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Quantifying energy use, carbon dioxide emission, and other environmental loads from island tourism based on a life cycle assessment approach

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ABSTRACT

The main purpose of industrial ecology is to evaluate and minimize impacts from economic activities of human society. Tourism as one economic activity, results in a full range of environmental impacts, but few applications of industrial ecology to tourism management have previously been discussed. Life cycle assessment (LCA) is used in this research to explore environmental impacts of island tourism, and then the environmental loads per tourist per trip can be found.

Penghu Island in Taiwan is taken as an example to examine this new approach. Various environmental loads in transportation, accommodation, and recreation activity sector are all inventoried and calculated here. In summary, per tourist per trip uses 1606 MJ of energy, 607 L of water, and emits 109,034 g of CO_2, 2660 g of CO, 597 g of HC, 70 g of NO_x. In addition, per tourist per trip also discharges 416 L of wastewater, 83.1 g of BOD, and 1.95 g of solid waste. In terms of energy use, the transportation consumes the largest energy (67%); in particular, the airplane sector. Moreover, per Penghu tourist results in more environmental loads than local people; for example, the amount of solid waste discharge per tourist is 1.95 kg per day, while that of per local people is 1.18 kg. Finally, the advantages and limitations of such LCA approach are also discussed.

1. Introduction

1.1. Tourism and environment

Tourism is now, according to the World Trade Organization, the world's biggest industry [1]. Globally, tourism has a gross output of over US $7 trillion, is responsible for 11.5% of global gross domestic product (GDP), and employs 200 million people, which is 11% of the world's workforce [2]. With 760 million international tourist arrivals recorded worldwide in 2004, tourism is a major global activity that has grown by 25% in the past 10 years [3]. The sheer size of the industry makes it important to consider its environmental impacts.

It is important for the industry to understand its impacts, because its products often depend on the appeal of attractive natural capital – clean beaches and oceans, pleasant climate, and wildlife. Tourism may therefore be vulnerable to its local impacts; for example, degradation of beaches or biodiversity loss. In addition, tourism also contributes to global environmental issues [4]. For example, traveling by airplane requires considerable amounts of fossil fuels and releases greenhouse gases into the atmosphere. In a report on aviation and the atmosphere by the Intergovernmental Panel on Climate Change (IPCC), it was estimated that aviation accounts for 2–3% of the world's total use of fossil fuels, with more than 80% consumed by civil aviation [5]. Olsthoorn also estimated that aviation's contribution to global anthropogenic CO_2 emissions is forecast to grow to 3–7% by 2050 [6].

Tourism development has become a major policy of the government of Taiwan to increase employment and economic growth. Several islands around Taiwan have attractive natural resources and then tourism activities have increased in the past 10 years. However, islands are extremely fragile integrated systems where any future development needs to be focused on sustainable and integrated options capable of reconciling the economy, human development and environmental conservation, especially the tourism activity [7]. Penghu, the biggest island around Taiwan, receives more than 500,000 tourists per year and some negative impacts have appeared [8]. Hence, the purpose of this research is to investigate the environmental loads from tourism in Penghu Island.

The negative environmental impacts resulted from tourism have discussed well [9–11]. However, most of the research related about tourism impacts is based on qualitative judgment, because

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Table 1
The indicators used in this research.

Category of services	Indicators
Transportation	Energy use
	Waste emission: CO_2, CO, HC, and NO_x
Accommodation	Energy use
	CO_2 emission
	Electricity use
	Water demand
	Solid waste discharge
	Wastewater discharge
	BOD discharge
Recreation activity	Energy use
	CO_2 emission

environmental impacts contributed by tourists are in fact not easy to quantify. In addition, quantified environmental loads are important for stakeholders of the tourism industry. Based on these quantifiable data, they can identify the problems directly and then propose more effective strategies. For example, the amount of solid waste from tourists is an important parameter to design the treatment equipment and procedures.

Hence, Life cycle assessment (LCA) approach was applied in this research to inventory the environmental loads of island tourism, to figure out the environmental loads, and to quantify these loads in terms of per tourist per trip. Since tourism is a composite product, when the tourists begin the trip, the life cycle of the "tourism product" starts; and when tourists finish their trip, the life cycle of the "tourism product" ends. Accordingly, every sector of the whole trip including transportation, accommodation, and recreation activity is all considered and the environmental loads of the whole trip can be inventoried under such approach.

1.2. Quantifying environmental loads from tourism

Although most of the literature related about tourism impacts is based on qualitative description, Kuo and Yu have proposed one method to quantify the environmental loads from tourism in 1997 and this method is convenient for managers to use [12]. The environmental loads from tourists in Shei-Pa National Park in Taiwan were calculated based on visitor information from questionnaires and combination per capita data. The water demand, the electricity used and the various forms of the environmental loads, including wastewater and solid waste discharge, were all surveyed and calculated on a per capita basis. Other researchers also applied the same calculation method to explore the environmental loads from New Zealand's domestic tourism industry [13–16]. Their work was focused on the energy consumption from tourism activities.

In addition, the US Environmental Protection Agency (USEPA) also uses the same methodology to quantify environmental impacts from selected leisure activities in the American [17]. USEPA employed various environmental indicators to assess particular sectors of tourism including: water use, biological oxygen demand of wastewater, total suspended solids in wastewater, energy use, air pollution (hydrocarbons, carbon monoxide, and nitrogen oxides), greenhouse gas emissions, and municipal solid waste generation.

Gössling [4] undertook a broad brushstroke analysis of the global impacts of tourism, focusing on 'change of land cover and land use', 'use of energy and its impacts', 'exchange of biota and species extinction', 'dispersion of diseases', and 'psychological consequences of travel'. His work drew from large data sets from sources such as the World Tourism Organization, and approximated figures such as total land-take attributable to tourism, and total energy consumption by tourism. However, the detailed analysis of specific holiday tourism products was still lack in this study.

In addition, Gössling et al. [18] used ecological footprint analysis (EFA) to assess the sustainability of Seychelle's tourism industry. They focused on footprints of 'fossil energy land', 'built-up land', 'food and fiber consumption', and 'total ecological impact'. Their study explored the potential of EFA to be used to analyze the sustainability of tourism destinations. In addition, Patterson [19] tried to conduct eco-efficiency analysis of New Zealand tourism, depicting inputs of profit per unit of environmental output, for energy use, water use, land use, water discharge, nitrate discharge, phosphorus discharge, biological oxygen demand discharge, and CO_2 emissions.

Gössling et al. [20] also made some efforts on eco-efficiency with regard to emissions of greenhouse gases. They analyzed several tourism destinations as case studies, and found travel distance to be the factor most likely to result in an unfavorable eco-efficiency, and that air travel was the most inefficient mode of transport. They also concluded that the eco-efficiency of holiday tourism products could be improved through longer durations of visit, and higher expenditure per visit. The eco-efficiency of the case studies was compared with those of other world industries, and tourism was found to be less eco-efficient than the global industry average.

In addition, Peeters et al. employed both ecological footprint and eco-efficiency to analyze the sustainability of the inbound Amsterdam tourism industry [21]. By analyzing where tourists

Table 2
The basic information of tourists to Penghu Island.

1. Length of stay (days)	Percentage (%)
1	1.0
2	6.40
3	60.40
4	24.10
≧5	8.10
2. Type of transportation (origin to Penghu Island)	
Airplane	97.50
Ship	2.50
3. Recreation activity	
Sight seeing	90.91
Historic sites visiting	11.40
Landscape visiting	20.90
Motorized water activity	61.18
Swimming	74.69
Nature watching	75.60
Rafting	66.70
Fishing	7.13

Table 3
Percentage (%) of different types of transportation within five recreational areas.

Type	Magong	Basha	Shiyeu	Wanan	Chimei
Motorcycle	47.6	61.5	59.8	57.7	63.5
Rental car	24.4	14.7	15.5	4.8	3.4
Tour bus	17.1	14.3	13.9	23.3	20.8
Small shuttle bus	9.0	7.3	8.8	13.2	11.8
Others	1.9	2.2	2.0	1.0	0.5

Table 4
Percentage (%) of stay at different types of accommodation in Magong.

Number of night	Hotel	Bed and breakfast	Campground	Private home
1	36.1	22.8	0	20.0
2	52.5	57.0	0	40.0
3	9.1	18.4	0	15.0
≧4	2.3	1.8	0	25.0