Tourism Management 81 (2020) 104161

Contents lists available at ScienceDirect

Tourism Management

journal homepage: http://www.elsevier.com/locate/tourman

Managing tourism emissions through optimizing the tourism demand mix: Concept and analysis

Ya-Yen Sun [a,*], Pei-Chun Lin [b], James Higham [c]

[a] The University of Queensland, St Lucia Campus, Brisbane, QLD, 4072, Australia
[b] Department of Transportation & Communication Management Science, National Cheng Kung University, No.1, University Road, Tainan City, 70101, Taiwan, ROC
[c] Department of Tourism, The University of Otago, 362 Leith Street, North Dunedin, Dunedin, 9016, New Zealand

ARTICLE INFO

Keywords:
Tourism carbon emissions
Mitigation
Optimization
Eco-efficiency
Goal programming
Market mix

ABSTRACT

Carbon mitigation strategies are an urgent and overdue tourism industry imperative. The tourism response to climate action has been to engage businesses in technology adoption, and to encourage more sustainable visitor behaviour. These strategies however are insufficient to mitigate the soaring carbon footprint of tourism. Building upon the concepts of optimization and eco-efficiency, we put forward a novel carbon mitigation approach, which seeks to pro-actively determine, foster, and develop a long-term tourist market portfolio. This can be achieved through intervening and reconfiguring the demand mix with the fundamental aim of promoting low carbon travel markets. The concept and the analytical framework that quantitatively inform optimization of the desired market mix are presented. Combining the "de-growth" and "optimization" strategies, it is demonstrated that in the case study of Taiwan, great potential exists to reduce emissions and sustain economic yields. The implications for tourism destination managers and wider industry stakeholders are discussed.

1. Introduction

In response to rapidly increasing global tourism emissions (Lenzen et al., 2018), carbon mitigation strategies for tourism have been principally directed toward visitor behaviour changes and technology adoption among firms (WTO-UNEP-WMO, 2008). The first strategy seeks to inspire travel decision changes toward more sustainable, less impactful behaviours. Travellers are encouraged to incorporate climate concerns into their tourist decision-making by reducing their travel frequency, extending the duration, choosing destinations that are close to home, and participating in non-motorised recreational activities, as well as modal shifts by substituting air transportation with land and public transportation where reasonable (WTO-UNEP-WMO, 2008). The second mitigation approach focuses on the supply side of tourism by seeking to reduce the high carbon energy demands of tourism firms. Tourism businesses are encouraged by incentive or punitive schemes to implement technological improvement for achieving improved emission efficiencies per service unit. Strategies have included the acceleration of fleet renewals, development and deployment of low carbon sustainable energy, and hotel refurbishments that include sustainability upgrades (UNEP & WTO, 2012). These approaches comply with what Geels, McMeekin, Mylan, and Southerton (2015) refer to as *reformist* approaches which seek to address change within the current socio-technical system, focusing on business eco-innovations based on the expectation of growing consumers' preferences for eco-efficient products.

Empirical observations, however, indicate a lack of meaningful progress based on these two strategies to date (Geels et al., 2015). Appealing to consumer carbon consciousness has been thoroughly researched and found to be ineffective in terms of significantly shifting consumer decision-making (Higham, Cohen, Cavaliere, Reis, & Finkler, 2016; Miller, Rathouse, Scarles, Holmes, & Tribe, 2010). Globally, there is a continuing trend of growing travel frequency, increasing long-haul travel, greater reliance on aviation and shorter stay per trip (Gössling, Hall, Peeters, & Scott, 2010; Sensagir, Eijgelaar, Peeters, de Bruijn, & Dirven, 2019; Sun & Lin, 2019). This pro-tourism paradigm places tourism as the fastest-growing sector in the world in 2018, expanding by 3.9% annually, higher than that of the global economy for the eighth consecutive year (WTTC, 2019). In addition, demand for air travel continues to accelerate. This is evidenced by the fact that total passenger-kilometres in aviation have increased 7.9% annually since 2011 (ICAO, 2018). Thus, increasing global tourism carbon emissions have been driven by increasing volume (numbers of visits) and intensity (emissions per traveller).

* Corresponding author.
E-mail addresses: y.sun@business.uq.edu.au (Y.-Y. Sun), peichunl@ncku.edu.tw (P.-C. Lin), james.higham@otago.ac.nz (J. Higham).

https://doi.org/10.1016/j.tourman.2020.104161
Received 7 February 2020; Received in revised form 14 May 2020; Accepted 20 May 2020
Available online 6 June 2020

Although new technology has the capacity to reduce carbon emissions, the speed of technological improvement lags behind tourism growth (Peeters, Higham, Kutzner, Cohen, & Gössling, 2016; Sun, 2016). Any marginal gains in emissions are more than offset by increased tourism consumption. This is especially evident in the air transport sector, which is the main source of tourism emissions, because the technological solutions related to aircrafts have largely been exhausted, leading to limited efficiency gains in the past decade and in the near future (Becken & Mackey, 2017; Peeters et al., 2016). Mitigation of tourism emissions has been hampered by infrastructure (e.g., road, rail, and airports) and superstructure (e.g., airline and cruise-line fleets) lock-in, and acute technical lock-in (e.g., aviation technologies). As a result, the global tourism carbon footprint continues to increase, expanding at 3.3% annually, and the current pathway foresees a doubling of tourism carbon emissions in the near future from the base year of 2005 (Lenzen et al., 2018; WTO-UNEP-WMO, 2008). It is clear that other approaches are needed to urgently respond to the climate challenge.

One fundamental problem for the ever-increasing tourism carbon emissions is the relentless pursuit of tourism maximization through 'boosterism' economic policies, in which continuing growth of visitor volume and expenditure is driven by economic imperatives with little consideration or concern expressed for the social and environmental impacts of tourism (Hall, 2009). Since substantially reducing tourism volume is less politically and socially feasible, the literature has suggested an alternative approach through optimizing tourism systems (Gössling, Ring, Dwyer, Andersson, & Hall, 2016; Lim & Cooper, 2009; Oklevik et al., 2019). Indeed, in a post-COVID-19 world where tourist numbers are likely to be significantly reduced in the medium term (Gössling, Scott, & Hall, 2020), the optimization of markets offers the potential to maximize the contribution of priority target markets to tourism recovery.

Optimization in tourism seeks to blend a complex set of competing objectives in order to create "an adaptive competitive destination niche market" that can deliver the best overall impacts (McElroy & Albuquerque, 2002). The fundamental idea is that certain visitor segments can deliver larger benefits and/or less harm per trip to the destination than others. Expanding the market share of higher performing visitor markets (while perhaps also suppressing counterpart market segments) will contribute to the enhanced overall economic, social, or environmental efficiency of tourism. Thus, through market segmentation adjustments, enhanced benefits and/or reduced harm from the baseline can be achieved without necessarily changing total visitor numbers. Such an approach complies with the call for system *reconfiguration* (Geels et al., 2015) in the pursuit of eco-efficiency (Gössling, Scott, & Hall, 2015).

Research that has adopted the optimization approach attempts to balance financial yield and other aspects of sustainable tourism, in order to prioritise segments with higher spending, longer length of stay (Gössling et al., 2016), that prefer local, small-scale experiences (Oklevik et al., 2019), display environmentally friendly behaviour (Moeller, Dolnicar, & Leisch, 2011), and incur lower carbon cost (Lundie, Dwyer, & Forsyth, 2007; Sun & Pratt, 2014). These contributions to the literature are insightful because they demonstrate the sustainability-profitability trade-off and identify visitors who make greater net positive contributions to the destination than others.

However, to put optimization concepts into practice, a detailed set of information is required. Decision-makers need to be advised on how these niche markets will grow, how to suppress less-preferred markets and by how much, and how to modify the market mix when a society moves towards placing different weightings on the economic, social and environmental objectives of tourism development. This requires a complex analytical model that can quantitatively profile the desired market mix, give a clear target to grow and/or degrow specific markets, and outline in detail the resulting consequences in terms of carbon reductions and other socio-economic aspects of tourism as the destination.

Because market optimization offers great potential to reduce tourism carbon emissions without sacrificing a significant and widely shared stream of tourism income, this article discusses the concept of market optimization and how it can best be developed quantitatively to deliver carbon mitigation objectives through a commitment to eco-efficiency. An innovative analytical approach is offered that takes into consideration the many constraints and trade-offs in the process of carbon reduction. The analytical approach is then applied and tested in the national case of Taiwan to demonstrate that a carbon reduction pathway is feasible through the informed and deliberate reconfiguration of the market mix at the national scale of analysis.

2. Optimizing the demand mix

Optimizing the demand mix effectively involves deliberately engineering discrete visitor segments so that overall anthropogenic greenhouse gas (GHG) emissions from tourism at a destination are reduced while, at the same time, seeking to maximize the collective benefits of tourism to the local/national economy, environment and society (Gössling et al., 2016). Optimization seeks to develop and encourage lower emission markets (and/or demarketing high emission segments), while carefully considering the collective economic and social impacts at the destination after market intervention and re-configuration.

The conceptual foundation of optimization is primarily based on inter-market variability in trip carbon emissions, where the carbon intensities per visitor vary greatly across segments. In the case of international tourism, Gössling et al. (2015) found that per-tourist international air emissions ranged from 370 to 1830 kg CO_2 for 11 major tourism countries. If including all consumption for the journey, trip emissions of international visitors also differ substantially by source markets, ranging from 2.5 tonnes to 9.5 tonnes CO_2-eq per trip for Australia among 12 visitor segments (Lundie et al., 2007). A similar result was also found in Taiwan where the trip emissions of international visitors from 16 countries differed up to a factor of 4–5, ranging from 0.6 tonnes to 2.9 tonnes CO_2-eq (Sun & Pratt, 2014). This consistent pattern of significant inter-market variability supports the conclusion that a 10% increase in visits from low emissions markets combined with strategies to suppress high emitting visitor segments offers great tourism decarbonization potential for a destination.

Optimizing the demand mix requires the effective operationalisation of discrete visitor market segmentation. Various aspects of tourism determine the carbon intensity of a journey. Because aviation accounts for the majority of overall trip emissions, distance travelled by air is a key factor that determines relative carbon intensity per visitor (Becken & Shuker, 2019; Gössling et al., 2015; Sharp, Grundius, & Heinonen, 2016). Long-haul markets are therefore generally much more carbon-intensive than visitors from proximal (nearby) source markets, even though they tend to stay longer and spend more per journey. First and foremost, this points to a strong environmental disincentive to develop high-growth long-haul markets, which is the current *modus operandi* of most national tourism strategies. Apart from distance from source markets (i.e., long-, medium- and short-haul international; domestic), key variables for the trip emissions include (in order— higher to lower carbon footprints):

- Length of stay (i.e., hours, days, weeks, months)
- Mode of domestic transportation (i.e., cruise; domestic aviation; electric campervan; bicycle)
- Visitor activities (i.e., heli-skiing - ski touring; jet boating – sea kayaking)
- Purpose of visit (i.e., event attendance; seasonal employment)
- Levels of consumption (i.e., luxury accommodation; local accommodation, food, produce)

These dimensions of tourism are typically integrated such that discrete markets may vary enormously in their carbon intensity. For example, cruise passengers may be associated with long-haul aviation (fly-in, fly-out), short length of stay onshore (hours), high energy visitor activities (during brief shore excursions) and high levels of consumption (luxury accommodation, imported food) (Howitt, Revol, Smith, & Rodger, 2010). Backpackers, by contrast, may be typified by longer length of stay (months), domestic transportation (public transport), wider economic contributions (seasonal labour) and low levels of consumption (local produce) (Fullagar, Markwell, & Wilson, 2012). Length of stay (LOS) is also linked to more dispersed visitor travel flows, as the availability of time allows tourists to visit regional destinations, thereby spreading the economic benefits of tourism away from high volume regional destinations, while reducing the climate impacts of high energy intensive transportation. All discrete visitor markets can be profiled in these respects, specifically as they relate to the carbon footprint of individual tourists within the segment (Gössling et al., 2015).

It is important to note that optimizing the demand mix is not a one-sided consideration that encourages low emission markets while demarketing high emission segments. It is a comprehensive approach that identifies key areas for emissions reduction, and at the same time, incurs the most social-economic benefits or the least socio-economic losses from any intended reconfiguration of the market. Especially, tourism is relevant to the progress of many United Nations Sustainable Development Goals (SDGs), including decent work and economic growth (SDG8), responsible consumption and protection (SDG12), and the sustainable use of oceans and marine resources (SGD14) (UNWTO, 2015). The transition to a decarbonized tourism future (SDG12 Climate Action) necessitates careful consideration of the social and economic contributions of tourism in local communities as well as regional and national economies. Incorporating the intricate relationships between economic, social, and environmental constraints is critically important to locate tourism emissions mitigation pathways that are socially and politically acceptable.

Of course, the inclusion of economic, social, *and* environmental objectives in tourism optimization leads to high levels of analytical complexity due to the need to balance competing goals of tourism development. Differing visitor segments contribute to various levels of impact (both positive and negative) to varying degrees (Oklevik et al., 2019). Segments that contribute to high visitor expenditure, typically, result in a higher carbon footprint; those who produce the lowest footprint may report a higher seasonality in arrivals, which may be an undesirable attribute in managing social impacts at the destination (Lundie et al., 2007). Therefore, maximization of one goal is typically at the expense of others. For this reason, optimizing the demand mix requires an analytical framework that can identify the desired market portfolio based on the preferences of decision-makers (government, the community, and firms) for competing objectives. Thus, optimization must be founded upon a methodological framework that comprehensively identifies key variables based on a rigorous theoretical model and comprehensive analytical processes, with explanation and justification.

3. The methodological framework

The proposed analytical framework is an iterative process involving the continuous monitoring of tourism socio-economic and environmental data, optimization analysis, and policy instruments that are capable of achieving the desired market mix (Fig. 1).

Step 1 National Tourism Account

The building blocks of the proposed framework are represented by a set of comprehensive, long-term, destination-level tourism accounts that encompass tourism emissions indicators as well as social-economic data that portray how tourism has rippled its effects across the economy and the society of the destination. Besides tourism carbon emissions, factors that determine trip carbon intensity are included, such as transport modes, distance travelled, lodging types and recreational activities

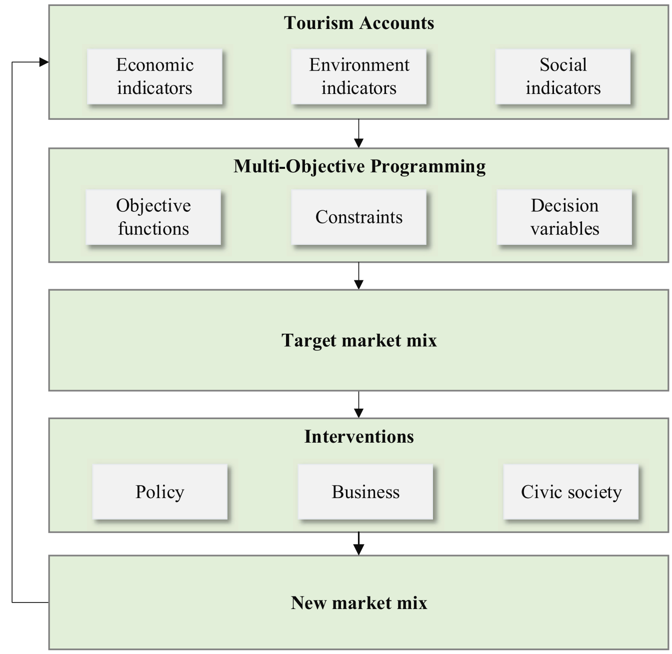


Fig. 1. The conceptual process of tourism demand optimization.

(Oklevik et al., 2019; Sensagir et al., 2019). For socio-economic accounts, there are different indices that give insights into multiple aspects of the destination (World Tourism Organization, 2004). The consideration of indicators primarily rests on the ultimate impacts the destination aims to address through the reconfiguration of the market mix. For regions that undergo economic hardship, priorities are generally given to economic goals, typically expressed in terms of revenue, GDP and employment (Zhang, 2016); for those that experience over-tourism, congestion index, residents tourism perception, and temporal and geographic dispersion indices are well suited to profile the desired market mix, alongside the tourism climate responsibility that is central to the analytical framework (Capocchi, Vallone, Pierotti, Amaduzzi, & Capocchi, 2019).

Tourism accounts are then used to calculate economic, environmental, and social intensity for individual segments. The intensity ratio represents the market segment by per-person impact, profiling the marginal benefits/costs that the destination faces when hosting one more visitor from that given group. These parameters also illustrate the trade-offs between emissions, economic contribution, and social benefits.

Step 2 The Optimization Analysis

Due to the complex and competing characteristics of individual segments, decision-makers have a multi-criteria environment in which they have to address tourism planning in terms of efficiency, effectiveness, and equity. The multi-criteria decision analysis (MCDA) using goal programming is used to identify and accurately profile the desired market mix. Multi-criteria decision analysis is one branch of operations research and management science which disciplines use to deal with the optimal allocation of scarce resources among competing activities by maximizing the desired benefits or minimizing the adverse effects using mathematical models (Colapinto, Jayaraman, & Marsiglio, 2017). Recent algorithmic developments and computational improvements have greatly advanced the application of MCDA in the planning of sustainability, in which economic, environmental, energy and social criteria are simultaneously considered (Jayaraman, Colapinto, Torre, & Malik, 2015; Linares & Romero, 2017). By allowing weights to be assigned to different criteria, MCDA presents pathways on energy use and emissions reduction through various options, a key step in envisioning the future for strategic planning and investment.

A typical optimization programme consists of several essential components: objective function, constraint variables and decision variables. The objective function specifies the goals that are to be ultimately achieved. This could be a single-objective or multiple-objective exercise, such as minimizing tourism carbon emissions and/or maximizing tourism employment. Constraints represent circumstances that must be met in order to locate the optimal solution. The model uses an inequality or equality function to define constraints on decisions, which may include consideration related to limited resources, contractual obligations, policy regulations or social expectations. These factors are the reality check for policy implementation. The final component, decision variables, describe those variables that are controlled and manipulated by stakeholders in order to realize the optimal result and the specified goals. To search for the optimal market portfolio, the decision variable (X_j) is expressed as the number of visitors per segment.

Besides these essential components, the optimal solution can be used to inform factors that are not modelled endogenously—these are referred to as derived variables. Since an optimization exercise involves a limited number of objectives and constraint variables, there are impacts that are not modelled, yet are influenced. For example, a carbon emission reduction model that is constrained by GDP, employment, and length of stay criteria will modify other tourism aspects, such as the tourism water footprint or the geographic dispersal of visitors. These derived variables inform policy makers on possible consequences that may range over a wide spectrum of planning issues.

Combining the aforementioned components into a single statement for the optimization analysis yields the following algebraic formula.

$$\text{Maximize or minimize} \quad z = \sum_{j=1}^{n} c_j x_j$$

$$\text{subject to}$$

$$\sum_{j=1}^{n} a_{ij} x_j \begin{Bmatrix} \leq \\ = \\ \geq \end{Bmatrix} b_i, \quad i = 1, \ldots, m$$

$$x_j \leq u_j, \quad j = 1, \ldots, n$$

$$x_j \geq 0, \quad j = 1, \ldots, n$$

The operation is to manipulate the decision variable, X_j, under the constraints to achieve the objective, Z. The constraints, including non-negativity restrictions and simple upper or lower bounds, define the feasible region of a problem. The collection of coefficients for all values for the indices (c_j, a_{ij}, b_i, u_j) are parameters that must be specified.

A specific solution approach to multiple objective problems is through goal programming, which requires that all objectives should come close to targets, each measured in its own scale. The distance-based process is to minimize the overall deviation of objectives from aspiration levels of goals (Colapinto et al., 2017). In operation, goal programming can be considered as an extension of standard optimization problems in which targets are specified for a set of constraints.

Step 3 Intervention

The optimization analysis calculates the desired market mix, profiling segments whose shares need to increase or decrease over the current baseline. The blueprint of the aspiration levels is built upon policy interventions that are effective to de-grow certain visitor segments while other more desirable markets or discrete market segments become target or 'engine' markets for the destination. Comprehensive strategies are called for from (1) policy, (2) business and (3) the civic society perspectives to collaboratively execute the market reconfiguration.

From the policy perspective, monetary and non-monetary incentives provide the most effective, front-line control of visitor number by segments. These measures range from visa regulation, bilateral air service agreements, and regional trade agreements in force, to carbon tax or subsidies that discriminate segments based on the emission intensity (Hall, 2014). Business capacities, on the other hand, may be engaged to leverage effective marketing and branding campaigns that offer a comprehensive package of advertising, sales, public relationship engagement, publicity and digital marketing to target prioritized segments (Morrison, 2013). The supplementary actions will then follow to enhance capacity building on infrastructure, software, and human resources in order to tailor services for the prioritized groups. For example, to accommodate the way Islamic tourists travel, a cohesive system is needed to develop infrastructure such as Muslim-friendly airports, hotels, health care or leisure attire (e.g., swimming suits), and human resources that can assist with Halal food or Halal tourism websites (Battour, 2018). Besides governmental and business strategies, civic society is the fundamental buffer that fosters a harmonized socio-political status between the departing and receiving regions. Significant for bilateral travel, positive social contacts require a friendly environment that breaks down intergroup stereotypes without alienating incoming visitors (Rowen, 2014). This is especially critical for developing visits from regions that may have had historically tense diplomatic relations, or continuing geopolitical issues with the destination country (Farmaki, 2017; Kim, Prideaux, & Timothy, 2016).

Step 4 Evaluation and readjustment

Policy interventions adjust the market mix from the business as usual (BAU) baseline and generate a new market mix. This then creates a circular effect to the economic, social, and environmental performance of tourism at the destination. Optimizing the market mix however is not a one-time exercise. The periodic, long term monitoring of tourism accounts along with the optimization analysis are needed to effectively locate the desired market mix on a continuing basis. The adaptive capacity of the process ensures that the dynamics of visitor behaviours, changing community preferences, and various political and social constraints are regularly considered and periodically reviewed.

4. Optimizing the tourism demand mix: an analysis of Taiwan

In this section, the proposed optimization analysis is applied to Taiwan, a destination that seeks growth in inbound tourism to maximize economic impacts, while confronting the high carbon intensity of tourism income (Sun & Pratt, 2014). In the past decade, tourism contributed to a higher proportion of Taiwan's national carbon emissions relative to its contribution to gross domestic product (Sun, 2014). This pattern is primarily driven by the country's relatively inferior production technology among tourism firms and high dependence on air transport, which is an inescapable reality for island destinations (Sun, 2019). Over the course of the last decade, technological improvements adopted by tourism firms were found to be insufficient to offset increased tourism consumption, leading to growth in tourism emissions and a deteriorating tourism carbon efficiency per dollar GDP. The challenge to stabilise and decrease tourism emission in Taiwan resembles those that are faced by many destinations globally (Lenzen et al., 2018).

Optimizing the Taiwan tourism visitor mix necessitates that a tourist quota planning problem is formulated as a multi-criteria decision analysis using goal programming. This requires detailed specification of the system boundary where each component is later translated into mathematical parameters and formulae. To demonstrate the flexibility of this

Table 1
System boundary of 4 scenarios for Taiwan tourism optimization analysis.

Variable	Scenario 1 (simple)	Scenario 2 (medium)	Scenario 3a (high complexity)	Scenario 3b (high complexity)	Scenario 4 (high complexity)
Objective function	I Environment: Min tourism CO_2	I Environment (1st priority): Min tourism CO_2 II Social: Min monthly fluctuation in total arrivals/Max length of stay	I Environment (1st priority): Min tourism CO_2 II Social: Min monthly fluctuation in total arrivals/Max length of stay III Economic: Max total visitor expenditure	I Economic (1st priority): Max total visitor expenditure II Environment: Min tourism CO_2 III Social: Min monthly fluctuation in total arrivals/Max length of stay	I Economic (1st priority): Max total visitor expenditure II Environment: Min tourism CO_2 III Social: Min monthly fluctuation in total arrivals/Max length of stay
Constraint	1 Reduce tourism CO_2 at least by 5% from the base-year tourism carbon emission total 2 Total visitor volume reduces by less or equal to 5%	1 Reduce tourism CO_2 at least by 5% from the base-year tourism carbon emission total 2 Total visitor volume reduces by less or equal to 5% 3 Individual visitor volume (by country) ±20%	1 Reduce tourism CO_2 at least by 5% from the last year tourism carbon emission base 2 Total visitor volume reduces by less or equal to 5% 3 Individual visitor volume (by country) ±20% 4 Total visitor spending reduces by less or equal to 10%	1 Reduce tourism CO_2 at least by 5% from the last year tourism carbon emission base 2 Total visitor volume reduces by less or equal to 5% 3 Individual visitor volume (by country) ±20% 4 Total visitor spending reduces by less or equal to 10%	1 Reduce tourism CO_2 at least by 5% from the last year tourism carbon emission base 2 Total visitor volume reduces by less or equal to 5% 3 Individual visitor volume (by country) ±20% 4 Total visitor spending reduces by less or equal to 10%
Decision variable	• Visitor quota by country	• Visitor quota by country	• Visitor quota by country	• Visitor quota by country	• Visitor quota by country
Derived variable	• Public transport use volume • Total visitor spending • Gini index	• Public transport use volume • Total visitor spending	• Public transport use volume	• Public transport use volume	• Public transport use volume
Parameter	• Visitor profile	• Visitor profile	• Visitor profile	• Visitor profile	• Visitor profile • Assume 20% carbon reduction for Australian travellers

framework, four scenarios, ranging from simple to highly complex, are proposed in Table 1. For the analysis of Taiwan, the objective variables reflect the most pressing issues confronting the destination. These include environmental (trip carbon emissions), social (seasonality in arrivals and length of stay) and economic variables (total visitor expenditure, a proxy for benefits on employment, value added and tax revenue). Overall, the model aims to address environmental concerns from tourism, to reduce seasonality and short-stay arrivals, and to maintain the indispensable economic contribution of foreign receipts. An expected outcome is to reconfigure the current tourism system to achieve a more stable, resilient, and sustainable tourism solution.

Basic constraints are specified as (1) an absolute emission reduction target that must be achieved, ensuring the model will locate a market mix that will collectively improve the carbon performance of tourism, and (2) an acceptable fluctuation of tourism volume, expenditure and individual market share, reflecting the societal capacity to cope with expenditure/volume fluctuation from tourism. The latter is especially important for the model to advise feasible solutions in practice. Without this, the optimization model is likely to recommend zero visitors from the carbon intensive segments (such as long-haul travellers from the US and Europe) while fully expanding low emission visitors from nearby regions. Completely restricting incoming visitors from certain countries is not socially and politically acceptable. In this paper, we thus suggest a ±20% fluctuation in visitor numbers from the baseline. Lastly, the percentage of inbound visitors that use public transportation for their journey in Taiwan is a derived variable, which allows decision-makers to assess how the volume of public transport from tourism will be indirectly influenced by the new market share.

Scenario 1 contains the most basic specification, incorporating one objective and two basic constraints on carbon reduction and tourism volume, respectively. Scenario 2 aims to address carbon mitigation and seasonality issues with one additional constraint, which requires the visitor share of any given segment to increase/decrease by less than a range from the baseline.

Scenario 3 demonstrates how the optimization results will be influenced by rotating the priorities of economic, social, and environmental objectives. In the model, objectives have to be determined, ranked, and weighted whereby the algorithm satisfies the first (most important) goal via adjusting the decision variables before searching for solutions that meet the consecutive objectives. This points to a critical consideration as to whether emission reduction is more strategically important than economic prosperity or social impacts. To test the sensitivity, Scenario 3A ranks emission reduction as the first priority and Scenario 3B selects economic rewards as the most important goal, while other parameters remain unchanged, *ceteris paribus*. These two scenarios allow decision-makers to contrast and comprehend the preferred market structure if priorities of objectives differ.

The three above-mentioned scenarios are driven by supply-side factors, as determined by the destination with an aim to actively seek the most desirable visitor portfolio. From the perspective of carbon management, visitors also have some locus of control. They can reduce their carbon footprint via carbon-offsetting or by voluntarily modifying their travel behaviours by using more environmental friendly services. Scenario 4 is thus designed to test whether demand driven initiatives can influence the optimization result. In this analysis, we assume 20% of Australian tourists will purchase carbon offsets for their journeys to Taiwan, allowing the carbon footprint per Australian tourist to be reduced by 20%. Other parameters remain unchanged as those specified in Scenario 3B.

All parameters in the model were obtained from Sun and Pratt (2014) research which provided the socio-economic and environmental performance of inbound visitors from 16 source countries to Taiwan (see Appendix 1). The parameters were multiplied by total inbound visits in 2018 to profile the tourism impacts that serve as the baseline for the current analysis. The carbon profile of visitors covered the direct emissions produced by tourism firms in Taiwan and international aviation emissions. Indirect emissions from the supply chains and emissions embedded through imports to Taiwan were not covered.

4.1. Analysis

This work specifies the following notation to formulate the multi-objective programming model:

I	the set of 16 main countries whose residents provided the most visits to Taiwan;
T	the set of planning time periods in the month;
c_i	the current number of tourists from country i in 2018, $\forall i \in I$;
x_i	the decision variable representing the tourist quota assigned to country i, $\forall i \in I$;
Baseline	
$\text{Cturist} = \sum_i (C_i)$	the number of tourists in 2018;
$\text{CCO2} = \sum_i (C_i * CO2_i)$	tourism emissions in 2018 where $CO2_i$ is the carbon emissions per person trip in segment i, $\forall i \in I$;
$\text{Cspending} = \sum_i (C_i * spending_i)$	the current tourism spending in 2018 where $spending_i$ is the spending per person trip in segment i, $\forall i \in I$;
$\text{CLOS} = \sum_i (C_i * stay_i) / \sum_i (C_i)$	the current average length of stay of all tourists in 2018 where $stay_i$ is the length of stay in segment i, $\forall i \in I$;
$\text{CMtourist}_t = \sum_i (C_i * pm_{it})$	the current number of tourist on month t, $\forall t \in T$; where pm_{it} = the percentage of tourist from country i on month t, $\forall i \in I$, $\forall t \in T$; $\sum_t pm_{it} = 1$, $\forall i \in I$;
$\text{Gini} = \dfrac{\sum_{\tau \in T}\sum_{t \in T} \lvert mtourist_t - mtourist_\tau \rvert}{2*12^2*\sum_{t \in T}\frac{mtourist_t}{12}}$	the degree of inequality in the number of visitations to Taiwan over the year where $mtourist_t$ is the monthly international tourist arrivals in t, $\forall t \in T$.

Factors that influence tourist quota planning are designated as constraints. In this model, four constraints are specified, and each scenario employs varied numbers of constraints. These include a minimum 5% reduction in tourism carbon emissions; a maximum 5% total visitor volume reduction; a ± 20% volume fluctuation for any given visitor segment; and a maximum 10% visitor expenditure reduction. Specifications of these parameters follow the de-growth philosophy, which allows the model to search for solutions that accommodate a reduction in tourism volume (Higgins-Desbiolles, Carnicelli, Krolikowski, Wijesinghe, & Boluk, 2019). The overall inbound tourism volume is therefore relaxed with a maximum reduction of 5% from the baseline.

Formulae are specified as:

1. The new level of tourism CO_2 is at least 5% less from the base-year tourism carbon emission base:

$$\text{CO2} \le 0.95*\text{CCO2}$$

2. The new level of visitor volume is at least 95% of the baseline level:

$$\sum_i X_i \ge 0.95*\text{Ctourist}$$

3. The new level of visitor volume from individual source markets varies with the range of ± 20% from the baseline:

$$X_i \le 0.8*C_i \quad \forall i \in I$$

4. The new level of visitor spending can only be reduced by less or equal to 10% from the baseline:

$$\text{Spending} \ge 0.9*\text{Cspending}$$

Scenario 1: Mathematical programming with single objective

Tourist quotas of the 16 countries/areas for the coming year (x_i) are determined by the following integer programming:

$$\text{Minimize} \quad CO_2 = (X_i * CO2_i)$$

s.t.

$$\text{CO2} \le 0.95*\text{CCO2}$$

$$\sum_i X_i \ge 0.95*\text{Ctourist}$$

Scenario 2–4: Lexicographic optimization

For solving the multi-objective model, this study adopted preemptive goal programming in which four objectives are ordered according to importance and priorities specified in Table 1. For Scenario 3A, we observed the following ranking: minimizing the national tourism CO_2 ($i = 1$), balancing the monthly fluctuation in total arrivals ($i = 2$), maximizing trip length in days ($i = 3$), and maximizing total tourism spending ($i = 4$). We considered the objective at priority i as definitively more important than the objective at the next lower level, $i+1$, but they are relaxed by a certain absolute amount when optimizing for the level $i+1$. With respect to the four imposed constraints, they are formulated as a lexicographic with 24 combinations ($4! = 4 \times 3 \times 2 \times 1 = 24$) (see Appendix 2 - Optimization formula).

5. Results

5.1. Inter-market variability

Inbound visitors by source countries exhibit different economic, social, and environmental impacts at the destination. To demonstrate intermarket variability, Fig. 2 shows the standardized value of visitor impacts across six indicators for visitors from the top 4 inbound markets to Taiwan: Mainland China (24%), Japan (18%), Hong Kong/Macau (15%), and USA (5%). A score of "5" represents the best performance and "1" is the worst on the indicator. An ideal visitor segment is expected to generate the maximum score across all six dimensions, implying their impacts are economically maximized, environmentally minimized and socially balanced.

Radar charts give insights into the competing performance of segments, mapping clearly how each visitor segment contributes and pollutes differently. For example, Japanese visitors produce a relatively small carbon footprint (586 kg CO2-eq/trip) but their length of stay is the shortest and they prefer to use private transportation when travelling in Taiwan. In contrast, visitors from the USA tend to stay longer and incur more expenditures but they are among the highest in terms of carbon emissions, averaging 1454 kg CO2-eq per trip. Chinese visitors have a superior environmental and economic performance; however, like visitors from Hong Kong/Macau, Chinese arrivals have a high propensity towards short-stay visits.

5.2. Optimization analysis

In the 2018 baseline, Taiwan hosted 1.11 million international visitors, and inbound tourism contributed about US$15.65 billion of foreign receipts. The average length of stay of foreign visitors was 6.73 days, and the Gini index was 0.049, reflecting a relatively even distribution of visits across months. Total inbound visitors contributed 7.69 million tonnes CO_2-eq, averaging around 707 kg CO_2-eq per person trip.

The optimization results are outlined in Fig. 3. Adjustments of market share across 16 source regions are displayed in the left column and the resulting impacts on the environment, society and economy of the destination are presented in the right column. The relative changes to the baseline (year 2018), instead of the absolute magnitude, are the focus. It is important to note that the model has capped the variation of individual market share to be within the range of 20%.

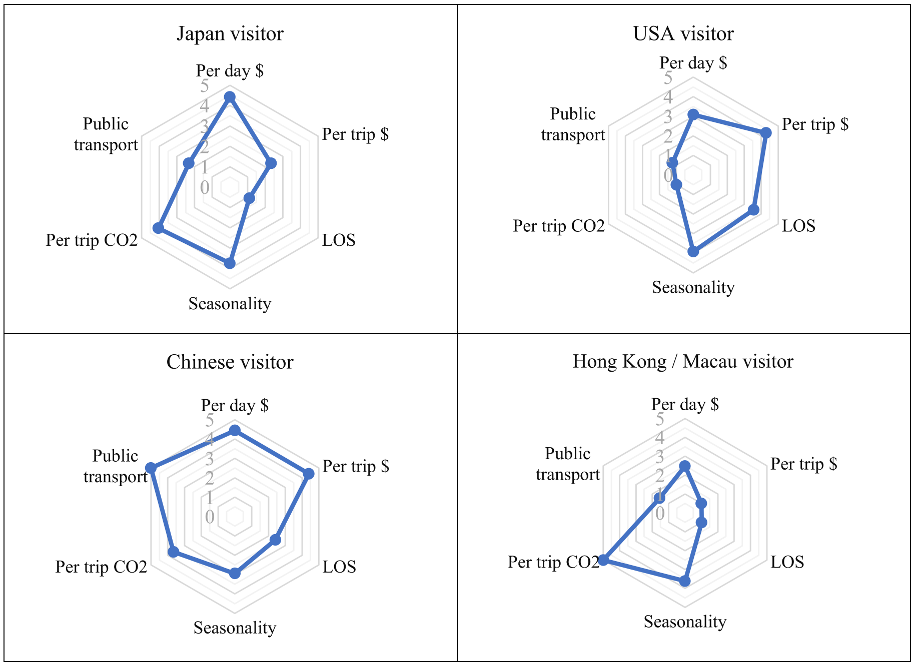


Fig. 2. Radar charts on 6 indicators for four international visitors to Taiwan.

For Scenario 1, the solution recommends a uniform 5% reduction in visitor numbers across segments to achieve the specific objective—reducing tourism emissions by 5%. As a consequence, this simple solution is expected to generate a 5% reduction in total visitor expenditure and no changes in seasonality and average length of stay. Scenario 1 corresponds to a simple intuition-driven approach, which logically involves receiving fewer tourists to achieve a simple pathway to reduce tourist emissions. In this setting, the market share remains unchanged.

With the addition of social objectives in the model, Scenario 2 begins to expand segments with the following characteristics: low carbon intensity per trip, longer stays, and an even distribution in monthly arrivals. Segments that are recommended to expand are: Indonesia and 'Other' Asian visitors who stay longer and produce lower emissions, and Malaysian visitors who have a low seasonality and lower emissions. Others segments are clearly less favourable. Under this scenario it is recommended that Mainland China is reduced by 5% in volume and others are reduced to the maximum (−20%). Overall, reconfiguration of the market mix will reduce arrivals from segments that are associated with high trip emissions and increase arrivals from Southeast Asia. This will allow total tourism carbon emission to be reduced by 5% and slightly improves the social aspects of tourism, leading to an extended length of stay and a better balance in the overall monthly arrivals. This scenario comes with a 4.5% reduction in tourist expenditure.

Scenario 3A and 3B demonstrate drastic differences when optimization objectives are guided by different priorities. Scenario 3A emphasizes the need for carbon reductions, followed by social and economic objectives, respectively. Segments that increase under Scenario 3A are South Korea (+20%), Hong Kong/Macau (+20%) and Japan (+10%), while others are recommended to reduce by the maximum extent (−20%). This solution creates the best mitigation scenario from the base year (−10.2%). The average emissions per inbound visitor increases in efficiency, improving from the baseline of 707 kg CO_2-eq to 657 kg (−5.5%). This solution however results in the biggest loss in visitor expenditure (−9.6%), with mixed social impact outcomes.

On the other hand, Scenario 3B prioritizes the economic significance of tourism under the goal of carbon reduction. Under Scenario 3B, the market mix is re-engineered to maintain a similar level of economic output from the baseline (−0.9%) while reducing total tourism emissions by 5.0%. Segments from South Korea, Hong Kong/Macau, Mainland China, and other Asian markets are preferred. The adverse effect of Scenario 3B is on social impacts. Visits from these four segments tend to occur in the winter months (Dec to Feb) to celebrate the Christmas holiday and the Chinese New Year. Increasing the market share of these segments is likely to aggravate the seasonality problem (12.4%) and reduce the average length of stay among all inbound visitors (2.4%). These may result in a lower quality of service, overcrowding, imbalance in revenue distribution, and a reduced quality of life for residents during the winter months.

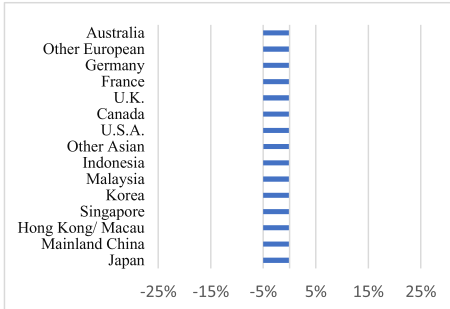
Scenario 4 supports the demand-driven factor in the optimization process. With a 20% carbon offset initiative assumed for Australian arrivals, the model reverses the suggestion from demarketing this segment from prior scenarios to increasing their visitor volume up to the 20% limit. Instead, the originally preferred market from Hong Kong/Macau is reduced from 18% to 10%. Compared to previous scenarios, Scenario 4 also suggests a relatively superior outcome in which Taiwan is able to achieve greater carbon reductions (from 5.0% to 5.3%), bear fewer seasonality and short-stay problems, and sustain a minimal reduction in total visitor consumption (−0.9%). Scenario 4 provides a clear demonstration that a significant and consistent consumer-driven initiative[1] in reducing their climate impact can greatly influence the visitor portfolio. The optimization result reflects the value of these environmental initiates, which subsequently changes the trade-offs between carbon emissions and the economic and social impacts among individual segments.

6. Discussion

Optimizing the demand mix offers great potential to mitigate national tourism emissions, if informed by methodologically rigorous research. The optimization model signals a pathway to reconfiguring the market mix of a destination, based on specified objectives and constraints, allowing trade-offs between the carbon intensity of tourist

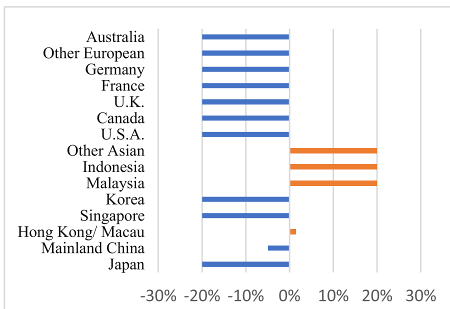
[1] If less than 20% of Australian travellers are engaged in a carbon offset, the optimization model will not recommend the Australian market. In other words, the carbon emissions of Australians have to reduce by at least 20% in order to outperform their counterparts from Hong Kong/Macau.

Market shares | **Outcomes**



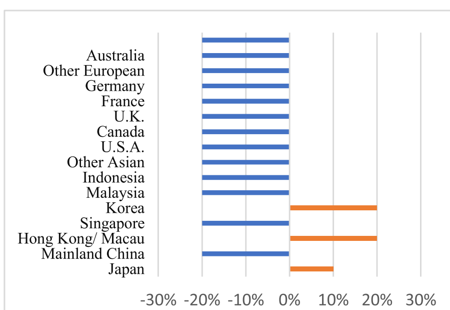
Scenario 1

- Total visitor number reduced by 5.0%
- Tourism emissions reduced by 5.0%
- Emission per visitor does not change
- Seasonality does not change
- LOS does not change
- Total spending reduced by 5.0%
- Public transport use does not change



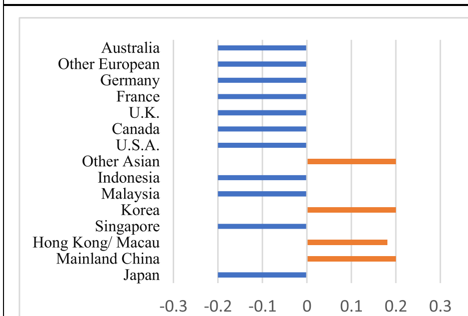
Scenario 2

- Total visitor number reduced by 5.0%
- Tourism emissions reduced by 5.0%
- Emission per visitor reduced by 0.01%
- Seasonality improved by 0.8%
- LOS increased by 2.9%
- Total spending reduced by 4.5%
- Public transport use increases by 0.7%



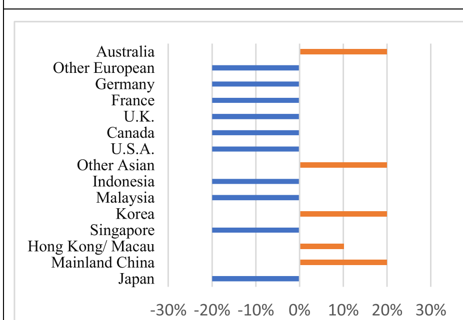
Scenario 3A

- Total visitor number reduced by 5.0%
- Tourism emissions reduced by 10.2%
- Emission per visitor reduced by 5.5%
- Seasonality improved by 0.8%
- LOS shorted by 5.6%
- Total spending reduced by 9.6%
- Public transport use reduced by 4.5%



Scenario 3B

- Total visitor number reduced by 5.0%
- Tourism emissions reduced by 5.0%
- Emission per visitor reduced by 2.0%
- Seasonality deteriorated by 12.4%
- LOS shorted by 2.4%
- Total spending reduced by 0.9%
- Public transport use increased by 4.9%



Scenario 4

- Total visitor number reduced by 1.6%
- Tourism emissions reduced by 5.3%
- Emission per visitor reduced by 3.7%
- Seasonality deteriorated by 11.8%
- LOS shorted by 1.9%
- Total spending reduced by 0.9%
- Public transport use increased by 3.6%

Fig. 3. Simulation results for 16 source marks to Taiwan across four scenarios. Note. Adjustments of market shares across 16 source regions from the baseline (year 2018) are displayed in the left column and the resulting impacts on the environment, society and the economy are in the right column.

arrivals and the socio-economic impacts of tourism to be carefully considered quantitatively. These pathways are less driven by intuition and difficult to predict if the objectives and constraints grow by a large number and involve non-linear parameters. Hence, the optimization model is a useful aid to assess the sensitivity of segment segments when different objectives, constraints, and magnitudes of adjustment are considered.

Destinations may use the model to develop their tourism carbon management strategies more systematically. The optimization results do not support a uniform cut in demand upon all segments for the purpose of carbon reduction. Such an approach is inefficient for the intended purpose as it reduces GHG emissions with a detrimental effect on socio-economic repercussions, making a simple de-growth approach politically and socially less acceptable. Rather, segments can be strategically encouraged or discouraged based on their marginal influences on the economy, society, and the environment. By doing so, destinations are able to achieve a more resilient and environmentally sustainable status. This is exemplified through Scenario 3B which achieves a 5% tourism carbon reduction while maintaining a similar level of tourist expenditure from the baseline. The optimization result provides an effective, evidenced-based mitigation pathway to stabilise and reduce tourism carbon emissions while safeguarding economic yield.

Scenarios 1–4 also point out that the best mitigation progress is only achievable through reducing aggregate tourism demand, i.e., a 5% reduction in the overall inbound tourism volume. This highlights the need to employ strategies that reduce visitor volume and optimise market segments in combination. Either relying on reducing visitor volume (Scenario 1) or employing market optimization to cope with an increasing visitation level does not create an optimal effect in carbon mitigation.

Scenario analysis supports the proposition that both demand and supply-driven initiatives are important in formulating the best outcome for the destination. For government-driven policies aimed at carbon mitigation, reduced reliance on intercontinental long-haul aviation markets will, under the current technical regime, be the most effective pathway forward. The loss of socio-economic benefits from reduced long-haul visitor arrivals can be compensated by developing short-haul markets that perform with a marginally high economic value or social contribution. This optimization result supports the conclusion that expanding short-distance travel can satisfy important priorities in the national tourism agenda.

However, we discover that the same agenda might also be achieved by visitor-driven actions. Scenario 4 demonstrates that with 20% of Australian travellers participating in the carbon offset initiative, this will re-categorize this group as those with a smaller carbon footprint. Subsequently, this long-haul segment is favoured. In other words, whether or not to develop carbon intensive markets would strongly depend on their carbon offset penetration rate and whether they are sufficiently significant to generate meaningful reduction measures. Without these self-contributing carbon actions, it remains unwise for the current national strategies to tap into geographically distant source markets. Alternatively, progressive governments might legislate to make carbon offsetting mandatory for long-haul visitor markets, in order to actually enforce demand-side measures to mitigate tourism carbon emissions (Gössling & Higham, 2020). Such a move could be applied based on market carbon intensity but be extended to include medium- and short-haul origin markets over time.

When using multiple criteria to prioritise visitor markets, several considerations arise: 1) the measurement attributes that represent the marginal impacts of tourism from individual segments; (2) the relative importance of each objective; (3) number and types of endogenous constraints in the model; and 4) the way visitor markets are segmented. As demonstrated in the four scenarios, results are sensitive to how system boundaries and key parameters are defined. This implies that a socially, politically, and financially feasible solution requires the optimization model to precisely reflect the preference of the host society through parameter specification. Especially, the issue of whether carbon mitigation should be prioritized over other socio-economic factors in the multi-objective modelling is critical. It determines ultimately how effective emission reduction can be achieved and the extent of adverse effects in the socio-economic dimensions of tourism. Optimizing the market mix therefore requires a conscious building process, based on collective opinions among stakeholders, to discuss, delineate and understand the implications of these parameters and the resulting model solutions.

The feasibility issue also extends to the market reconfiguration in consideration of each market's relative importance. Particular segments may be difficult to reduce or increase in magnitude because of changing market potential or political considerations over time. Small source markets, such as Hong Kong/Macau, are less likely to sustain continuing growth in outbound travel even if they are preferred segments (for Taiwan). In contrast, large emerging markets such as China, India or Russia require aggressive strategies if they are identified as those that should be reduced. In addition, there is a long-term relationship between international trade and bilateral travel flow (Kulendran & Wilson, 2000). Restricting visitors from trade countries may have a negative flow-on effect on the economy because certain transactions are facilitated by business visits from international trade patterns. This then requires careful consideration to achieve a delicate balance in terms of how many and what types of visa should be issued to business and leisure travellers. These context-dependent issues pose real challenges in share adjustments in the short term and will vary substantially for each destination. For technical aspects, these factors can be incorporated by relaxing constraints in the model for a "soft" target. This will enhance the feasibility of the model solution with tourism planning.

Transforming the market mix however cannot deliver a perfect solution for the multi-objective maximization at all scales and requires support from two aspects of social resilience. The first relates to how complex tourism systems interconnect and what determines the capacity of a destination to absorb disturbances through feedback loops (Mai & Smith, 2018). Since optimizing the market mix at the national level does not guarantee an optimized outcome at the regional scale of analysis, certain regions and sectors may be more economically and socially disadvantaged than others in this process. For example, the new market mix may lead to a tourist-populated metro city at the expense of developing off-season tour activities at the rural regions, which may then lead to more complex dilemmas in income disparities, social inequalities, or fiscal imbalances.

Transforming the market mix can be considered as a predictable long-term disturbance to communities and entrepreneurs (Lew, 2013). This is an added disturbance on top of how climate change has impacted the tourism system through tourist behaviour changes (Gössling, Scott, Hall, Ceron, & Dubois, 2012), and industry operations, i.e., ski resorts (Rutty et al., 2017). Future research can address how social resilience at different scales should be examined and enhanced for their vulnerability to shocks, especially with respect to economic redistribution. Such research is important to address the challenge as to whether they can retain "essentially the same function, structure, feedbacks and therefore identity" (Walker et al., 2006, p. 14) in the phases of market share re-engineering.

Currently, few countries adopt systematic strategies to encourage low environmental impact visitors. Practices exist in Bhutan where a tariff system is combined with requirements for guided tours and certain spatial restrictions for attracting "upmarket" tourists who are interested in exploring aspects of culture and nature where the itinerary carries a minimal environmental burden (Gurung & Seeland, 2008; Nyaupane & Timothy, 2010). The UK on the other hand has implemented a distance-dependent Air Passenger Duty, where flights over 6000 miles face seven times more tax than those of less than 2000 miles (Daniel, Hall, & Gossling, 2012). Fig. 1 indicates the need for collective interventions on policy, business, and civil society to facilitate successful market reconfiguration. Whether a particular strategy is effective for a given market and under what context it is effective reflect another level of social resilience at the host destination. The wider application of this model is required to identify barriers and hotspots in implementing market reconfiguration in the interests of market optimization, and to explore how different nations may best respond to the challenge of mitigating tourism greenhouse gas emissions.

7. Conclusion

Optimizing the demand mix is a pro-active approach for destination governments to determine, foster, and develop a long-term tourist portfolio that can collectively meet a nation's agenda to achieve carbon mitigation priorities in the tourism sector. This paper identifies an important gap in implementing the concept due to a lack of precision modelling that can quantitatively profile the desired market mix, give a clear target for national tourism agencies to expand or contract specific markets, and inform the resulting consequences on carbon reductions and other socio-economic aspects of tourism. In response, we propose an innovative analytical framework based on multi-criteria decision analysis (MCDA) using goal programming. This framework informs an evidence-based pathway that stabilizes and reduces tourism carbon emissions while balancing economic yields through the market mix approach.

The proposed framework calls for a new paradigm in tourism market planning. The current approach toward the tourism market mix is largely passive. Tourist numbers from an individual source market are critically influenced by macro-level factors such as economic growth rates, exchange rates, oil prices, demographic factors, inflation, and/or bilateral transportation capacities (Prideaux, 2005). National tourism bureaus thus use these factors to forecast the trajectory of visitor volume from individual segments in the long term, evident in the global and country-level tourism forecast reports (Tourism Research Australia, 2019; UNWTO, 2011). This approach unavoidably favours source markets with high arrivals growth potential, such as those countries that are experiencing rapid economic growth. In this mindset, destinations accept visitors that seek to visit with little or no consideration given to the desired market mix. By pro-actively managing the tourism market mix, destination managers exercise portfolio selections to induce a gradual and moderate change in the visitor mix in order to minimize risks and maximize benefits based on the decision-makers' strategic preferences. Employing optimization and de-growth strategies in combination, we demonstrate that in the case study of Taiwan, great potential exists to reduce emissions and sustain economic yields, in order to achieve progressively more climatically sustainable tourism sector performance over time.

This analytical framework can be applied at all scales of the tourism system, from the global to the national and regional, drawing on existing Tourism Satellite Account, international visitor survey and domestic tourist survey data. From the carbon mitigation perspective, optimizing the demand mix has a critical contribution to make to the eco-efficiency and sustainable management of tourism destinations. This should occur while continuing to advance the equally important imperatives of fostering sustainable travel behaviours (e.g., carbon offsetting for unavoidable air travel emissions under the current technical regime) and improving the eco-efficiency of tourism firms. These multiple pathways offer rich possibilities for further research into tourism optimization in the pursuit of a climate-safe tourism future.

Impact statement

Currently, governments have two tools on hand to mitigate the ever increasing carbon emissions associated with tourism: fostering sustainable travel behaviours (e.g., carbon offsetting for unavoidable air travel emissions) and improving the eco-efficiency of tourism firms. Empirical observations, however, indicate a lack of meaningful progress based on these two strategies to date and tourism carbon emission has been increasing at 3.3% annually. This paper suggests an additional avenue for tourism carbon management, which is, to pro-actively determine, foster, and develop a long-term tourist portfolio that can collectively meet a nation's agenda to achieve carbon mitigation priorities in the tourism sector. An analytical framework is provided to quantitatively profile the desired market mix, give a clear target for national tourism agencies to expand or contract specific markets, and inform the resulting consequences on carbon reductions and other socio-economic aspects of tourism. This tool allows the concept of market optimization to be translated into feasible, practical, and useful national strategies in mitigating tourism carbon emissions.

Declaration of competing interest

None.

CRediT authorship contribution statement

Ya-Yen Sun: Conceptualization, Resources, Visualization, Writing - original draft. **Pei-Chun Lin:** Methodology, Formal analysis, Writing - original draft. **James Higham:** Conceptualization, Writing - review & editing.

Acknowledgements

We thank anonymous reviewers for their constructive comments to the previous version of this paper. Financial support from the Taiwan Ministry of Science and Technology under MOST 107-2410-H-006-100-MY2 is gratefully acknowledged.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tourman.2020.104161.

References

Battour, M. (2018). Muslim travel behavior in Halal tourism. In L. Butowski (Ed.), *Mobilities, tourism and travel behavior: Contexts and boundaries* (pp. 3–16). Rijeka, Croatia: InTech.

Becken, S., & Mackey, B. (2017). What role for offsetting aviation greenhouse gas emissions in a deep-cut carbon world? *Journal of Air Transport Management, 63*, 71–83. https://doi.org/10.1016/j.jairtraman.2017.05.009.

Becken, S., & Shuker, J. (2019). A framework to help destinations manage carbon risk from aviation emissions. *Tourism Management, 71*, 294–304.

Capocchi, V., Pierotti, A., & Capocchi. (2019). Overtourism: A literature review to assess implications and future perspectives. *Sustainability, 11*(12). https://doi.org/10.3390/su11123303.

Colapinto, C., Jayaraman, R., & Marsiglio, S. (2017). Multi-criteria decision analysis with goal programming in engineering, management and social sciences: A state-of-the art review. *Annals of Operations Research, 251*, 7–40.

Daniel, S., Hall, C. M., & Gossling, S. (2012). *Tourism and climate change: Impacts, adaptation and mitigation*. Taylor and Francis.

Farmaki, A. (2017). The tourism and peace nexus. *Tourism Management, 59*, 528–540.

Fullagar, S., Markwell, K., & Wilson, E. (2012). *Slow tourism: Experiences and mobilities* (Vol. 54). Bristol, UK: Channel View Publications.

Geels, F. W., McMeekin, A., Mylan, J., & Southerton, D. (2015). A critical appraisal of Sustainable Consumption and Production research: The reformist, revolutionary and reconfiguration positions. *Global Environmental Change, 34*, 1–12.

Gössling, S., Hall, C. M., Peeters, P., & Scott, D. (2010). The future of tourism: Can tourism growth and climate policy be reconciled? A mitigation perspective. *Tourism Recreation Research, 35*(2), 119–130.

Gössling, S., & Higham, J. (2020). The low carbon imperative: Destination management under urgent climate change. *Journal of Travel Research* (In-press).

Gössling, S., Ring, A., Dwyer, L., Andersson, A.-C., & Hall, C. M. (2016). Optimizing or maximizing growth? A challenge for sustainable tourism. *Journal of Sustainable Tourism, 24*(4), 527–548.

Gössling, S., Scott, D., & Hall, C. M. (2015). Inter-market variability in CO2 emission-intensities in tourism: Implications for destination marketing and carbon management. *Tourism Management, 46*, 203–212.

Gössling, S., Scott, D., & Hall, C. M. (2020). Pandemics, tourism and global change: A rapid assessment of COVID-19. *Journal of Sustainable Tourism*, 1–20. https://doi.org/10.1080/09669582.2020.1758708.

Gössling, S., Scott, D., Hall, C. M., Ceron, J.-P., & Dubois, G. (2012). Consumer behaviour and demand response of tourists to climate change. *Annals of Tourism Research, 39*(1), 36–58.
Gurung, D. B., & Seeland, K. (2008). Ecotourism in Bhutan. *Annals of Tourism Research, 35*(2), 489–508.
Hall, C. M. (2009). Degrowing tourism: Décroissance, sustainable consumption and steady-state tourism. *Anatolia, 20*(1), 46–61.
Hall, C. M. (2014). *Tourism and social marketing*. Abingdon: Routledge.
Higgins-Desbiolles, F., Carnicelli, S., Krolikowski, C., Wijesinghe, G., & Boluk, K. (2019). Degrowing tourism: Rethinking tourism. *Journal of Sustainable Tourism, 27*(12), 1926–1944.
Higham, J., Cohen, S. A., Cavaliere, C. T., Reis, A., & Finkler, W. (2016). Climate change, tourist air travel and radical emissions reduction. *Journal of Cleaner Production, 111*, 336–347.
Howitt, O. J. A., Revol, V. G. N., Smith, I. J., & Rodger, C. J. (2010). Carbon emissions from international cruise ship passengers' travel to and from New Zealand. *Energy Policy, 38*(5), 2552–2560.
ICAO. (2018). API data service. Retrieved from https://www.icao.int/safety/iStars/Pages/API-Data-Service.aspx.
Jayaraman, R., Colapinto, C., Torre, D. L., & Malik, T. (2015). Multi-criteria model for sustainable development using goal programming applied to the United Arab Emirates. *Energy Policy, 87*, 447–454.
Kim, S., Prideaux, B., & Timothy, D. (2016). Factors affecting bilateral Chinese and Japanese travel. *Annals of Tourism Research, 61*, 80–95.
Kulendran, N., & Wilson, K. (2000). Is there a relationship between international trade and international travel? *Applied Economics, 32*(8), 1001–1009. https://doi.org/10.1080/000368400322057.
Lenzen, M., Sun, Y.-Y., Faturay, F., Ting, Y.-P., Geschke, A., & Malik, A. (2018). The carbon footprint of global tourism. *Nature Climate Change, 8*(6), 522–528.
Lew, A. A. (2013). Scale, change and resilience in community tourism planning. *Tourism Geographies, 16*(1), 14–22.
Lim, C. C., & Cooper, C. (2009). Beyond sustainability: Optimising island tourism development. *International Journal of Tourism Research, 11*(1), 89–103.
Linares, P., & Romero, C. (2017). A multiple criteria decision making approach for electricity planning in Spain: Economic versus environmental objectives. *Journal of the Operational Research Society, 51*(6), 736–743.
Lundie, S., Dwyer, L., & Forsyth, P. (2007). Environmental-economic measures of tourism yield. *Journal of Sustainable Tourism, 15*(5), 503–519.
Mai, T., & Smith, C. (2018). Scenario-based planning for tourism development using system dynamic modelling: A case study of Cat Ba island, Vietnam. *Tourism Management, 68*, 336–354.
McElroy, J. L., & Albuquerque, K.d. (2002). Problems for managing sustainable tourism in small islands. In GDJ, & AY (Eds.), *Island tourism and sustainable development: Caribbean, Pacific, and Mediterranean experiences* (pp. 15–31). Westport, CT: Praeger.
Miller, G., Rathouse, K., Scarles, C., Holmes, K., & Tribe, J. (2010). Public understanding of sustainable tourism. *Annals of Tourism Research, 37*(3), 627–645.
Moeller, T., Dolnicar, S., & Leisch, F. (2011). The sustainability–profitability trade-off in tourism: Can it be overcome? *Journal of Sustainable Tourism, 19*(2), 155–169.
Morrison, A. M. (2013). *Marketing and managing tourism destinations*. Oxon, UK: Routledge.
Nyaupane, G. P., & Timothy, D. J. (2010). Power, regionalism and tourism policy in Bhutan. *Annals of Tourism Research, 37*(4), 969–988.
Oklevik, O., Gössling, S., Hall, C. M., Steen Jacobsen, J. K., Grøtte, I. P., & McCabe, S. (2019). Overtourism, optimisation, and destination performance indicators: A case study of activities in Fjord Norway. *Journal of Sustainable Tourism, 27*(12), 1804–1824.
Peeters, P., Higham, J., Kutzner, D., Cohen, S., & Gössling, S. (2016). Are technology myths stalling aviation climate policy? *Transportation Research Part D: Transport and Environment, 44*, 30–42.
Prideaux, B. (2005). Factors affecting bilateral tourism flows. *Annals of Tourism Research, 32*(3), 780–801.
Rowen, I. (2014). Tourism as a territorial strategy: The case of China and Taiwan. *Annals of Tourism Research, 46*, 62–74.
Rutty, M., Scott, D., Johnson, P., Pons, M., Steiger, R., & Vilella, M. (2017). Using ski industry response to climatic variability to assess climate change risk: An analogue study in Eastern Canada. *Tourism Management, 58*, 196–204.
Sensagir, I., Eijgelaar, E., Peeters, P., de Bruijn, K., & Dirven, R. (2019). Travelling large in 2017: The carbon footprint of Dutch holidaymakers in 2017 and the development since 2002. Retrieved from Breda, the Neitherland: https://pure.buas.nl/en/publications/ab05819f-9947-4eb5-81ce-9ba8d6db7c8e.
Sharp, H., Grundius, J., & Heinonen, J. (2016). Carbon footprint of inbound tourism to Iceland: A consumption-based life-cycle assessment including direct and indirect emissions. *Sustainability, 8*(11), 1147.
Sun, Y.-Y. (2014). A framework to account for the tourism carbon footprint at island destinations. *Tourism Management, 45*, 16–27.
Sun, Y.-Y. (2016). Decomposition of tourism greenhouse gas emissions: Revealing the dynamics between tourism economic growth, technological efficiency, and carbon emissions. *Tourism Management, 55*, 326–336. https://doi.org/10.1016/j.tourman.2016.02.014.
Sun, Y.-Y. (2019). Global value chains and national tourism carbon competitiveness. *Journal of Travel Research, 58*(5), 808–823.
Sun, Y.-Y., & Lin, P.-C. (2019). How far will we travel? A global distance pattern of international travel from both demand and supply perspectives. *Tourism Economics, 25*(8), 1200–1223.
Sun, Y.-Y., & Pratt, S. (2014). The economic, carbon emission, and water impacts of Chinese visitors to Taiwan: Eco-efficiency and impact evaluation. *Journal of Travel Research, 53*(6), 733–746.
Tourism Research Australia. (2019). *Tourism forecasts 2019* (Retrieved from Canberra, Australia).
UNEP & WTO. (2012). *Tourism in the green economy background report* (Retrieved from Madrid, Spain).
UNWTO. (2011). *Tourism towards 2030/global overview*. Madrid, Spain: World Tourism Organization.
UNWTO. (2015). *Tourism and the sustainable development goals*. Madrid, Spain: World Tourism Organization.
Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. (2006). A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society, 11*(1).
World Tourism Organization. (2004). *Indicators of sustainable development for tourism destinations: A guidebook*. Madrid, Spain: World Tourism Organization.
WTO-UNEP-WMO. (2008). *Climate change and tourism: Responding to global challenges*. Spain: World Tourism Organization.
WTTC. (2019). *Benchmarking travel & tourism*.
Zhang, J. (2016). Weighing and realizing the environmental, economic and social goals of tourism development using an analytic network process-goal programming approach. *Journal of Cleaner Production, 127*, 262–273.

Ya-Yen Sun is a senior lecturer at the University of Queensland, Australia. Her interest is in applying the macro-level modelling tools to understand tourism economic impacts and tourism environmental impacts.

Pei-Chun Lin is a Professor at the National Cheng Kung University, Taiwan, and is Executive Editor for Asia Pacific Management Review. Her primary research interests are in supply chain optimization and logistics information management.

James Higham is a Professor at the University of Otago, New Zealand. James has two current streams of research interest, including 'climate change and long-haul aviation' and 'the interplay of sport and tourism'.