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The effect of tourism on teleconnected ecosystem services and urban sustainability: An emergy approach

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ABSTRACT

Tourism plays an increasingly critical role in national and urban economies. While tourist spending particularly benefits urban economies, the growth of urban tourism has gradually intensified cities' reliance on external resources and significantly influenced resource-supplying areas. This study adopts the concept of urban land teleconnections (ULTs) to discuss how the cultural ecosystem services in the tourism industry have affected distant areas in general and how the increased tourist flow has intensified Taipei's dependence on external resources and challenged its urban sustainability in particular. An emergy-based analysis is conducted to evaluate the contribution of material flows triggered by urban tourism into the urban ecological-economic system and to demonstrate how urban tourism has increased the city's reliance on external distant areas. The analysis highlights the biophysical value created by external resources in the economic system. Driven by growing urban tourism during 2000–2016, Taipei witnessed considerable material inflow, including construction materials for newly built hotels, gasoline for sightseeing buses, food for tourists, and money through retail consumption. These material inflows are converted into emergy flows to analyze the effects of tourism-driven material flows on urban sustainability. The results show that emergy inflows driven by urban tourism considerably increased the flow of construction materials needed to build hotels to meet tourists' accommodation needs. As a result, the total emergy driven by Taipei tourism increased fifteen-fold since 2000 and crested in 2015. However, the demand for tourism-related resources triggered changes in land use and land cover in distant resource-supplying areas. Such ULTs further contributed to unequal ecological exchanges. Our findings highlight the need for urban sustainability assessments to account for the impact of ULTs driven by urban tourism on distant resource-supplying areas. In addition, tourism planning and management should not be a facet but a core element of urban planning objectives.

1. Introduction

Globalization and the increasing efficiency and reach of transportation systems have accelerated distal connections and the flows of people, goods, and services (Haberl et al., 2009). However, despite contemporary urbanization processes and globalization, cities and their hinterlands are not necessarily co-located. In other words, the ecological footprint of cities far surpasses those of their adjacent peri-urban and rural areas, creating the phenomenon of spatial leapfrogging (Seto et al., 2012). Consequently, urban systems depend on resources from distant provisioning areas, whose ecosystems are in turn pressured by production demands (Krausmann et al., 2003; Haberl and Krausmann, 2007). The widening spatial segregation of production and consumption constitutes a major challenge in urban governance and the sustainability of social-ecological systems (Haberl et al., 2009; Verburg et al., 2015). Thus, there is a need to understand teleconnections between resource-producing areas and resource-consuming urban areas. The concept of ULTs was proposed to decouple interrelations between urban processes and distal land changes and to explore the implications of these connections on sustainability. The concept breaks away from the notion that geographical locations must be self-sufficient to achieve urban sustainability and instead emphasizes the role of complex

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dynamic processes between linked distant locations (Seto et al., 2012). Conflicts in ecological distribution and unequal ecological exchanges further contribute to growing sustainability concerns in both urban and distant rural areas (Huang and Chiu, 2020; Lee et al., 2019). Therefore, discussions on urban sustainability must consider distant areas, the connections with resource-use systems, and the increasing interdependencies of ecological and social systems (Brondizio et al., 2009; Colston et al., 2015; Huang and Chiu, 2020).

Tourism is a key economic activity that significantly contributes to the global economy. Although tourism products are locally consumed, the tourism industry and related investments are inherently global (Ashworth and Page, 2011). In 2019, the travel and tourism industry both directly and indirectly contributed 10.4 percent of the global GDP (World Travel and Tourism Council [WTTC], 2020). One of the main categories of cultural ecosystem services is natural capital in the tourism industry (MA, 2005). Ecosystem services are benefits that humans directly and indirectly obtain from ecosystems. Since the Millennium Ecosystem Assessment (2005) popularized the concept of ecosystem services and established an assessment framework, interactions between ecosystem services and human society have been widely studied. Natural landscapes offer humans the opportunity to benefit from ecosystem services (Willis, 2015). The rapid increase in global population, infrastructure development, and need for leisure time has created a growing demand for ecosystem tourism (MA, 2005), attracting tourists to remote areas.

Given its rapid growth at the global level, the importance of tourism has become increasingly apparent in national and urban economies. Tourism can create jobs in the service industry as well as contribute to the growth of the primary and secondary sectors through the demand for raw materials and manufactured goods. This is known as the multiplier effect, which in its simplest form denotes the number of times that tourist spending is circulated in a country's economy (Rusu, 2011). However, tourism leakages occur when related goods and services are not locally produced (Jönsson, 2015). A tourist destination may have a larger impact on distant locations, rather than neighboring regions, that provide resources for tourism-related goods and services. Therefore, the spatial impacts of tourism cannot be solely viewed as a spillover effect, which is the indirect or unintentional impact of an area's tourism industry on tourist flows to nearby regions (Yang and Fik, 2014). Tourism effects can also be explained from the viewpoint of spatial externalities across regions (Fingleton and Lopez-Bazo, 2006). This makes it imperative to account for the spatial effects on distant areas through resource flows driven by tourism.

Since the propagation of urbanization in ancient Mesopotamia (Karski, 1990; Edwards et al., 2008), urban environments have become prominent tourist destinations. Cities are multifunctional places that can accommodate a large number of tourists and effortlessly absorb visitors to the extent of making them economically and physically invisible (Ashworth and Page, 2011). Tourism is generally deemed a "clean" industry (Orbasli, 2000). However, contemporary urban tourism not only utilizes the facilities and infrastructures of the destination city but also relies on resources, goods, and services from distant areas. This raises concerns about the intensifying reliance on distant regions for external resources and the impact of such dependence on urban sustainability.

Land teleconnections resulting from tourism have been defined as the physical movement of people creating connections between the destination and their places of origin (Güneralp et al., 2013). The ULTs framework is not a large-scale model that captures every complexity in a real-world system; rather, it aims to clarify land changes triggered by urban processes (Seto et al., 2012). One approach to studying ULTs is material flow analyses using spatially explicit data. Assessing the sources, pathways, and sinks of materials in an urban system helps identify the spatial connections between production and consumption (Seto et al., 2012; Güneralp et al., 2013). Material flow analyses also offer a better understanding of the ULTs between urban areas and resource-providing areas by tracing product pathways, thereby clearly illustrating the increasing urban dependence on external resource inflow (Huang and Chiu, 2020). However, material flow analyses neglect quality differences, material characteristics and energy flows, and the complex interactions between human society and nature (Huang et al., 2006). This makes it difficult to check for unequal ecological exchanges within the connections between urban and rural areas. Nevertheless, the contributory value of different material flows to the urban ecological economic system can be evaluated by incorporating an emergy synthesis, a donor-based environmental accounting approach, in a material flows analysis (Odum, 1996; Brown and Ulgiati, 2004). Employing the emergy synthesis methodology, Huang and Chiu (2020) showed how urban sustainability is linked to rural areas through teleconnected resource flows and further assessed the equalities and inequalities in ecological exchanges through material and monetary flows.

Several studies have adopted emergy synthesis to discuss the sustainability and impacts of tourism. Brown and Ulgiati (2001), for example, used the emergy method to evaluate tourist resorts in Mexico and Papua New Guinea. They concluded that the efficient use of indigenous resources and a positive emergy balance of payments are likely to increase economic investments linked to the preservation of environmental support areas and sustainable development. A series of emergy-based research has been conducted on the functioning and efficiency of Macao's tourism and gambling industries (Lei and Wang, 2008; Lei et al., 2010, 2011). Vassallo et al. (2009) examined tourism sustainability using an Italian coastal resort region as a case study and evaluated the economic, social, and environmental impacts of tourism. Lee et al. (2019) demonstrated how ULTs from Taipei's tourism pose a challenge to the rural planning and agro-souvenir production of distant connected areas. However, only few studies have discussed the effect of urban tourism on the sustainability of destination cities. Thus, this study employs the emergy approach and the concept of ULTs to elucidate the challenges facing urban sustainability as a result of urban areas' increasing reliance on the external resource inflows triggered by tourism. The analysis incorporates the material flows driven by Taipei's urban tourism in the emergy synthesis to evaluate their contribution and interactions with the natural environment and socioeconomic systems.

2. Methodology

2.1. Tourism growth in Taipei City

Taiwan is an island country with an area of 35,808 square kilometers and a population of 23.6 million in 2019. The island offers a wealth of scenic landscape and natural wonders, such as Taroko Gorge, Sun Moon Lake, and barrier reefs in Kenting National Park, etc. (Fig. 1). Tourism is one of the most critical and rapidly growing industries in Taiwan.

In 2018, the country reported more than 11 million inbound visitors, almost a three-fold increase since 2008 (Taiwan Tourism Bureau [TTB], 2019). In 2015, approximately 30% of Taiwan's inbound tourists visited natural attractions across the island (TTB, 2016). However, given the low accessibility of the scattered scenic spots, inbound tourists must stop over in Taipei City, significantly contributing to the city's tourism. Taipei City, covering an area of 271 square kilometers with a population of 2.6 million in 2019, is a major destination city for foreign visitors (Fig. 1). On average, 85% of the inbound visitors to Taiwan have visited Taipei in recent years (TTB, 2019). The gradual increase in Taipei tourists since 2000 has brought significant monetary benefits to the urban economy (Fig. 2). Taipei's inbound visitors increased from 1.5 million in 2000 to more than 9.3 million by 2018, generating more than USD 8 billion in tourism revenue (TTB, 2019; Department of Information and Tourism, Taipei City Government [TPEDOIT], 2019). The daily expenditure per tourist in Taipei City averaged at USD 250 during 2012–2018 (Fig. 3). In 2018, the average daily expenditure per tourist was USD 249.06. Retail shopping (60.29%) accounted for the highest proportion of tourist spending, followed by expenditures for accommodation (18.39%) and meals (15.02%) (TPEDOIT, 2019).

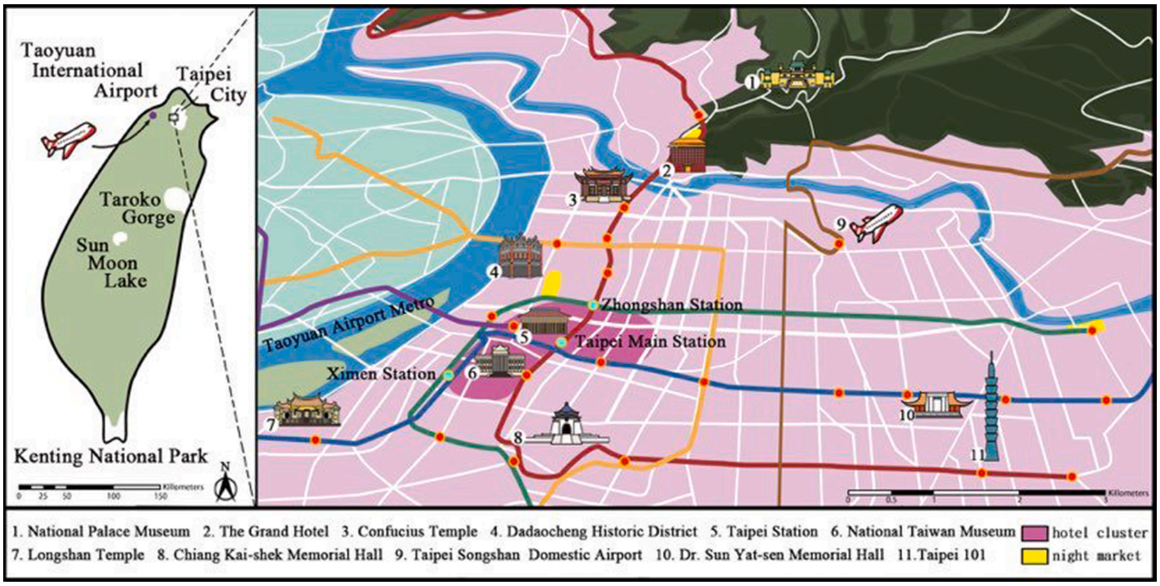

Fig. 1. Main attractions in Taipei City.

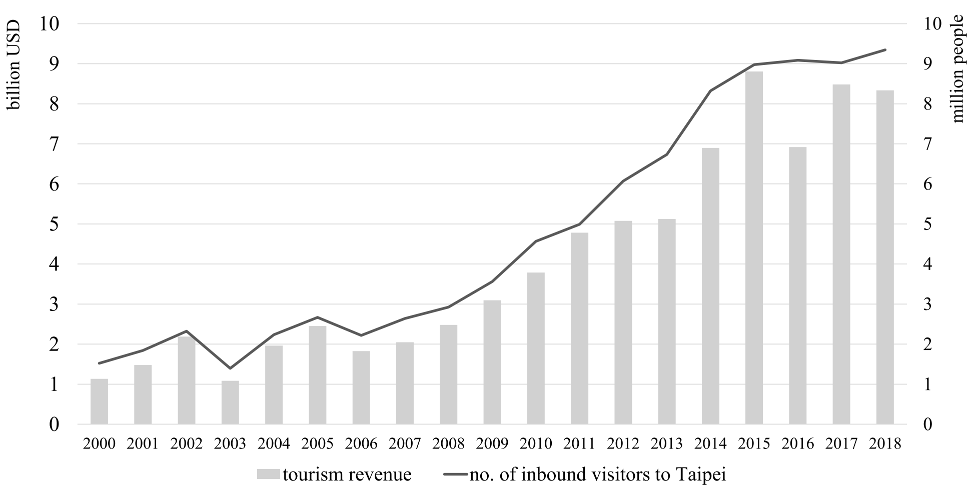

Fig. 2. Annual number of inbound visitors and tourism revenue for Taipei City Source: TTB, 2019′.

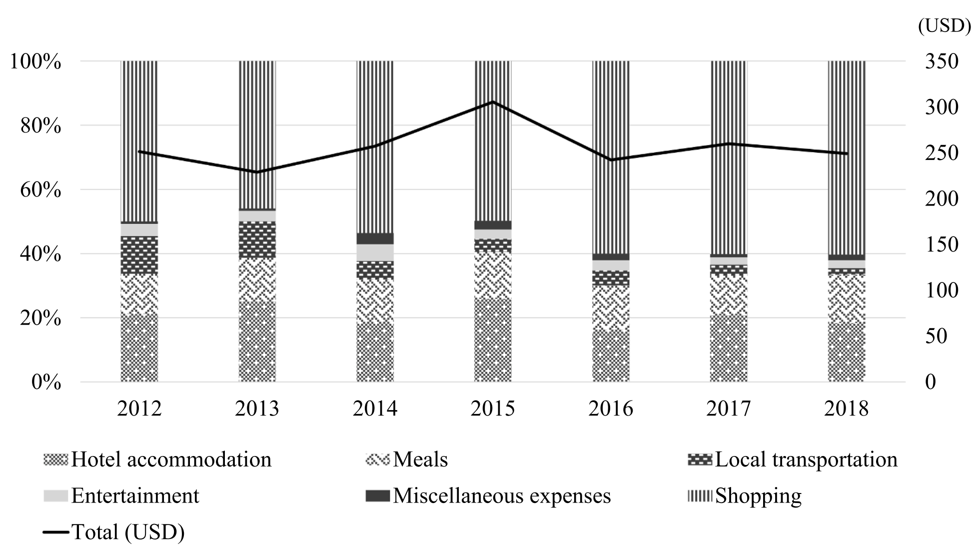

Fig. 3. Average daily expenditure per visitor and tourist spending categories in Taipei City Source: TTB, 2019; TPEDOIT, 2019.

With the expanding inbound tourism in Taipei City, the number of hotels increased from 360 in 2010 to 648 in 2019 and that of hotel rooms rose from 24,000 to 42,000 (TTB, 2020). The floor area of new hotels, including newly built ones and those set up in renovated buildings, was as high as 4.57 million square meters in 2015 (Lee et al., 2020). Most of the new hotels are spatially located near metro stations. The area along Ximen metro station, Taipei Main Station, and Zhongshan station is the largest hotel cluster (Fig. 1). The expansion of accommodation facilities is positively correlated with the number of Taipei's inbound visitors (Lee et al., 2020). However, the need to cope with tourist demands generates further resource inflows. Thus, urban tourism intensifies Taipei's dependence on external resources from distant areas, thereby raising concerns regarding the effects of tourism on urban sustainability.

2.2. Research framework and emergy method

This study is a follow-up research based on the work of Lee et al. (2020), who utilized a material flow accounting approach to demonstrate the material flows driven by tourist spending in Taipei City during 2000–2016. The authors examined tourist spending data on accommodation, meals, local transportation, and shopping to estimate the construction material inflows for newly built hotels, food consumption, fuel for sightseeing buses, and souvenir shopping, respectively. This study adopts the emergy approach to evaluate the contribution value of material flows and the biophysical value of resources in urban ecological-economic systems and to demonstrate the role of urban tourism in increasing a city's reliance on external distant areas (Fig. 4). The emergy approach accounts for the inputs of energy and goods and services necessary to process raw materials into products as the embodied energy of material flow.

The emergy methodology developed by Odum (1996) is theoretically grounded in ecology, general system theory, and thermodynamics. Odum (1988) defined ecosystem principles wherein energy flows between an ecosystem's components also generate hierarchies in the system. Energy hierarchy can be represented by spatially heterogeneous human-dominated landscapes (Lee et al., 2013). All living systems within the landscape are hierarchically and spatially organized and characterized by energy transfers, material recycling, and exchanges of human services. The urban–rural linkage is also hierarchically and spatially organized. Cities receive energy and material in various forms, such as food, water, and construction materials, from rural areas and in turn provide human services to these areas. The spatial patterns and urban–rural linkages are shaped and modified by changes in the global economy and mobility trends, which result in energy and material flows between cities and distant rural areas. The functional differences of system components in the spatially disconnected urban–rural system can also be evaluated based on hierarchical energetic flows.

Emergy is the amount of energy directly or indirectly consumed to create a product or service (Odum, 1996). The first step in the emergy methodology is illustrating a diagram of the energy system. This helps to identify and integrate the contributing resources from outside the system, including human resources and those freely available in the environment, and their relations with internal system storages. The diagram is used to construct emergy tables for the flows of energy, materials, labor, or services. The raw data on each flow are then multiplied by their unit emergy value (UEV) and converted into emergy units:

$$\text{Emergy}_i = \text{Energy}_i \times \text{UEV}_i \tag{1}$$

where Energy_i is the available energy of the *i*th input, UEV_i is the unit emergy value of the *i*th flow or product, and Emergy_i is the emergy of the *i*th flow. The emergy indices can be used to conduct a holistic analysis of the contributions from the natural environment to the human economy and the policies addressing the effects of tourism-driven material flows on urban sustainability.

2.2.1. Energy system diagram of taipei's tourism

The energy system diagram for Taipei's tourism illustrates ULTs between the urban tourism system in Taipei City and the distant areas of Taiwan, along with resource inflows and outflows and energy pathways between the two systems for tourist consumption (Fig. 5). Taiwan's natural landscape and Taipei's urban infrastructure and image are the key factors attracting tourists to Taipei City. However, owing to the highly urbanized nature of Taipei City and its surrounding areas, tourism-related resources and materials are not produced locally. Therefore, in addition to renewable energy, non-renewable energy and materials from distant areas are needed to sustain tourism activities in Taipei City. Taiwan already imports crude oil because the island has limited domestic energy resources, but tourist inflows from elsewhere in Taiwan to Taipei City increases the demand for resources such as food and gasoline. Further, the rise in tourist demand for accommodation increases the need for the construction of new hotels, thus triggering the inflow of construction materials. There is also an inflow of commodities in the form of souvenirs from outside Taipei City. In sum, tourist spending on accommodation, food, local transportation, and shopping is the key factor driving the demand for additional energy resources and materials, such as food, gasoline, and construction materials, which interacts with other tourist consumption activities in Taipei City.

2.2.2. Conversion of materials into emergy equivalents

Resource inflows driven by urban tourism are estimated on the basis of the material flow accounting of tourist spending in Taipei City. UEV is the solar emergy required to create a unit of energy or material (Odum, 1996). The emergy flow of each resource is obtained by multiplying the amount of resource flow by its UEV (Eq. (1)). UEVs in Table 1 are used to convert resource flows into emergy flows. This study uses UEVs relative to the 12E + 24 sej/year baseline (Brown et al., 2016).

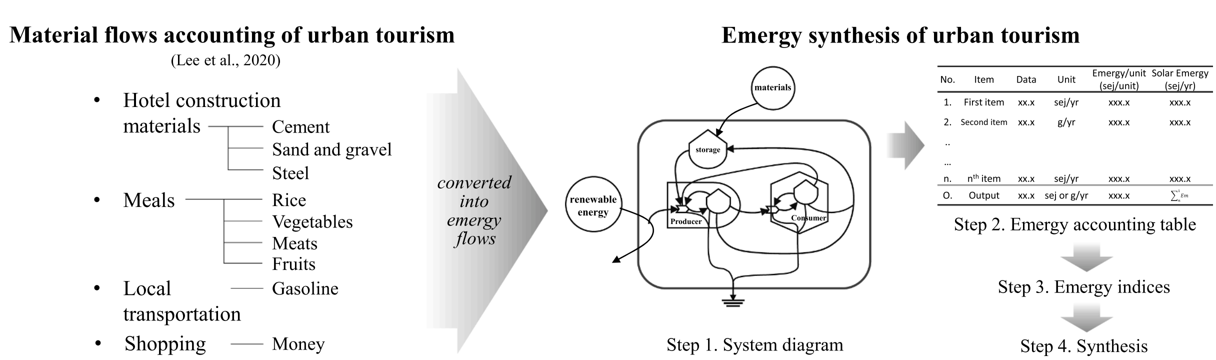

Fig. 4. Conversion of material flow accounting into emergy analysis.

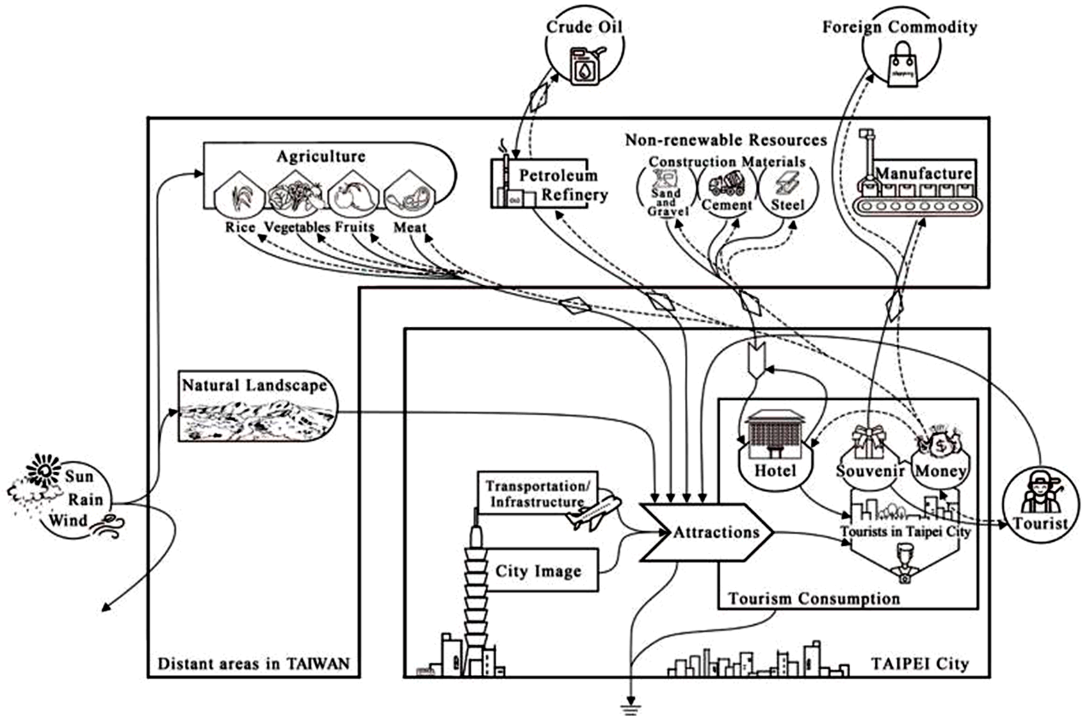

Fig. 5. Energy system diagram of a conceptual model of the study area Source: Adapted from Lee et al. (2020).

Table 1
Unit energy value (UEV) of each item of material inflow.

Tourist spending category	Items of inflows	Raw data unit	Unit emergy value UEV	Source
Local transportation	Gasoline*	Joule	8.39E + 04 (sej/J)	[1]
Meals	Rice	Kilogram	4.81E + 12 (sej/ kg)	[2]
	Vegetables	Kilogram	1.38E + 12 (sej/ kg)	[2]
	Fruits	Kilogram	2.49E + 12 (sej/ kg)	[2]
	Meats**	Joule	1.03E + 06 (sej/J)	[3]
Shopping (SE)	Shopping spending	NTD	4.15E + 10 (sej/ NT$)	[4]
Hotel construction materials (CM)	Cement*	Gram	2.30E + 09 (sej/ g)	[5]
	Sand and gravel**	Gram	1.72E + 09 (sej/ g)	[3]
	Steel*	Gram	2.26E + 09 (sej/ g)	[1]

[1] Odum, 1996; [2] Adapted from Chen (1999); [3] Campbell et al., 2005; [4] Chiu et al., 2019; [5] Pulselli et al., 2008.
*Original UEVs are calculated using the planetary baseline of 9.44E + 24 sej/-year and converted to the baseline of 12E + 24 sej/year (Brown et al., 2016) by multiplying the factor of (12/9.44).
**Original UEVs are calculated using the planetary baseline of 9.26E + 24 sej/year and converted to the baseline of 12E + 24 sej/year (Brown et al., 2016) by multiplying the factor of (12/9.26).

2.2.3. *Emergy indices*

Table 2 presents the emergy indices used to evaluate the contributions and effects of tourism-driven energy and material flows on the ecological-economic interface of Taipei City's tourism and to compare the emergy flows of tourism activities with those of Taipei City.

Table 2
Emergy indices used in this study.

Indices	Expression	Note
Relative shares of Taipei's tourism emergy (%)	$Em_{cat.i}$ / $U_{tourism}$	$Em_{cat.i}$: emergy of *i* category of tourism emergy $U_{tourism}$: total emergy inflows driven by Taipei's tourism
Ratio of tourism emergy to total emergy used for each tourist spending category (%)	$U_{tourism}$ / U_{Taipei}	U_{Taipei}: total emergy inflows of Taipei; $U_{tourism}$: total emergy inflows driven by Taipei's tourism
Ratio of shopping spending (SE) to wholesale and retail sales amounts (%)	Em_{SE} / $Em_{W\&R}$	Em_{SE}: emergy of tourists' shopping spending; $Em_{W\&R}$: emergy of Taipei's wholesale and retail sales amounts
Construction materials (CM) used for new hotels (%)	Em_{CM_NH} / Em_{CM_Taipei}	Em_{CM_NH}: emergy of construction materials used for new hotels; Em_{CM_Taipei}: emergy of construction materials imported into Taipei

3. Results

Table 3 presents the estimation results of the emergy inflows driven by Taipei's tourism in 2015. All energy inflows in the energy system diagram for Taipei's tourism system (Fig. 5) are converted into solar emergy joule. The largest flow from renewable sources, the energy of rain (chemical), is chosen as the renewable energy inflow to avoid double counting. Shopping expenditure reports the highest emergy flow (2.15E + 21 sej), and sand and gravel has the highest emergy (1.19 *E* + 21 sej) in the construction materials category. Fig. 6 shows the index of the relative shares of the contributors to Taipei's tourism emergy for 2015. Tourists' shopping expenditure constitutes the main resource inflow driven by urban tourism, followed by construction materials for newly built hotels (39.1%), gasoline for sightseeing buses (5.6%), food (2.6%), and renewable energy (1.6%). Tourists' shopping expenditure

Table 3
Emergy inflows driven by Taipei's urban tourism in 2015.

	Items of inflow energy	Raw data	UEV* (sej/unit)	Source**	Solar emergy (sej)
1.	Renewable energy				6.91E + 19
	(1) Sun (J)	1.15E + 18	1.00E + 00		1.15E + 18
	(2) Wind (J)	3.86E + 16	8.00E + 02	[1]	3.09E + 19
	(3) Rain (geopotential) (J)	4.43E + 10	1.28E + 04	[1]	5.67E + 14
	(4) Rain (chemical) (J)	3.25E + 15	2.13E + 04	[1]	6.91E + 19
	(5) Rain (chemical-absorbed) (J)	1.60E + 15	2.13E + 04	[1]	3.40E + 19
2.	Food				1.07E + 20
	(1) Paddy rice (kg)	2.55E + 06	4.81E + 12	[2]	1.22E + 19
	(2) Vegetables (kg)	5.72E + 06	1.38E + 12	[2]	7.94E + 18
	(3) Fruits (kg)	6.78E + 06	2.49E + 12	[2]	1.69E + 19
	(4) Meats (J)	6.85E + 13	1.03E + 06	[3]	7.03E + 19
3.	Gasoline (J)	2.80E + 15	8.39E + 04	[4]	2.35E + 20
4.	Construction materials				1.64E + 21
	(1) Sand and gravel (g)	6.94E+11	1.72E+09	[3]	1.19E + 21
	(2) Cement (g)	1.07E+11	2.30E+09	[5]	2.46E + 20
	(3) Steel (g)	9.17E+10	2.26E+09	[4]	2.07E + 20
5.	Shopping expenditure (NTD)	5.18E+10	4.15E+10	[6]	2.15E + 21
Total (U)					4.14E + 21

Emergy flow calculation.
1. Renewable energy.
(1) Sun = (area 271.8 km^2) (1E + 10 cm^2/km^2) (average solar radiation 112 kcal/cm^2/year) (4186 J/kcal) (1− albedo 10%) (UEV 1.00E + 00 sej/J) = 1.15E + 18 sej/year.
(2) Wind = (area 271.8 km^2) (1E + 06 m^2/km^2) (density of wind energy 45.08 W/m^2) (3.15 *E* + 07 s/year) (disperse to surface 10%) (UEV [1] 8.00E + 02 sej/J) = 3.09E + 19 sej/year.
(3) Rain (geopotential) = (average height 11 m) (area 271.8 km^2) (1E + 06 m^2/km^2) (evapotranspiration 2.519 m/year) (runoff coefficient 0.6) (9.8 m/s) (UEV [1] 1.28E + 04 sej/J) = 5.67E + 14 sej/year.
(4) Rain (chemical) = (area 271.8 km^2) (1E + 06 m^2/km^2) (evapotranspiration 2519.2 mm/year) (1.0E − 3) (water density 1.0E+06 g/m^3) (Gibbs free energy 4.74 J/g) (UEV [1] 2.13E + 4 sej/J) = 6.91E + 19 sej/year.
(5) Rain (chemical-absorbed) = (area 271.8 km^2) (1E + 06 m^2/km^2) (evapotranspiration 2.519 m/year) (water density 1.0E + 06 g/m^3) (Gibbs free energy 4.74 J/g) (UEV [1] 2.13E + 4 sej/J) = 3.40E+19 sej/year.
2. Food.
(1) Paddy rice = (per capita daily rice supply 0.125 kg/capita/day) (average length of stay 2.27 days) (inbound visitors to Taipei 8.98E + 06 persons/year) (UEV [2] 4.81E + 12 sej/kg) = 1.22E + 19 sej/year.
(2) Vegetables = (per capita daily vegetables supply 0.281 kg/capita/day) (average length of stay 2.27 days) (inbound visitors to Taipei 8.98E + 06 persons/year) (UEV [2] 1.38E + 12 sej/kg) = 7.94E + 18 sej/year.
(3) Fruits = (per capita daily fruits supply 0.333 kg/capita/day) (average length of stay 2.27 days) (inbound visitors to Taipei 8.98E + 06 persons/year) (UEV [2] 2.49E + 12 sej/kg) = 1.69E + 19 sej/year.
(4) Meat = (per capita daily meat supply 213.86 g/capita/day) (15,730 J/g) (average length of stay 2.27 days) (inbound visitors to Taipei 8.98E + 06 persons/year) (UEV [3] 1.03E + 06 sej/J) = 7.03E + 19 sej/year.
3. Gasoline = (number of rental sightseeing buses 16,307) (average mileage of rental sightseeing bus 59,598 km/year) (average fuel consumption per kilometer 0.304 L/km) (percentage of inbound tourists visiting Taipei among total inbound tourists 86%) (percentage of group inclusive tours 29.23%) (9000 kcal/L) (4186 J/kcal) (UEV [4] 8.39E + 04 sej/J) = 2.35E + 20 sej/year.
4. Construction materials.
(1) Sand and gravel = [(floor area of newly built hotels by Steel Structures construction 203,963.86 m^2) (sand and gravel requirement 1699.425 kg/m^2) + (floor area of newly built hotels by Steel-Reinforced Concrete construction 113,693.78 m^2) (sand and gravel requirement 2278.575 kg/m^2) + (floor area of newly built hotels by Reinforced Concrete construction 33,717.53 m^2) (sand and gravel requirement 2614.95 kg/m^2)] (1000 g/kg) (UEV [3] 1.72E + 09) = 1.19E + 21.
(2) Cement = [(floor area of newly built hotels by SC construction 203,963.86 m^2) (cement requirement 261.45 kg/m^2) + (floor area of newly built hotels by SRC construction 113,693.78 m^2) (cement requirement 350.55 kg /m^2) + (floor area of newly built hotels by RC construction 33,717.53 m^2) (cement requirement 402.3 kg /m^2)] (1000 g/kg) (UEV [5] 2.30E + 09) = 2.46E + 20.
(3) Steel = [(floor area of newly built hotels by SC construction 203,963.86 m^2) (rebar requirement 70 kg/m^2) + (floor area of newly built hotels by SC construction 203,963.86 m^2) (requirement of steel beams 136 kg/m^2) + (floor area of newly built hotels by SRC construction 113,693.78 m^2) (rebar requirement 118 kg/m^2) + (floor area of newly built hotels by SRC construction 113,693.78 m^2) (steel beams requirement 271 kg/m^2) + (floor area of newly built hotels by RC construction 33,717.53 m^2) (rebar requirement 149 kg/m^2) + (floor area of newly built hotels by RC construction 33,717.53 m^2) (steel beams requirement 12 kg/m^2)] (1000 g/kg) (UEV [4] 2.26E + 09) = 2.07E + 20 sej/year.
5. Shopping expenditure = (5.18E + NTD10) (UEV [6] 4.15E + 10 sej/NTD) = 2.15E + 21 sej/year.
*Unit emergy value as per the baseline of 12.0E + 24 sej/year (Brown et al., 2016).
**Sources: [1] Brown & Ulgiati (2016), [2] Adapted from Chen (1999), [3] Campbell et al. (2005): original UEVs are calculated using the planetary baseline of 9.26E + 24 sej/year and are converted to the baseline of 12E + 24 sej/year (Brown et al., 2016) by multiplying the factor of (12/9.26), [4] Odum (1996): original UEVs are calculated using the planetary baseline of 9.44E+24 sej/year and converted to the baseline of 12E + 24 sej/year (Brown et al., 2016) by multiplying the factor of (12/9.44), [5] Pulselli et al. (2008): original UEVs are calculated using the planetary baseline of 9.44E + 24 sej/year and converted to the baseline of 12E+24 sej/year (Brown et al., 2016) by multiplying the factor of (12/9.44), [6] Chiu et al. (2019).

also accounts for more than half of the annual tourism emergy flow, indicating that tourism money triggered the supply of souvenir commodities, including manufacturing in distant areas and wholesale and retail trade in Taipei City. The emergy of non-renewable resources (gasoline and construction materials) makes up 44.7% of tourism emergy, suggesting that even though tourism is commonly considered a service sector in a city, its operation is based on large inputs of non-renewable resources.

The emergy flows of Taipei's tourism during 2000–2016 can be further aggregated into four categories (Table 4). The marginal increase in the annual emergy inflow prior to 2007 is consistent with the slow growth of Taipei's tourism sector (Fig. 2). Total tourism emergy continued to increase after 2007 and reached the first peak of 2.77E + 21 sej in 2011 owing to the steady rise in tourists' shopping expenditure. The rapid growth of inbound tourists also stimulated increases in the emergy flows of construction materials, gasoline, and food. In 2015, total emergy crested 4.14E + 21 sej as a result of surging requirements for construction materials to meet tourists' accommodation demands. However, there was a downward trend in 2016 because of a decline in newly built hotels and tourists' shopping expenditures.

The emergy of shopping expenditures accounted for the majority of tourism emergy, whereas that of food and gasoline accounted for a small proportion. The emergy flows of the construction materials used for new hotels fluctuated over the study period and influenced the total emergy flows of tourism. Over the past decade, steel-reinforced concrete (SRC) and steel structures (SC) have become increasingly popular in the construction of new hotels in Taipei. The huge demand for steel beams and rebars significantly contributed to the increase in the emergy flows of construction materials.

4. Discussion

The major challenge when incorporating energetic hierarchy in the discussion on urban–rural linkage is defining the boundary of the system

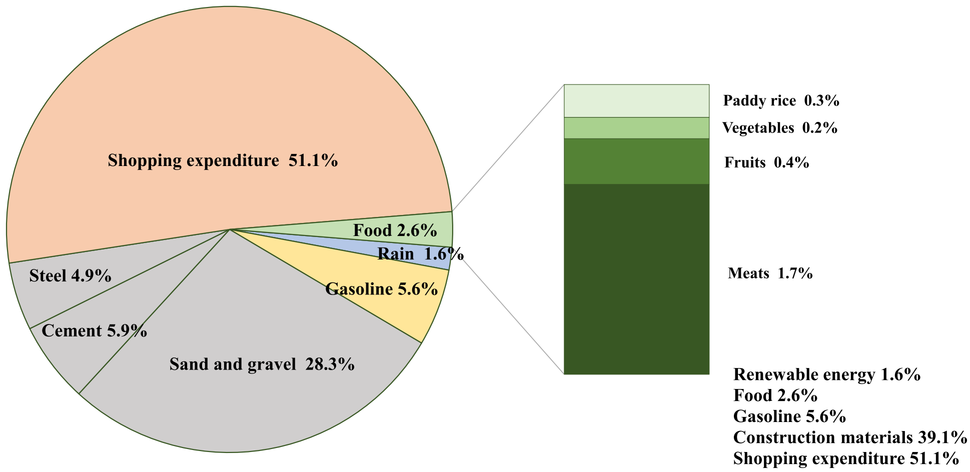

Fig. 6. Relative shares of Taipei's tourism emergy ($Em_{cat.i}$ / $U_{tourism}$), 2015.

Table 4
Emergy inflows driven by urban tourism Unit: sej.

Year	Gasoline	Food					Shopping	Construction materials for new hotels				**Total**
		Rice	Vegetables	Fruits	Meats	Total		Cement	Sand	Steel	Total	
2000	3.56E+19	2.74E+18	1.57E+18	3.50E+18	1.39E+19	2.17E+19	1.54E+20	8.47E+18	4.12E+19	9.24E+18	5.89E+19	2.70E+20
2001	7.12E+19	3.31E+18	2.10E+18	4.61E+18	1.70E+19	2.70E+19	2.39E+20	7.24E+18	3.52E+19	2.85E+18	4.53E+19	3.82E+20
2002	6.24E+19	4.16E+18	2.93E+18	6.35E+18	2.16E+19	3.51E+19	3.95E+20	1.87E+19	9.08E+19	7.34E+18	1.17E+20	6.09E+20
2003	5.36E+19	2.45E+18	1.63E+18	3.73E+18	1.29E+19	2.07E+19	2.14E+20	9.30E+18	4.52E+19	3.66E+18	5.82E+19	3.46E+20
2004	9.62E+19	3.71E+18	2.48E+18	5.50E+18	2.00E+19	3.17E+19	3.71E+20	1.00E+18	4.87E+18	3.94E+17	6.26E+18	5.05E+20
2005	1.39E+20	4.15E+18	2.57E+18	5.47E+18	2.21E+19	3.43E+19	5.45E+20	9.31E+18	4.52E+19	3.66E+18	5.82E+19	7.76E+20
2006	1.42E+20	3.32E+18	2.21E+18	4.89E+18	1.83E+19	2.87E+19	4.58E+20	3.68E+19	1.79E+20	1.45E+19	2.30E+20	8.59E+20
2007	1.45E+20	3.68E+18	2.32E+18	5.17E+18	1.94E+19	3.05E+19	5.92E+20	8.86E+18	4.30E+19	3.48E+18	5.53E+19	8.23E+20
2008	1.64E+20	4.12E+18	2.55E+18	5.59E+18	2.09E+19	3.32E+19	7.34E+20	8.26E+19	4.01E+20	5.00E+19	5.34E+20	1.46E+21
2009	1.84E+20	5.53E+18	3.44E+18	7.10E+18	2.85E+19	4.45E+19	1.19E+21	7.06E+19	3.43E+20	5.90E+19	4.73E+20	1.89E+21
2010	2.19E+20	6.70E+18	4.39E+18	9.60E+18	3.68E+19	5.75E+19	1.41E+21	7.40E+19	3.60E+20	4.74E+19	4.81E+20	2.17E+21
2011	2.53E+20	7.13E+18	4.90E+18	1.08E+19	4.11E+19	6.39E+19	1.71E+21	1.13E+20	5.47E+20	8.05E+19	7.41E+20	2.77E+21
2012	2.37E+20	8.54E+18	5.57E+18	1.22E+19	4.73E+19	7.36E+19	2.00E+21	3.03E+19	1.47E+20	2.98E+19	2.07E+20	2.52E+21
2013	2.20E+20	9.35E+18	6.25E+18	1.35E+19	5.00E+19	7.91E+19	1.93E+21	4.80E+19	2.33E+20	3.14E+19	3.12E+20	2.54E+21
2014	2.28E+20	1.14E+19	7.61E+18	1.63E+19	6.33E+19	9.86E+19	2.16E+21	1.32E+20	6.42E+20	1.18E+20	8.92E+20	3.38E+21
2015	2.35E+20	1.22E+19	7.94E+18	1.69E+19	7.03E+19	1.07E+20	2.15E+21	2.46E+20	1.19E+21	2.07E+20	1.64E+21	4.14E+21
2016	1.81E+20	1.18E+19	8.41E+18	1.58E+19	6.85E+19	1.04E+20	1.68E+21	3.93E+19	1.91E+20	1.81E+19	2.48E+20	2.21E+21

being studied. Attracted by the cultural ecosystem service of tourism in Taiwan, tourists converge on Taipei City as their first point of arrival. Their accompanying resource consumption needs trigger resource inflows from distant rural areas to meet this demand. The impact and teleconnection effects of such energy and material flows across the city boundary on the distant areas providing the resources is an essential topic that requires study. The results of the emergy synthesis employed in this study explain the linkage between the spatial organization of energy and material flows across the boundary and the topic of sustainability, and show that land teleconnection effects on the distant areas from the provisioning of ecosystem services can be included in discussions about the effect of tourism on sustainability.

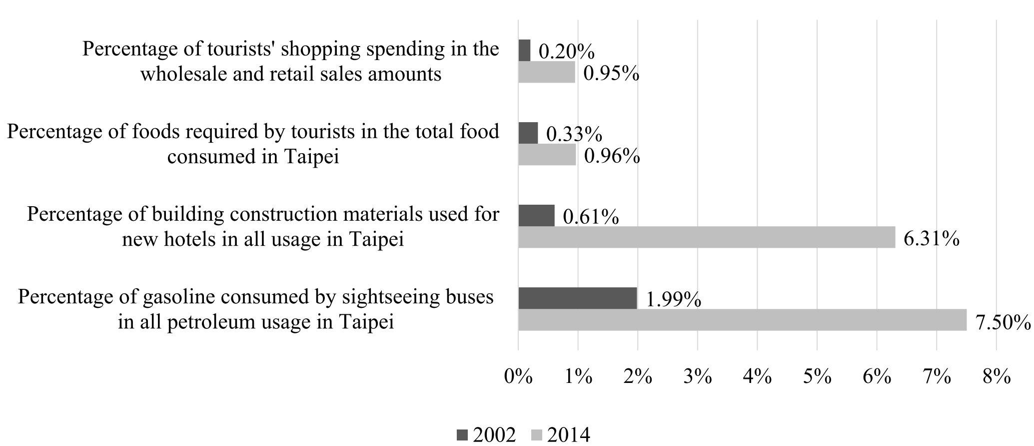

Fig. 7. Percentage of tourism emergy categories in Taipei City ($U_{tourism}$ / U_{Taipei}).

4.1. Increasing role of tourism in Taipei

Fig. 7 illustrates the percentage changes for each category of tourism emergy in Taipei City ($U_{tourism}$ / U_{Taipei}) between 2002 and 2014. More specifically, it shows an increasing proportion of emergy flows in Taipei driven by urban tourism. The emergy flows of the construction materials used for hotels accounted for 6.3% of citywide usage in 2014, which is a ten-fold increase since 2002. Sightseeing buses composed 7.5% of petroleum usage in Taipei in 2014, highlighting the influence of increased tourism demands on fuel consumed by the transportation sector. From 2002 to 2014, the proportions of food and shopping expenditures driven by tourism in total emergy flows increased two- and threefold.

Tourists' shopping expenditures and construction materials for new hotels significantly increased the total emergy inflows driven by Taipei's tourism. While shopping expenditures was a major contributor to tourism emergy, tourist spending accounted for less than 1% of Taipei's wholesale and retail sales amounts. Nevertheless, tourists' shopping expenditures increased thirteen-fold during 2000–2014 and continued to increase Taipei's wholesale and retail sales, despite the rate of inbound visitors increasing only five times during the same period (Fig. 8).

Fig. 9 illustrates the correlation between the annual emergy flow of construction materials for new hotels and the tourism emergy of the previous year. This relationship highlights how tourism growth has stimulated the construction of new hotels. The emergy of newly built hotels is positively correlated with the total tourism emergy in the previous year, indicating that the large quantity of new hotel construction was triggered by the growth of urban tourism in Taipei City.

The findings for the emergy flow of construction materials for new hotels highlight a fluctuating trend of total tourism emergy over the past decade. The number of new hotels significantly increased after 2008 in response to the rapid growth of inbound visitors. Only six new hotel constructions were completed in 2000 and this number increased to 60 by 2015. The total floor area of new hotels increased from 10,507 m^2 in 2000 to 351,375 m^2 in 2015. The construction of massive hotels significantly increased the imports of construction materials into Taipei City. Fig. 10 shows the percentages of each category of construction materials used to build the hotels and the total amount of construction materials used in Taipei. For comparison, the amounts of sand, cement, and steel are converted into emergy unit. The rate of materials consumed for hotel construction was a mere 0.23% of total usage in 2000, and this rate increased to more than 6.3% by 2014. This indicates that new hotel buildings are a major force driving the inflow of construction materials. Further, the percentages of sand, cement, and steel used for new hotel construction were less than 1% of the total amount for each category in 2000. However, post-2008, these rates were maintained at 2%, 3%, and above 7%, respectively. The progress in construction technology, steel structures, and SRC composite replaced the use of reinforced concrete composite in hotel construction and created a considerable demand for steel beams and rebars. In 2014, the construction of new hotels consumed more than one-third of the total building steel used in Taipei.

4.2. Tourism effects on urban sustainability

Taipei is the key business and commercial center of Taiwan, although the city is far from self-sufficient. The tertiary sector accounted for 75.4% of the total economy in Taipei City, while the secondary sector and agriculture only contribute 23.4% and 1.2% respectively (Taipei City Office of Commerce [TCOC], 2019). Taipei is highly dependent on external resources, materials, and goods to satisfy citizens' daily needs. Fig. 11 shows the trends of increasing emergy flows driven by tourism during 2000–2016, indicating the role of tourism is gradually intensifying Taipei's dependence on external resources. Moreover, the construction materials used to build new hotels have shaped the urban structure and become urban assets. The follow-up operations and maintenance, however, have created the continuous need for energy, goods, and services, thus increasing the city's dependence on external sources.

Given the highly urbanized characteristics and industrial structures of Taipei City and its surrounding peri-urban areas, tourism-related resources and materials cannot be locally produced. As a result, certain distant locations supplying resources, materials, or goods to Taipei City have witnessed changes in land use and coverage as an outcome of ULTs. For instance, in 2006, the self-sufficiency rates of rice, vegetables, and fruits in Taipei were only 1.95%, 6.27%, and 0.53%, respectively (Lin, 2014). The Changhua-Yunlin-Chiayi area, located in central and southern Taiwan, supplies vegetables and fruits to tourists. However, the average emergy exchange ratio of fruits and vegetables between the Changhua-Yunlin-Chiayi area and Taipei is approximately 0.27, indicating unequal ecological exchanges. Simply put, local farmers did not receive an equivalent amount of emergy for the agricultural products sold to Taipei, resulting in industrial transformation and land use changes in the Changhua-Yunlin-Chiayi area (Huang and Chiu, 2020). Therefore, urban sustainability assessments cannot neglect the tele-connected resource flows impacted by urban activities.

Taiwan has limited domestic energy resources. In 2018, Taiwan imported almost 98.06% of its energy resources to satisfy its energy demand (Bureau of Energy, Ministry of Economic Affairs [BoE], 2019). According to the state-owned petroleum corporation, about half of the island's oil is imported from the Middle East, 40% is from the United States, and about 10% is from Latin America. Thus, the increasing gasoline consumption by sightseeing buses further intensifies Taipei's dependence on energy imports and enlarges its ecological footprint. In addition, there is growing demand for mineral resources reflected in the

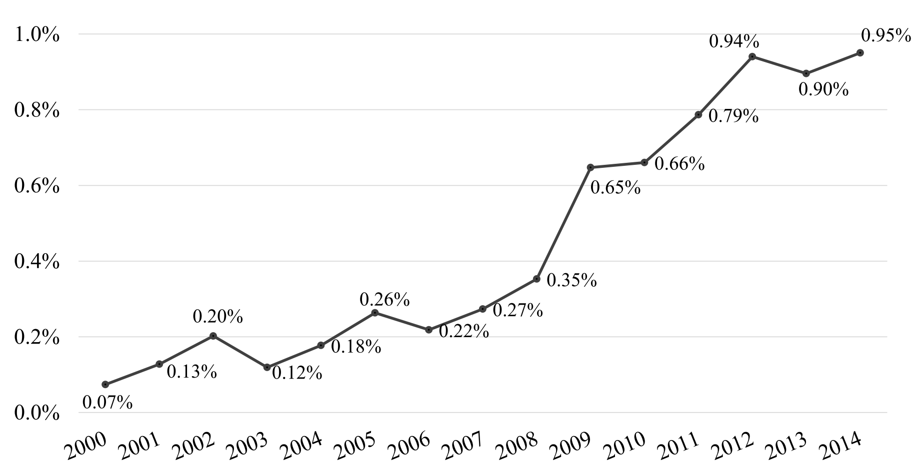

Fig. 8. Percentage of tourists' shopping expenditure in wholesale and retail sales in Taipei (Em_{SE} /$Em_{W\&R}$).

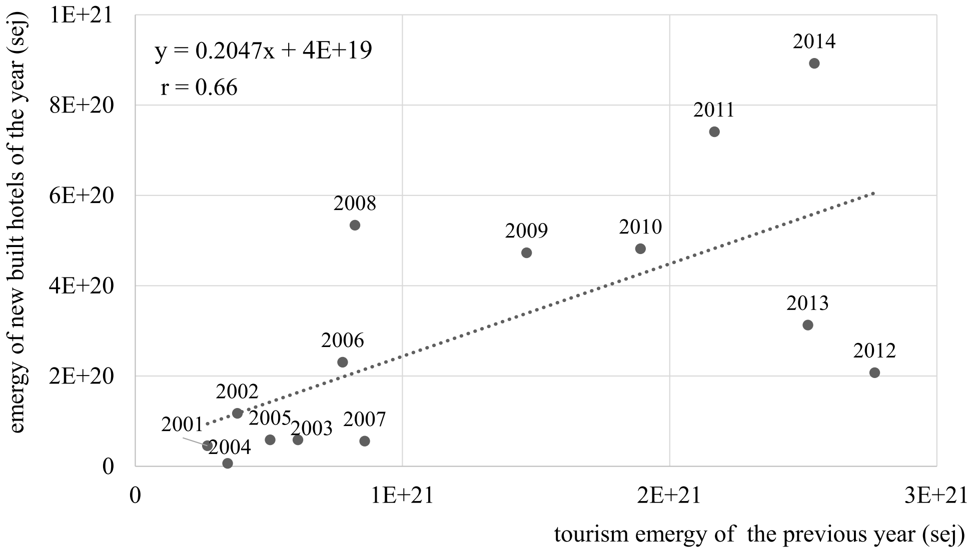

Fig. 9. Relationship between annual newly built hotel emergy and tourism emergy in the previous year.

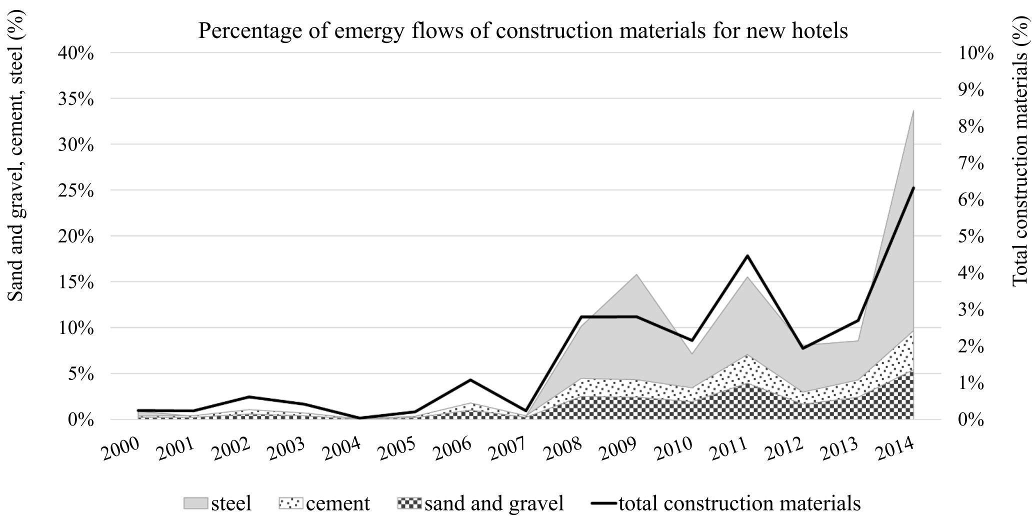

Fig. 10. Percentage of construction materials used to build new hotels in the total construction materials used in Taipei (Em_{CM_NH} / Em_{CM_Taipei}).

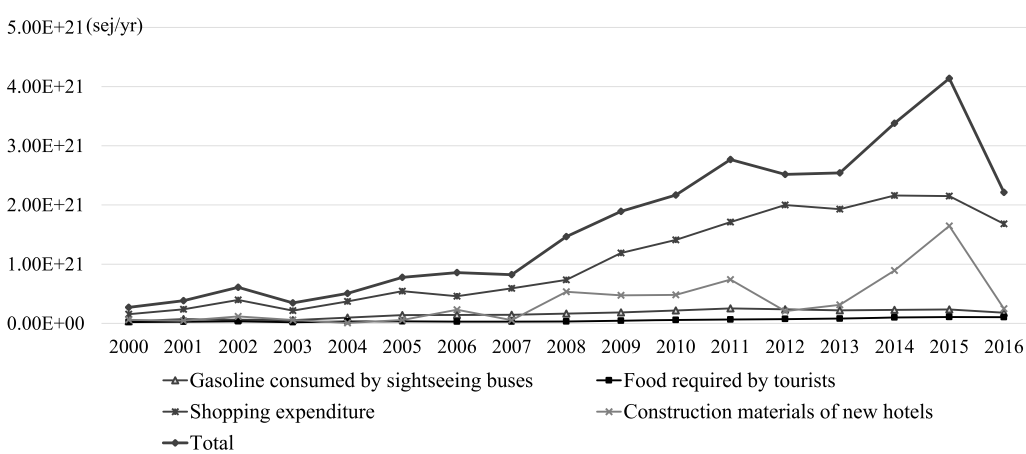

Fig. 11. Annual emergy inflows driven by Taipei's tourism.

requirement of construction materials to build new hotels. Taipei receives its construction materials from distant areas; for example, sand and cement processed from marble are mined in eastern Taiwan. The demand for construction materials is another external force driving the land use of resource-supplying areas (Güneralp et al., 2013). Mining oil and mineral resources not only converts the landscape and land cover but also requires additional goods and services to process the raw materials into petroleum products and construction materials. The demand for construction materials has become a major factor contributing to mineral development and production and to the conversion of farmlands or forests into mining lands in eastern Taiwan (Chiu et al., 2019). While tourist expenditures benefit urban economies, the growth of urban tourism has gradually intensified cities' reliance on external resources. Urban sustainability assessments must pay more attention to the influences of ULTs on resource-supplying areas.

5. Conclusions

The spatial spillover effect of the cultural ecosystem services offered in remote natural landscapes in Taiwan on Taipei induces the phenomenon of urban land teleconnections (ULTs). This study demonstrates the increasing role of tourism in Taipei City and its influence on urban sustainability using an emergy synthesis to convert material flows driven by urban tourism into energetic flows. Emergy inflows driven by Taipei's urban tourism have particularly increased the inflows of construction materials to build new hotels and of gasoline for sightseeing buses. While tourists' shopping expenditures accounted for less than 1% of Taipei's wholesale and retail sales, it had a thirteen-fold increase during 2000–2014, even though inbound visitors increased only five times during the same period. The growth of urban tourism in Taipei City has resulted in a large number of newly constructed hotels, which in turn has increased the demand for mineral resources. The need to meet tourist demands has further intensified Taipei's dependence on the ecosystem services of distant areas. Given the highly urbanized characteristic of Taipei City and its surrounding areas, tourism-related resources and materials cannot be locally sourced. Thus, the increasing emergy inflows driven by tourism have further intensified Taipei's dependence on external resources. However, certain resource-supplying areas meeting the increasing demand of resources, materials, and goods directly and indirectly driven by urban tourism have experienced changes in land use and land cover. The spatial spillover effects of resource imports from distant areas further drive ULTs and lead to spatial trade-offs among ecosystem services. The ULTs have further resulted in unequal ecological exchanges between the urban and distant areas.

Even though the environmental impact of cities has surpassed their urban boundaries, urban sustainability assessments continue to focus on localism. More specifically, teleconnected resource-supplying areas that are remote from urban destinations have been neglected. Tourism is a rapidly growing industry and a major contributor to the global, national, and even urban economy. However, urban planning has yet to account thoroughly for the impact of cities on distant areas or the forces driving distant areas. Our findings highlight the need to further incorporate the influences of ULTs in the scope of urban sustainability assessments. In addition, tourism planning and management should be a core element rather than a mere facet of urban planning objectives. Furthermore, while urban tourism has experienced continuous growth in Taipei, the sudden decrease in tourists owing to the COVID-19 pandemic has had a significant impact on such tourism and related industries. This research could be extended further to evaluate if the continuous over-supplies of hotels will result in negative emergy investment and whether a decline in tourists' resource consumption will have a positive influence on urban sustainability.

CRediT authorship contribution statement

Ying-Chieh Lee: Conceptualization, Funding acquisition, Methodology, Formal analysis, Writing - original draft. **Pei-Ting Liao:** Data curation, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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