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An Appraisal of Green Gross Provincial Product of a Tourist Island - An Analysis Focusing on Phuket

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ABSTRACT

This study incorporated provincial input-output tables into the environmental assessment process for Phuket - an island with an economy based largely on tourism. The life cycle assessment approach was employed considering five impact categories including climate change, fossil scarcity, water, eutrophication and land use for green gross provincial product (GGPP) calculation. Degradation cost and depletion cost originating from global warming and fossil resource scarcity were the main contributors. The results indicated that for a tourism-based economy such as Phuket, industries associated with tourism, such as accommodation and food service activities, wholesale and retail trade and repair of motor vehicles, as well as transportation and storage are highly profitable, but also impose heavier environmental burdens compared to other sectors. The sectoral GGPP of electricity, gas, steam, and air conditioning supply, as well as water supply, sewerage, waste management and remediation activities, involved more in local residents' living, accounted for 25% and 50% of the sectoral gross provincial product (GPP), respectively. In 2015, Phuket GGPP was 160 billion THB, corresponding to 96% of the Phuket GPP. As Phuket relies heavily on its beautiful environment to bring economic value, it is imperative to protect it against environmental damages especially irrecoverable ones.

HIGHLIGHTS

This study applies provincial input-output (IO) tables developed for assessment of a tourism-based economy to reveal the study area's environmental costs and green gross provincial product (GGPP).

1. INTRODUCTION

In an attempt to preserve and safeguard natural resources and environment for long-term human well-being, sustainable development has emerged as a significant issue over the past decades. It emphasizes the balance between economic growth and environmental preservation to maintain the environmental vitality. To progress along this path, there is ongoing effort to propose and formulate appropriate indicators for measuring growth (Adewumi et al., 2023).

As a common indicator of economic development, gross domestic product (GDP) is typically used to represent the growth of a national economy over a specific period. While useful in measuring economic development, concerns have been raised that GDP does not accurately reflect the well-being of a national economy (Schweinfest et al., n.d). One of the most frequent criticisms of GDP is that it totally omits the environment, or rather, counts the environmentally harmful activities as economic output (Chan et al., 2022). For instance, forest-based industries

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could foster GDP growth (Li et al., 2019), but could negatively influence well-being and economic development since it causes deforestation. As an effort to include environmental damage into economic growth assessment, green gross domestic product (GGDP) has been proposed as an indicator to measure the growth of a national economy under the context of sustainable development (Wei et al., 2020). GGDP is defined as the difference of traditional GDP and the costs from environmental deterioration and resources depletion (Wu and Han, 2020). Further efforts have been made to implement this indicator on regional (Yang and Poon, 2009) or provincial (Qi et al., 2021; Cai and Hu, 2024) scales, revealing disparities in environmental damage for different economic structures.

Over the course of the past 60 years, tourism has continually developed and significantly contributed to the growth of the global economy (Greco et al., 2017). According to the World Travel and Tourism Council, before COVID in 2019, travel and tourism generated 9.17 trillion USD, representing 10.4% of the global gross domestic product (GDP). About 10% of employment opportunity worldwide came from this industry (World Travel and Tourism Council, 2021a). Despite the intense vulnerability to environmental, political, and socio-economic variations, tourism has resiliently overcome countless challenges and obstacles (Novelli et al., 2018). Even after the occurrence of the destructive pandemic COVID 19, which caused a substantial reduction in travel and tourism's income to 4.78 trillion USD in 2020, it achieved a rapid recovery. In 2021, this industry contributed 5.81 trillion USD, equivalent to 6.1% of the global economy, experiencing a vast increase of 21.7% compared to the industry's income in the previous year (World Travel and Tourism Council, 2021b).

Besides the substantive economic gains, there are also several damaging environmental consequences as a result of tourism development (Zhong et al., 2011). Infrastructure construction, energy and resource consumption, and pollution and waste from tourist activities have resulted in serious adverse environmental and ecological damages (Davenport and Davenport, 2006). Tourism is one of the most significant consumers of energy. An increase in tourist activities could result in a rise in energy consumption from transportation, food services, accommodation, and other tourism operation processes (Acaroğlu et al., 2023). Furthermore, tourism also accounted for 11% of the greenhouse gas (GHG) emissions worldwide (World Travel and Tourism Council, 2021a). Other effects such as deforestation (Chakraborty and Ghosal, 2024) and water pollution (Bi and Li, 2024) are additional environmental issues that could arise directly or indirectly as a result of tourism. Poor management could intensify those damages (Sunlu, 2003). Given the worldwide concern to alleviate serious damage series caused by tourism, more effort is demanded for information on the environmental burdens caused by tourism which is an important step in the mitigation process (Li et al., 2023).

There are several methods that are widely applied to assess environmental impacts such as green performance map, environmental value stream map, life cycle assessment (LCA) (Shahbazi et al., 2019), material flow analysis (Xu et al., 2024), and cumulative effects assessment (Greaves and Parrott, 2024). From a variety of approaches, LCA is commonly regarded as one of the most suitable and encompassing approaches to assess environmental burden through transparent evaluation procedures and in-depth analysis (Curran et al., 2017). The combination of LCA and input-output (IO) tables can enable the measurement of environmental burdens caused by both industries and from final demand (Liang et al., 2024), including governments and residents' activities.

As an effective tool providing information on the interrelationships between the inputs and outputs of industries (Markaki and Papadakis, 2024), the application of LCA and input-output tables can offer insights into how economic sectors should be modified since the input-output tables provide information on the connections between different industries, producers, and purchasers. For instance, if there is a requirement to reduce agricultural production, this method could forecast the potential impacts of this reduction in the related sectors, such as manufacturing (Miller and Blair, 2009). Therefore, it is applied as the main method to assess environmental impacts in this study.

Building on this framework, most IO-LCA applications have been conducted at the national level, where comprehensive input-output tables and environmental extensions are readily available, such as in Thailand (Kunanuntakij et al., 2017), China (Wang et al., 2020), and Brazil (Brito et al., 2025). At the provincial level, existing studies are often based on officially available regional input-output tables, as in the cases of Guizhou Province (Yi et al., 2020) and Shenyang City (Chen et al., 2020), while the construction of fully survey-based provincial input-output tables remains highly data-intensive and is frequently constrained by limited availability of regional statistics. In this context, this research contributes to the literature by taking an initial step toward applying IO-LCA at the provincial scale through the use of a localization technique to adapt national input-output data to provincial conditions. Rather than aiming to construct a complete provincial input-output table for Phuket, the study demonstrates how a non-survey regionalization approach can be employed to approximate provincial inter-industry relationships under conditions of data scarcity. This methodological contribution provides a practical and transferable starting point for green gross provincial product (GGPP) assessment in data-constrained tourism-oriented provinces.

This study aims to demonstrate an evaluation of GGPP applying input-output analysis of Phuket, a tourist island in the southern part of Thailand. GGPP is an indicator developed on the same conceptual basis as GGDP, but it is utilized to reflect the negative externalities associated with the final goods and services of a province. Phuket is selected as the study area due to its 11th rank among the leading tourist destinations worldwide in 2017 (CNN, 2017). According to a study conducted by C9 Hotelworks organization, hotels and restaurants, a major component of tourism, contributed 35% of Phuket's gross provincial product (GPP) (C9 Hotelworks, 2015) manifesting the important role played by tourism in the economic growth of this province. Before COVID 19, from 2014 to 2018, Phuket attracted an average of 13.1-13.4 million tourists annually (Maswongssa, 2020). It is administratively divided into 17 sub-districts as presented in Figure 1.

The outcomes of this study are the illustration of Phuket's environmental perspective in terms of numerical value and revealing Phuket's industries mostly responsible for environmental burdens, thus being able to provide recommendations for regulation with the aim of improvement. Furthermore, this study could also serve as a model for other tourist destinations to incorporate environmental burdens into their economic accounting by applying input-output analysis. This framework could also facilitate the acquisition of additional data while shaping policies for a specific area.

2. METHODOLOGY

2.1 Materials

There are two main categories of data in this paper: national input-output tables, which record the flows of goods and services between suppliers and consumers within Thailand; and activity data of fuel consumption, electricity consumption, food consumption, water use, waste disposal, and land use. The data was mainly obtained from governmental organizations as presented in Table 1.

The economic sectors were categorized according to the standard system comprising 19 sectors established by NESDC. To enhance readability and comprehension, abbreviated names for these sectors are created as shown in Table 2.

Table 1. Sources of information used in this study

Data	Sources
Energy	Energy Policy and Planning Office (EPPO) National Statistical Office of Thailand (NSO)
Land use	Land Development Department (LDD)
Waste	Provincial Office of Natural Resources and Environment Phuket
Water	Provincial Water Authority (PWA) National Statistical Office of Thailand (NSO)
Wastewater	Regional Environment Office 15 (EPO)
Thailand input-output tables	Office of the National Economic and Social Development Council (NESDC)

Table 2. Economic sector names presented in the paper

NESDC system	Abbreviated names
Agriculture, forestry, and fishing	Agriculture
Mining and quarrying	Mining and Quarrying
Manufacturing	Manufacturing
Electricity, gas, steam and air conditioning supply	Energy Supply

Table 2. Economic sector names presented in the paper (cont.)

NESDC system	Abbreviated names
Water supply; sewerage, waste management and remediation activities	Water Supply and Cleaning Activities
Construction	Construction
Wholesale and retail trade and repair of motor vehicles	Trade Activities
Transportation and storage	Transportation and Storage
Accommodation and food service activities	Accommodation and Food Service
Information and communication	Information and Communication
Financial and insurance activities	Finance and Insurance
Real estate activities	Real Estate
Professional, scientific, and technical activities	Research
Administrative and support service activities	Administrative Activities
Public administration and defense; compulsory social security	Public Administration and Social Security
Education	Education
Human health activities	Human Health
Arts, entertainment, and recreation activities	Arts, Entertainment, and Recreation
Other service activities	Other Activities

Figure 1. Study area - Phuket

2.2 Methods

2.2.1 Environmental input-output assessment

1) National input-output table analysis

Input-output table or the basic Leontief input-output model is normally created from economic statistical data of an identified region such as a nation, a state, or province. Input-output tables show the basic information of the production flows of each industry. There are two ways to consume products of industry. First, products go into the manufacturing processes of other industries. Second, products go into customer's consumption. Input- output tables represent the number of products from an industry (considered as a producer) that go into other industries (considered as consumers) and to customers (final demand). The rows in value added account for non-industrial input, such as labor, needed to create products. Therefore, in general, the column shows the required input of each sector in order to produce the output of an industry. The row describes the distribution of an industry's products to other industries and customers.

The sum of sectoral value added equals to the sum of sectoral final demand. Each of them is equal to the gross domestic product of a country or gross provincial product of a province. In technical form, input-output tables are written as shown in Table 3.

Table 3. The standardized form of input-output tables

Industry		Buying sector (i)				Final demand	Total output
		1	2	…	n		
Selling sector (j)	1	z_{11}	z_{12}	…	z_{1n}	f_1	X_1
	2	z_{21}	z_{22}	…	z_{2n}	f_2	X_2
	…	…	…	…	…	…	…
	n	z_{n1}	z_{n2}	…	z_{nn}	f_n	X_n
Payment sector	Value added	v_1	v_2	…	v_n		
Total output		X_1	X_2	…	X_n		

x_i is the total amount of product i
f_i is the final demand for product i
z_{ij} is the intermediate consumption of product i required by sector j

The basic equation can be written as:

$$X_1 = z_{11} + z_{12} + \ldots + z_{1n} + f_1 = \sum_{j=1}^{n} z_{ij} + f_i \qquad (1)$$

For every sector:

$$\begin{aligned} X_1 &= z_{11} + z_{12} + \ldots + z_{1n} + f_1 \ldots \\ X_i &= z_{i1} + z_{i2} + \ldots + z_{in} + f_i \ldots \\ X_n &= z_{n1} + z_{n2} + \ldots + z_{nn} + f_n \ldots \end{aligned}$$

or

$$X = \begin{pmatrix} x_1 \\ \ldots \\ x_n \end{pmatrix} \qquad Z = \begin{pmatrix} z_{11} & \ldots & z_{1n} \\ \ldots & \ldots & \ldots \\ z_{n1} & \ldots & z_{nn} \end{pmatrix} \qquad F = \begin{pmatrix} f_1 \\ \ldots \\ f_n \end{pmatrix}$$

and

$$A = \begin{pmatrix} a_{11} & \ldots & a_{1n} \\ \ldots & \ldots & \ldots \\ a_{n1} & \ldots & a_{nn} \end{pmatrix}$$

In the matrix form, it can be written as:

$$\begin{aligned} x_i &= \textstyle\sum_{j=1}^{n} z_{ij} + f_i = \sum_{j=1}^{n} a_{ij}\, x_j + f_i \\ &\Rightarrow X = (A \times X) + F \\ &\Rightarrow X \times (I - A) = F \\ &\Rightarrow X = (I - A)^{-1} \times F \end{aligned}$$

In the first step, the industrial coefficient matrix A of Thailand was calculated using information from governmental sources. It should be noted that A represents the industrial coefficient matrix of Thailand, I is an identity matrix, X is a matrix of total output of Thailand, and F is matrix of final demand.

The supplementary file contains the details of calculation results. The code system outlined in Table A1 is used to represent all sectors in this file. The results of Thailand industrial coefficient matrix A are presented in Table A2.

2) Provincial input-output tables

Given the variation between national and regional economy, specific input-output tables have been considered for smaller geographic scales. Regions, provinces, or other geographic scales might have less resources for data collection related to input-output tables construction. Less effort is involved in estimating regional input-output tables from the national input-output tables than surveying information to create region-specific input-output tables (Miller and Blair, 2009). There are several techniques to convert regional input-output tables from national ones. One of the most common methods is using location quotients (Kowalewksi, 2015) which uses primary conversion factors to adjust corresponding national coefficients to obtain regional coefficients. The application of techniques depends on the available data that regions or provinces have. This method is considered time and budget saving to construct provincial input-output tables (Flegg et al., 2021) and is useful for policy makers or government officers.

This study constructed the provincial input-output tables from Thailand's national input-output tables as shown step by step in Figure 2. The 180 sectors of the Thailand input-output tables were reorganized into 19 sectors in accordance with the Thailand Standard Industrial Classification 2009 (TSIC-2009) (Department of Employment, 2009). This reorganization was carried out using the conversion quotient from national input-output tables to provincial input-output tables calculated based on sectoral GDP of Phuket.

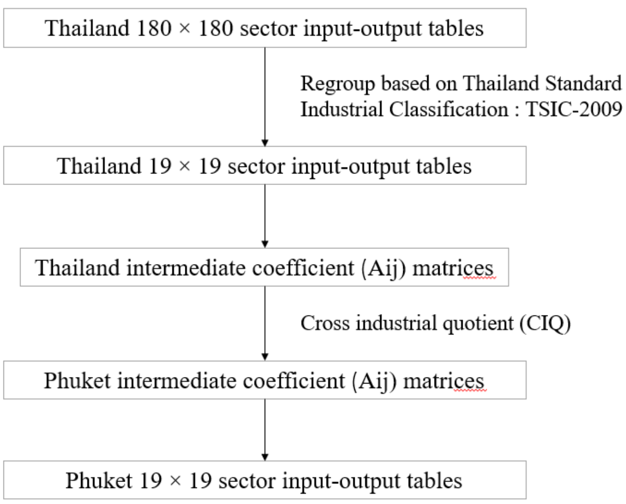

Figure 2. Process of provincial input-output tables construction

Then, the cross industrial quotation was applied to calculate the Phuket co-efficient matrix. Conversion factor from national input-output tables to provincial input-output tables, called Cross Industry Quotient (CIQ), was obtained by using Equation 2 (Miller and Blair, 2009):

$$\mathrm{CIQ}_{ij}^{PK} = \left(\frac{\frac{x_i^{PK}/x_i^{TH}}{x^{PK}/x^{TH}}}{\frac{x_j^{PK}/x_j^{TH}}{x^{PK}/x^{TH}}}\right) = \left(\frac{x_i^{PK}/x_i^{TH}}{x_j^{PK}/x_j^{TH}}\right) = \left(\frac{f_i^{PK}/f_i^{TH}}{f_j^{PK}/f_j^{TH}}\right) \tag{2}$$

Where: x_i^{PK} is the sum of product i in Phuket; x_i^{TH} is the sum of product i in Thailand; x_j^{PK} is the gross output of sector j in Phuket; x_j^{TH} is the gross output of sector j in Thailand; x^{PK} is the gross output of Phuket; x^{TH} is the gross output of Thailand; f_i^{PK} is the final demand for product i in Phuket; f_i^{TH} is the final demand for product i in Phuket; f_j^{PK} is the final demand for sector j in Phuket; f_j^{TH} is the final demand for sector j in Thailand.

The coefficient matrix of Phuket was then calculated using the Equation 3:

$$a_{ij}^{rr} = \begin{cases} \left(\mathrm{CIQ}_{ij}^{PK}\right) a_{ij}^{TH} & \text{if } \mathrm{CIQ}_{ij}^{PK} < 1 \\ a_{ij}^{TH} & \text{if } \mathrm{CIQ}_{ij}^{PK} \geq 1 \end{cases} \tag{3}$$

Where: a_{ij}^{rr} the interindustry coefficient of Phuket; CIQ_{ij}^{PK} the cross industrial quotient of Phuket; a_{ij}^{TH} the interindustry coefficient of Thailand.

The interpretation of CIQ is that if the product i in Phuket relative to the product i in Thailand is larger than the output of sector j in Phuket relative to the output of the sector j in Thailand ($\mathrm{CIQ}_{ij}^{PK} \geq 1$), the product i is sufficient for the sector j's needs within Phuket. In contrast, if the product i in Phuket relative to the product i in Thailand is smaller than the output of sector j in Phuket relative to the output of sector j in Thailand, the product i is insufficient for the sector j's needs within Phuket; then the needs of product i for the sector j is imported and coefficient a_{ij}^{rr} is downscaled by $\mathrm{CIQ}_{ij}^{PK}(a_{ij}^{TH})$ if $\mathrm{CIQ}_{ij}^{PK} < 1$. The CIQ of this study is presented in the Table A3 in the supplementary data.

There are several techniques introduced to convert regional input-output tables from national one. Those techniques use primary conversion factors to adjust corresponding national coefficients to obtain regional coefficients. The application of techniques depends on different available data that regions or provinces have. This method is considered time and budget saving to construct provincial input-output tables (Flegg et al., 2021). Among those approaches, location quotients is considered as one of the most common methods used in regionalizing input-output tables (Kowalewksi, 2015; Pominova et al., 2022). The first introduced location quotient was Simple Location Quotient (SLQ). However, this technique overlooks the impacts of the demanding sector. One of the initial enhancements of the SLQ was the cross-industry quotient (CIQ) (Kowalewski, 2015). This technique considers both the effects of supplying sectors and demanding sectors (Okamoto, 2014). While there are numerous studies on SLQ and CIQ, there are very limited studies on Supply-Demand Pool Approaches, Fabrication Effects, or Regional Purchase Coefficients. The choice of the best regionalization method often hinges on the quality and availability of data, as different methods have varying data requirements. Supply-Demand Pool Approaches regionalize national input-output tables using national supply and use tables rather than national input-output tables as a reference (Piispala, 2000). As a result, this method requires different data sets than those employed in this study. Several studies highlight that Regional Purchase Coefficients are often considered the most unreliable component of non-survey approaches (Lazarus et al., 2002). Furthermore, CIQ stands out for its advantages of adaptability as a non-survey method. It could be used for different regions with various economic context under the condition of limited data availability. As it does not require data-intensive collection, it is also considered as a resource-saving method (Flegg et al., 2021). Although it cannot be competed to precision of more data-intensive techniques, its feasibility makes it practical tool for regional economic analysis, particularly in the contexts with limited resources.

After matrix A of Phuket (Table A4 in the supplementary data) was obtained, the next step was the calculation of the inverse matrix $(\mathrm{I}-\mathrm{A})^{-1}$ and $\mathrm{X}=(\mathrm{I}-\mathrm{A})^{-1}\times\mathrm{F}$ (Note that: I is identity matrix).

The conversion factor, calculated using CIQ technique, can be applied when data on the final demand (or GDP) of each economic component is available. Therefore, this study employed the CIQ technique to convert Thailand input-output tables to Phuket input-output tables.

2.2.2 Environmental burden assessment

ReCiPe 2016 - a life cycle impact assessment method at the midpoint and endpoint levels was employed to evaluate the environmental burdens caused by human activities in Phuket. ReCiPe 2016 is a multi-impact LCIA method and is among the most comprehensive frameworks available for environmental impact assessment. It quantifies impacts at the midpoint level across 18 categories, which can be further aggregated into endpoint damage categories— human health, ecosystem quality, and resource availability—and, if required, into a single weighted score (Cespi et al., 2025). The impact assessment process is illustrated in Figure 3.

Across numerous studies throughout years, tourism has been recognized as one of the significant contributors to energy consumption (Shan and Ren, 2023) and GHG emissions (Gössling et al., 2023). As an island having tourism as a major economic driver, Phuket is expected to exhibit significant figures on fuel consumption and GHG emissions. Solid waste (Hayati et al., 2020) wastewater (Wells et al., 2016), and land use change (Iversen et al., 2024) are also acknowledged as major issues in a tourist island requiring suitable management. As Phuket has been experiencing water shortage frequently (Sattraburut et al., 2024), water use category was also included in this study. There is no notable sign of particulate matter pollution detected on this island (Kumlom, 2021); hence, it is not included in this study. Since mining - the main source of heavy metal has been closed since 1992 (Akkajit et al., 2018) and tourism is a relatively insignificant source of contamination compared to past mining operations, (Akkajit et al., 2018; Puttiwongrak et al., 2019), this category is also excluded. Therefore, five impact categories were assessed in this study, including global warming, fossil resource scarcity, water use, eutrophication, and land cover loss. With the ultimate goal of evaluating GGPP of Phuket, two global impact categories-global warming and fossil resource scarcity were assessed based on consumption-based approach, while local impacts were assessed based on production-based approach, focusing only on factors directly affecting and caused by this island.

The impact assessment was done using the Equation 4:

$$\text{Emissions/pollutant} = \text{Activity data} \times \text{Emission/pollution factor} \tag{4}$$

The national input-output tables record the intersectoral flows between industries in a given period, usually a year. Initially, the researchers considered the data at country level, for which the economic activities are categorized into different sectors. The data captures the monetary values associated with the production and distribution of an industry at national level. On the other hand, at the provincial level, there are cases that goods are imported from outside. In this case, the data focuses on the monetary values related to the distribution of products of an industry. In this context, the data from input-output tables can be effectively utilized to allocate the resource consumption or calculate environmental emissions/pollutants when integrated with the statistical data. In this study, it was used for the environmental burden allocations in global warming, fossil resource scarcity, water use, and eutrophication. Together with statistical data from government sources, it provides a holistic impact assessment for a tourist island such as Phuket.

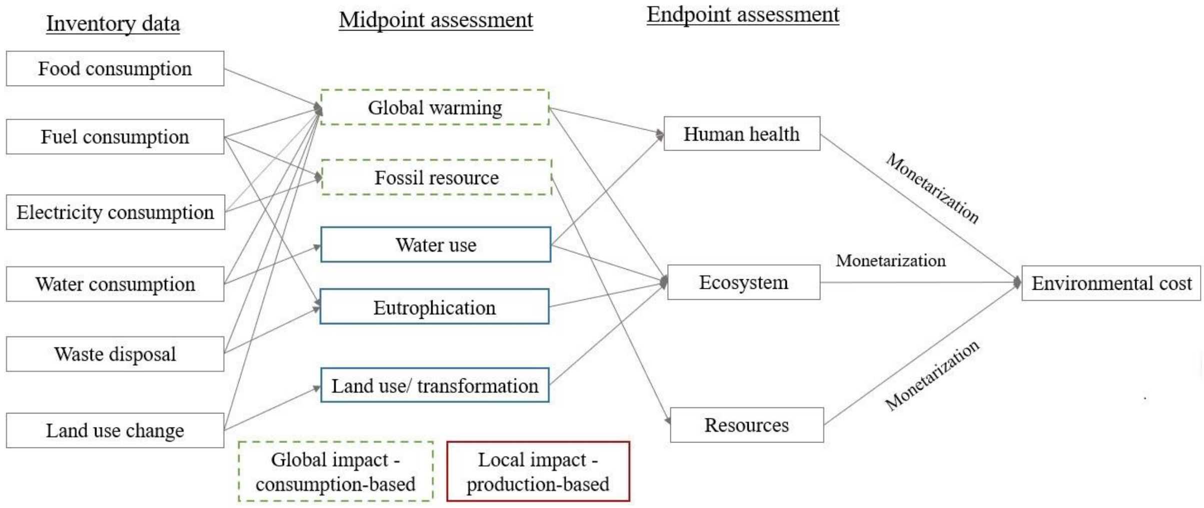

Figure 3. Impact assessment process of this study

2.2.3 Environmental cost assessment

After the step of environmental impact assessment, monetization process was applied to calculate the environmental costs. The monetization factors were obtained from the previous study (Kaenchan and Gheewala, 2017) which offers factors estimated based on Thailand conditions.

This paper utilized the Thailand input-output tables for the year 2015, which offer the most updated data. It serves as an example of applying input-output analysis in yearly accounting and highlights the benefits it provides.

Concerning the instabilities in monetary values across different years, all amounts were standardized to a single year 2015 using the Equation 5:

$$\text{Value}_{TH_{t^*}} = \text{Value}_{TH_t} \times (1+r)^{(t^*-t)} \quad (5)$$

Where; $\text{Value}_{TH_{t^*}}$ represents the monetization factors of Thailand in 2015, t is the year of currency accounted in valuation, t^* is the base year of calculation (2015), Value_{TH_t} represents the monetization factors that needed to convert, r is the average inflation rate of Thailand over accounted period, acquired from World Bank (World Bank, 2024). In this study, r is the average inflation rate of Thailand in from 2011 to 2015.

The degradation cost is calculated using Equation 6:

$$\text{Degradation cost} = \text{Total emissions/pollutants} \times \text{environmental cost per unit} \quad (6)$$

The depletion cost is calculated using Equation 7:

$$\text{Depletion cost} = \text{Total amount of resources consumed} \times \text{environmental cost per unit} \quad (7)$$

2.2.4 Green gross provincial product calculation

According to the System of Environmental-Economic Accounting (SEEA), environmental costs comprise of degradation cost, depletion cost, and defensive cost. Degradation cost refers to the potential monetary loss as a result of damage arising from deterioration of human health and ecosystem. Depletion cost represents the expense associated with the raw material and resources extraction from the stocks, considering the return to the natural condition. Defensive cost is the expenditure involved in environmental protection and prevention (Kunanuntakij et al., 2017). The final GGPP is calculated using Equation 8:

$$\text{GGPP} = \text{Traditional GPP} - \text{environmental costs} \quad (8)$$
$$= \text{Traditional GPP} - (\text{degradation cost} + \text{depletion cost} + \text{defensive cost})$$

The life cycle environmental burdens caused by global impacts were included in the GGPP calculation. While for local impacts, only the direct impact was included.

3. RESULTS AND DISCUSSION

3.1 The application of provincial Phuket input-output analysis to environmental assessment

3.1.1 Global impact assessment

The total GHG emission of Phuket in 2015 was 3,317.6 kt CO_2 equivalent, excluding emissions from Land Use, Land-Use Change and Forestry (LULUCF). It accounted for 0.8% of Thailand's GHG emissions. The contribution of LULUCF was 68.1 kt CO_2 equivalent. The largest emission contributor to global warming was electricity consumption, as presented in Figure 4, with approximately 1,455.2 kt CO_2 equivalent. Fuel consumption occupied the second biggest portion with 1,100.6 kt CO_2 equivalent. At the third place was food consumption with 502.1 kt CO_2 equivalent. The two insignificant emission sources were water consumption and wastewater contributing 11.1 and 2.1 kt CO_2 equivalent, respectively.

In terms of economic sectors-related GHG emissions, as presented in Figure 5, Energy Supply occupied the largest share, contributing approximately 1,085.8 kt CO_2 equivalent. Accommodation and Food Service accounted for the second largest proportion, contributing roughly 296.4 kt CO_2 equivalent. The third place was Transportation and Storage with 275.4 kt CO_2 equivalent. The Water supply and Cleaning Activities hold the fourth-largest share, totaling almost 222.7 kt CO_2 equivalent, followed by Trade Activities with 166.8 kt CO_2 equivalent.

Given that Phuket is a tourist island, it is not surprising that sectors closely relevant to tourism activities, such as Accommodation and Food Service activities, Transportation and Storage, as well as Trade Activities, contributed significantly to the provincial GHG emissions. Also, sectors catering for residential daily living, such as (i) Energy Supply, as well as (ii) Water Supply and Cleaning Activities claimed even higher positions. Despite the number of tourists in Phuket during 2015 being significantly higher (around four times more) than the local population, the GHG emissions related to tourists remained approximately three times lower compared to that of the local population. This is due to the transient nature of tourists, who typically stay on the island for only short periods and do not reside there year-round like the residents. If adjusted to the same basis, converting number of tourists to residents staying on this island for the whole year, the number of tourists was significantly lower than the resident population. In addition, Phuket also has nearly 200,000 people who are not registered in the household system. This was also highlighted by the data provided by Thailand Greenhouse Gas Management Organization (TGO). It shows that when compared on the same basis, the number of tourists were 4.4 times less than the number of Phuket residents (TGO, 2013).

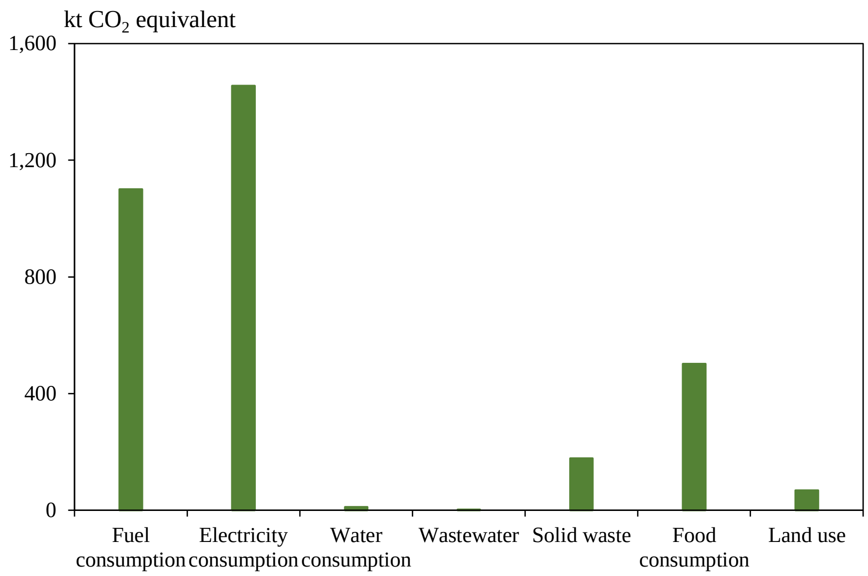

Figure 4. Global warming potential sources in Phuket

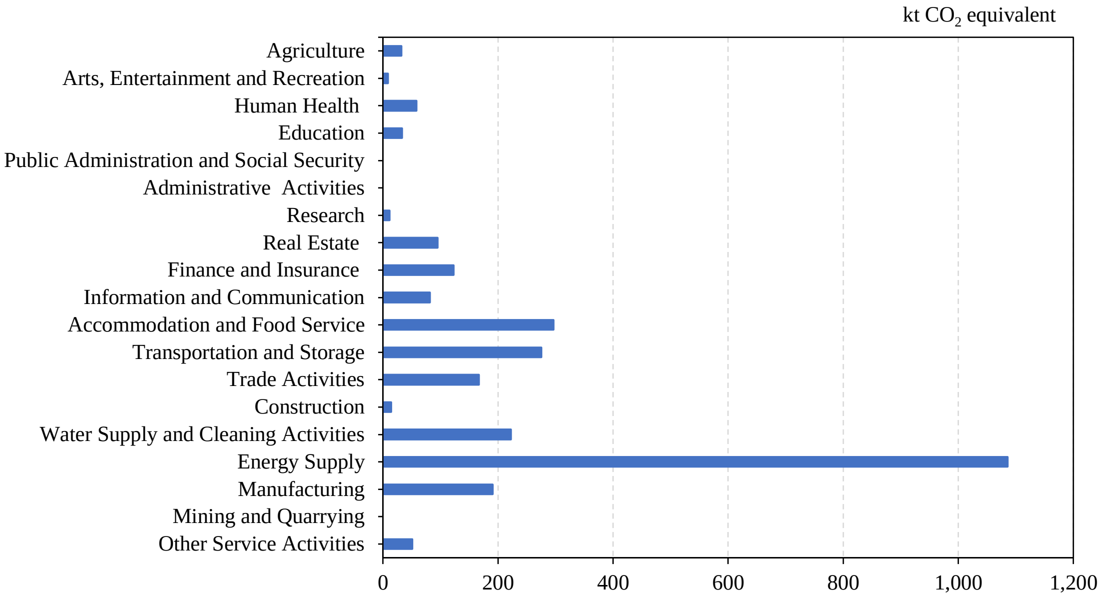

Figure 5. Global warming potential by economic sectors in Phuket in 2015

On the other hand, these figures also provide an example of a substantial disparity between national and provincial assessment results concerning various economic core sectors. At the national level, manufacturing and agriculture, two significant economic sectors, contributing 27% and 9% to the national GDP, also were significant emission sources, contributing 60% and 22% to the national GHG emissions, accordingly (Kunanuntakij et al., 2017). However, at the provincial level, these two sectors were comparatively insignificant, accounting for merely 9% and 1% of Phuket's overall GHG emissions, respectively, which corresponds to a contribution of 2% and 3% to the Phuket's GPP. This aligns with the reality that Phuket relies heavily on tourism as its main source of income, directly contributing 41% to Phuket's GPP and production industries are not highly developed there.

In 2015, Phuket's overall fuel consumption amounted to 581.7 kt of oil equivalent. As illustrated in Figure 6, Energy Supply still held the most substantial share, accounting for 291.2 kt oil equivalent. Being the second largest consumer, Transportation and Storage accounted for 74.8 kt oil equivalent. Accommodation and Food Service claimed the third biggest share with 50 kt oil equivalent, higher than the next one which was Manufacturing at 47.5 kt oil equivalent.

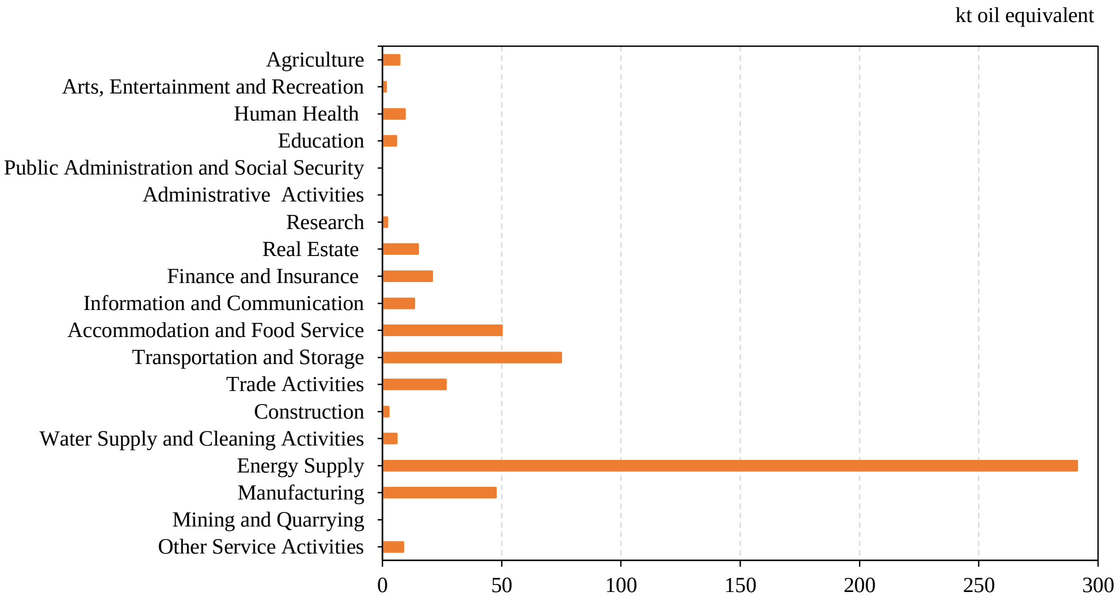

Figure 6. Fuel consumption by economic sectors in Phuket in 2015

As presented in Figure 7, the most consumed types of fuel in Phuket in 2015 were natural gas with 184.4 kt oil equivalent. Next was diesel with 152.2 kt oil equivalent. It was closely followed by gasohol, accounting for 138 kt oil equivalent. Coal and lignite occupied the fourth largest share, with 40.3 kt oil equivalent.

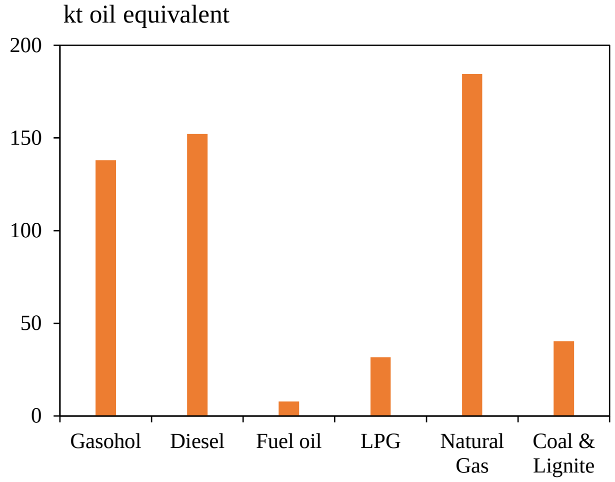

Figure 7. Fossil consumption by types in Phuket in 2015

3.1.2 Local impact assessment

Water use represents an important local environmental impact, reflecting the pressures of economic activities on regional water resources. Previous research has demonstrated that assessment based on regional input-output tables for a single province provided lower figures compared to the statistical data (Long et al., 2020). In this study, Phuket, a province with three main water? supply sources - including Provincial Waterwork Authority, private sector and groundwater, poses the possibility of exacerbating this issue, as one source, such as groundwater, may not be recorded in economic transactions. The input-output assessment indicates that provincial water consumption was about 15 million m^3, which was 24.8% lower than the water consumption figure provided by the Provincial Waterworks Authority. Hence, this study proposes combining government statistics with the input-output analysis to evaluate environmental impacts associated with economic activities at the provincial level, thereby avoiding potential underestimation.

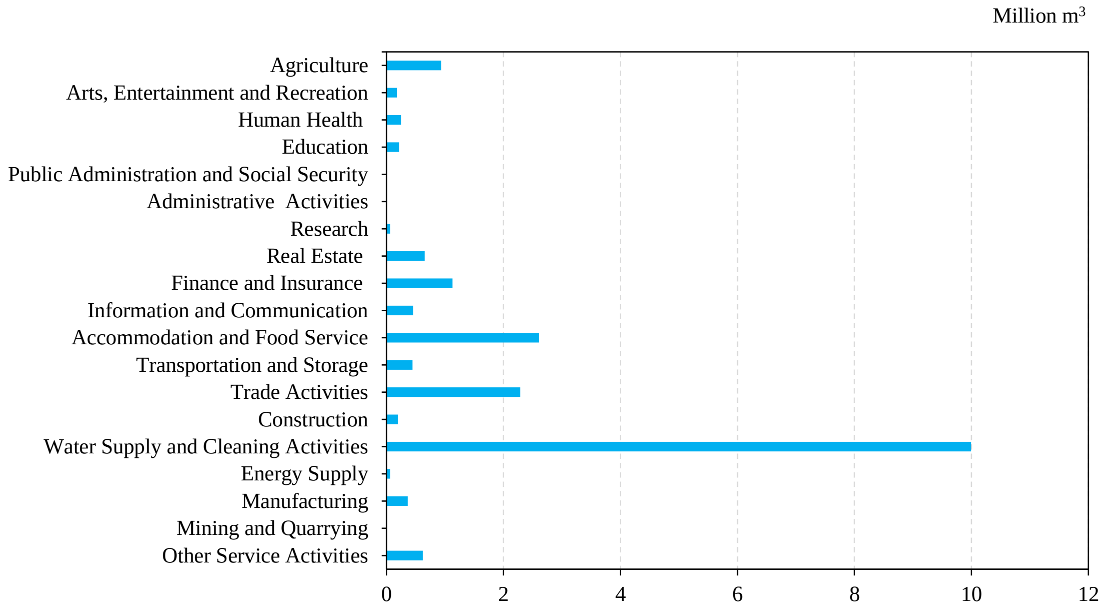

Figure 8. Water consumption by economic sectors in Phuket in 2015

Based on the statistical data, the total water consumption in Phuket in 2015 was approximately 20.5 million m^3. From the input-output analysis, the largest portion of water consumption was attributed to Water supply and cleaning activities. Ranked in first place, this sector consumed roughly 10 million m^3 as shown in Figure 8. It is associated with residential living serving essential functions such as water supply for daily cooking and facilitating cleaning and sanitation activities. Other sectors closely related to tourism also contributed significantly to water consumption. At the second place, Accommodation and Food Services consumed about 2.6 million m^3. Trade activities had the third largest consumption with approximately 2.3 million m^3. This result is also in the line with a study discussing the situation in Hawai'i-one of the most famous tourist islands. The study in Hawai'i indicates that residents are also the most substantial consumers, accounting for 55% of the island's water consumption, while hotel and resorts accounted for only 5% of the total water consumption (DeMaagd et al., 2022). Another study also reveals that residents commanded the greatest portion of water consumption on the Island of Ibiza in Spain's, accounting for 84.4% of the island's total water usage (Pérez et al., 2020).

Given that the Provincial Waterworks Authority is one of the main water sources for hotels, along with private suppliers, and water collected and produced by the hotels (Sattraburut et al., 2024), its supply is pretty sensitive to fluctuation in tourist numbers, as indicated in Figure 9. It surged during the tourist season, which is typically during the dry season from December to March (Sattraburut et al., 2024). The water sold from this source peaked in April, primarily due to the occurrence of Songkran, one of Thailand's largest festivals which attracts many tourists and also involves a lot of water. The tourist number during the high season is 42% higher than during the low season, leading to the notable increase in water demand from tourism. Moreover, the reduced precipitation during dry season also exacerbates water shortage on this island during tourism periods. A project worth 3.5 billion THB to construct a pineline from Phang Nga to enhance water availablity in Phuket, was approved in 2019 (The Phuket News, 2020). If this project is completed by 2040 to provide sufficient amount of water (33.18 million m^3) for the tourism sector (Sattraburut et al., 2024), merely Accommodation and Food Service could generate revenue of 280.25 billion THB for Phuket, which is 80 times the construction cost of the pipeline.

Not only the water quantity, but the estimated result also reveals that 305.5 t N equivalent was emitted in 2015 in, equivalent to the nitrogen content in approximately 664 tons of urea fertilizer applied in a year. These emissions contribute to local eutrophication, a process where excess nutrients lead to overgrowth of algae in water bodies, affecting water quality. As seen in Figure 10, Water Supply and Cleaning Activities emerged as the primary contributor to eutrophication with 169.5 t N equivalent. Following in second place was Energy Supply, contributing 93.7 t N equivalent. Transportation and Storage contributed the third largest share with 27.9 t N equivalent. In terms of emission-related activities, nearly 50% of the nitrogen emissions originated from wastewater treatment. Furthermore, approximately 0.06 million m^3 per day of untreated wastewater was discharged directly into the environment in 2015. This escalating degradation underscores the urgent need for a response to improve the Phuket's wastewater treatment capacity and management since it affects not only the daily lives of its residents but also tourism reputation such as Bang Tao beach's case, where untreated wastewater entering a local canal caused the water to turn black, impacting the beach's environment and tourism activities. (The Phuket News, 2019).

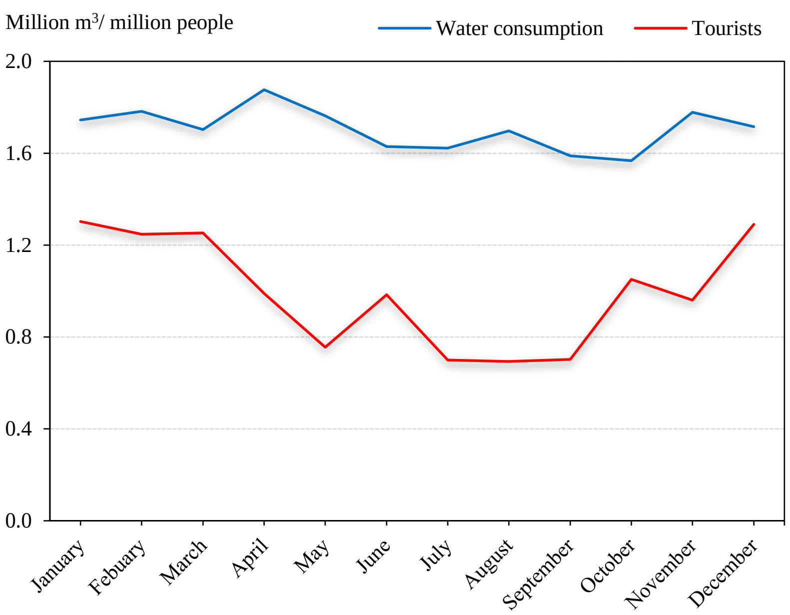

Figure 9. Monthly water sales (million m^3) by the Provincial Waterworks Authority and tourist numbers (million people) in Phuket in 2015

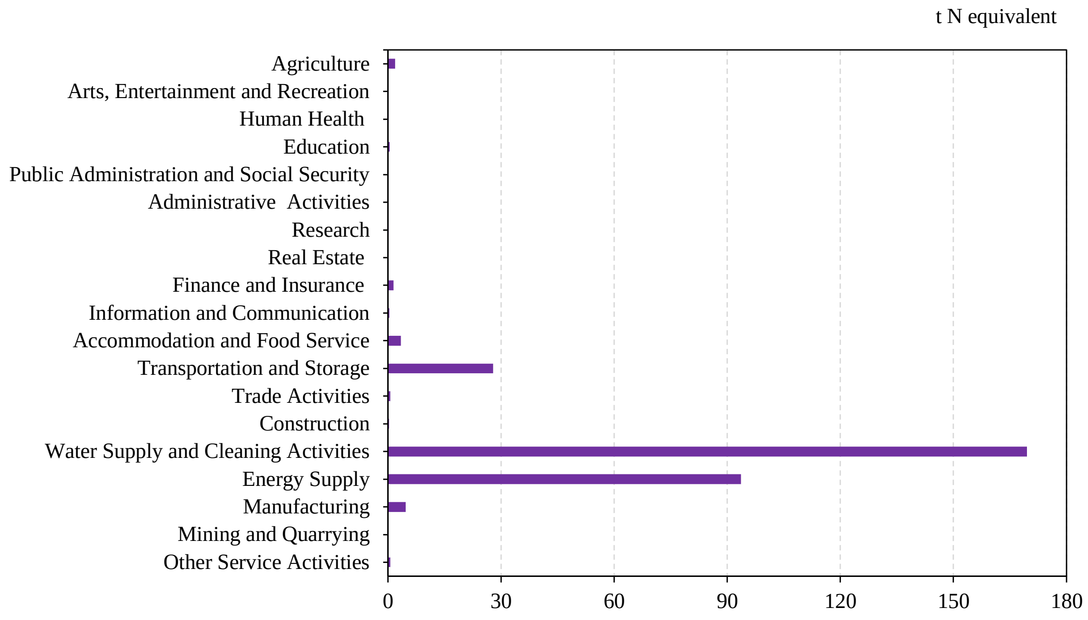

Figure 10. Eutrophication by sector in Phuket in 2015

As presented above, the main contributors for all considered categories were industries related to tourism including Accommodation and Food Service activities, Transportation and Storage, Wholesale and retail trade and repair of motor vehicle. Indutries associated with the local residents' consumption such as (i) Energy Supply, as well as (ii) Water supply and cleaning activities also made noteworthy contributions. Other sectors with less direct relevance to tourism, such as Manufacturing and Education, resulted in less negative environment impacts. Since there was not an enormous demand of infrastructure construction for tourism at that time, the adverse effect on this island's environment from the construction sector was also not substantial.

3.2 Environmental costs and green gross provincial product of Phuket

Phuket's total environmental costs in 2015 were 6.7 billion THB with depletion and degradation contributing 60% and 35%, equaling 4 and 2.4 billion THB, respectively. The remaining of 5%, equaling to 310 million THB, was contributed by defensive cost, which is six times less than degradation cost.

The primary component of degradation cost was global warming with a contribution of 2.2 billion THB, followed by land use with 147 million THB. On the other hand, a loss of 1.6 billion THB was attributed to problems related to human health, more than twofold of the loss caused by damage to ecosystems.

Fossil resource scarcity and global warming emerged as the two main drivers with the most substantial impacts on Phuket's environmental costs, as illustrated in Figure 11. These figures could be used in assessing the environmental damage caused by various issues and raising public awareness to address and improve environmental problems.

Phuket's defensive costs were primarily spent on the construction and expansion of infrastructure for waste disposal and wastewater treatment. The expense on infrastructure construction for wastewater treatment accounted for 90% of the total defensive cost. The details of defensive costs are listed in Table A5 in the supplementary file.

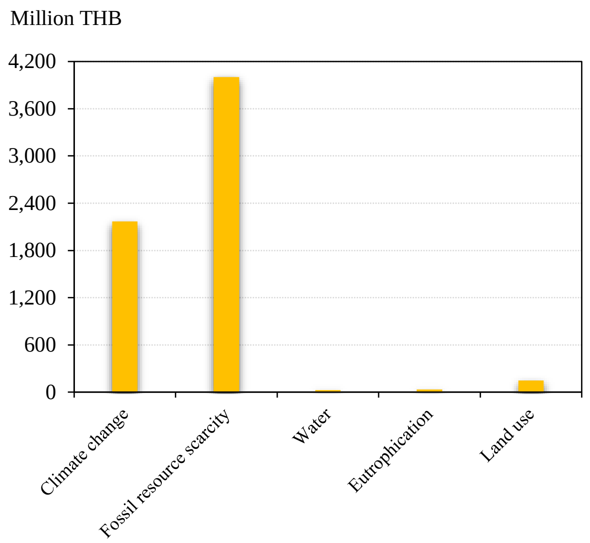

Figure 11. Distribution of environmental costs (except defensive costs) across major impact categories in Phuket in 2015

From an economic sector perspective, the sector incurring the highest environmental cost was Energy Supply, totaling 2.6 billion THB. Accommodation and Food Service secured the second position with 707.1 million THB. The third place was Transportation and Storage with 586.9 million THB. Trade Activities followed closely in fourth place with 402 million THB.

Industries related to tourism including Transportation and Storage, as well as Accommodation and Food Service were significant contributors to the provincial environmental costs. This is consistent with other studies suggesting that transportation (Stefanica, 2017) and accommodation (Mota et al., 2024) significantly contributed to the environmental burden of tourism. When the patterns of major impacts on tourism in different locations are quite similar as presented (Campos et al., 2024), effective policies or innovative solutions in one area can be a good model for other areas around the world.

The consumption of residents and government greatly contributed to the environmental costs of two sectors (i) Energy Supply, as well as (ii) Water Supply and Cleaning Activities. This consumption accounted for 73.5% and 60.3% of the total environmental costs incurred by these two sectors, respectively. This highlights the essential role that residents and goverment play in improving Phuket's environmental performace. Therefore, it is crucial to establish policies that promote and raise awareness among residents regarding responsible consumption through various approaches, such as green procurement (Wang et al., 2021), which can help fulfill their needs while preserving the environment (Liu and Tobias, 2024).

Since Phuket is a tourism-based island, the primary pillars of its economy are industries associated with tourism. They contributed significantly to the Phuket GPP. Accommodation and Food Services - one of the vital components of tourism, plays a major role by contributing 69.1 billion THB to the GPP. Transportation and Storage came in second place with 34.6 billion THB. Trade Activities was the third largest contributor with 8.9 billion THB.

Despite causing potential economic loss at approximately 6.6 billion THB, this amount is not deemed significant compared to the GPP of Phuket. The GGPP of Phuket in 2015 was 160 billion THB, equal to 96% of the GPP of Phuket. As shown in Figure 12, which presents both GPP and GGPP by sector, the sectors encompassing the demand of local residents such as (i) Energy Supply, as well as Water Supply and Cleaning Activities exhibited the lowest sectoral GGPP. On the other hand, tourism-driven sectors generate substantial economic value while accounting for a comparatively smaller share of environmental costs relative to their contribution to GPP. This distinction indicates that sustainability efforts in Phuket should adopt a dual approach: promoting responsible consumption and resource efficiency among residents, while guiding tourism activities toward low-impact growth through improved infrastructure, cleaner technologies, and effective planning. Together, coordinated actions targeting both residents and tourists are essential for maintaining economic benefits while reducing environmental pressures on the island. It should be noted that the comparison between residents and tourists in this study is based on aggregate sectoral demand rather than normalization on a per-capita basis. This approach reflects the overall pressure exerted by different demand groups on provincial economic sectors and highlights the importance of responsible consumption by residents in achieving sustainable development on the island.

As can be seen, in Phuket, tourism-related sectors such as Accommodation and Food Services, and Transportation and Storage are major contributors to provincial GDP, while sectors such as Energy Supply and Water Supply and Cleaning Activities account for the highest environmental costs. This divergence highlights that sectors driving economic growth are not always those imposing the greatest environmental burden. From a policy perspective, this finding underscores the need for differentiated strategies: tourism planning should focus on improving resource efficiency and environmental performance in high-GDP tourism sectors, whereas environmental policies should prioritize demand-side management and cleaner production in sectors with high environmental costs. For resource management, aligning economic development objectives with environmental performance through instruments such as green procurement, efficiency standards, and integrated planning is essential for enhancing the sustainability of tourism-based islands.

However, the environmental costs presented are only from the five impact categories considered. There are many other impacts that are problematic to quantify, such as coral bleaching, floods and landslides, which cause deaths. In addition, the data for defensive costs extracted from government reports are only calculated for items that are clearly identified for environmental protection efforts. However, in practice, there are environmental costs included in other budget categories, such as travel expenses paid for environmental care activities. If we add together environmental costs that are both clearly quantifiable and difficult to accurately assess, the cost should be a lot higher and there would be some losses that cannot be recovered.

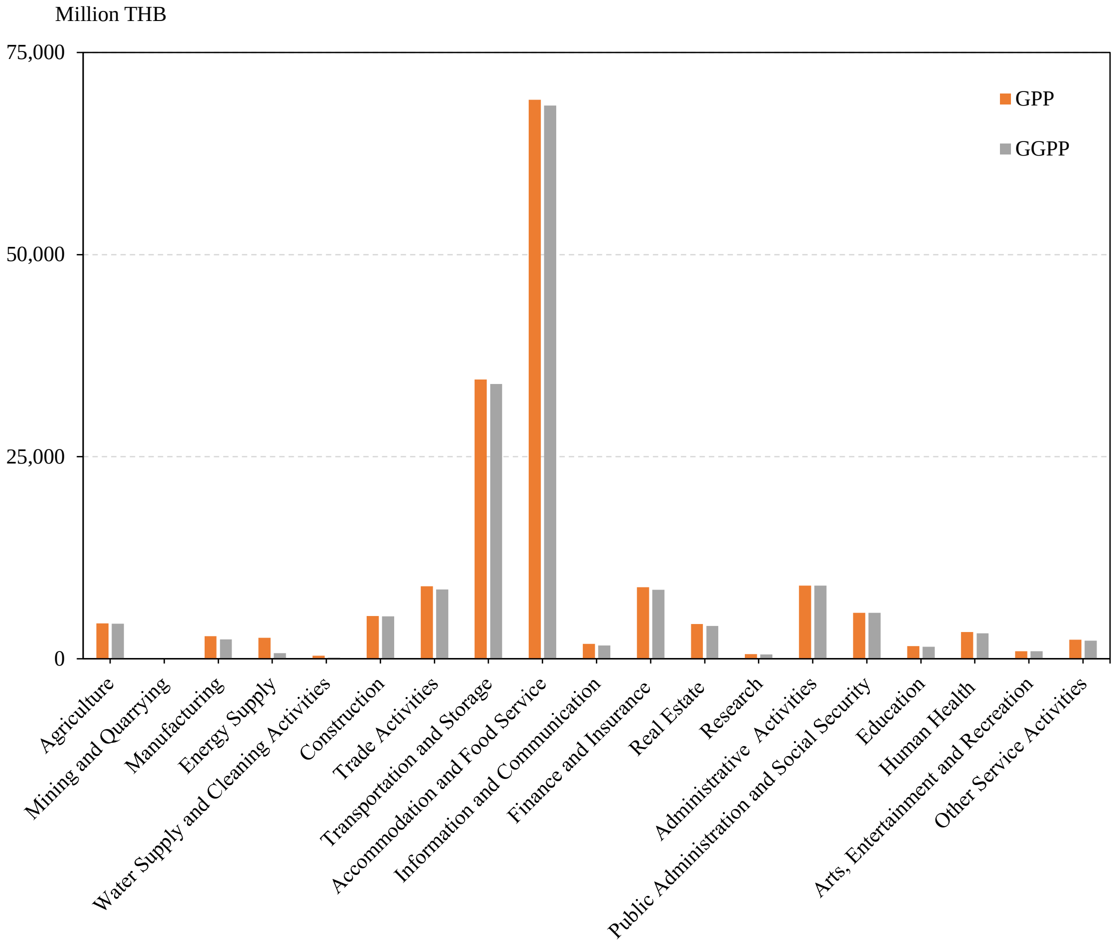

Figure 12. Phuket gross provincial product (GPP) and green gross provincial product (GGPP) across major economic sectors in Phuket in 2015

Acknowledging that environment plays a crucial role in tourism development, the primary sectors contributing to the island's GPP, and considering the substantial GGPP of this island after accounting for environmental costs, it is recommended to increase the budget allocated to environmental protection to mitigate the existing burden, prioritizing urgent issues significantly affecting to residents' daily lives and tourism. Such support also can also facilitate sustainable development.

The use of national cost factors for provincial-level valuation may influence the absolute magnitude of environmental cost estimates, as local socioeconomic conditions may differ from national averages. However, such effects are expected to have a limited impact on the relative comparison across sectors and on the overall interpretation of GGPP results.

A sensitivity analysis was conducted to assess the influence of uncertainty in monetization factors on environmental cost estimates. The monetization factors were varied by ±10%, and the results show a proportional response across all impact categories, including climate change, fossil fuel scarcity, water scarcity, and eutrophication. Specifically, a 10% increase in monetization factors led to a corresponding 10% increase in environmental costs for each category, indicating a linear relationship. At the aggregate level, the total environmental cost of Phuket in 2015 increased from 6,378.56 million THB in the base case to 7,001.67 million THB under the +10% scenario. These results suggest that while the absolute magnitude of environmental costs is sensitive to monetization assumptions, the relative contributions of impact categories and the overall interpretation of the results remain robust.

4. CONCLUSION

This study outlines the procedure for constructing a provincial input-output table and subsequently, the method to apply it for the environmental assessment of Phuket, an island having tourism-based economy. It also contributes to the literature in the field of economic accounting intergrating environmental assessment.

It is worth noting that for a tourist island like Phuket, which relies on external goods, it is recommended to use input-output tables for environmental burden allocation. This is particularly valuable for industries that do not have production lines on this island, such as gasoline refinery, as the data provided is the costs associated with goods distribution. Unlike national-scale input-output tables, which capture cradle-to-gate impacts of industries, island-level tables mainly provide information on the distribution of goods. Nevertheless, these data can still be used to evaluate the environmental impacts of economic activities on the island.

The calculated outcomes reveal that Phuket's overall environmental costs reached nearly 6.6 billion THB. The predominant components of the environmental cost were degradation cost and depletion cost, primarily driven by fossil resource scarcity and global warming with 90% contribution.

Sectors linked to tourism, such as transportation and repair, alongside Accommodation and Food Services activities, emerged as substantial contributors to the environmental costs of the province. The findings also indicate that residents and government are the primary drivers of the sectors that have a significant impact on environmental costs, including (i) Energy Supply which stands for electricity, gas, steam, and air conditioning supply, as well as (ii) Water Supply and Cleaning Activities which stands for water supply, sewerage, waste management and remediation activities. This underscores the crucial roles that residents and government play in enhancing Phuket's environmental performance.

Given the different economic structures of provinces compared to countries, conducting assessment at provincial level is crucial to identify the appropriate areas of focus to establish effective policy and management targets. Sectors linked to tourism, for examples, Accommodation and Food Service, as well as Transportation and Storage, received higher earnings but also incurred more significant environmental burdens compared to other industries. It also suggests that, in addition to policies aimed at fostering economic development, there should be policies targeting the environmental performance of sectors related to tourism.

Given the importance of environment to tourism, the findings suggest boosting environmental spending aiming at enhancing environmental quality, resolving current environmental issues, and advancing sustainability efforts.

Some degree of uncertainty arises from the use of the CIQ method to regionalize the national input-output table, particularly in provinces with a service- and tourism-oriented economic structure such as Phuket. While the CIQ approach may not fully capture all import leakages associated with tourism-related activities, it remains a practical approximation given current data availability. Potential deviations between national and provincial production structures may affect the magnitude of estimated inter-industry linkages; however, the overall economic relationships and relative sectoral contributions are still reasonably represented. Consequently, the resulting GGPP estimates should be interpreted as indicative measures of green economic performance rather than precise point estimates.

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Anh Thi Nguyen, Shabbir H. Gheewala, Kritana Prueksakorn; Writing - review and editing, Hong Anh Thi Nguyen, Shabbir H. Gheewala, Kritana Prueksakorn; Funding acquisition, Hong Anh Thi Nguyen, Shabbir H. Gheewala, Kritana Prueksakorn; Resources, Shabbir H. Gheewala, Kritana Prueksakorn; Supervision, Shabbir H. Gheewala, Kritana Prueksakorn.

DECLARATION OF CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

REFERENCES

Acaroğlu H, Güllü M, Seçilmiş C. Climate change, the by-product of tourism and energy consumption through a sustainable economic growth: A non-linear ARDL analysis for Turkey. Environmental Science and Pollution Research 2023;30:1-15.

Adewumi AS, Onyango V, Moyo D, Al Waer H, Dawodu A. Conceptualising the characteristics of the indicators of a neighbourhood sustainability assessment framework in a developing country context. Environmental Impact Assessment Review 2023;102:Article No. 107197.

Akkajit P, Jaileak K, Suteersak T, Prueksakorn K. Assessment of heavy metals in sediment at Saphan Hin, Phuket. Chemical Engineering Transactions 2018;70:301-6.

Bi C, Li S. Does tourism development contribute to the green water-use efficiency of the Yellow River Basin in China? Journal of Environmental Management 2024;351:Article No. 119933.

Brito KS, Barroso PDB, Cavaliero CKN. The relevance of input-output analysis in public policy propositions for green hydrogen in Brazil. International Journal of Hydrogen Energy 2025;145:1033-46.

Cai G, Hu H. Green GDP accounting system from the perspective of resources and environment and a case study of Chongqing. Applied Mathematics and Nonlinear Sciences 2024;9(1): Article No.1-13.

Campos C, Dias AC, Quinteiro P, Gutiérrez D, Villanueva-Rey P, Gallego M, et al. Assessing the environmental impacts of three different types of accommodations in Portugal and Spain by using an LCA approach. Science of the Total Environment 2024;927:Article No. 172230.

Cespi D, Ciacci L, Chiarini A, Trova E, Acciai C, Ciabatti I, et al. Environmental life cycle assessment (LCA) of oxidative desulfurization of gas condensate in a novel oxidation system. Environmental Pollution 2025;371:Article No. 125958.

Chakraborty P, Ghosal S. An eco-social exploration of tourism area evolution in mountains through stakeholders' perspective. Environmental Development 2024;49:Article No. 100963.

Chan JY, Alfieri A, Edens B. Moving beyond GDP and achieving our common agenda with natural capital accounting [Internet]. 2022 [cited 2024 Apr 3]. Available from: https://www.un.org/development/desa/dpad/wpcontent/uploads/sites/45/publication/PB_144.pdf.

Chen T, Wang C, Zhang Y, Zhou S. Green GDP measurement of Shenyang City based on energy value analysis. Global NEST Journal 2020;22(4):447-54.

CNN. The top tourist destinations in 2017 [Internet]. 2017 [cited 2018 May 24]. Available from: https://edition.cnn.com/travel/article/top-tourist-destinations2017/index.html.

Curran AM, Rosenbaum KR, Baitz M, Prox M, Ciroth A. Goal and scope definition in life cycle assessment. In: LCA Compendium - The Complete World of Life Cycle Assessment. Dordrecht: Springer; 2017. p. 63-120.

C9 Hotelworks. Phuket 2015 Economic overview. Asset Management and Hospitality Consulting; 2015.

Davenport J, Davenport JL. The impact of tourism and personal leisure transport on coastal environments: A review. Estuarine, Coastal and Shelf Science 2006;67:280-92.

DeMaagd N, Fuleky P, Burnett K, Wada C. Tourism water use during the COVID-19 shutdown: A natural experiment in Hawai'i. Annals of Tourism Research 2022;97: Article No. 103475.

Department of Employment. Thailand Standard Industrial Classification (TSIC) 2552 [Internet]. 2009 [cited 2018 May 24]. Available from: https://www.doe.go.th/prd/assets/upload/files/vgnew_th/d8a88846bfef391bbf9602fe0ba18d1b.pdf.

Kowalewski J. Regionalization of national input-output tables: Empirical evidence on the use of the FLQ formula. Regional Studies 2015;49(2):240-50.

Kumlom T. Study of particulate dusts in Phuket municipality, Phuket Province. PKRU Science and Technology Journal 2021;5:36-47.

Flegg AT, Lamonica GR, Chelli FM, Recchioni MC, Tohmo T. A new approach to modelling the input-output structure of regional economies using non-survey methods. Journal of Economic Structures 2021;10:1-31.

Gössling S, Balas M, Mayer M, Sun YY. A review of tourism and climate change mitigation: The scales, scopes, stakeholders and strategies of carbon management. Tourism Management 2023;95:Article No. 104681.

Greaves C, Parrott L. Re-grounding cumulative effects assessments in ecological resilience. Environmental Impact Assessment Review 2024;105:Article No. 107403.

Greco G, Cenciarelli GV, Allegrini M. Tourism's impacts on the costs of municipal solid waste collection: Evidence from Italy. Journal of Cleaner Production 2017;177:62-8.

Hayati Y, Adrianto L, Krisanti M, Pranowo WS, Kurniawan F. Magnitudes and tourist perception of marine debris on small tourism island: Assessment of Tidung Island, Jakarta, Indonesia. Marine Pollution Bulletin 2020;158: Article No. 111393.

Iversen EK, Grimsrud K, Lindhjem H, Navrud S. Mountains of trouble: Accounting for environmental costs of land use change from tourism development. Tourism Management 2024;102 Article No. 104870.

Kaenchan P, Gheewala SH. Budget constraint and the valuation of environmental impacts in Thailand. International Journal of Life Cycle Assessment 2017;22:1678-91.

Kowalewksi J. Regionalization of national input-output tables: Empirical evidence on the use of the FLQ formula. Regional Studies 2015;49(2):240-50.

Kunanuntakij K, Varabuntoonvit V, Vorayos N, Panjapornpon C, Mungcharoen T. Thailand Green GDP assessment based on environmentally extended input-output model. Journal of Cleaner Production 2017;167:970-7.

Lazarus WF, Platas DE, Morse GW. IMPLAN's weakest link: Production functions or regional purchase coefficients? Journal of Regional Analysis and Policy 2002;32:33-49.

Li G, Zhang Y, Wang Y, Wang Y, Tian J. Evaluation and analysis of tourism resources and environmental carrying capacity (TRECC) of 278 cities in China: A pressure-support perspective. Journal of Cleaner Production 2023;420:Article No. 138359.

Li Y, Mei B, Linhares-Juvenal T. The economic contribution of the world's forest sector. Forest Policy and Economics 2019;100:236-53.

Liang J, Wang S, Liao Y, Feng K. Carbon emissions embodied in investment: Assessing emissions reduction responsibility through multi-regional input-output analysis. Applied Energy 2024;358:Article No. 122558.

Liu L, Tobias GR. The impact of environmental literacy on residents' green consumption: Experimental evidence from China. Cleaner and Responsible Consumption 2024;12:Article No. 100165.

Long Y, Yoshida Y, Liu Q, Zhang H, Wang S, Fang K. Comparison of city-level carbon footprint evaluation by applying single- and multi-regional input-output tables. Journal of Environmental Management 2020;260:Article No. 110108.

Markaki M, Papadakis S. Productive structure optimization under macroeconomic constraints based on input-output analysis. Structural Change and Economic Dynamics 2024;70(C):91-105.

Maswongssa B. Public Policy Recommendations for Enhancing Hotel Business Order in Phuket Thailand [dissertation]. Bangkok, The Graduate School of Tourism Management, National Institute of Development Administration; 2020.

Miller RE, Blair PD. Input-Output Analysis: Foundations and Extensions. 2nd ed. Cambridge, UK: Cambridge University Press; 2009.

Mota L, Leite E, Ghasemi V. Exploring the impact of climate change on lodging establishments: A systematic literature review. Quality and Quantity 2026;60:8143-68.

Novelli M, Burgess LG, Jones A, Ritchie BW. 'No Ebola… still doomed' - The Ebola-induced tourism crisis. Annals of Tourism Research 2018;70:76-87.

Okamoto N. Does Regional Size Matter in Regionalization of National Input-Output Table by the FLQ Formula? - A Case Study of China [dissertation]. Chuo University; 2014.

Pérez DMG, Martín JMM, Martínez JMG, Sáez-Fernández FJ. An analysis of the cost of water supply linked to the tourism industry: An application to the case of the Island of Ibiza in Spain. Water 2020;12(7):Article No. 2006.

Piispala J. On regionalising input-output tables: Experiences from compiling regional supply and use tables in Finland. Proceedings of the 13th International Conference on Input-Output Techniques; 2020 Aug 21-25; University of Macerata, Italy; 2000.

Pominova M, Gabe T, Crawley A. The stability of location quotients. Review of Regional Studies 2022;52:296-320.

Puttiwongrak A, Suteerasak T, Mai PK, Hashimoto K, Gonzalez JC, Rattanakom R, et al. Application of multi-monitoring methods to investigate the contamination levels and dispersion of Pb and Zn from tin mining in coastal sediments at Saphan Hin, Phuket, Thailand. Journal of Cleaner Production 2019;218:108-17.

Qi S, Huang Z, Ji L. Sustainable development based on green GDP accounting and cloud computing: A case study of Zhejiang Province. Scientific Programming 2021;2021:1-8.

Sattraburut T, Prueksakorn K, Kitcharoen T, Amattayakul T, Pinitsuwan P, Pratum C. The connection between Phuket's water supply and the hotel sector's water use for assessment of tourism carrying capacity. Sustainability 2024;16(2):Article No. 621.

Schweinfest S, Alfieri A, Chan YJ, Edens B. The rise, fall and rethinking of green GDP [Internet]. n.d. [cited 2024 Apr 3]. Available from: https://seea.un.org/news/rise-fall-and-rethinking-green-gdp.

Shahbazi S, Kurdve M, Zackrisson M, Jönsson C, Kristinsdottir AR. Comparison of four environmental assessment tools in Swedish manufacturing: A case study. Sustainability 2019;11(7):Article No. 2173.

Shan Y, Ren Z. Does tourism development and renewable energy consumption drive high-quality economic development? Resources Policy 2023;80:Article No. 103270.

Stefanica M. Environmental impact of transportation in the tourism industry - dimensions and actions. Studies and Scientific Researches: Economics Edition 2017;(25):84-9.

Sunlu U. Environmental impacts of tourism. CIHEAM Options Méditerranéennes: Série A. Séminaires Méditerranéens 2003;57:263-70.

Thailand Greenhouse Gas Management Organization (TGO). Executive Summary: Development Project for Reporting Greenhouse Gas Information at the Large City Level and Appropriate Greenhouse Gas Reduction Plans. TGO; 2019 (in Thai).

The Phuket News. Wastewater pouring onto Phuket beaches comes under fire, again [Internet]. 2019 [cited 2024 Apr 13]. Available from: https://www.thephuketnews.com/wastewater-pouring-onto-phuket-beaches-comes-under-fire-again-71399.php.

The Phuket News. Phang Nga water pipeline back on the agenda [Internet]. 2020 [cited 2024 Apr 16]. Available from: https://www.thephuketnews.com/phang-nga-water-pipeline-back-on-the-agenda-90105.php.

Wang Q, Wang S, Zhang M, Bu Z, Liu J. Green public procurement as a promoter for green consumption: From the perspective of individual's knowledge. Cleaner and Responsible Consumption 2021;3:Article No. 100035.

Wei Y, Li Y, Liu X, Wu M. Sustainable development and green gross domestic product assessments in megacities based on the emergy analysis method - A case study of Wuhan. Sustainable Development 2020;28(1):294-307.

Wells EC, Zarger RK, Whiteford LM, Mihelcic JR, Koenig ES, Cairns MR. The impacts of tourism development on perceptions and practices of sustainable wastewater management on the Placencia Peninsula, Belize. Journal of Cleaner Production 2016;111:430-41.

World Bank. Inflation, GDP deflator (annual %) [Internet]. 2024 [cited 2024 Jan]. Available from: https://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG?locations=TH.

World Travel and Tourism Council (WTTC). A net zero roadmap for travel & tourism: Proposing a new target framework for the travel & tourism sector [Internet]. 2021a [cited 2024 Jan]. Available from: https://wttc.org/Portals/0/Documents/Reports/2021/WTTC_Net_Zero_Roadmap.pdf.

World Travel and Tourism Council (WTTC). Global economic impact and trends 2021 [Internet]. 2021b [cited 2024 Jan]. Available from: https://www.lagenziadiviaggimag.it/wp-content/uploads/2021/07/Global-Economic-Impact-and-Trends-2021.pdf?x58896.

Wu S, Han H. Sectoral changing patterns of China's green GDP considering climate change: An investigation based on the economic input-output life cycle assessment model. Journal of Cleaner Production 2020;251:Article No. 119764.

Xu Y, Geng Y, Tian X, Shen W, Gao Z. Uncovering the key features of platinum metabolism in China during 2001-2022: A dynamic material flow analysis. Journal of Cleaner Production 2024;446:Article No. 141323.

Yang C, Poon JP. Regional analysis of China's Green GDP. Eurasian Geography and Economics 2009;50(5):547-63.

Yi QG, Chen HT, Li X, Ma C. Comprehensive assessment of regional sustainability via emergy, green GDP and DEA: A case study in Guizhou Province, China. Applied Ecology and Environmental Research 2020;19(1):597-609.

Zhong L, Deng J, Song Z, Ding P. Research on environmental impacts of tourism in China: Progress and prospect. Journal of Environmental Management 2011;92(11):2972-83.