDGs) by contributing to climate action (SDG 13), energy security, energy provision, industry, innovation and infrastructure (SDG 9), clean and affordable energy (SDG 7). Energy efficiency improvements may lead to a decline in tourism's energy consumption and therefore may decrease its harmful environmental effects. Thus, related to sustainable tourism and ecotourism principles, tourism's social and environmental goals can be achieved by the implementation of energy efficiency applications in the tourism sector.

After this brief introduction, the literature is reviewed in the second section. This section is followed by the sections related to methodological issues, information on data, and empirical results. Lastly, the study concludes with policy suggestions.

2. Review of Literature

Various studies examine energy efficiency and carbon efficiency in the tourism sector employing various methods. Table 1 shows the details related to these studies. Some studies show that tourism contributes to overall energy and carbon efficiency. Tang et al. (2018), Li et al. (2019), Mester et al. (2023), and X. R. He et al. (2022) can be given as examples. However, some studies show the high energy requirement of the tourism sector and its undesirable effect on carbon emissions. These studies include Pablo-Romero et al. (2021), Bianco (2020), L. M. He et al. (2020), Becken et al. (2001), Tabatchnaia Tamirisa et al. (1997), J. Liu et al. (2011), Moutinho et al. (2015), and Robaina-Alves et al. (2016).

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Table 1: Studies analyzing energy and carbon efficiency in tourism sector

Author	Country	Period	Method	Results
Tabatchnaia Tamirisa et al. (1997)	Hawaii	1987	Input-output analysis	A considerable share of total energy and fuel consumption is due to the tourist arrivals. As foreign tourist share increases in total tourist arrivals, they expect an increase in energy and fuel demand.
Becken et al. (2001)	New Zealand	1998- 1999	Analysis of survey data considering different accommodation categories	Hotels were found to have the most significant energy consumption. Energy intensity was also affected by various sets of factors other than business size. A negative weak effect of occupancy level was shown for energy efficiency.
J. Liu et al. (2011)	Chengdu city of China	1999-2004	Decomposition analysis method	Transportation was shown to be the primary cause of carbon emission and major energy-consuming subsector. Industry scale and expenditure size were found to increase emissions, but they indicated the favorable effect of energy intensity. The effects of increased expenditure and industry size outweigh the impact of energy intensity decline.
Moutinho et al. (2015)	Portugal	2000-2012	Decomposition analysis	Only capital-intensity productivity decreases carbon dioxide emission intensity. All other factors increase it, i.e., tourism intensity, carbonization index, energy as a ratio of fixed capital formation, and labor over tourism consumption structural effect.
Robaina-Alves et al. (2016)	Portugal	2000- 2008	Logarithmic mean divisia index-based decomposition analysis	Tourism activity was shown to increase carbon emissions.
Tang et al. (2018)	Wulingyuan area of China	1979-2015	Theory of life cycle assessment bottom-up analysis method, and material flow	Results indicate energy and carbon efficiency improvements by progression over the stages of tourism life cycle. Tourism is less energy- and carbon-intensive than other industries.
Li et al. (2019)	32 OECD economies	1995-2012	Panel ARDL model.	They found the importance of tourism investment for long-run energy efficiency improvement in the overall economy, transportation and residential sectors.
Bianco (2020)	Italy	1995-2017	Index decomposition analysis	An increase in various forms of hospitality structures was found to increase electricity consumption. However, for the recent periods of their analysis, they showed an improvement in energy efficiency due to regulations and policies.
L. M. He et al. (2020)	China	2005-2013	Biennial Malmquist index	They showed that tourism is less energy efficient than the industrial sector.
Pablo-Romero et al. (2021)	9 European countries	2004-2012	Decomposition analysis	Countries with higher levels of tourism activity were found to have higher electricity consumption and to be affected more by the economic crisis.
X. R. He et al. (2022)	China	2007-2019	Spatial panel data methods	They found the favorable direct and spatial spillover impact of urban tourism activities on carbon intensity reduction and green economic efficiency improvement for 280 cities.
Mester et al. (2023)	27 European Union countries	1995-2019	Dumitrescu-Hurlin causality test	They showed a one-way causal relationship from the tourism development index to the energy intensity index.
Alfaisal et al. (2024)	BRICS countries	1990-2021	Method of Moment Quantile Regression model, Dumitrescu–Hurlin panel causality test	International tourism, energy efficiency, and renewable energy use decrease carbon emissions. Economic growth increases emissions. There is evidence of long-run and two-way causal relationships between all variables.
Deka et al. (2024)	Sub-Saharan African countries	1990-2020	Cross-sectionally augmented autoregressive distributive lag model, dynamic panel data model	Carbon emissions decline because of energy efficiency improvements and renewable energy usage. Carbon emissions increase due to non-renewable energy consumption and economic growth. The effect of tourist arrivals is shown to be insignificant.
Gössling, Humpe, et al. (2024)	29 tourism companies	2015-2019	Decomposition analysis	There are colossal subsector and firm-level differences in emission intensities. There are increases in emissions despite yearly progress in emission intensity reduction.
Gössling, Vogler, et al. (2024)	12 National Tourism Organizations in Europe, the USA, and Canada	2019-2022	Graphical and Statistical Analysis	Distance plays an important role in the reduction of emissions from tourism activities. 62% of emissions are caused by 17% of the most distant arrivals.
Jiang and Lv (2024)	100 countries	2003- 2020	Panel data methods	Tourism increases carbon emissions, but digitalization decreases the adverse effects of tourism, especially in high-income countries.
H. W. Liu et al. (2024)	China	2008-2019	Spatial Durbin model	Tourism carbon efficiency improvements are achieved by urbanization, government support, and technological innovation. Regional differences and spatial effects are found to be significant determinants of efficiency. Tourism carbon efficiency declines due to growth and transportation infrastructure. Adverse spatial spillover effects of education, government support, and green infrastructure were shown.
Mou (2024)	China	2006-2021	Logarithmic mean Divisia index model, Panel data model	There are increases in tourism-related carbon emissions. These emissions increase because of economic growth, tourism, urbanization, and a decrease in the development of the tertiary industry.
Phu et al. (2024)	ASEAN countries	2012-2017	Panel Data Methods	Economic growth, international trade, household consumption, tourism, and fossil fuel consumption increase carbon emissions. Energy intensity and urbanization decrease emissions.
Si and Tang (2024)	China	2000-2019	Coupling coordination degree model	Tourism and tourism-related carbon emissions were shown to be closely related. Tourism development increases tourism carbon emissions. However, regional differences are shown.

Author	Country	Period	Method	Results
Sun et al. (2024)	World	2009–2020	Input-output analysis, Structural Decomposition Analysis	There are 3.5% annual increases in tourism-related emissions globally between 2009 and 2019. The carbon intensity of tourism is high. Although technological and supply chain efficiency improvements decrease carbon intensity, tourism consumption growth increases intensity at a higher level.
Wu et al. (2024)	China	2010-2019	Tapio decoupling index	City-level differences in tourism-related carbon emission changes relative to tourism growth exist.
J. Zhang and Xia (2024)	China	2002–2022	Environmentally extended input-output model, Super-slacks-based measure model, Panel Tobit model, Geographic Detector	Direct tourism-related carbon emissions were shown to be increasing, but indirect emissions have a decreasing trend, focusing on tourist hotels. The carbon emission efficiency of tourist hotels is improved by scale, sectoral structure, energy efficiency, economic growth, and energy-saving technology.
Y. P. Zhang (2024)	China	2000- 2022	Province-based descriptive analysis	Tourism increases carbon emissions.
Zhao et al. (2024)	China	2005-2022	Structural Equation Model	Tourism has been shown to increase carbon emission efficiency, directly and indirectly, through its effect on industrial structure and environmental regulation.
C. Chen and Wu (2025)	China	2000-2019	Panel Threshold Model	After certain levels of tourism concentration and population density, the digital economy contributes to reducing tourism-related carbon emissions. Their findings are in line with the Environmental Kuznets Curve hypothesis. Energy intensity, urbanization, and technological innovation capacity decrease carbon emissions.
Kocak et al. (2025)	23 Asia-Pacific countries	2000-2019	Panel quantile regression analysis	Tourism and economic growth increase energy efficiency, but urbanization and industrialization decrease it in the long run. Tourism decreases the use of clean energy.
H. W. Liu et al. (2025)	China	2008-2019	Spatial Durbin model, geographically and temporally weighted regression model	They showed an inverted U-shaped relationship between tourism clustering and tourism carbon emission efficiency, regional spillover effects, and the heterogeneous impacts of agglomeration on efficiency across provinces. Their results show the favorable effects of education and the direct effects of economic development, foreign direct investment, and transport accessibility. They found negative spillover impacts of economic development, environmental regulation and transport accessibility.
M. S. Wang and Zuo (2025)	Changdao Island of China	2016-2021	Driving, pressure, state, impact, and response model, Analytical Hierarchy Process method	Tourism-related carbon emissions decrease due to clean energy usage, the decline in tourism activities, and a transition to low-carbon tourism.
Y. Wang et al. (2025)	China	2005- 2019	Gravity model, quadratic assignment process model, and spatial network analysis	The carbon efficiency of urban tourism increases, but there are city-level differences. Developed cities have higher carbon efficiency levels. Carbon efficiency spatial connection is shown to be affected by R&D investments, the digital economy, the market size of tourism, the industry structure, education, and economic development favorably. However, government expenditure was found to affect it negatively.

Source: *Author's elaboration*

Moreover, this study reviews the literature on energy intensity and carbon intensity determinants. Table 2 provides information related to these studies. Studies analyze different countries using wide range of methods considering different time periods. In the studies, important factors affecting energy efficiency and carbon efficiency are taken as economic development, industrialization, renewable energy consumption, nonrenewable energy consumption, foreign direct investment inflow, trade openness, environmental technologies, domestic investment, tax revenues, fiscal decentralization, retail price index, regional consumption, economic policy uncertainty, export diversification, economic growth, urbanization, institutional quality, and financial development to name a few. This study aims to contribute to the literature by analyzing the tourism sector's effect, considering the impacts of other variables such as economic complexity, uncertainty, and environmental policy stringency.

3. Methodology

This study employed panel data methods. At the beginning of the analysis, cross-sectional dependency tests were performed. Based on the results of cross-sectional dependency tests, appropriate panel unit root tests were employed considering the time dimension of the panel series. Long run relationships can be tested if all panel series are I(1). The models in equations (1) and (2) were estimated using panel data on 24 countries over 2013-2020 and considering countrywise heterogeneity, common shocks over time, and carbon and energy intensity persistency to deal with autocorrelation and cross-sectional dependency in error terms. In the estimation of these dynamic panel data models, this study employed bias corrected Least Square Dummy Variable (BCLSDV) dynamic panel data estimator introduced by Bun and Kiviet (2003), Kiviet (1999), and Kiviet (1995). In the analysis using unbalanced panel data with a small number of cross-sectional units, BCLSDV was shown to perform better than GMM and Least Square Dummy Variable estimators, as Bruno (2005) discussed.

Table 2: Recent studies analyzing energy intensity and carbon intensity determinants

Author	Country	Period	Method	Results
Bashir et al. (2020)	29 OECD countries	1990-2015	Panel quantile regressions, sequential estimation, system GMM, and difference GMM	Export diversification, economic growth, trade, financial development, and democratic accountability have favorable effects on energy efficiency. Urbanization and bureaucratic quality were found to increase energy intensity.
M. Chen et al. (2021)	Middle East and North African countries	1990-2016	Cross-sectional Autoregressive Distributed Lag model	Technological innovation and structural economic transformation improve energy efficiency, while population growth and shadow economy have adverse impacts. The interaction effect of the shadow economy with technological innovation further shows that energy efficiency will decline despite a high level of technological innovation if there are intensive shadow economy activities. Energy efficiency contributes to economic transformation and technological innovation.
W. Zheng (2021)	China	2000-2017	Panel data analysis	Marketization, high technological FDI inflow, and higher FDI share in the manufacturing sector decrease electricity intensity. However, FDI participation, import-oriented FDI, trade liberalization, and share of secondary industry increase it. Environmental pollution control investment was shown to have no significant effect. More FDI participation and import-oriented FDI were shown to improve energy efficiency only if associated with higher marketization levels.
H. L. Zheng et al. (2021)	Global level data on 43 countries and 56 sectors	2005-2014	Multiregional input-output analysis, panel quantile regression model, and complex network theory	The industrial driving effect and its topological structure are important determinants of energy intensity. Under high energy intensity, to reduce energy intensity, countries should decrease their effect on other countries; however, for lower energy intensity levels, their findings indicate that international co-operation with more countries and more influential countries decreases energy intensity. Higher effects and dependence on other countries were found to increase energy intensity.
Zhong et al. (2021)	Global level data on 21 regions	1971-2014	Tapio decoupling and Logarithmic Mean Divisia indices	For residential buildings in high- and upper-middle-income regions, they found a decline in energy intensity and a decoupling of energy intensity from economic development. Substantial energy savings potentials were investigated for lower-middle income regions. The commercial buildings of high-income (upper-middle and lower-middle income) regions showed a reduction (increase) in energy intensity.
Zhu et al. (2021)	China	2005-2017	Three-stage data envelopment analysis, Spatial autocorrelation analysis, Tobit model	The findings indicate an increase in carbon emissions and a decline in carbon emission efficiency. Industry scale and investment in research and development were found to increase carbon emission efficiency, but energy intensity, capital formation rate, and water intensity were shown to decrease it.
Paramati et al. (2022)	28 OECD countries	1990-2014	Panel data analysis	Environmental technologies, economic growth, and trade openness are essential in reducing energy intensity.
S. Yu et al. (2022)	82 countries	1996-2016	Dynamic panel threshold regression model	Energy intensity declined with economic development and renewable energy consumption. It increases with non-renewable energy consumption.
Deng et al. (2024)	China	2004-2017	Spatial panel data methods	They showed the positive effect of economic policy uncertainty and its spillover effect. Their results indicate favorable total, direct, and indirect impacts of national income and total investment but undesirable direct and total effects of electricity consumption. In addition, they show that the increase in regional consumption and fiscal decentralization in surrounding regions increases the carbon emission intensity of the region, but tax revenues and retail price index decrease. They also found a positive direct effect of tax revenues.
Lin et al. (2024)	China	2005-2020	Fixed effects model	Carbon intensity is decreased by digitalization.
Tran (2025	Comprehensive and Progressive Agreement for Trans-Pacific Partnership countries	2000-2015	Data envelopment analysis	Significant differences were shown in the energy efficiency of countries. Developed countries perform better.

Source: *Author's elaboration*

$$eintensity_{i,t} = \alpha_{1,i} + \tau_{1,t} + \beta_{1,1}eintensity_{i,t-1} + \beta_{1,2}lgdppc_{i,t} + \beta_{1,3}lgdppc_{i,t}^{2} + \beta_{1,4}ltourism_{i,t} + \beta_{1,5}environment_{i,t} + \beta_{1,6}fuelimports_{i,t} + \beta_{1,7}popdensity_{i,t} + \beta_{1,8}industry_{i,t} + \beta_{1,9}renewable_{i,t} + \beta_{1,10}urban_{i,t} + u_{1,i,t} \quad (1)$$

$$co2intensity_{i,t} = \alpha_{2,i} + \tau_{2,t} + +\beta_{2,1}co2intensity_{i,t-1} + \beta_{2,2}lgdppc_{i,t} + \beta_{2,3}ltourism_{i,t} + \beta_{2,4}ltourism_{i,t} \times environment_{i,t} + \beta_{2,5}fuelimports_{i,t} + \beta_{2,6}investment_{i,t} + \beta_{2,7}industry_{i,t} + \beta_{2,8}renewable_{i,t} + \beta_{2,9}popdensity_{i,t} + \beta_{2,10}trade_{i,t} + \beta_{2,11}unemployment_{i,t} + \beta_{2,12}urban_{i,t} + \beta_{2,13}governance_{i,t} + \beta_{2,14}fdi_{i,t} + \beta_{2,15}eci_{i,t} + \beta_{2,16}uncertainty_{i,t} + u_{2,i,t} \quad (2)$$

Where, $u_{j,i,t} \sim iidN(0, \sigma^2)$, $\alpha_{j,i}$ and $\tau_{j,t}$ show the error term, country-specific fixed effects and time effects for each model *j*=1,2, country *i*=1,…,24, year *t*=2013,...,2020, respectively. In equation (1), energy intensity ($eintensity$) is explained by lagged $eintensity$ ($eintensity_{-1}$), logarithm of real Gross Domestic Product per capita ($lgdppc$), square of logarithm of $lgdppc$ ($lgdppc^2$), international tourist arrivals ($ltourism$), environmental policy stringency index ($environment$), fuel imports ($fuelimports$), population density ($popdensity$), industrial value added ($industry$), renewable energy consumption ($renewable$), and urbanization ratio ($urban$). On the other hand, equation (2) shows that carbon intensity ($co2intensity$) may be determined by lagged $co2intensity$ ($co2intensity_{-1}$), $lgdppc$, $ltourism$, interaction term between $ltourism$ and $environment$ ($ltourism \times environment$), $fuelimports$, fixed capital formation rate ($investment$), $industry$, $renewable$, $popdensity$, trade openness ($trade$), unemployment rate ($unemployment$), $urban$, governance ($governance$), foreign direct investment inflows (fdi), economic complexity index (eci), and uncertainty index ($uncertainty$). Age dependency ratio and real effective exchange rate are also included, but final model excludes these variables due to multicollinearity and insignificance. These models in equation (1) and equation (2) are obtained based on general to specific modelling approach.

Following Bashir et al. (2020), carbon intensity and energy intensity were taken as a proxy measure of energy efficiency. The dynamic model is employed to consider autocorrelation in energy intensity, as discussed by S. Yu et al. (2022), and carbon intensity persistency. One may expect a positive and persistent impact of previous energy and carbon intensity levels on current levels because of the cumulative nature of changes in energy consumption (S. Yu et al., 2022) and carbon emissions, stranded assets, and path dependency.

Economic growth may affect energy intensity in three ways similar to its effect on environmental degradation, as Ahmad et al. (2021) explained: scale effect, composition effect, and technical effect. Economic growth may initially require higher energy consumption; this effect is called the scale effect. As economies grow, structural shifts may occur from heavy industry to service sector. This may lead to lower energy consumption based on the composition effect. Lastly, the technical effect implies that as economies grow further due to technological improvement, efficiency gains may lead to lower energy consumption and, therefore, lower energy intensity. One may expect a Kuznets curve-type relation between economic growth and energy intensity. Technological innovation facilitates sectoral transformation and low carbon economy transition, introducing various novelties related to energy efficiency and renewable energy (Chen et al., 2021; Kihombo et al., 2021).

Nevertheless, the countries following extensive development path may not benefit from technological progress for energy efficiency improvement because their economic growth depends on increasing production inputs, and energy demand may also increase due to the marginal cost declines in products and services after the technological improvement, which is called as the rebound effect, therefore, due to rebound effect, one may also expect an increase in energy intensity (S. Yu et al., 2022). For power generation, technological innovation may also lead to a decline in power prices as it may increase total factor productivity in power stations. This may lead to the purchase of new electrical devices, machines, and equipment, and therefore, technological innovation may increase energy usage, both directly and indirectly (Saudi et al., 2019). On the other hand, intensive growth mode may lead to energy efficiency improvement as it depends on quality and overall efficiency improvement. In our sample, most countries are developed, so one may expect a negative effect of per capita income on energy and carbon intensities. Moreover, environmental awareness may rise as income increases; this may also reduce both carbon and energy intensities.

Economic structure is also essential. A higher proportion of manufacturing-added value in GDP may be expected to increase energy consumption as these sectors consume energy intensively in their production processes. Structural transformations in the economies, i.e., the transition from energy-intensive industrial economies to service economies, may lead to less energy and carbon intensity by changing the nature of innovation (Chen et al., 2021) and based on knowledge and innovation, transition to less energy and carbon-intensive economies can be achieved. Based on this argument, an inverted U-shaped relation between economic growth and energy intensity can also be expected. However, the service sector may provide more job opportunities, leading to higher living standards, per capita national income, and energy consumption (Chen et al., 2021). Energy intensity may increase as a result of structural economic transformation. The tourism sector is a part of the service sector, and based on the above argument, it may contribute to a reduction in energy and carbon intensities and, therefore, facilitate a low-carbon economic transition.

Environmental policy stringency may lead to declining fossil fuel-based energy consumption and carbon emissions. Carbon and energy intensities may increase if there is a lock-in with inefficient technology, weak environmental laws, and a lack of ecological impact assessment of project financing (Kihombo et al., 2021). The model also includes the interaction effect of more stringent environmental policies and tourism activities to measure the effect of stringent environmental policies on energy efficiency improvement associated with a higher level of tourism development.

Nonrenewable energy consumption may also lead to higher energy intensity because of its effects on energy supply security, sustainable and stable economic growth of countries, and various characteristics of these energy sources, such as vulnerability to wars, economic crises, technical problems, reserve limitations, and uneven geographical distribution (S. Yu et al., 2022). Thus, fossil fuel imports may cause delays in energy efficiency improvements and increase energy and carbon intensities.

A higher level of investment may decrease carbon and energy intensities if there is a shift towards more efficient technologies and appliances in fixed capital formation. However, purchasing new devices, machines, and equipment may increase energy usage, both directly and indirectly, and therefore may increase energy and carbon intensities.

Renewable energy consumption accelerates technological innovation, trade openness, industrial structural and infrastructure upgrading, and energy mix optimization by substituting fossil fuels, productivity, job creation, and economic growth while it reduces energy import dependency and ensures energy supply security and resilient supply chains (S. Yu et al., 2022). Moreover, countries can achieve energy efficiency by employing renewable energy-based technologies or increasing productivity in their production processes (Chen et al., 2021). As a result, one expects energy intensity to decline.

Globalization may lead to higher energy efficiency through technology transfer among the countries due to trade and foreign direct investment flows, but it may also lead to higher carbon and energy intensity by creating pollution havens, i.e., may induce higher energy and carbon intensive production (Nathaniel, 2021; S. Yu et al., 2022). As W. Zheng (2021) discussed, trade openness may decrease the energy and carbon intensity through technology transfer between countries. Using these advanced and new technologies, countries may employ their resources more efficiently to produce goods and services. However, if technology transfers are limited across countries, these efficiency gains may not occur (W. Zheng, 2021).

Unemployment may cause a decline in the purchasing power of individuals, associated with a decline in energy consumption, and cause a decline in carbon and energy intensities. However, as individuals cannot afford to own energy-efficient appliances, machines, and equipment, energy consumption and energy and carbon intensities cannot decline.

Urbanization and population density may cause higher energy consumption as economic activities increase (Bashir et al., 2020). Moreover, it provides easy access to various services and goods, necessitating energy consumption. Efficiency gains can also be obtained due to the scale effects (Kihombo et al., 2021) because urbanization may change infrastructure, patterns of consumption and production, and transport modes (Bashir et al., 2020). This may lead to lower energy and carbon intensity. Better institutional quality may facilitate the implementation of various energy efficiency policy instruments and increase their effectiveness in reducing energy and carbon intensity (Ahmad et al., 2021).

The economic complexity index shows the capabilities of a country, technological and structural changes, and economic progress (Ahmad et al., 2021), and based on trade data, it was proposed by Hidalgo et al. (2009). Higher ECI means higher technology-intensive exports, shows higher technological development levels, and may imply higher usage of energy-saving technologies (Fang et al., 2021; Nathaniel, 2021). Therefore, one may expect lower energy and carbon intensity associated with higher ECI. On the other hand, as export quality and trading improve, energy consumption is expected to increase (Bashir et al., 2020). Production may necessitate higher energy consumption; therefore, higher economic complexity may cause higher energy and carbon intensity. One may also expect inverted U-shape relations between them (Chu & Le, 2022). At the beginning of their development path, countries with higher knowledge levels may use energy intensively. After some threshold of economic complexity, countries may shift from energy-intensive to technology-intensive economies, which may also lead to less energy intensity.

Uncertainty causes delays in investment (Bernanke, 1983) and may also delay investments related to energy efficiency improvement, therefore increase energy intensity (J. Yu et al., 2021). Nevertheless, it may also cause economic contraction and a reduction in energy consumption, reducing energy intensity (Chu & Le, 2022).

4. Data

The study used annual balanced panel data on 24 countries from 2013 to 2020 based on data availability. The data set includes energy intensity (MJ/$2017 PPP GDP) [EG.EGY.PRIM.PP.KD], CO2 emissions intensity (kg per 2021 PPP $ of GDP) [EN.ATM.CO2E.PP.GD.KD], gross fixed capital formation (% of GDP) [NE.GDI.FTOT.ZS], per capita real GDP (constant 2021 international PPP $)

Table 3: Descriptive statistics

Variable	Mean	Std dev.	Coefficient of Variation (%)	Min	Max
$eintensity$	3.9610	1.5448	39.0002	1.9600	8.2500
$co2intensity$	0.1817	0.1138	62.6365	0.0540	0.5705
$lgdppc$	10.6627	0.4377	4.1046	9.4596	11.3582
$ltourism$	16.8520	1.2131	7.1983	13.7057	19.2091
$environment$	2.898698	0.967305	33.3703	0.78	4.89
$ltourism \times environment$	48.9458	16.8319	34.3888	11.4636	90.9687
$fuelimports$	12.6217	6.9885	55.3685	0.7234	37.3147
$investment$	22.5739	5.9104	26.1825	10.6874	44.5188
$industry$	24.3184	6.1175	25.1558	13.3547	44.1767
$renewable$	19.5029	14.9744	76.7805	1.9200	61.2900
$popdensity$	153.5222	148.7408	96.8855	3.0106	531.1090
$trade$	78.2223	35.4556	45.3268	31.3102	168.3950
$unemployment$	8.1899	5.8626	71.5832	2.3500	27.6900
$urban$	78.7134	10.1976	12.9554	53.0130	98.0790
$governance$	0.9156	0.7838	85.5966	-0.8033	1.8563
fdi	2.6885	11.8648	441.3223	-40.0863	106.5730
eci	1.0951	0.7567	69.0957	-0.6337	2.5501
$uncertainty$	0.2927	0.2060	70.3831	0.0348	1.3429

Source: *Own Calculation*

[NY.GDP.PCAP.PP.KD], international tourist arrivals [ST.INT.ARVL], fuel imports (% of merchandise imports) [TM.VAL.FUEL.ZS.UN], industry share (% of GDP) [NV.IND.TOTL.ZS], renewable energy consumption (% of total final energy consumption) [EG.FEC.RNEW.ZS], population density (people per sq. km of land area) [EN.POP.DNST], trade openness [NE.TRD.GNFS.ZS], unemployment rate [SL.UEM.TOTL.ZS], urban population (% of total population) [SP.URB.TOTL.IN.ZS], corruption control [CC.EST], government effectiveness [GE.EST], regulatory quality [RQ.EST], political stability [PV.EST], rule of law [RL.EST], voice and accountability [VA.EST], foreign direct investment inflows (% of GDP) [BX.KLT.DINV.WD.GD.ZS], economic complexity index, uncertainty index, and environmental policy stringency index. The data source is The World Bank (2024) and The World Bank (2024) World Development Indicators Database for all panel series, excluding the uncertainty, and environmental policy stringency indexes. For the uncertainty index, and environmental policy stringency index, Ahir et al. (2022), and Organisation for Economic Cooperation and Development [OECD] (2024) are data sources, respectively. Using natural logarithms, per capita real GDP and international tourist arrivals were transformed. Governance is obtained by taking averages of corruption control, rule of law, regulatory quality, government effectiveness, political stability, and voice and accountability.

Table 3 shows descriptive statistics. Energy intensity, carbon intensity, logarithm of per capita real Gross Domestic Product, logarithm of international tourist arrivals, environmental policy stringency index, interaction term between $ltourism$ and $environment$, fuel imports, fixed capital formation rate, industrial value added, renewable energy consumption, population density, trade openness, unemployment rate, urbanization ratio, governance, foreign direct investment inflows, economic complexity index, and uncertainty index are on average, 3.96, 0.18, 10.66, 16.85, 2.90, 48.95, 12.62%, 22.57%, 24.32%, 19.50%, 153.52, 78.22%, 8.19%, 78.71%, 0.976, 2.69%, 1.10, 0.29 over the years and across the countries, respectively. The coefficient of variation indicates that foreign direct investment net inflows has the highest variability across countries and over time. The variance inflation factors calculated as 2.55 and 4.43 show the absence of any severe collinearity among independent variables in models (1) and (2), respectively.

5. Empirical Results

Except for foreign direct investment inflow, all series exhibit cross-sectional dependency. Due to the short time dimension (T=8), based on the assumption of a common unit root process for all countries, Levin et al. (2002) panel unit root test was employed. Following the suggestion of Levin et al. (2002), the series was cross-sectionally demeaned to eliminate cross-sectional dependency. All series were found to be stationary. The results are given in Table 4.

Table 4: Unit root tests

Variable	CD Test	Levin et al. (2002) Test
$eintensity$	31.46***	-8.4885***
$co2intensity$	37.58***	-4.2658***
$lgdppc$	32.65***	-5.9114***
$ltourism$	44.18***	-7.9605***
$environment$	9.52***	-21.2905***
$ltourism \times environment$	8.42***	-33.9992***
$fuelimports$	39.25***	-12.4014***
$investment$	10.14***	-4.8257***

Variable	CD Test	Levin et al. (2002) Test
$industry$	2.09**	-12.2331***
$renewable$	22.80***	-3.5403***
$popdensity$	14.71***	-11.7560***
$trade$	18.83***	-6.5080***
$unemployment$	14.70***	-5.7207***
$urban$	39.03***	-3.9908***
$governance$	9.67***	-5.4535***
fdi	-0.18	-4.2658***
eci	3.05***	-7.7054***
$uncertainty$	8.10***	-8.8603***

Source: *Own Calculation*

In Table 5, estimation results are presented. Heteroscedasticity, autocorrelation and cross-sectional dependency tests were performed for OLS and within estimations. Their results indicate evidence of heteroscedasticity. Results show that intervals of reasonable estimates for $eintensity_{-1}$and $co2intensity_{-1}$ are 0.3678-0.9876 and 0.5627-0.9393 obtained from OLS estimations of pooled dynamic models shown in columns (1) and (4) and within estimations of fixed effects dynamic panel data models shown in columns (2) and (5). Therefore, coefficient estimates of $eintensity_{-1}$ and $co2intensity_{-1}$ are within these intervals. However, they are close to 1, indicating that there is a high level of persistency in energy and carbon intensities.

The columns (3) and (6) of Table 5 show estimation results for models (1) and (2) estimated by BCLSDV, respectively. Bootstrapped standard errors are calculated to correct standard errors in the presence of heteroscedasticity. Findings indicate that energy and carbon intensity may decline as real income per capita and renewable energy consumption increase. This finding is also in line with S. Yu et al. (2022), Bashir et al. (2020) and Paramati et al. (2022). In contrast, X. R. He et al. (2022) showed that carbon intensity increases with economic development in China. In addition, a U shape relationship was shown between real income per capita and energy intensity. After some level of real income per capita, energy intensity may increase.

Fuel imports, population density, industrial development, and urbanization may increase energy and carbon intensity. Similar findings were also shown by Bashir et al. (2020), Chen et al. (2021), W. Zheng (2021), and Zhu et al. (2021). Industrial structure was found to decrease carbon intensity by X. R. He et al. (2022). Zhu et al. (2021) show an adverse impact of energy intensity on carbon intensity. Bashir et al. (2020) also found the adverse effect of urbanization on energy intensity. Environmental policy stringency leads to an increase in energy intensity, but its effect is statistically insignificant. X. R. He et al. (2022) found a direct positive effect of environmental regulation on carbon intensity but a favorable spillover impact.

Table 5: Estimation results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
$eintensity_{-1}$	0.9876***	0.36779***	0.83018***			
	(0.01027)	(0.06538)	(0.14468)			
$lgdppc$	1.32221	-18.8866***	-38.690***	0.00615	-0.02978	-1.406***
	(1.16014)	(6.07887)	(13.41379)	(0.00375)	(0.02042)	(0.06651)
$lgdppc^2$	-0.06097	0.88685***	1.82438***			
	(0.05606)	(0.29738)	(0.64016)			
$ltourism$	-0.01108	0.01070	0.10166	-0.0025**	0.00077	0.1221***
	(0.01572)	(0.04818)	(0.09368)	(0.00098)	(0.00278)	(0.00909)
$environment$	-0.01810	-0.02560	0.16073			
	(0.01785)	(0.06198)	(0.11454)			
$fuelimports$	0.00038	0.01977***	0.02994***	-0.00001	0.00064*	0.0031***
	(0.00241)	(0.00607)	(0.01005)	(0.00016)	(0.00038)	(0.00108)
$popdensity$	-0.00014	0.00196	0.01883**	-0.00001*	-0.00018	0.0036***
	(0.00012)	(0.00480)	(0.00953)	(0.00001)	(0.00028)	(0.00077)
$industry$	-0.00113	0.04495***	0.06230**	0.00044*	0.00117*	0.0110***
	(0.00224)	(0.01173)	(0.02550)	(0.00024)	(0.00062)	(0.00220)
$renewable$	-0.00232	-0.0234***	-0.0675***	-0.0003***	-0.0010**	-0.041***
	(0.00147)	(0.00776)	(0.02148)	(0.00009)	(0.00046)	(0.00167)
$urban$	-0.00163	0.04132*	0.13693**	-0.00010	-0.00065	0.0334***
	(0.00140)	(0.02190)	(0.06557)	(0.00008)	(0.00117)	(0.00465)
$co2intensity_{-1}$				0.9393***	0.5627***	0.9153***
				(0.01267)	(0.05811)	(0.06221)
$ltourism$				-0.00004	0.00003	0.0039***
$\times environment$				(0.00006)	(0.00020)	(0.00054)
$investment$				0.00018	0.0014***	0.0231***
				(0.00017)	(0.00052)	(0.00187)
$trade$				0.00002	0.00001	0.0015**

				(0.00002)	(0.00017)	(0.00064)
$unemployment$				0.0006***	0.00078*	0.0216***
				(0.00020)	(0.00046)	(0.00140)
$governance$				-0.00117	-0.01513	-0.0828**
				(0.00185)	(0.00938)	(0.03565)
fdi				0.00001	-0.00002	0.0004***
				(0.00004)	(0.00004)	(0.00013)
eci				0.00059	0.01338*	-0.071***
				(0.00133)	(0.00701)	(0.02019)
$uncertainty$				0.00784**	0.00206	-0.227***
				(0.00326)	(0.00353)	(0.01146)
constant	-6.78840	98.3350***		-0.02584	0.40012*	
	(6.04216)	(30.25565)		(0.04832)	(0.21753)	
HC	56.33***	1670.07***		117.68***	1003.1***	
	(0.0000)	(0.0000)		(0.0000)	(0.0000)	
AC	-1.1	-0.47		-0.36	1.08	
	(0.271)	(0.637)		(0.717)	(0.279)	
CD	0.34	-0.218		-0.58	-0.965	
	(0.733)	(0.8271)		(0.565)	(0.3347)	

Notes: **, **, *** show p<0.1, p<0.05 and p<0.01, respectively. Coefficient estimates on country-specific and time-period fixed effects are not shown but are available upon request. In parentheses, standard errors and for BCLSDV bootstrapped standard errors are given. (1) Pooled OLS for model (1), (2) Fixed Effects Estimation for model (1), (3) BCLSDV for model (1), (4) Pooled OLS for model (2), (5) Fixed Effects Estimation for model (2), (6) BCLSDV for model (2). For BCLSDV, the initialization of bias correction was done by the Anderson-Hsiao estimator. HC, AC and CD indicate heteroscedasticity, autocorrelation and cross-sectional dependency tests.*
Source: *Own Calculation*

Furthermore, carbon intensity increases with tourism development, investment, trade, unemployment, and foreign direct investment inflows. More stringent environmental policies may further increase the undesirable impact of tourism activities. The findings of Moutinho et al. (2015) and Robaina-Alves et al. (2016) support the results related to the undesirable effect of tourism on carbon intensity. In addition, adverse impacts of tourism were also reported by Pablo-Romero et al. (2021), Bianco (2020), L. M. He et al. (2020), Becken et al. (2001), Tabatchnaia Tamirisa et al. (1997), and J. Liu et al. (2011). The positive impact of tourist arrivals on energy intensity was found to be statistically insignificant. However, in contrast to the above results, the findings of Tang et al. (2018), X. R. He et al. (2022), and Li et al. (2019) show a favorable impact of tourism on overall energy efficiency improvement. Adverse effect of investment is also reported by Zhu et al. (2021). Moreover, on the contrary, X. R. He et al. (2022) showed the favorable effect of FDI on carbon intensity. On the other hand, similar to the findings, W. Zheng (2021) found positive effects of FDI participation, import-oriented FDI, and trade liberalization on electricity intensity, but high technological FDI inflow, and higher FDI share in the manufacturing sector were shown to decrease electricity intensity. Findings of Paramati et al. (2022) and Bashir et al. (2020) indicate that energy efficiency improves with trade openness. On the other hand, governance, economic complexity, and uncertainty have been shown to reduce carbon intensity. Similar findings were also obtained by Paramati et al. (2022) and Bashir et al. (2020) for energy intensity. However, some studies (Deng et al., 2024; Persakis, 2024) show that uncertainty increases carbon intensity.

6. Conclusion

This study examines tourism's impact on energy and carbon intensities using data on 24 countries over 2013-2020 and panel data techniques. Findings indicate the unfavorable effect of tourism on carbon intensity. Therefore, there is room for energy efficiency improvements in the tourism sector. The results suggest the requirement of various policies' implementation for energy efficiency improvements, giving special attention to the tourism sector. First, the sustainable development of the tourism sector should be ensured by considering its tremendous environmental side effects (X. R. He et al., 2022). Awareness of resource management, interest, organizational and psychological factors are important issues that can facilitate the implementation of energy efficiency programs (Becken et al., 2001). Energy efficiency improvements can be obtained through managerial innovations, technological innovations, developing energy literacy, adoption of new technologies, energy auditors, forecasting, monitoring, and controlling energy consumption, as discussed by Becken et al. (2001), Coles et al. (2016), Cabello Eras et al. (2016) and Chen et al. (2021). Therefore, enhancing economic agents' capabilities (sensing capability, seizing capability, absorptive capacity, reconfiguring capabilities) is crucial for energy management and, thus, energy efficiency improvement (Pace, 2016). For monitoring, controlling, and reducing energy consumption, developing and implementing suitable energy performance indicators is proven essential by Cabello Eras et al. (2016). Also, as discussed by Zhong et al. (2021), there can be differences between the countries; local-level policies should be designed in such a way that for high-income countries, there can be little room for further energy intensity decline based on the implementation of existing policies; therefore, the technological and socio-economic system can be rearranged. On the other hand, for lower- and middle-income countries, existing policies, such as building efficiency standards for new buildings and electrical appliances, can be implemented. Awareness raising, act, and implementation of environment protection laws, lower interest loans, subsidies, tax exemptions, people-private-public partnerships, and university-industry collaborations may provide incentives for the implementation of energy efficiency programs in residential, industrial, and commercial sectors and technological innovation related to energy efficiency (Chen et al., 2021; Kihombo et al., 2021; Nathaniel, 2021; Paramati et al., 2022). Institutional quality should be improved, and product complexity, industrial productive structure, and manufacturing structure should be considered in energy policies, as suggested by Ahmad et al. (2021). Environmentally friendly urban planning and transportation policies are essential to increase energy efficiency (Bashir et al., 2020; Kihombo et al., 2021). Credibility, predictability, and transparency of economic policies are also crucial to decrease economic policy uncertainty (Chu & Le, 2022), influencing carbon intensity in this study. Gössling et al. (2015) suggest focusing on nearby market development instead of long-haul without lowering tourism growth to a great extent. This suggestion may also improve energy efficiency. In addition, sustainable forms of tourism may also contribute to energy efficiency improvements by causing behavioral changes and strengthening institutions which are responsible for resource management as highlighted by Stronza et al. (2019). Lastly, due to data unavailability, the analysis cannot cover the period after 2020. Future studies should analyze the impact of tourism sector on energy efficiency by employing data which cover the period after Covid-19 pandemic and consider other countries. The focus of this study is on energy efficiency. However, the tourism sector uses other resources also, for example, water. Therefore, future studies should consider other aspects of efficiency and indicators which measure heavy usage of resources in tourism activities, its environmental and social consequences. In this context, policy recommendations can be formulated in line with ecotourism and other types of sustainable tourism.

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INFO PAGE

Tourism's impact on energy efficiency: A panel data analysis

Abstract

Countries have continued to focus on the issues related to the energy crisis, climate change, and the transition to a low-carbon economy. Energy consumption is essential for countries' economic growth as energy provides various services for industrial, residential, and transportation sectors. However, heavy use of fossil fuels may cause many environmental problems and climate change. This dilemma forces countries to implement various policies. Policies implemented for energy efficiency improvement form one avenue to reach climate change mitigation and environmental goals, ensure sustainable economic development and transition to a low-emission regime. This study employs energy and carbon intensity as indicators to evaluate energy efficiency. As economies grow, structural shifts may occur from heavy industry to service sector. This may lead to lower energy consumption. However, the service sector may provide more job opportunities, leading to higher living standards, per capita national income, and energy consumption. Energy intensity may increase as a result of structural economic transformation. As part of the service sector, tourism may contribute to the transition to a low-carbon economy. Therefore, based on panel data techniques, this study aims to analyze the tourism sector's impact on energy and carbon intensities using data on 24 countries over 2013-2020. Findings show the importance of energy efficiency improvements in the tourism sector to reduce economies' energy intensity and carbon intensity. In conclusion, countries should implement various policies to strengthen energy efficiency improvements in all industries while giving special attention to tourism.

Keywords: *Energy intensity, Carbon intensity, Tourism, Panel data analysis.*

Authors

Full Name	Author contribution roles	Contribution rate
Gülsüm Akarsu:	*Conceptualism, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision*	*100%*

Author statement: *Author(s) declare(s) that All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.* ***Declaration of Conflicting Interests:*** *The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article*

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