Tourism Management 95 (2023) 104681

Contents lists available at ScienceDirect

Tourism Management

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

A review of tourism and climate change mitigation: The scales, scopes, stakeholders and strategies of carbon management

Stefan Gössling [a,e,*], Martin Balas [b], Marius Mayer [c,f], Ya-Yen Sun [d]

[a] Western Norway Research Institute, PO Box 163, 6851, Sogndal, Norway
[b] Biosphere Reserves Institute (BRI), University for Sustainable Development Eberswalde, Eberswalde, Schicklerstraße 3, 16225, Eberswalde, Germany
[c] Munich University of Applied Sciences, Faculty of Tourism, Schachenmeierstraße 35, 80636, München, Germany
[d] UQ Business School, The University of Queensland, Brisbane, Qld, 4072, Australia
[e] Linnaeus University, School of Business and Economics, Universitetsplatsen 2, 39182, Kalmar, Sweden
[f] University of Innsbruck, Department of Strategic Management, Marketing and Tourism, SME & Tourism, Universitätsstraße 15, 6020, Innsbruck, Austria

ARTICLE INFO

Keywords:
Climate change
Decarbonization
Destination management
Net-zero emissions
I/O analysis
Science-based targets

ABSTRACT

Tourism needs to reduce emissions in line with other economic sectors, if the international community's objective of staying global warming at 1.5°-2.0 °C is to be achieved. This will require the industry to half emissions to 2030, and to reach net-zero by mid-century. Mitigation requires consideration of four dimensions, the Scales, Scopes, Stakeholders and Strategies of carbon management. The paper provides a systematic review of these dimensions and their interrelationships, with a focus on emission inventory comprehensiveness; allocation principles at different scales; clearly defined responsibilities for decarbonization; and the identification of significant mitigation strategies. The paper concludes that without mitigation efforts, tourism will deplete 40% of the world's remaining carbon budget to 1.5 °C. Yet, the most powerful decarbonization measures face major corporate, political and technical barriers. Without worldwide policy efforts at the national scale to manage the sector's emissions, tourism will turn into one of the major drivers of climate change.

1. Introduction

The world has agreed to stay global warming at 1.5° to 2 °C compared to pre-industrial levels, for which it will be necessary to reduce emissions of greenhouse gases to net-zero by mid-century (IPCC, 2022a; UNFCCC, 2018). As a result, there is a pressing need to identify strategies that can significantly reduce emissions throughout the world economy. Tourism has considerable relevance for achieving this goal, as it includes various vital emission subsectors such as aviation, and is estimated to have been responsible for 8% of global CO_2-equivalent emissions in 2013 (Lenzen et al., 2018). Tourism is also a growth sector, further emphasizing the importance of mitigation (Gössling & Peeters, 2015), specifically since a COVID-19 rebound is evident and future high growth rates are expected (ICAO, 2020; UNWTO, 2022). Carbon management, including CO_2 as well as other greenhouse gases, is thus a key management challenge for the sector (Gössling, 2011).

This paper reviews the literature on climate change mitigation. To this end, an analysis of the situation is followed by the introduction of the S4C model of carbon management that considers four key dimensions of decarbonization: Scale, Scope, Stakeholder and Strategy. Any science-based decarbonization trajectory relies on the measurement of a range of greenhouse gases along the supply chain (scope), including global, national, subnational and firm perspectives (scale). Questions of transparency and accountability need to be resolved to determine responsibilities for mitigation (stakeholder). Measures to significantly reduce emissions (strategy) are identified. Based on the S4C model, recommendations are then made to advance net-zero goals in tourism.

1.1. Global climate stabilization goals and tourism

The IPCC (2022a) reports that global net anthropogenic greenhouse gas emissions amounted to 59 ± 6.6 $GtCO_2$-equivalent in 2019, 54% more than in 1990. There is consequently an acceleration in emissions that adds to the historical built-up of CO_2 in the atmosphere. The IPCC (2022a) concludes that historic emissions of CO_2 (1850–2019) have increased global temperatures to two thirds of 2 °C (67% probability), with 2 °C being defined as the upper limit for acceptable warming, and a desirable 1.5 °C limit. This has been agreed on by the international

* Corresponding author. Western Norway Research Institute, PO Box 163, 6851, Sogndal, Norway.
E-mail address: sgo@vestforsk.no (S. Gössling).

https://doi.org/10.1016/j.tourman.2022.104681
Received 26 July 2022; Received in revised form 18 October 2022; Accepted 19 October 2022
Available online 10 November 2022

community in the Paris Agreement (UNFCCC, 2018). Staying global warming at this level implies that a total amount of 890 $GtCO_2$ can still be emitted before the critical temperature threshold of 2 °C will be exceeded. The amount represents the remaining carbon budget, within a range of 640–1160 Gt CO_2 (67% probability to 2 °C; IPCC, 2022a). To stay within the more desirable limit of 1.5 °C, a carbon budget of 510 $GtCO_2$ remains before this objective is no longer achievable with reasonable likelihood (medium estimate, >50% probability; IPCC, 2022a).

The COVID-19 pandemic has led to a short-term decline in emissions (Le Quéré et al., 2021; Friedlingstein et al., 2022). At the time of writing in July 2022, a rebound in many economic sectors including tourism is evident, though the Ukraine war has disrupted global fuel and commodity chains. This has caused significant inflation and fears of recession (IMFBlog, 2022), and a rise in fuel costs (Trading Economics, 2022). However, there is currently limited evidence that global emissions of greenhouse gases decline in significant ways (Eurostat, 2022).

Continued growth in emissions is problematic in any economic sector, as steep cuts are needed in the immediate future to avoid depleting the remaining carbon budget (IPCC, 2022a). To stay within 1.5 °C will "require global greenhouse gas emissions to peak before 2025 at the latest, and be reduced by 43% by 2030" (IPCC, 2022b, no page). The European Union is currently the only region that has adopted science-based decarbonization targets, with pledges to cut emissions by 55% by 2030, compared to 1990 levels, and "climate neutrality" by mid-century (European Commission, 2022). However, some important economic sectors, such as international aviation or shipping, are not fully covered under this policy (Joung, Kang, Lee, & Ahn, 2020; Lyle, 2018). China, Russia and other significant countries are not committed to required emission reductions: For example, China seeks to "peak" in emissions "before 2030", while the Russian Federation aims to reduce emissions by 30%, accounting for the "maximum absorptive capacity of forests" and subject to "balanced social economic development" (UNFCCC, 2022; quotes from national submissions).

Tourism is a significant contributor to emissions of greenhouse gases, for which various assessments have been presented over the years (Table 1). Early global estimates concluded that transportation, accommodation and activities are responsible for about 5% of global direct energy use and emissions (Gössling, 2002; UNWTO, UNEP & WMO, 2008). A more recent analysis by Lenzen et al. (2018), including more sub-sectors, found that tourism is responsible for 8% of warming from CO_2 and other long-lived greenhouse gases (methane, nitrous oxide, hydrofluorocarbons, chlorofluorocarbon, sulfur hexafluoride, nitrogen trifluoride) in the year 2013, an estimate that includes indirect emissions from suppliers. This is equivalent to between 3.9 and 4.5 Gt CO_2-equivalent, and does not account for aviation's additional warming at flight altitude[1] Adding aviation's non-CO_2 contribution to climate change on the basis of an effective radiative forcing weighting increases tourism's contribution to global warming to 10% in 2013. No recent scientific assessments of the magnitude of emissions from tourism are available, though WTTC-UNEP-UNFCCC's (2021: p. 13) "net-zero" report suggests that tourism may have emitted some 5.4 $GtCO_2$-equivalent in 2019[2] (not including aviation non-CO_2 warming). As shown in Table 1, transport is by far the most important contributor to emissions, specifically road and air transport.

Aviation is the most important tourism subsector in terms of growth in emissions. Between 1960 and 2018, the sector grew by a factor of 6.8 to an estimated total of 1034 Mt CO_2 (Lee et al., 2021). An estimated 75% of this fall on commercial passenger transport, including a 4% share of private aviation (Gössling & Humpe, 2020). Further growth is expected in the sector's post-COVID rebound and longer-term developments: Industry expects that aviation will double or even triple to 2050 (ICAO, 2020). Apart from its central role in emission growth, aviation is also of relevance in the context of responsibilities for mitigation, as only a small share of its emissions is covered by existing legal frameworks (Gössling & Humpe, 2020).

Tourism is also poised to grow as an overall system. Its resource and emission-growth dynamics have been illustrated by UNWTO, UNEP & WMO, 2008, Gössling and Peeters (2015) and Lenzen et al. (2018). National studies pointing to continued emission growth in tourism include China (Meng, Xu, Hu, Zhou, & Wang, 2016), New Zealand (Sun & Higham, 2021), Portugal (Robaina-Alves, Moutinho, & Costa, 2016), Sweden (Gössling & Hall, 2008), Spain (Cadarso, Gómez, López, Tobarra, & Zafrilla, 2015), Taiwan (Sun, 2016), or Norway (Sun, Gössling, & Zhou, 2022). Continued growth is also expected by industry (WTTC-UNEP-UNFCCC, 2021; see also Table 2), with the UNWTO (2022) acknowledging that even though there is an 'ambition' to *half* emissions from tourism by 2030, the likely scenario is a 25% increase.

The paradox of continued growth expectations and simultaneous hopes to see very significant emission reductions is evident in all industry documents (Table 2). For instance, ICAO (2016b), IATA (2021, 2022), and ATAG (2021) expect aviation to at least triple in its fuel use, and double in its emissions in the period 2020–2050. In terms of measures to reduce emissions, it is emphasized that air travel will become more efficient and that a share of emissions will be "abated". Currently not existing technologies are proposed as future solutions, including significantly more costly sustainable aviation fuels. Offsetting remains a major part of its strategy, with a focus on afforestation. While a role of government is acknowledged, carbon taxes are rejected by the sector. These contradictions mirror a lack of viability and reliability (Gössling & Lyle, 2021; Grewe et al., 2021; Guix et al., 2021; Peeters, Higham, Kutzner, Cohen, & Gössling, 2016). As Table 2 indicates, this is equally true for tourism more generally.

1.2. Mitigation challenges

Fig. 1 illustrates the mitigation challenge for tourism, depicting expected emission growth (red dotted line) in comparison to the "ambition scenario" presented by WTTC, UNEP & UNFCCC (2021; green line), and a trajectory towards net-zero emissions aligned with a 1.5 °C objective in reference to IPCC (2022b, blue dotted line). The figure reveals two important insights: First, there is a discrepancy between sector's expected growth in emissions, the less likely "ambition scenario", and necessary emission reductions to stay within 1.5 °C. As the preceding section has revealed, it is unclear how the gap between these trajectories will be closed. Expected annual growth rates of 3% (aviation) and 5% (all other tourism-related industries) (WTTC-UNEP-UNFCCC, 2021) are in stark contrast to a necessary reduction by 5% per year from current levels (linear integration to net-zero). To align growth expectations and decarbonization needs requires decarbonization at a rate of 8%–10% per year. Such rates are impossible to achieve. For comparison: In 2020, the first year of the COVID-pandemic, global emissions declined by an estimated 6% (Friedlingstein et al., 2022). Notably, aviation almost completely suspended its operations, illustrating the systemic implications of very steep mitigation trajectories.

The impossibility of accommodating further growth and emission reductions aligned with scientific targets was already outlined in the UNWTO, UNEP & WMO, 2008 report "Climate Change and Tourism – Responding to Global Challenges". Even in the most ambitious mitigation scenario, the sector's emissions were projected to fall by just 16% (2005–2035) if growth continued. National studies confirm this. For example, research for Norway has shown that under a continued tourism

[1] Aviation is not easily compared to other emission sub-sectors, because of this sub-sector's contribution to non-CO_2 emissions, i.e. contrail cirrus and cirrus cloudiness, as well as nitrous oxide emissions. At flight altitude, these make additional, though short-lived contributions to warming. Integrated as effective radiative forcing, non-CO_2 warming renders aviation's contribution to global warming three times larger than from CO_2 alone (Lee et al., 2021).

[2] Own calculation based on a 17% share of emissions from aviation (915 Mt CO_2) detailed in the report.

Table 1
Global tourism emissions (Mt and percentages).

Source	Gössling (2002)	WTO-UNEP-WMO (2008)	Peeters and Dubois (2010)	UNWTO & ITF (2019)	WTTC-UNEP-UNFCCC (2021)	Lenzen et al. (2018)
Reference year	2001	2005	2005	2016	2019	2013
Subsectors included						
Agriculture						353 (8%)
Mining						121 (3%)
Food						194 (4%)
Goods						534 (12%)
Utilities						0 (0%)
Construction						139 (3%)
Trade						0.2 (0%)
Hospitality unspecified						58 (1%)
Accommodation	81 (6%)	274 (21%)	275 (24%)		324 (26%)	282 (6%)
Food & beverage serving						227 (5%)
Transport unspecified		45 (3%)	38 (3%)	76 (5%)	27 (2%)	871 (20%)
Road transport	680 (49%)	420 (32%)	305 (26%)	671 (46%)		602 (14%)
Rail transport	108 (8%)			20 (1%)		55 (1%)
Air transport	467 (33%)	515 (40%)	504 (43%)	679 (47%)	915 (72%)	547 (12%)
Water transport	8 (1%)					98 (2%)
Services	55 (4%)	48 (4%)	48 (4%)			350 (8%)
TOTAL	1399	1303	1170	1446	1266	4430
Contribution to global CO_2-equivalent emissions	5.3%	2.8%	2.5%	2.9%	2.5%	8.0%
Including air transport with a factor 3[a]						
Air transport (Mt CO_2-equivalent)	1401	1545	1512	2037	2745	1641
TOTAL	2333	2333	2178	2804	3096	5524
Percentage of air transport emissions	60%	66%	69%	73%	89%	30%
Sector's contribution to global CO_2-equivalent emissions (%)	8.8%	5.0%	4.7%	5.7%	6.2%	10.0%
Scopes included						
Visitor expenditure						
Transport	v	v	v	v	v	v
Accommodation	v	v	v		v	v
Activities	v	v	v			v
Food						v
Shopping						v
Emissions						
Direct effect (scope 1 + scope 2)	v	v	v	v	v	v
Indirect effect (scope 3)						v

[a] Calculation considers aviation's effective radiative forcing at flight altitude at three times the warming of CO_2.

growth scenario, country-wide decarbonization rates would have to be 30 times higher than observed rates to approach net-zero by 2050 (Sun, Gössling, & Zhou, 2022). Decarbonization challenges for tourism have now been repeatedly outlined (Becken, 2019; Becken, Whittlesea, Loehr, & Scott, 2020; Gössling, Humpe, Fichert, & Creutzig, 2021; Scott & Gössling, 2022; Scott, Peeters, & Gössling, 2010), with the central conclusion that tourism will not achieve carbon-neutrality under continued growth scenarios.

Fig. 1 highlights a second insight of importance, i.e. the difference between immediate (blue dotted line) and postponed mitigation efforts, as in WTTC-UNEP-UNFCCC's (2021) "ambition scenario" (green line). Following the decarbonization trajectory of the "ambition scenario" will mean that the carbon budget will be depleted much faster than in the rapid reduction scenario represented by the blue dotted line. Even greater is the gap between a business-*as*-usual and a 1.5 °C reduction scenario. In terms of absolute emissions, the difference between the 'worst' (red line) and the desired (blue line) trajectory may amount to several hundred Gt CO_2 between 2022 and 2050.

At continued emission rates of about 5 $GtCO_2$-equivalent per year (Table 1), tourism is likely to become a major factor in the depletion of the remaining carbon budget. If growth cancels out efficiency gains, the sector will emit 200 $GtCO_2$-equivalent over the period 2022–2050. This will deplete 22.5% of the remaining carbon budget to 2 °C, and 40% of the budget to 1.5 °C. The estimate underlines the need for tourism to engage in immediate decarbonization efforts, and to critically assess the implications of continued growth.

2. Methodology

As the preceding sections suggest, decarbonization involves four interrelated and interdependent dimensions, here described as the four S of carbon management: Scale, Scope, Stakeholder, and Strategy (Fig. 2).

- "Scale" refers to the level at which emissions can be measured or mitigation strategies be devised and implemented, i.e. the global, national, destination (sub-national) or business-level.
- "Scope" is the most complex dimension, as it defines the emissions to be included or excluded. There are four elements of Scope: (1) the subsectors to be included, such as accommodation, transport, activities, food or shopping; (2) the visitor segments to be considered with respect to domestic tourism, inbound tourism and outbound tourism (allocation), (3) the extent of the supply chain that is evaluated, for instance in terms of scopes 1–3 at the business level, or direct and indirect emissions at the destination level, and (4) the type of emissions that are included: CO_2, other long-lived greenhouse gases, and the non-CO_2 warming from air transport. Ultimately, the decision to include certain components is guided by allocation principles and data availability.
- "Stakeholder" defines accountability, i.e. the question as to who is responsible for reducing emissions. Without clearly assigned responsibilities, progress on decarbonization is unlikely. Responsibilities may be assigned to multiple stakeholders, as any country's pledges to reduce emissions have to be passed on to businesses, as well as consumers. Policymakers are thus relevant at different scales, as they implement legal frameworks setting common

Table 2
Industry perspectives on growth and decarbonization.

Sub-sector	Growth & decarbonization	Measures proposed	Responsibility
Aviation: ICAO (2016b)	Fuel consumption growth by a factor 2.8 to 3.9 (2010–40), and a factor 4–6 (2010–50). "Carbon-neutral growth" means continued emissions of 1 $GtCO_2$ per year	• Advancements in aircraft technology • Operational improvements • Sustainable alternative fuels • Carbon offsets No absolute target	Unclear.
Aviation: IATA (2021)	Emissions double between 2020 and 2050 21.2 Gt CO_2 "abated" between 2020 and 2050; 90% of mitigation through offsetting (2020–2030) 50% of mitigation through offsetting (2030–2040)	• Sustainable aviation fuels: 65% • Offsetting/carbon capture: 19% • New technologies: 13% • Infrastructure/operations improved: 3% Opposes carbon taxes.	Airlines, governments (regulations, frameworks, incentives), aircraft and engine manufacturers, fuel-producing companies, airports, air navigation services providers
Aviation: ATAG (2021)	Growth in emissions to 2 Gt CO_2 in 2050. Compound annual growth rate between 2.3 and 3.3% 2019–2050 Net-zero in 2050	• New technologies lead to 12–34% emission reduction in 2050 • Infrastructure/operations: 7–10% • Sust. aviation fuels: 53–71% • Out-of-sector market-based measures: 6–8%	Aviation sector, governments/policy makers, energy industry, finance community, research institutions
Cruises: Oxford Economics/CLIA (2021)	Net-zero in 2050 CO_2 emissions reduced −40% in 2030 (compared to 2008)	• Technological improvements • More operational efficiency • Shore-side power • Alternative/zero-carbon fuels	Cruising industry, governments/regulators, fuel processing industry
Hotels: Sustainable Hospitality Alliance (2017)	Further strong growth expected. Emissions reductions of 89.5% (2010–50) necessary (to stay within 2 °C) 66% emission reduction by 2030, half of which is achieved by hotels.	• Increasing efficiency of equipment and operations • Renewable energy use • 'Electrification' • Restructuring and innovation of operations	Hotel owners cooperate with stakeholders in the value chain and destination, involve guests
Tourism (all sub-sectors): WTTC-UNEP-UNFCCC (2021)	Compound annual growth rate: 3% for aviation; 5% for other industries (2023 onwards). All businesses should aim to reach net zero "as soon as they can".	Accommodation: • Energy efficiency improvements • Operational improvements • Sustainable procurement and sustainable sourcing • Transition to low carbon energy • Reducing waste Tour Operators • Trip footprint • Office energy & waste • Other business travel Aviation • Improvements to existing aircraft technology • New aircraft technology • Operational efficiency • Sustainable Aviation Fuels Cruises • Operational efficiency • Lower carbon fuels • Efficient technologies • New technologies OTAs & TAs • Lower carbon energy sources • More sustainable business travel • Office improvements • Procurement • Consumer and partner education	Unclear. Highlights the need for collaboration in and beyond value chains; important roles for governments/public sector.

Source: ATAG, 2021; IATA, 2021; Oxford Economics/CLIA, 2021; Sustainable Hospitality Alliance, 2017.

rules for mitigation, which may include national, sub-national (destination), or business levels.

- "Strategy" is concerned with the mechanisms of emission reductions in significant ways, through the principles of Avoid, Reduce, Substitute and Remove as originally devised by IEMA in 2009 (IEMA, 2022).

The review and analysis of the literature in this paper follows the S4C model. To advance a state-of-the-art understanding of these dimensions, a combination of a thematic and systematic literature review (Bryman, 2016) was conducted. This includes a qualitative/quantitative view on Scale and Scope, and a qualitative evaluation of Stakeholder and Strategy. This approach is favored because a considerable number of papers have delved into the complexities of Scope, allowing for a

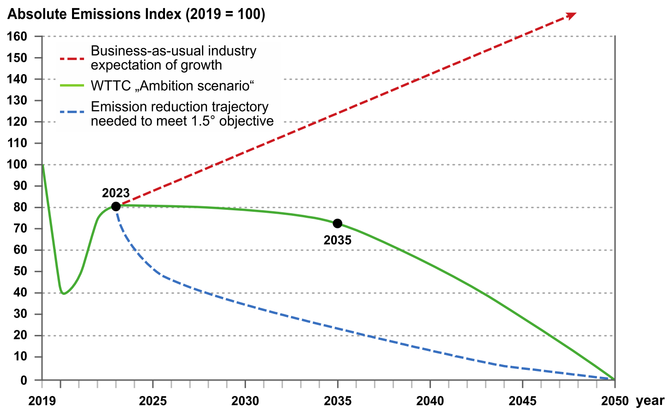

Fig. 1. Growth in tourism and global carbon budget.
Source: based on IPCC (2022b), WTTC-UNEP-UNFCCC (2021).

Fig. 2. The four S of carbon management.

quantitative analysis of this aspect. Emphasis is also put on this issue because mitigation relies on the understanding of where emissions occur.

Relevant papers were identified through two processes. First, the curated database on tourism and climate change (Scott & Gössling, 2022) identifies a total of n = 155 papers focused on greenhouse gas emissions, mitigation and carbon management in tourism, published between 1986 and 2020. This database underlies the qualitative part of the analysis, updated based on online searches for the period 2021–2022 (using Google Scholar and EBSCO). In a parallel process, a specific search for papers on emission assessment frameworks was conducted using the Web of Science, including peer-reviewed papers published over the past two decades (2002–2022). To identify papers, "tourism" was searched in combination with 'carbon', 'climate change', 'mitigation', 'emissions', and 'greenhouse gas'. This yielded a total of n = 117 studies in the initial search, which were screened for relevance in regard to assessment frameworks. A total of n = 58 papers were removed as irrelevant, and another n = 7 published in languages other than English. The remaining n = 51 papers were checked for omissions by a screening of their reference lists, which in an iterative search led to the identification of another n = 11 papers of relevance. Overall, n = 62 papers were considered relevant for the quantitative evaluation.

The qualitative evaluation of the literature focuses on an account of developments in the field over the past 25 years. Relevant knowledge is again summarized in relation to the S4C model. In regard to strategy, the identification of the most significant opportunities to reduce emissions is not straight forward. While measures for decarbonization have been presented by industry (ATAG, 2021; IATA, 2021; ICAO, 2016b; Oxford Economics/CLIA, 2021; McKinsey, 2022; Sustainable Hospitality Alliance, 2017; WTTC-UNEP-UNFCCC, 2021), reports lack validity and reliability, as illustrated by ICAO's CORSIA scheme (Gössling & Lyle, 2021).

The assessment of the five largest emissions sub-sectors thus raises the question of the significance of measures to achieve emission reductions, specifically since some of the most relevant measures appear to be politically 'taboo' (Gössling & Cohen, 2014). For example, air travel in private aircraft or premium classes causes multiple times the emissions of travel in economy class. Banning these most energy-intense forms of travel will only affect the convenience of a small share of air travellers, and not affect the transport function of aviation. Even though some discussion of private air transport has emerged recently (The Wall Street Journal, 2022), it is less likely that policymakers will adopt such measures globally. Complexities such as these are outlined, and the measures proposed for the subsectors consequently represent opportunities that also illustrate barriers to decarbonization. Mitigation options are derived from the literature, compared, and evaluated regarding potentials. This follows an expert-based approach that is necessarily subjective and indicative.

Quantitative data is generated and evaluated only in the context of 'scale' and 'scope'. This process was guided by an evaluation scheme, focused on relevant categories related to the S4C model, i.e. spatial focus, purpose, assessment method, allocation principle, visitor segment, subsectors, comprehensiveness, consideration of greenhouse gases, and assessment standard. To identify these, variables were coded as multinomial or binary categories or open text fields; the latter were then restructured into categories (Nowell, Norris, White, & Moules, 2017). The viability of this coding scheme was pre-tested on ten randomly selected publications before it was applied to all publications. A regular cross-check of results secured the consistency of the review-process.

A notable limitation of this paper is the exclusion of national Environmental Kuznets Curve investigations, which seek to determine whether the development of tourism increases or decreases the carbon intensity of an economy, and whether this has (in the past) or will (in the future) increase national emissions; often in scenarios where other economic sectors decline in importance. This body of research alone is significant, with one recent meta-study identifying n = 81 peer-reviewed studies published between 2013 and 2021 (Sun, Gössling, & Zhou, 2022). However, as findings of the meta-review suggest a low consensus on relationships, while studies fail to account for emissions from international air travel and global trade in products needed for tourism, a main conclusion is that this line of research needs methodological improvement to make valid contributions to the understanding of emission developments.

3. Results

3.1. Scale

Emissions from tourism have been investigated at scales ranging from individual firms to destinations (communities, cities, counties, states), national tourism systems, and as a share of global contributions to climate change. A general observation is that these studies can be distinguished by purpose, which may include the understanding of emissions from tourism as an economic sector, specific subsectors (accommodation, etc.), tourism products, markets, trips, or travel motivation (Becken, 2002; Becken, Frampton, & Simmons, 2001; Becken & Simmons, 2002; Eijgelaar, Thaper, & Peeters, 2010; Falk & Hagsten, 2021; Gössling, Ring, Dwyer, Andersson, & Hall, 2016; Whittlesea &

Owen, 2012). Assessments have included financial aspects, such as revenue, in relation to emissions (Gössling et al., 2005; Sun, Lin, & Higham, 2020) to gain longitudinal perspectives on emission growth and for comparison with other economic sectors (e.g. Sun, Lin, & Higham, 2020). As initially outlined for the global level, national studies are often not comparable, as they rely on different assessment frameworks (Gössling, 2013).

3.2. Scope

Tourism's contribution to climate change was overlooked for long periods of time, as the thinking was dominated by notions of tourism as a 'white', pollution-free industry (Kasim, 2006), in which the sector was only subsequently seen as having relevance for climate change. Since the early 2000s, studies have sought to develop frameworks for calculations of greenhouse gas emissions from tourism systems, and usually with an applied angle geared towards reductions. National, subsector-specific, or trip-specific assessments began to emerge in the 2000s (Becken, 2002; Becken et al., 2001; Becken & Patterson, 2006; Becken & Simmons, 2002; Patterson & McDonald, 2004). These relied on bottom-up or top-down methods to determine emissions. Bottom-up assessments aggregate emissions from all elements of travel consumption by tracking units of tourism service consumption (for instance on the basis of guest nights) and multiplying these by their energy use and emissions (emissions per guest night). Top-down methods use existing data, for instance for bunker fuels, to derive estimates of emissions. This omits 'indirect' emissions (Cadarso et al., 2015; Dwyer, Forsyth, Spurr, & Hoque, 2010; Filimonau, Dickinson, Robbins, & Reddy, 2013; Filimonau, Dickinson, Robbins, & Reddy, 2011). Bottom-up approaches are thus suitable for smaller regions at the sub-national level, individual tourism subsectors, or trips. At this level of analysis, their potential advantage is the provision of detailed emission profiles for specific travel activities with more limited data requirements. For firms, more detailed scopes of analysis were formally introduced in 2001, to provide accounting and reporting standards. These refer to direct emissions that are owned or controlled by a company (scope 1), indirect emissions from the generation of purchased electricity, steam, heat, or cooling (scope 2), as well as emissions caused by activities of a company, but not sourced or controlled by it (scope 3), for instance emissions from suppliers (Greenhouse Gas Protocol, 2022).

With the development of environmental accounting methods, comprehensive top-down assessment methods were introduced. These trace visitor expenditure throughout the economy and identify the corresponding impact (emissions) along the chains of production and distribution. Within this line of research, both environmentally extended input-output (EEIO) model and the more dynamic Computable General Equilibrium (CGE) model provide tools to assess the complete scopes of tourism emissions by subsectors, and in standardized territorial grids (such as emissions associated with imports and exports). Based on these models, tourism emissions have been analysed at global (Lenzen et al., 2018) and national level (Table 3), as well as larger subnational territorial levels (mostly level 2 of the international OECD classification; OECD, 2022).

As tourism is an economic activity that involves residents and

Table 3
Carbon inventory principles, national scale.

Principle/ Responsibility	Type of analysis	Description	Includes emissions from				Source
			Domestic tourism	Inbound tourism	Outbound tourism (market)	Outbound tourism (destination)	
Production (polluter allocation)	Kyoto Protocol Framework (KPF)	Emissions from production incurred within the national territory and offshore areas over which the country has jurisdiction	++-	+–	+–	—+	Eggleston, Buendia, Miwa, Ngara, and Tanabe (2006)
	Production-based approach (PBA)	Emissions directly produced by tourism industries, from imports used as inputs in producing goods and services to the country's tourism industry	+++	+++	++-	–	Dwyer et al. (2010)
	Tourism producer responsibility (TPR)	Emissions in an area that are linked to the supply of domestic tourism goods and services	+++	++-	++-	–	Cadarso et al. (2015)
	Production accounting principle (PAP)	Territorial emissions that are directly produced by tourism industries and their suppliers, disregarding where the good is consumed	++-	++-	++-	—+	Sun et al. (2019)
Consumption (beneficiary allocation)	Residence-based accounting (RBA)/ Consumption Accounting Principle (CAP)	Emissions allocated to the residence of tourists (national tourism)	+++	–	+++	++++	Lenzen et al. (2018) Sun et al. (2019)
Destination (recipient allocation)	Expenditure-based approach (EBA)	Emissions from expenditures by non-resident-based and domestic tourists on tourism in the country	+++	+++	+++	–	Dwyer et al. (2010)
	Total Tourism carbon footprint (TCF)	Tourism producer responsibility added with emissions to the target destination	+++	+++	+++	–	Cadarso et al. (2015)
	Destination-based accounting (DBA)	Emissions allocated to the tourism destination	+++	+++	+++	–	Becken and Patterson (2006) Lenzen et al. (2018)
	Tourism Satellite Accounting Principle (TSAP)	Domestic and foreign emissions that are produced to support all travel activities within the geographic territory of an economy	+++	+++	+++	–	Sun et al. (2019)

Pluses/minuses refer to included/excluded under inventory principle: +– domestic consumption; - + - air transport; – + imported goods; — + exports (only relevant in outbound tourism).
Source: adopted from Sun et al., 2019, Sun, Cadarso, & Driml, 2020, expanded.

foreigners travelling to national or international destinations, with expenditures in different locations, and services produced domestically and internationally, it is difficult to define the components to be incorporated in emission inventories at scales below the global. For example, if a tourist arrives in a country, is the country accountable for the visitor's emissions from travel to the country, the return to his home country, both, or none? In the absence of a common standard, Sun, Cadarso, and Driml (2020) propose three main guiding principles for national carbon inventories, which may be production, consumption, or 'destination' guided. These are summarized in Table 3, and may also be applied at the sub-national destination scale, for instance by communities, counties or states with the corresponding data. Production and consumption are common carbon accounting principles at the national and business level (Lenzen, Murray, Sack, & Wiedmann, 2007). The destination principle is specifically relevant given tourism's multi-sectoral character across various spatial scales. Emissions can be considered under the three general principles with the aim of specifying responsibilities, i.e. emissions allocated to producers in a specific destination (polluter allocation), the loci of tourism consumption (consumer or beneficiary allocation), or the territory where tourism activities occur (recipient allocation). The idea is to put the country of production, the country of consumption and the country of residence of travellers into perspective (Sun, Lenzen, & Liu, 2019).

Interrelationships between the three principles are illustrated in Fig. 3, which shows that there are eight emission components linked to domestic, inbound and international tourism. Each component can be interpreted as emissions generated by people from [country of residence] at [country of consumption] for consuming services produced by firms located at [country of production]. For example, cube 1 refers to emissions generated by foreign tourists within the destination for consuming services produced by domestic firms. Based on this system, complex allocation issues in tourism can be resolved, such as allocating responsibilities for international aviation emissions or supply chain effects. For example, Singapore airlines flying Australians from Sydney to London, would associate flight emissions with cube 2 for Singapore, cube 3 for the UK, and cube 8 for Australia. Depending on the allocation principles, these specific flight emission can then be assigned to Singapore (polluter allocation), UK (recipient allocation) or Australia (beneficiary allocation).

Details on principles and types of analysis are illustrated in Table 3 for national studies. The different scopes of tourism consumption (domestic consumption, air transport, imported goods, exported goods) determine the emissions included under each principle. Aviation is the most relevant subsector, and should not be omitted in assessments (Becken & Patterson, 2006; Dwyer et al., 2010; Sun, 2014; Sun et al., 2019; Sun & Higham, 2021). Imported goods for domestic production processes also influence total tourism emissions (Dwyer et al., 2010; Filimonau et al., 2013; Whittlesea & Owen, 2012), but their allocation varies depending on inventory principle.

Table 3 thus illustrates the complexities in using different accounting frameworks, and the incomparability of the results. Given the importance of national scale assessments, specifically in regard to

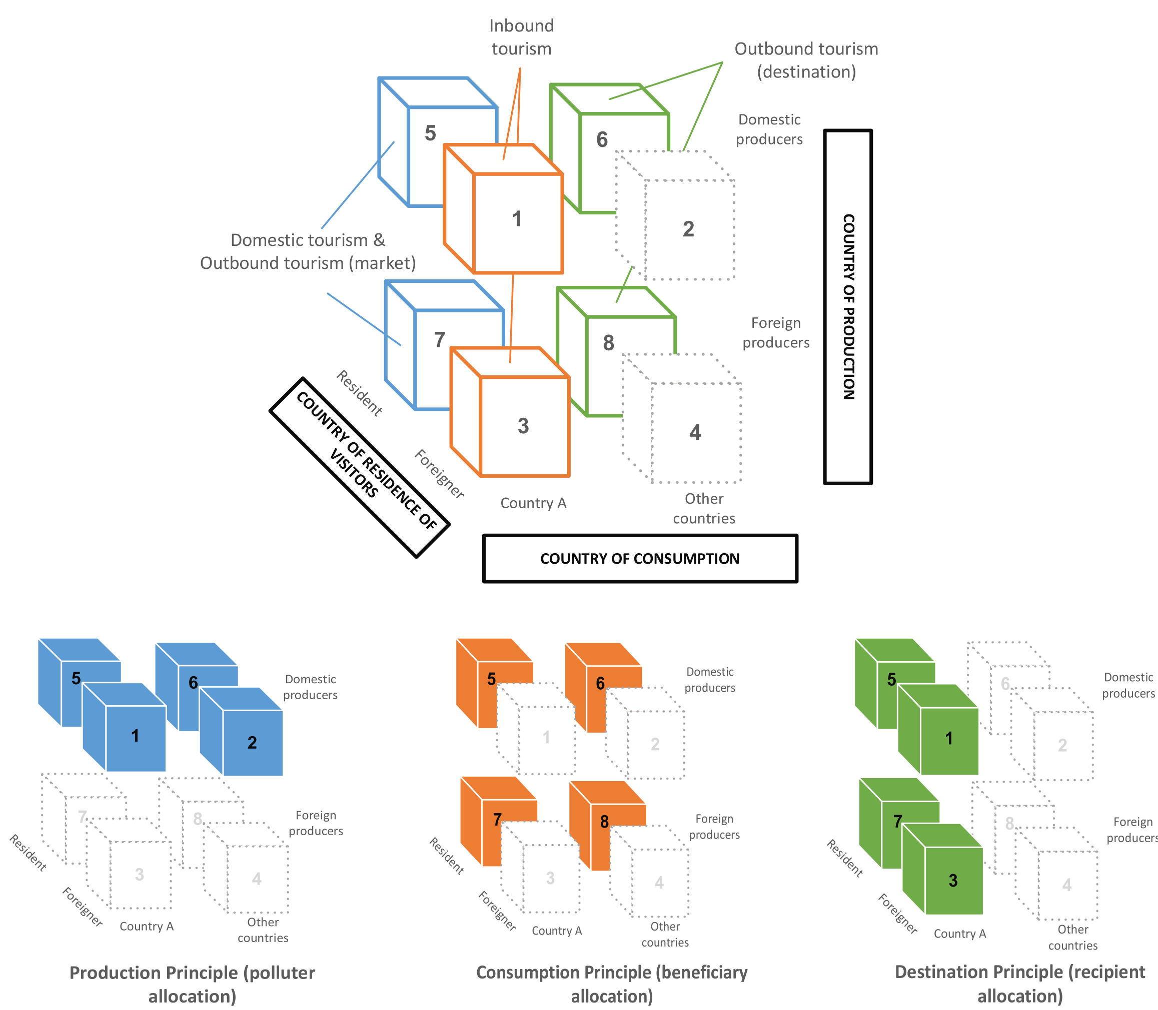

Fig. 3. Allocation principles based on country of production, country of consumption and country of residence of visitors.

accountability (Stakeholder) and decarbonization (Strategy), it is desirable that emission inventories be harmonized. Here, the TSAP that incorporates Tourism Satellite Accounts and the EEIO model based on the System of Environmental-Economic Accounting (SEEA), has been recommended by UNWTO . Acknowledging methodological limitations (Sun, Cadarso, & Driml, 2020, Sun & Wong, 2014), EEIO analyses provide robust and comparable approaches to national tourism carbon assessments, and account for all emissions in the system, including long-lived greenhouse gases (Cadarso, Gómez, López, & Tobarra, 2016; Cadarso et al., 2015; Sun et al., 2019). EEIO also allows for a differentiated consideration of emission sources, and the identification of high-emission subsectors (Sun, Gössling, & Zhou, 2022; Sun & Higham, 2021). As EEIO analyses integrate economic and environmental data, they can advise on mitigation strategies that are less economically disruptive, or inspire the definition of win-win markets (low emissions, high profitability) (Gössling et al., 2005; Gössling & Higham, 2021). EEIO analyses do not consider non-CO_2 emissions from aviation, which however can be integrated retrospectively.

The calculation of emissions at the sub-national destination scale – especially for jurisdictions below the national level (OECD territory 3, and below; OECD, 2022) such as a city or tourist region– is complex and there is no consensus on the most suitable approach (Cai, 2016; Dwyer et al., 2010; Hoque et al., 2010; Munday, Turner, & Jones, 2013; Tang & Ge, 2018; Tsukui, Ichikawa, & Kagatsume, 2017; Whittlesea & Owen, 2012). Destinations have to define emission scopes individually and are limited by data availability. There are trade-offs between comprehensiveness and effort. For instance, data collection from individual businesses in the destination is time-consuming, though it improves the quality of results and can serve the added purpose of engaging stakeholders in net-zero ambitions. At the state or province scale, regional Tourism Satellite Accounts or comprehensive visitor survey data may be available. EEIO approaches have been used in Shanghai, China (Tang & Ge, 2018); Wales, UK (Munday et al., 2013); South Tyrol, Italy (Cai, 2016); Tokyo and Kyoto, Japan (Tsukui et al., 2017); Auckland and Queensland, Australia (Pham, Meng, & Becken, 2022), and Scotland (Sun, Gössling, & Zhou, 2022). The scope of these subnational studies varies and international aviation emissions are often omitted.

Where no data is available, empirical studies often have collected information on energy throughput (direct energy use) for CO_2, hence omitting indirect emissions (Kelly & Williams, 2007; Konan & Chan, 2010; Kuo, Lin, Chen, & Chen, 2012; Rico et al., 2019). Their focus has often been on smaller units of analysis, such as tourism segments (El Hanandeh, 2013; Thongdejsri & Nitivattananon, 2019); sites (Li & Zhang, 2020; Susilorini et al., 2022; WWF Germany, 2013), cities (Rico et al., 2019; VisitValencia, 2019); events (Cooper & McCullough, 2021), or transport (Antequera, Pacheco, Díez, & Herrera, 2021; Boussauw & Decroly, 2021; Gunter & Wöber, 2022). Another group of studies has modelled emissions (Huang & Tang, 2021; Luo, Mou, Wang, Su, & Qin, 2020; Tang & Huang, 2021), used decomposition analyses (Yu, Bai, & Liu, 2019), or developed indices (Zha, He, Liu, & Shao, 2019; Zhang & Zhang, 2020).

A few studies combine top-down and bottom-up approaches at the subnational level and seek to overcome shortcomings of each method. Whittlesea and Owen (2012) for example developed and applied a hybrid I/O and activity-based destination and scenario emission tool for South-West England that allowed a calculation of direct and indirect supply-chain emissions for multiple subsectors with the support of primary business-data and EEIO. In addition, they also included scenario-based analyses and examined mitigation strategies and emission reduction potentials of tourism activities.

Last, at the business scale, emissions may be calculated following established frameworks and international standards such as ISO 14064 and ISO 14040 for the Corporate Carbon Footprint (CCF), ISO 14067 and PAS 2050 for the Product Carbon Footprint (PCF) or the Greenhouse Gas Protocol for general business-related emission calculations (Becken & Bobes, 2016). Other frameworks include the Hotel Carbon Measurement Initiative (HCMI), the Airport Carbon and Emissions Reporting Tool (ACERT), or the Carbon Management Tool for Tour Operators (CARMACAL). Benefits of these tools include a practical user-friendly access to GHG-assessments and opportunities for comparison on the basis of key performance indicators, such as energy use per guest night (Gössling & Peeters, 2015). These tools, however, are limited to direct emissions. The recent developments encourage the combination of the bottom-up approach with the EEIO method by leveraging the latter in tracking down indirect, higher order effects (Scope 3 emissions) (Crawford, Bontinck, Stephan, Wiedmann, & Yu, 2018; Malik, Egan, Du Plessis, & Lenzen, 2021).

Table 4 provides an overview of aspects with relevance in emission assessments, and studies that have discussed these. The table summarizes the issues discussed in the preceding section, and the need to consider various dimensions in assessments, starting with clearly defined system boundaries.

Fig. 4 analyses the sample of papers (n = 62) in regard to the main aspects of Scale and Scope, i.e. spatial focus, assessment methodology, allocation principle, sub-sectors, the comprehensiveness of assessment, and accountability. Note that total counts can exceed n = 62, as some studies include multiple approaches to specific aspects. Results show that 82% of the studies have analysed emissions at the national and subnational destination level, using predominantly top-down (37% of studies) and bottom-up methodologies (32%). Life Cycle Assessments (LCA) were applied by only seven studies, mostly in a business or product-related context. About half of the top-down and two thirds of the bottom-up approaches use destination-based allocation principles. About half of the analysed publications investigate multiple subsectors, one in ten is focused on single aspects of the tourism system, and one third uses a TSA-based approach. This is also reflected in the comprehensiveness of assessments, as a large share of papers (42%) only considers direct emissions. Last, a relevant finding is that a broad majority of papers (77%) assigned mitigation responsibilities to governmental bodies. This is discussed in the following section.

3.3. Stakeholder

To reduce emissions, it is necessary to assign responsibilities, as mitigation represents a cost. As Fig. 4 indicates, responsibilities are discussed in all of the papers reviewed, with a majority proposing key roles for policymakers at the national scale. Governments can implement policies, but mitigation efforts will ultimately rest with producers or consumers. Notably, industry reports such as WTTC-UNEP-UNFCCC (2022) or McKinsey (2022) see responsibilities for mitigation with firms, though they highlight roles for governments in providing incentives, subsidies, or financing Research & Development. Consumers, on the other hand, will primarily reduce their demand for carbon-intense goods and services when these are priced higher (Gössling & Dolnicar, 2022). There is currently limited evidence of climate governance in tourism contexts, specifically not in terms of a measurable decline in absolute emissions (Becken et al., 2020; OECD & UNEP, 2011).

A potential barrier to decarbonization are industry's persistent greenwashing efforts. Examples include the VW diesel deception (Aurand et al., 2018), and the automobility industry's efforts to water down legislation seeking to reduce emissions (Paterson, 2000). Airlines provide misleading information to customers (Guix, Ollé, & Font, 2022), while aviation industry sustainability targets proposed since 2000 have been found missed, abandoned, or no longer been reported on (Possible, 2022). Discourses on aviation technology 'solutions' rarely survive the headlines they generate, and have subsequently replaced each other (Peeters et al., 2016). Some jurisdictions have for this reason sought to increase transparency on emissions, in efforts to guide investors. For example, the European Union acknowledges that "the information that companies report is not sufficient" (EC, 2021, no page). To close the "accountability gap", the European Union's Corporate Sustainability

Table 4
Overview of aspects (scale & scope) in emission assessments.

Aspect	Categories				Source
Scale					
Spatial focus	Global	National	Subnational	Business	Sun and Higham (2021)
Purpose	Total/relative emissions	Intensities/eco-efficiencies	Targets/ benchmarking	Projections/scenarios	Sun et al. (2021)
Scope					
Assessment method	Top-Down Input-Output Analysis	Bottom-Up Multiplication	Bottom-Up Process Analysis (LCA)	Mixed Approaches	Whittlesea and Owen (2012) Wiedmann and Minx (2008)
Allocation principle	Production related Principle "polluter pays"	Consumption related Principle "beneficiary pays"		Destination related Principle "recipient pays"	Sun et al. (2019 & 2020b)
Visitor segment	Domestic	Inbound		Outbound	Patterson and McDonald (2004) Sun et al. (2019 & 2020b)
Subsector	Single	Multiple		TSA-specific	Becken and Patterson (2006)
Comprehensiveness	Direct (scope 1)	Indirect/induced (scope 2–3)			Filimonau et al. (2011) Hunter (2002)
GHG consideration	CO_2	CO_{2e}/non-CO_2			Gössling (2000)
Assessment Standard	GHG-Protocol	ISO 14064/PAS 2050	SNA		Gao, Liu, and Wang (2014) Becken and Bobes (2016)

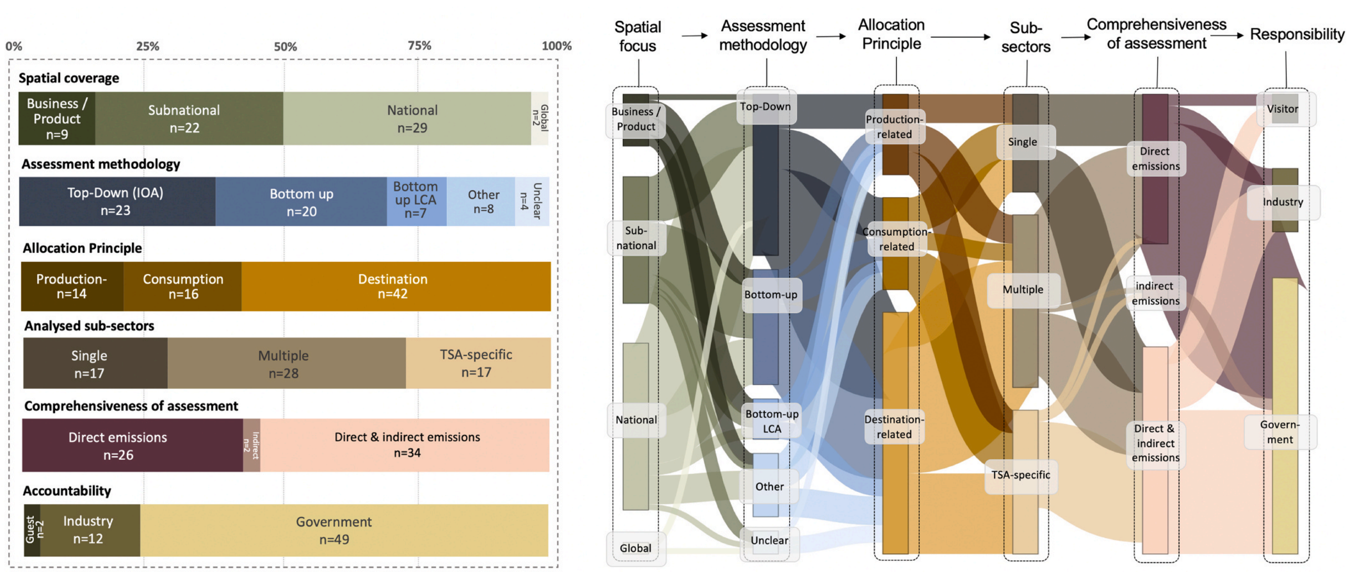

Fig. 4. Quantitative analysis of papers.

Reporting Directive will in the future force small and medium-sized enterprises to report on sustainability, and support the G20 initiative to introduce global sustainability reporting standards building on the Task Force on Climate-related Financial Disclosures' work. Results are intended to guide investors, with the European Central Bank already announcing to put greater emphasis on emissions in the future (Banking Supervision, 2022).

This points to the importance of assigning responsibilities at different scales (Table 5). At the global level, the Paris Agreement (UNFCCC, 2015) represents the world's consensus on stabilizing warming. It is an agreement ratified by nations, though non-binding in character: emission reductions have to be achieved at the aggregated national level. Countries thus submit Nationally Determined Contributions (NDCs) to the UNFCCC, in which they pledge to reduce emissions. These are

Table 5
Emission reduction responsibilities.

Scale	Ambition	Basis	Responsibility	Character	Mechanism
Global	Paris Agreement	Carbon budgets to 1.5 °C/2.0 °C	National ratification	Non-binding	Agreement
National	Nationally Determined Contributions (NDCs)	Greenhouse gas inventories (UNFCCC)	National pledges	Non-binding	Pledges
Subnational	Voluntary commitments	Self-defined boundaries	Local government	Non-binding	Pledges
Business	Disclosure, Emission Allowance (EU ETS)	GHG Protocol, others	Regional (EU), national	Binding/Non-binding	Reductions, Auctioning, Trading
Consumer	Reductions in per capita emissions	Per capita emissions	Individual	Binding	Taxes, fees

achieved by addressing businesses (production) and citizens/residents (consumption). Depending on country and/or region, laws may force companies to reduce emissions, or to participate in auctioning and trading. For example, the EU Emissions Trading System (EU ETS) is the world's largest carbon market, in which large emitters have to reduce emissions by 43% to 2030 compared to 2005, corresponding to a linear annual decarbonization rate of 2.2% per year (EC, 2022).

Carbon taxes have important roles in reducing emissions by making production (and consumption) more expensive, to increase the interest in energy savings and emission reductions, or to discourage consumption (e.g. Falk & Hagsten, 2019). At the sub-national level, destinations may pledge to voluntarily achieve emission reductions. Consumers are not legally responsible to reduce their individual emissions, but their consumption patterns are highly relevant for aggregated emission growth (Barros & Wilk, 2021). As the overview shows, legislation is specifically relevant at the national level, where policies of relevance can be introduced with a binding character for industry.

An added complexity is that countries communicate their ambitions to reduce emissions in Nationally Determined Contributions, which partially covers tourism, but excludes international aviation and shipping. As originally agreed upon in the Kyoto Protocol (1997, article 2-2), aviation bunker fuels used for international operations were to be treated through the International Civil Aviation Organization (ICAO) and the World Maritime Organization (WMO), and this provision has not changed despite all economic sectors now being covered by the 2015 Paris Agreement (Gössling & Lyle, 2021).

Given the shortcomings of the proposals made to reduce emissions from these sectors by ICAO (2016a,b) and IMO (2020), Lyle (2018) argues that national accountability will be a necessary precondition to force airlines into adopting new fuels and technologies. Mitigation in this sector will also have to integrate production and consumption perspectives, as there is much evidence that continued growth in fuel demand, driven by super emitters (Barros & Wilk, 2021), will negate progress on decarbonization.

The situation is somewhat similar for shipping and in particular cruises. Though these tourism subsectors are very small in comparison to aviation, they represent the most energy and carbon intense tourism products on a per trip or per tourist basis (Eijgelaar et al., 2010). Emissions from global shipping have consistently grown and approximately doubled between 1990 and 2020, with industry forecasts of accelerating growth that may again triple these between 2020 and 2050 (IEA, 2020; IMO, 2020). This is problematic, given that IMO (2020) defined an emission reduction goal of 50% by 2050 that is incompatible with decarbonization timelines to 1.5°-2° C (Joung et al., 2020). Carnival, MSC Cruises, and TUI Cruises have announced carbon neutrality to 2050 (WTTC-UNEP-UNFCCC, 2021); yet, it remains unclear whether pledges will result in actual emission reductions.

More generally, an Accenture analysis of 250 travel and tourism businesses found that only 42% had climate targets, and a mere 8% science-based targets (WTTC-UNEP-UNFCCC, 2021). The overall situation characterizing tourism is thus one of non-binding and conflicting responsibilities, specifically in regard to the most important emission sub-sectors. Will governments assume responsibility for these emissions, and force businesses to reduce these? Much evidence seems to suggest that continued emission growth needs to be expected: Only few destinations, notably at the sub-national scale, have explicit goals to reduce emissions in ambitious ways, or to focus on qualitative growth. Businesses regularly seek to expand, specifically when operating at global or multiple country scales. The UNWTO advocates continued growth, yet encourages the sector "to embrace a low carbon pathway" (UNWTO, 2022, no page). As discussed in the introduction, continued growth and science-based targets for decarbonization cannot be aligned. These contradictions highlight the relevance of defining timelines over which emission reductions will be achieved, continuous monitoring, and the introduction of policy-regimes forcing the different subsectors to decarbonize.

3.4. Strategy

Mitigation needs to be organized in ways that is significant, yet ideally not disruptive to the system in a way that jeopardizes employment or profitability. The challenge is to half emissions to 2030, which sets linear annual decarbonization rates at about 5%, and higher – unattainable – rates, should subsectors continue to grow in emissions. Industry-wide reports (WTTC-UNEP-UNFCCC, 2021) do not provide answers as to how significant emission reductions will be achieved in practice. This situation characterizes the entire tourism industry (Table 2), and requires a discussion of systemic issues.

3.4.1 Systemic considerations

As highlighted by Geels, Sovacool, Schwanen, and Sorrell (2017), system change requires consideration of technologies, infrastructures, organizations, markets, regulations, and user practices. 'Strategy' should thus be concerned with technology innovation, transition policies, and consumer behavior. Given the complete lack of evidence of decarbonization through industry initiatives, governance will determine the success of mitigation initiatives. Here, the evidence is that only regulatory and market-based policies will contribute to significant emission cuts, though voluntary policies have relevance in supporting social norm change (Gössling & Dolnicar, 2022; Gössling & Lyle, 2021). As some policies have a greater potential for emission reductions than others, the former need to be prioritized on the basis of impact assessments. There is also a need to consider policies in structured, hierarchical ways. As an example, carbon taxes will reduce demand, and hence diminish the amount of fossil fuels that need to be substituted.

Policies may be easiest to design in focusing on the main emission-generating subsectors, i.e. aviation, automobility, water-transport, accommodation, and food. They may focus on avoiding, reducing, or substituting fossil energy use. Policies need to lead to immediate cuts in emissions, but they may nevertheless consider economic objectives. For instance, if an objective is to maintain tourism's global revenue and employment potential, it is important to remember that domestic tourism accounts for 72% of total global tourism expenditure (The World Bank, 2022). For aviation, there is evidence that just one percent of the world population, the frequent travelers in private aircraft or premium classes, account for 50% of all emissions. Long-haul trips are specifically problematic. For instance, Dubois and Ceron (2009) calculate that the 2% of the longest flights cause 43% of aviation emissions of outbound flights from France.

These insights can for example be used by national tourism organizations to reconsider marketing efforts. Research shows that differences in the emissions from travel to a destination vary by up to a factor 30 (Gössling, Scott, & Hall, 2015). As an example, the average arrival to Austria from nearby Switzerland will entail a few kg CO_2, as visitors may use efficient transport modes such as electric trains running on renewable electricity. This compares unfavorably to an overseas arrival from Australia by air, which may cause the equivalent of thousands of kilograms of CO_2. Changes in the market mix of a country are likely the single most powerful measure to bring down emissions nationally, specifically if combined with measures to increase length of stay (Gössling, Scott, & Hall, 2018). As countries relying on international tourist arrivals are also vulnerable to fuel price volatility and carbon pricing (Scott, Hall, & Gössling, 2019), there are also potential benefits in economic stability. Destinations may thus seize marketing efforts in some countries, or even consider demarketing and de-growth strategies (Hall, 2009; Hall & Wood, 2021). For discussions of climate-focused destination management, see also Gössling and Higham (2021); Oklevik et al., 2019; Peng, Saboori, Ranjbar, and Can (2022); Sun and Higham (2021).

3.4.2 Measures by subsector

This reviews the main tourism emission subsectors, representing at least 62% of overall global tourism emissions (Fig. 5). Measures listed

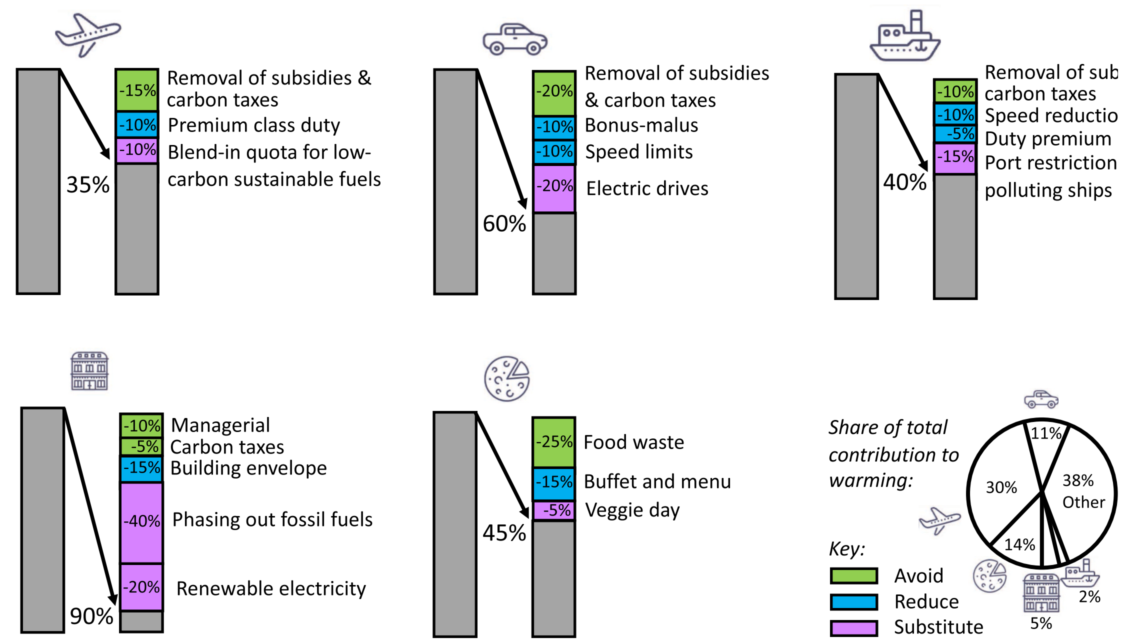

Fig. 5. Estimated mitigation potentials for sub-sectors, no growth scenario*.
*Scope 1 and 2, no growth scenario to 2030.
Source: Aviation: Craps, 2021; Falk & Hagsten, 2019; Fichert et al., 2014; Gössling et al., 2017; Gössling et al., 2021; Markham et al., 2018; McKinsey, 2022; Car: Barth & Boriboonsomsin, 2008; d'Haultfoeuille et al., 2014; Habibi et al., 2019; Østli et al., 2021; UBA, 2021; Yang et al., 2019; Cruises: IMO, 2020; Joung et al., 2020; Accomodation: Becken & McLennan, 2017; Bohdanowicz & Martinac, 2007; Gössling, 2011; Jandrokovic et al., 2012; Jelle, 2011; Sozer, 2010; Food: Filimonau et al., 2017; Filimonau & Delysia, 2019; Gössling, 2011; Poore & Nemecek, 2018; Pradhan et al., 2013; Reynolds et al., 2019; Visschers & Siegrist, 2015; Westhoek et al., 2014.

consider the hierarchy of avoid, reduce and substitute for scopes 1 and 2, with reduction potentials to 2030. Mitigation at the scales proposed will require a steady-state tourism economy without further growth in arrivals. This acknowledges that the global tourism geography will have to change and that regulatory policies will have to be implemented (Peeters & Eijgelaar, 2014; Peeters & Landré, 2011). While such policies are unlikely at the global scale, there is precedent, as evidenced by Venice's visitor fee, introduced in 2022, to limit arrivals (Euronews, 2022), or France's short-haul flight bans, introduced in 2021 (BBC, 2021).

A general issue characterizing the transport sector are significant subsidies forwarded to aviation, automobility, and water-transport. This distorts perspectives on the cost of transportation. For some sectors such as air transport, the variety and scale of different subsidies is not even known (Gössling, Fichert, & Forsyth, 2017), but the sector received more than US$130 billion in the first pandemic year alone – including government-backed loans and guarantees; recapitalization through state equity; flight subsidies; deferral and/or waiver of taxes and charges; grants; and private equity (Abate, Christidis, & Purwanto, 2020). The cost of carbon is another negative externality of air transport, as is the exemption of international flights from value added taxes (Pearce, 2003). Subsidies have contributed to the observed decline in the real cost of air travel, which IATA (2019) suggests fell by 60% over the past 20 years. If subsidies were removed, demand for air transport would likely fall (cf. Falk & Hagsten, 2019; Fichert, Forsyth, & Niemeier, 2014; Markham, Young, Reis, & Higham, 2018). This is also true for road and water transport (Merk, 2020; Van Beers & de Moor, 2001; Wang, Xu, & Guo, 2021). A general insight pertaining to all transport is thus that to remove subsidies and to internalize the full cost of carbon will lead to a decline in transport demand and affect the choice of transport modes as well as of car models, flight classes, or cabin preferences (Craps, 2021; Gössling, Hanna, Higham, Cohen, & Hopkins, 2019; Habibi, Hugosson, Sundbergh, & Algers, 2019; Østli, Fridstrøm, Kristensen, & Lindberg, 2021).

To reduce emissions from transport, it will also be necessary to consider non-linear changes in price structures. Per passenger, premium class air travel requires 3–9 times more fuel than economy class travel (The World Bank, 2013). This also applies for water transport (cabin size). Cars, vans, and mobile homes require significantly more fuel than small cars. Yet, as high emitters are also high-income earners (Oswald, Steinberger, Ivanova, & Millward-Hopkins, 2021), they are less affected by proportional carbon taxes. This can be addressed on the basis of significant duties for premium class flights or landing fees for private aviation and cruises (Gössling & Lyle, 2021), or bonus-malus systems for cars (d'Haultfoeuille, Givord, & Boutin, 2014). Mandated speed reductions for all transport modes can significantly diminish fuel use for all transport modes, including shipping (IMO, 2020) and automobility (Barth & Boriboonsomsin, 2008; UBA, 2021). Speed reductions will also make alternatives more attractive, specifically if investments are made to further improve competitive advantages, for instance including networks of high-speed railways (e.g. Yang, Lin, Li, & He, 2019).

Substitution in transport contexts will mostly refer to technology innovation. This includes alternative fuels for aviation and water-transport, or electric drives for cars. Substitution holds a considerable potential to 2030 and beyond (Gössling et al., 2021; Joung et al., 2020). Given the significantly higher cost of alternative fuels, there remains a market-issue, as airlines are unlikely to introduce solutions that increase their operational cost. It is for this reason that consultancy McKinsey (2022) recommends that governments subsidize alternative fuels, a proposition that undermines the need to reduce subsidies. It is also a risky strategy, given that the responsibility for alternative fuel production is shifted to government. Mandated blend-in quotas are thus favorable, as they force industry to find solutions, and airlines to reconsider their volume growth model (Gössling, 2020). For vehicles, market-based approaches are also relevant, as shown by Østli et al. (2021) for Norway. Here, a strongly CO_2-differentiated tax regime exempting electric vehicles from VAT has been shown to efficiently change car fleet composition. Even more effective are regulatory policies: the European Union has agreed that new cars must be emission-free after 2035 (DW, 2022). Last, the shipping sector's carbon neutral objectives fall short of science-based targets (cf. IMO, 2020), prompting Joung et al. (2020) to call for regulation and market-based measures (see also Garcia, Foerster, & Lin, 2021).

Accommodation represents energy-intense infrastructure, including both electricity needs to power air conditioning, appliances and lighting, and primary energy consumption (oil, gas) for central heating and warm water generation (Bohdanowicz & Martinac, 2007). Depending on location, heating requires most energy, followed by hot water, and may often rely on fossil fuels (Jandrokovic, Mandl, & Kapusta, 2012; Sozer, 2010). In warm climates, air conditioning consumes considerable amounts of electricity (Jandrokovic et al., 2012). Main measures to avoid energy use thus include campaigns to raise staff awareness and knowledge (Coles, Dinan, & Warren, 2016; Gössling, 2011), the insulation of buildings, including a role for greenery to cool buildings in warm climates (Jelle, 2011), solar roofs and balconies to reduce energy consumption from the grid (Creutzig et al., 2017), and the replacement of oil or gas-based energy systems with heat pumps (Bernath, Deac, & Sensfuβ, 2019; Lund, Ilic, & Trygg, 2016). All electricity should be sourced from renewable energy suppliers. Measures such as these can be implemented through regulatory and market-based policies, and within short periods of time, as these measures are, with the exception of building envelopes, economically meaningful. In contrast to other subsectors, accommodation thus has a chance to become largely carbon-neutral in its operations to 2030.

Food is a complex source of greenhouse gases, as emissions are caused at stages from production to packaging, transport to distribution, and preparation to presentation (Poore & Nemecek, 2018). The most significant source of emissions is food waste (Reynolds et al., 2019), with estimates that one third of all edible food is wasted during the supply chain (Gustavsson, Cederberg, Sonesson, Van Otterdijk, & Meybeck, 2011). Meals also entail significant differences in emissions depending on composition, as vegan or vegetarian dishes are less carbon-intense than meat-based menus. For instance, Pradhan, Reusser, and Kropp (2013) found that differences between low and high calorie diets translated into a factor four in emissions (1.43–6.1 kg CO_2-equivalent per person per day). In a global study, Poore and Nemecek (2018) concluded that a worldwide change to vegetarian diets could half greenhouse gas emissions. Menu and buffet designs thus hold considerable potential to reduce emissions, as consumers are willing to reduce plate waste (Antonschmidt & Lund-Durlacher, 2021), or to consume more vegetarian/vegan or climate friendly options (Filimonau, Lemmer, Marshall, & Bejjani, 2017; Visschers & Siegrist, 2015).

Fig. 5 illustrates the mitigation potential of the measures. Policies could potentially half emissions from the five subsectors studied (scope 1 and 2), the greatest challenge represented by aviation. While some measures could be implemented in the short term (carbon taxes), others will take more time due to legal complexities (removal of subsidies). Yet others, such as alternative fuel production, will be determined by limits to production upscaling. Even though the selected options are promising avenues to emission cuts, there remains political and technical uncertainty. Policies would have to be introduced at the national level, and worldwide. Currently, the EU is the only jurisdiction with decarbonization timelines aligned with 2 °C goals. Aviation and shipping are seen to be the responsibility of ICAO and WMO. Whether policymakers will implement significant legislation thus remains uncertain.

3.4.3. *Carbon removal*

Results suggest that limiting warming to 1.5 °C is unachievable without further mitigation efforts. Industry has repeatedly pointed at a central role for carbon offsetting and removal (ICAO, 2016a; UNWTO, 2022; WTTC-UNEP-UNFCCC, 2021). Carbon removal (IPCC, 2022a), refers to "technologies, practices, and approaches that remove and sequester carbon dioxide from the atmosphere and durably store the carbon in geological, terrestrial, ocean reservoirs or in products" (IPCC, 2022a, pp. 12–35). Carbon removal involves consideration of sink types (land-based biological, ocean-based biological, geochemical and chemical), timescales (decades to thousands of years), and storage media (buildings, vegetation/soils/sediment, geological formations, minerals, marine sediment) (IPCC, 2022a).

Land-based biological removal includes afforestation, reforestation and improved forest management to store carbon in biomass and soils, sediments and buildings made of wood. This can be achieved through carbon sequestration through agricultural and pasture management, as well as the introduction of biochar, a coal created through pyrolysis of biomass (IPCC, 2022a; Smith et al., 2016). Yet another option is the combination of bioenergy production with carbon capture and storage in geological, terrestrial, or ocean reservoirs, or in products. Peat- and (coastal) wetland restoration and carbon capture by vegetation in the coastal zones, such as tidal marshes, mangroves and seagrasses are also referred to as blue carbon management. This also includes ocean-based approaches involving biological (fertilization of nutrient-limited areas) or chemical means (enhancing alkalinity with carbonate or silicate rocks). Enhanced weathering accelerates natural weathering of minerals to remove CO_2 from the atmosphere and storage in soils, land or the deep ocean. Direct Air Carbon Capture and Storage (DACCS) filters CO_2 from the ambient air, while bioenergy with carbon capture and storage seeks to store carbon geologically, for instance in depleted oil and gas fields. These approaches vary considerably regarding their technology readiness and costs (IPCC, 2022a).

Table 6 shows that the theoretical potential for carbon removal is considerable, but all approaches are limited by the availability of land, water, energy, and financial resources. There are risks for ecosystems and storage losses through the reversal of carbon flows. Some of the strategies amount to geoengineering, which creates new risks. Tourism also competes with other sectors for carbon removal. However, there is a potential for emission reductions as an *additional* activity for tourism stakeholders. As this cannot be mandated, actions would be voluntary and predominantly small-scale. For aviation and shipping, there are opportunities to engage in direct air carbon capture or bioenergy with carbon capture projects to produce synthetic fuels – a potential future technology pathway. While linkages of carbon removal to tourism should be explored in greater detail, there is currently no evidence to suggest that these schemes will play a significant role in decarbonizing the sector to 2030, also given their low technology readiness.

4. Towards net-zero

This review has outlined that tourism has a central role in emission growth and the depletion of the global carbon budget. Aviation is the most relevant subsector in this development, with the lowest potential for emission reductions. Tourism will have to change in very significant ways to become aligned with net-zero goals. The S4C model proposes that significant and immediate emission reductions in tourism will depend on emission assessments (Scales), the consideration of all greenhouse gases and aviation's contribution to non-CO_2 warming (Scope), the definition of timelines and responsibilities for decarbonization (Stakeholder), and regulation through policy frameworks with a focus on immediate and significant emission reductions (Strategy). There is little evidence of an organized emission reduction approach in any of these four dimensions, let alone in their combination.

As most policies to reduce emissions can be implemented at the country level, national assessments become the most important level of analysis and action. Here, findings suggest that TSAP in combination with environmentally extended input-output modelling (EEIO) approaches are the most suitable emission assessment framework. Destination allocation is recommended, i.e. the measurement of direct and indirect emissions associated with tourism consumption from domestic, inbound and outbound activities within a country. International air transport emissions can be included in this accounting method, as bunker fuel data is often readily available and can serve as a benchmark for tracking developments in this most relevant sub-sector. Tourism

Table 6
Carbon removal strategies (sorted by Technology Readiness Level).

Carbon removal strategy	Mitigation potential ($GtCO_2$ per year)	Cost (US$ per ton CO_2)	Technology Readiness Level	Risks	Tourism opportunities
Afforestation/ reforestation	0.5–10	0–240	8–9	Wildfires	Planting trees, engaging in afforestation/reforestation projects (accommodation, gastronomy, services, DMOs, NTOs)
Soil carbon sequestration in croplands and grasslands	0.6–9.3	45–100	8–9	Subsequent carbon loss	Cooperation with farmers to increase soil carbon (accommodation, gastronomy, services, DMOs, NTOs)
Peatland and coastal wetland restoration	0.5–2.1	n.d.	8–9	Drought	Cooperation with nature conservation groups (accommodation, gastronomy, services, DMOs, NTOs)
Agroforestry	0.3–9.4	n.d.	8–9	Food production	Cooperation with farmers and the forest sector (accommodation, gastronomy)
Improved Forest management	0.1–2.1	n.d.	8–9	Biodiversity loss	Cooperation with forest owners (e.g. state forests), nature conservation groups (accommodation, gastronomy, services, DMOs, NTOs), specifically in context of protected areas
Biochar	0.3–6.6	10–345	6–7	Loss of biodiversity, carbon stock	Cooperation with farmers (accommodation, gastronomy)
Direct Air Carbon Capture and Storage	5–40	100–300	6	Energy use	Combination with synthetic fuel production (aviation, water transport)
Bioenergy with carbon capture and storage	0.5–11	15–400	5–6	Land, water	Combination with synthetic fuel production (aviation, water transport)
Enhanced weathering	2–4	50–200	3–4	Mining	Investments by aviation, water transport
Blue carbon in coastal wetlands	<1	n.d.	2–3	Ecosystem	Cooperation with nature conservation groups in coastal areas (accommodation, gastronomy, services, DMOs, NTOs)
Ocean fertilization	1–3	50–500	1–2	Ecosystem	Investments by aviation, water transport
Ocean alkalinity enhancement	1–100	40–260	1–2	Ecosystem	Investments by aviation, water transport

n.d.: no data; Technology Readiness Level: scale from 1 to 9 with 9 being the most mature technology.
Source: adapted from IPCC, 2022a, 2022b, expanded.

Satellite Accounts have already been established in more than 60 countries, representing up to 90% of global tourism consumption (Lenzen et al., 2018). Global databases for economic-environmental accounts are also widely available and provide long-term country-specific parameters that include emission coefficients (Sun, 2016). Benefits of this approach include opportunities for longitudinal analyses and progress on decarbonization, international comparison, the identification of specifically carbon-intense economic subsectors, and consideration of economic aspects, such as the carbon-intensity of revenue.

Lenzen et al. (2018) integrated existing TSAs and visitor expenditure data into a global multi-region input-output database (MRIO) to estimate national tourism emissions for 160 countries in the period 2009–2013. The two approaches of residence-based accounting (RBA) and destination-based accounting (DBA) were compared to evaluate both consumer-driven and industry-related emissions. In the future, this approach may be complemented with an aggregation of national I/O analyses, when these become available in sufficient number. To achieve this, tourism assessments may be integrated in the UNFCCC's national greenhouse gas inventories, to create a global database and a unified approach to measuring that will allow to assign responsibilities for emissions from international aviation and water transport.

Destinations at the sub-national level will face difficulties in applying top-down approaches because of the aggregated nature of macroeconomic and environmental accounting data that comes with major limitations especially for smaller tourism regions (Cai, 2016; Dwyer, Mellor, Livaic, Edwards, & Kim, 2004; Klijs, Peerlings, & Heijman, 2015). In addition, local tourism planning often needs finer degrees of process details such as emissions from different transport modes or accommodation providers that can be used for the design of mitigation policies. The complexity of measuring emissions is a potential barrier to the involvement of individual (business) stakeholders, and is often perceived as complicated, time-consuming and costly. The understanding of benefits will be important for mobilizing stakeholders.

Comparable and comprehensive data has a high value. Where destinations – for instance at the community, county or state level - have regional TSA-data, I/O-based top-down calculations are thus recommended. Where such data does not exist, bottom-up approaches may be used (Fig. 6). Such approaches focus on tourism emissions in a specific jurisdiction (destination allocation at the subnational level) and provide a general understanding of resource use and emissions. Calculations can be based on visitor volumes and activities that are then connected with differentiated information on specific tourism industries. For example, information on transportation emissions from domestic air travel, inbound air travel, private and rented vehicles, or public transport is usually available. Domestic, inbound, and other tourism segments can be distinguished. This information is also specifically relevant for destination management. Potential weaknesses of this approach are the reliance on averaged emission-factors, lack of detailed visitor-data, and the omission of indirect emissions. Destination specific data, sourced from businesses, can improve the quality of assessments. In combination with this approach, it is advisable to develop climate action plans based on scope 1 and scope 2 emissions that provide ballpark figures. These can be used to make recommendations for short-term action.

Finally, businesses, depending on size, have their own responsibilities. This may be the EU ETS for large emitters in the European Union or the upcoming European Corporate Sustainability Reporting Directive which includes a double-materiality risk assessment for climate change and a climate action plan that is in accordance with the European climate mitigation target (European Commission, 2021). Non-financial accounting is also increasingly demanded by financial markets (e.g. Task Force on Climate-related Financial Disclosures). For small and medium sized enterprises, the rising cost of energy is likely a future driving factor in avoiding and reducing energy use, for which it is necessary to understand where energy is wasted. Smaller businesses may focus on assessments using established accounting frameworks, such as ISO, PAS, or GHGP and at least include scope 2 emissions, and also identify and assess relevant indirect emission sources.

The overall process of decarbonization is ideally embedded in positive feedback-loops, as mitigation efforts have to be upscaled swiftly. Fig. 7 illustrates this, distinguishing the different institutions and their influence on policies supporting mitigation, ambitions in regard to

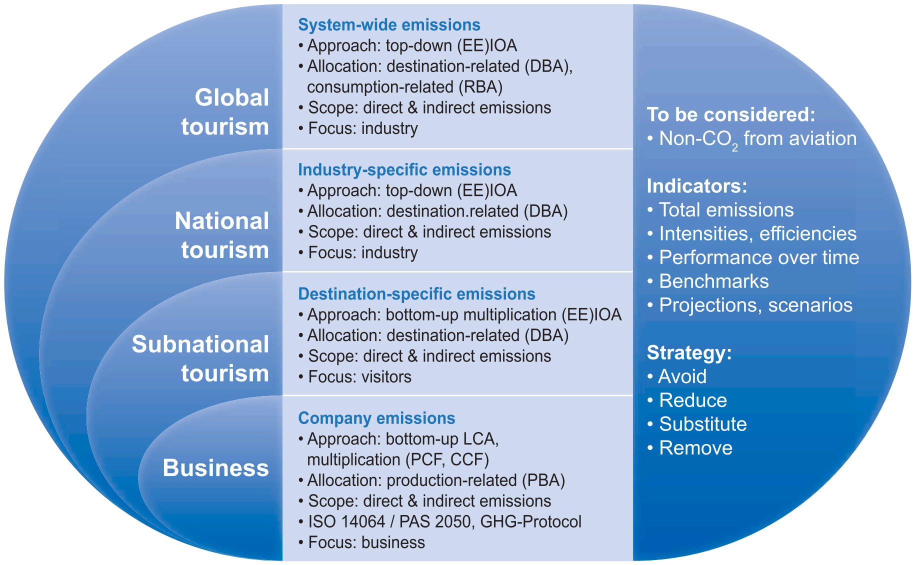

Fig. 6. Approaches to decarbonization.

Fig. 7. Net-zero self-reinforcing feedback loops.

decarbonization levels and timelines, the showcasing of best practice, the development of new strategies, as well as the communication of climate change mitigation as a societal priority reinforced by emerging social norms. Through such an interplay of actions at different scales, mitigation efforts gain traction. To date, major roadblocks to decarbonization remain the lack of governance and industry dishonesty in regard to the challenges. 15 years ago, UNWTO, UNEP & WMO, 2008: 38) concluded that:

> “Tourism can and must play a significant role in addressing climate change as part of its broader commitment to sustainable development. […] Tourism as a non-negligible contributor to climate change has the responsibility to reverse the growth trajectory of its GHG emissions over the next three decades to a more sustainable emissions pathway.”

Yet, one and a half decades later, the sector’s emissions continue to rise, suggesting that it is high time for the sector to heed its own conclusions.

5. Future research directions

The review of the literature on calculating emissions at different levels of scale reveals important knowledge gaps. At the most basic level, and following the relationships outlined in this paper, mitigation will demand political interventions and the willingness of businesses to engage with the net-zero challenge. Following the S4C model, important research questions include:

Scale. How are responsibilities for emission reductions distributed between global institutions, governments, destinations and businesses, and how can common goals be formulated? For example, ICAO has presented a net-zero roadmap with a focus on offsetting rather than transitioning to alternative fuels. Governments are thus required to implement feed-in quotas, with research questions related to policy-making and international coordination, changes in cost/price structures, and airline profitability. These issues also have relevance for cruises.

Scope. While this research has presented the best approaches towards emission reductions at different scales of analysis, it is of importance to better understand the barriers for businesses and destinations in calculating emissions. Are there ways in which calculations can be made easier and comparable? Can destinations learn from each other through common assessment frameworks?

Stakeholder. To assign responsibilities for progress on mitigation will be key to achieving emission reductions. It is equally important to identify transition bearers and barriers, i.e. the companies, destinations and countries moving towards decarbonization as well as those currently representing obstacles to progress. Reasons for resistance to change need to be identified, as well as opportunities to overcome institutional and structural barriers.

Strategy. For businesses and destinations, carbon management will be inspired by views on profitability and robust tourism management systems. For this it is paramount to understand how changing price structures or carbon policies will affect tourism, and whether this will result in new equilibria in global tourism flows. Firms and destinations will also want to know how regulatory policies will affect their business models. For example, market-mix changes can significantly reduce emissions, but this will also imply gains or losses in economic bottom lines. Specific forms of tourism will become significantly more expensive, making it desirable to develop carbon intensity indicators for different travel products. Overall, there is a huge consultancy demand at the national and destination level, requiring an upscaling of educational efforts.

Author statement file with CRediT roles

Stefan Gössling, Martin Balas: Conceptualization, Martin Balas, Stefan Gössling: Data curation, Formal analysis, Stefan Gössling, Martin Balas: Methodology, Stefan Gössling, Martin Balas: Project administration, Stefan Gössling, Martin Balas, Marius Mayer, Ya-Yen Sun: Visualisation, Stefan Gössling, Martin Balas, Marius Mayer, Ya-Yen Sun: Writing - original draft, Stefan Gössling, Martin Balas, Marius Mayer, Ya-Yen Sun: Writing - review & editing.

Impact statement

Tourism is a significant source of greenhouse emissions. It is also an economic sector that faces considerable technical, financial and political decarbonization barriers. This paper reviews the available literature, and discusses the scales, scopes, stakeholders and strategies of carbon management in tourism within the framework of the S4C model. It makes recommendations for mitigation on the basis of emission assessment frameworks and significant decarbonization strategies. The paper is thus intended as the blueprint for mitigation in tourism that addresses specifically industry and policymakers.

Funding

No funding has been received for this research.

Declaration of competing interest

None.

References

d'Haultfoeuille, X., Givord, P., & Boutin, X. (2014). The environmental effect of green taxation: the case of the French bonus/malus. *The Economic Journal, 124*(578), F444–F480. https://doi.org/10.1111/ecoj.12089

Abate, M., Christidis, P., & Purwanto, A. J. (2020). Government support to airlines in the aftermath of the COVID-19 pandemic. *Journal of Air Transport Management, 89*, Article 101931. https://doi.org/10.1016/j.jairtraman.2020.101931

Antequera, P. D., Pacheco, J. D., Díez, A. L., & Herrera, C. D. (2021). Tourism, transport and climate change: The carbon footprint of international air traffic on islands. *Sustainability, 13*(4), 1795. https://doi.org/10.3390/su13041795

Antonschmidt, H., & Lund-Durlacher, D. (2021). Stimulating food waste reduction behaviour among hotel guests through context manipulation. *Journal of Cleaner Production, 329*, Article 129709. https://doi.org/10.1016/j.jclepro.2021.129709

ATAG. (2021). *Waypoint 2050. Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency: a Vision of Net-Zero Aviation by Mid-century*, 2nd edition. Retrieved from https://www.atag.org/our-publications/latest-publications.html.

Aurand, T. W., Finley, W., Krishnan, V., Sullivan, U. Y., Abresch, J., Bowen, J., et al. (2018). The VW diesel scandal: A case of corporate commissioned greenwashing. *Journal of Organizational Psychology, 18*(1). https://doi.org/10.33423/jop.v18i1.1313

Banking Supervision. (2022). *2022 climate risk stress test*. Retrieved from 20 July 2022.

Barros, B., & Wilk, R. (2021). The outsized carbon footprints of the super-rich. *Sustainability: Science, Practice and Policy, 17*(1), 316–322. https://doi.org/10.1080/15487733.2021.1949847

Barth, M., & Boriboonsomsin, K. (2008). Real-world carbon dioxide impacts of traffic congestion. *Transportation Research Record, 2058*(1), 163–171. https://doi.org/10.3141/2058-20

BBC. (2021). *France moves to ban short-haul domestic flights*. Retrieved from 21 July 2022.

Becken, S. (2002). Analysing international tourist flows to estimate energy use associated with air travel. *Journal of Sustainable Tourism, 10*(2), 114–131. https://doi.org/10.1080/09669580208667157

Becken, S. (2019). Decarbonising tourism: Mission impossible? *Tourism Recreation Research, 44*(4), 419–433. https://doi.org/10.1080/02508281.2019.1598042

Becken, S., & Bobes, L. (2016). *Proving the Case: Carbon reporting in travel and tourism*. Griffith University/Amadeus IT Group.

Becken, S., Frampton, C., & Simmons, D. (2001). Energy consumption patterns in the accommodation sector—the New Zealand case. *Ecological Economics, 39*(3), 371–386. https://doi.org/10.1016/S0921-8009(01)00229-4

Becken, S., & McLennan, C.-L. (2017). Evidence of the water-energy nexus in tourist accommodation. *Journal of Cleaner Production, 144*, 415–425. https://doi.org/10.1016/j.jclepro.2016.12.167

Becken, S., & Patterson, M. (2006). Measuring national carbon dioxide emissions from tourism as a key step towards achieving sustainable tourism. *Journal of Sustainable Tourism, 14*(4), 323–338. https://doi.org/10.2167/jost547.0

Becken, S., & Simmons, D. G. (2002). Understanding energy consumption patterns of tourist attractions and activities in New Zealand. *Tourism Management, 23*(4), 343–354. https://doi.org/10.1016/S0261-5177(01)00091-7

Becken, S., Whittlesea, E., Loehr, J., & Scott, D. (2020). Tourism and climate change: Evaluating the extent of policy integration. *Journal of Sustainable Tourism, 28*(10), 1603–1624. https://doi.org/10.1080/09669582.2020.1745217

Bernath, C., Deac, G., & Sensfuß, F. (2019). Influence of heat pumps on renewable electricity integration: Germany in a European context. *Energy Strategy Reviews, 26*, Article 100389. https://doi.org/10.1016/j.esr.2019.100389

Bohdanowicz, P., & Martinac, I. (2007). 'Determinants and benchmarking of resource consumption in hotels – case study of hilton international and scandic in europe'. *Energy and Buildings, 39*, 82–95.

Boussauw, K., & Decroly, J. M. (2021). Territorializing international travel emissions: Geography and magnitude of the hidden climate footprint of Brussels. *Urban Planning, 6*(2), 285–298. https://doi.org/10.17645/up.v6i2.3905

Bryman, A. (2016). *Social research methods*. Oxford University Press.

Cadarso, M., Gómez, N., López, L. A., & Tobarra, M. (2016). Calculating tourism's carbon footprint: Measuring the impact of investments. *Journal of Cleaner Production, 111*, 529–537. https://doi.org/10.1016/j.jclepro.2014.09.019

Cadarso, M.-Á., Gómez, N., López, L.-A., Tobarra, M.-Á., & Zafrilla, J.-E. (2015). Quantifying Spanish tourism's carbon footprint: The contributions of residents and visitors: A longitudinal study. *Journal of Sustainable Tourism, 23*(6), 922–946. https://doi.org/10.1080/09669582.2015.100849

Cai, M. (2016). Greenhouse gas emissions from tourist activities in South Tyrol: A multiregional input-output approach. *Tourism Economics, 22*(6), 1301–1314. https://doi.org/10.1177/1354816616669008

Coles, T., Dinan, C., & Warren, N. (2016). Energy practices among small-and medium-sized tourism enterprises: A case of misdirected effort? *Journal of Cleaner Production, 111*, 399–408. https://doi.org/10.1016/j.jclepro.2014.09.028

Cooper, J. A., & McCullough, B. P. (2021). Bracketing sustainability: Carbon footprinting March Madness to rethink sustainable tourism approaches and measurements. *Journal of Cleaner Production, 318*, Article 128475. https://doi.org/10.1016/j.jclepro.2021.128475

Craps, A. (2021). What are the changes in LCA passengers' mobility practices? Insights from a European survey. *Transportation Research Interdisciplinary Perspectives, 12*, Article 100477. https://doi.org/10.1016/j.trip.2021.100477

Crawford, R. H., Bontinck, P.-A., Stephan, A., Wiedmann, T., & Yu, M. (2018). Hybrid life cycle inventory methods – a review. *Journal of Cleaner Production, 172*, 1273–1288. https://doi.org/10.1016/j.jclepro.2017.10.176

Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. *Nature Energy, 2*(9), 1–9. https://doi.org/10.1038/nenergy.2017.140

Dubois, G, & Ceron, J. P. (2009). Carbon Labelling and Restructuring Travel Systems: Involving Travel Agencies in Climate Change Mitigation. In S. Gössling, C. M. Hall, & D. B. Weaver (Eds.), *Sustainable Tourism Futures. Perspectives on Systems, Restructuring and Innovations* (pp. 222–239). London: Routledge.

DW. (2022). *EU agrees new cars must be emissions-free after 2035*. Retrieved from 21 July 2022.

Dwyer, L., Forsyth, P., Spurr, R., & Hoque, S. (2010). Estimating the carbon footprint of Australian tourism. *Journal of Sustainable Tourism, 18*(3), 355–376. https://doi.org/10.1080/09669580903513061

Dwyer, L., Mellor, R., Livaic, Z., Edwards, D. J., & Kim, C. (2004). Attributes of destination competitiveness: A factor analysis. *Tourism Analysis, 9*(1), 91–101. https://doi.org/10.3727/1083542041437558

EC (European Commission). (2021). *Questions and answers: Corporate sustainability reporting directive proposal*. Retrieved from 20 July 2022.

EC (European Commission). (2022). *Climate strategies & targets*, 14 July 2022.

Eggleston, H., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). IPCC guidelines for national greenhouse gas inventories. Retrieved from *General guidance and reporting. Institute for Global Environmental Strategies. Japan, 1*, 25 July 2022.

Eijgelaar, E., Thaper, C., & Peeters, P. (2010). Antarctic cruise tourism: The paradoxes of ambassadorship,"last chance tourism" and greenhouse gas emissions. *Journal of Sustainable Tourism, 18*(3), 337–354. https://doi.org/10.1080/09669581003653534

El Hanandeh, A. (2013). Quantifying the carbon footprint of religious tourism: The case of Hajj. *Journal of Cleaner Production, 52*, 53–60. https://doi.org/10.1016/j.jclepro.2013.03.009

Euronews. (2022). *Venice sets date for introduction of ticketing and entry fees*. Retrieved from 25 July 2022.

Eurostat. (2022). *Quarterly greenhouse gas emissions in the EU*. Retrieved from.

Falk, M. T., & Hagsten, E. (2019). Short-run impact of the flight departure tax on air travel. *International Journal of Tourism Research, 21*(1), 37–44. https://doi.org/10.1002/jtr.2239

Falk, M. T., & Hagsten, E. (2021). Determinants of CO2 emissions generated by air travel vary across reasons for the trip. *Environmental Science and Pollution Research, 28*(18), 22969–22980. https://doi.org/10.1007/s11356-020-12219-4

Fichert, F., Forsyth, P., & Niemeier, H. M. (2014). Auswirkungen der deutschen Luftverkehrssteuer auf das Passagieraufkommen. Eine Zwischenbilanz. *Zeitschrift für Verkehrswissenschaft, 85*(3), 167–193.

Filimonau, V., & Delysia, A. (2019). Food waste management in hospitality operations: A critical review. *Tourism Management, 71*, 234–245. https://doi.org/10.1016/j.tourman.2018.10.009

Filimonau, V., Dickinson, J. E., Robbins, D., & Reddy, M. V. (2011). A critical review of methods for tourism climate change appraisal: Life cycle assessment as a new approach. *Journal of Sustainable Tourism, 19*(3), 301–324. https://doi.org/10.1080/09669582.2010.527345

Filimonau, V., Dickinson, J., Robbins, D., & Reddy, M. V. (2013). The role of "indirect" greenhouse gas emissions in tourism: Assessing the hidden carbon impacts from a holiday package tour. *Transportation Research Part A: Policy and Practice, 54*, 78–91. https://doi.org/10.1016/j.tra.2013.07.002

Filimonau, V., Lemmer, C., Marshall, D., & Bejjani, G. (2017). 'Nudging' as an architect of more responsible consumer choice in food service provision: The role of restaurant menu design. *Journal of Cleaner Production, 144*, 161–170.

Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Bakker, D. C., Hauck, J., et al. (2022). Global carbon budget 2021. *Earth System Science Data, 14*(4), 1917–2005.

Gao, T., Liu, Q., & Wang, J. (2014). A comparative study of carbon footprint and assessment standards. *Int. J. Low Carbon Technol., 9*(3), 237–243. https://doi.org/10.1093/ijlct/ctt041

Garcia, B., Foerster, A., & Lin, J. (2021). Net zero for the international shipping sector? An analysis of the implementation and regulatory challenges of the IMO strategy on reduction of GHG emissions. *Journal of Environmental Law, 33*(1), 85–112. https://doi.org/10.1093/jel/eqaa014

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science, 357*(6357), 1242–1244.

Gössling, S. (2000). Sustainable tourism development in developing countries: some aspects of energy-use. *Journal of Sustainable Tourism, 8*(5), 410–425. https://doi.org/10.1080/09669580008667376

Gössling, S. (2002). Global environmental consequences of tourism. *Global Environmental Change, 12*(4), 283–302.

Gössling, S. (2011). *Carbon management in tourism*. London: Routledge.

Gössling, S. (2013). National emissions from tourism: An overlooked policy challenge? *Energy Policy, 59*, 433–442. https://doi.org/10.1016/j.enpol.2013.03.058

Gössling, S. (2020). Risks, resilience, and pathways to sustainable aviation: A COVID-19 perspective. *Journal of Air Transport Management*. https://doi.org/10.1016/j.jairtraman.2020.101933

Gössling, S., & Cohen, S. (2014). Why sustainable transport policies will fail: European union climate policy in the light of transport taboos. *Journal of Transport Geography, 39*, 197–207.

Gössling, S., & Dolnicar, S. (2022). *A review of air travel behavior and climate change. WIRE Climate Change*.

Gössling, S., Fichert, F., & Forsyth, P. (2017). Subsidies in aviation. *Sustainability, 9*(8), 1295.

Gössling, S., & Hall, M. (2008). Swedish tourism and climate change mitigation: An emerging conflict? *Scandinavian Journal of Hospitality and Tourism, 8*(2), 141–158.

Gössling, S., Hanna, P., Higham, J., Cohen, S., & Hopkins, D. (2019). Can we fly less? Evaluating the 'necessity'of air travel. *Journal of Air Transport Management, 81*, 101722.

Gössling, S., & Higham, J. (2021). The low-carbon imperative: Destination management under urgent climate change. *Journal of Travel Research, 60*(6), 1167–1179. https://doi.org/10.1177/0047287520933679

Gössling, S., & Humpe, A. (2020). The global scale, distribution and growth of aviation: Implications for climate change. *Global Environmental Change, 65*, 102194.

Gössling, S., Humpe, A., Fichert, F., & Creutzig, F. (2021). COVID-19 and pathways to low-carbon air transport until 2050. *Environmental Research Letters, 16*(3), 34063.

Gössling, S., & Lyle, C. (2021). Transition policies for climatically sustainable aviation. *Transport Reviews, 41*(5), 643–658.

Gössling, S., & Peeters, P. (2015). Assessing tourism's global environmental impact 1900–2050. *Journal of Sustainable Tourism, 23*(5), 639–659. https://doi.org/10.1080/09669582.2015.1008500

Gössling, S., Peeters, P., Ceron, J. P., Dubois, G., Patterson, T., & Richardson, R. B. (2005). The eco-efficiency of tourism. *Ecol. Econ., 54*(4), 417–434.

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. https://doi.org/10.1016/j.tourman.2014.06.021

Gössling, S., Scott, D., & Hall, C. M. (2018). Global trends in length of stay: Implications for destination management and climate change. *Journal of Sustainable Tourism, 26*(12), 2087–2101. https://doi.org/10.1080/09669582.2018.1529771

Greenhouse Gas Protocol. (2022). *Corporate standard*. Retrieved from 14 July 2022.

Grewe, V., Gangoli Rao, A., Grönstedt, T., Xisto, C., Linke, F., Melkert, J., et al. (2021). Evaluating the climate impact of aviation emission scenarios towards the Paris agreement including COVID-19 effects. *Nature Communications, 12*(1), 1–10.

Guix, M., Ollé, C., & Font, X. (2022). Trustworthy or misleading communication of voluntary carbon offsets in the aviation industry. *Tourism Management, 88*, Article 104430. https://doi.org/10.1016/j.tourman.2021.104430

Gunter, U., & Wöber, K. (2022). Estimating transportation-related CO 2 emissions of European city tourism. *Journal of Sustainable Tourism, 30*(1), 145–168. https://doi.org/10.1080/09669582.2021.1939708

Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. (2011). *Global food losses and food waste*. Rome: FAO.

Habibi, S., Hugosson, M. B., Sundbergh, P., & Algers, S. (2019). Car fleet policy evaluation: The case of bonus-malus schemes in Sweden. *International Journal of Sustainable Transportation, 13*(1), 51–64. https://doi.org/10.1080/15568318.2018.1437237

Hall, C. M. (2009). Degrowing Tourism: Décroissance, sustainable consumption and steady-state tourism. *Anatolia, 20*(1), 46–61. https://doi.org/10.1080/13032917.2009.10518894

Hall, C. M., & Wood, K. J. (2021). Demarketing tourism for sustainability: Degrowing tourism or moving the deckchairs on the titanic? *Sustainability, 13*(3), 1585. https://doi.org/10.3390/su13031585

Hoque, S., Forsyth, P., Dwyer, L., Spurr, R., Ho, T. V., & Pambudi, D. (2010). *The carbon footprint of Queensland tourism*. CRC for Sustainable Tourism: Griffith University.

Huang, T., & Tang, Z. (2021). Estimation of tourism carbon footprint and carbon capacity. *Int. J. Low Carbon Technol., 16*(3), 1040–1046. https://doi.org/10.1093/ijlct/ctab026

Hunter, C. (2002). Sustainable tourism and the touristic ecological footprint. Environment. *Development and Sustainability 4*, 7–20. https://doi.org/10.1023/A:1016336125627

IATA. (2019). *Economic performance of the airline industry*. Retrieved from.

IATA. (2021). *Resolution on the industry's commitment to reach net zero carbon emissions by 2050*. Retrieved from.

IATA. (2022). *Net zero Resolution Fact sheet*. Retrieved from.

ICAO. (2016a). *Carbon offsetting and reduction scheme for international aviation (CORSIA)*. Retrieved from.

ICAO. (2016b). *ICAO environmental report 2016: Aviation and climate change*. Retrieved from.

ICAO. (2020). *Economic impacts of COVID-19 on Civil aviation*. Retrieved from 15 June 2020.

IEA (International Energy Agency). (2020). *International shipping*. Retrieved from.

IEMA. (2022). *GHG Management Hierarchy updated for net-zero*. Available.

IMFBlog. (2022). *Facing a darkening economic outlook: How the G20 can respond*. Retrieved from.

IMO. (2020). *IMO action to reduce greenhouse gas emissions from international shipping*. Retrieved from.

IPCC. (2022a). *Climate Change 2022. Mitigating climate change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. WMO/UNEP.

IPCC. (2022b). The evidence is clear: The time for action is now. *We can halve emissions by, 2030*. Available.

Jandrokovic, M., Mandl, D., & Kapusta, F. (2012). *Energiekennzahlen in Dienstleistungsgebäuden. Kennzahlen zum Energieverbrauch, die relevantesten Einsparpotenziale und Hauptverbraucher in ausgewählten Branchen – Bürobetriebe, Einzelhandel, Non Food, Lebensmitteleinzelhandel, Gastronomie, Hotellerie (3- und 4-Stern) – im Rahmen des Projektes EV-DLB – energieverbrauch im Dienstleistungssektor. Wien: Energieinstitut der Wirtschaft GmbH*.

Jelle, B. P. (2011). Traditional, state-of-the-art and future thermal building insulation materials and solutions–Properties, requirements and possibilities. *Energy Build., 43*(10), 2549–2563. https://doi.org/10.1016/j.enbuild.2011.05.015

Joung, T. H., Kang, S. G., Lee, J. K., & Ahn, J. (2020). The IMO initial strategy for reducing Greenhouse Gas (GHG) emissions, and its follow-up actions towards 2050. *Journal of International Maritime Safety, Environmental Affairs, and Shipping, 4*(1), 1–7. https://doi.org/10.1080/25725084.2019.1707938

Kasim, A. (2006). The need for business environmental and social responsibility in the tourism industry. *International Journal of Hospitality & Tourism Administration, 7*(1), 1–22. https://doi.org/10.1300/J149v07n01_01

Kelly, J., & Williams, P. W. (2007). Modelling tourism destination energy consumption and greenhouse gas emissions: Whistler, British columbia, Canada. *Journal of Sustainable Tourism, 15*(1), 67–90. https://doi.org/10.2167/jost609.0

Klijs, J., Peerlings, J., & Heijman, W. (2015). Usefulness ofnon-linear input–output models for economic impact analyses in tourism and recreation. *Tourism Economics, 21*(5), 931–956. https://doi.org/10.5367/te.2014.0398

Konan, D. E., & Chan, H. L. (2010). Greenhouse gas emissions in Hawai'i: Household and visitor expenditure analysis. *Energy Economics, 32*(1), 210–219. https://doi.org/10.1016/j.eneco.2009.06.015

Kuo, N., Lin, C., Chen, P., & Chen, Y. (2012). An inventory of the energy use and carbon dioxide emissions from island tourism based on a life cycle assessment approach. *Environmental Progress & Sustainable Energy, 31*(3), 459–465. https://doi.org/10.1002/ep

Le Quéré, C., Peters, G. P., Friedlingstein, P., Andrew, R. M., Canadell, J. G., Davis, S. J., et al. (2021). Fossil CO2 emissions in the post-COVID-19 era. *Nature Climate Change, 11*(3), 197–199.

Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., et al. (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment, 244*, 117834.

Lenzen, M., Murray, J., Sack, F., & Wiedmann, T. (2007). Shared producer and consumer responsibility — theory and practice. *Ecological Economics, 61*(1), 27–42.

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. https://doi.org/10.1038/s41558-018-0141-x

Li, Y., & Zhang, L. (2020). Ecological efficiency management of tourism scenic spots based on carbon footprint analysis. *Int. J. Low Carbon Technol., 15*(4), 550–554. https://doi.org/10.1093/ijlct/ctaa023

Lund, R., Ilic, D. D., & Trygg, L. (2016). Socioeconomic potential for introducing large-scale heat pumps in district heating in Denmark. *Journal of Cleaner Production, 139*, 219–229. https://doi.org/10.1016/j.jclepro.2016.07.135

Luo, Y., Mou, Y., Wang, Z., Su, Z., & Qin, Y. (2020). Scenario-based planning for a dynamic tourism system with carbon footprint analysis : A case study of xingwen global geopark, China. *Journal of Cleaner Production 254*. https://doi.org/10.1016/j.jclepro.2020.119999

Lyle, C. (2018). Beyond the ICAO's CORSIA: Towards a more climatically effective strategy for mitigation of civil-aviation emissions. *Climate Law, 8*(1), 104–127.

Malik, A., Egan, M., Du Plessis, M., & Lenzen, M. (2021). Managing sustainability using financial accounting data: The value of input-output analysis. *Journal of Cleaner Production, 293*, Article 126128. https://doi.org/10.1016/j.jclepro.2021.126128

Markham, F., Young, M., Reis, A., & Higham, J. (2018). Does carbon pricing reduce air travel? Evidence from the Australian 'clean energy future' policy, july 2012 to june 2014. *Journal of Transport Geography, 70*, 206–214. https://doi.org/10.1016/j.jtrangeo.2018.06.008

McKinsey. (2022). *Making net-zero aviation Possible*. Retrieved from 16 July 2022.

Meng, W., Xu, L., Hu, B., Zhou, J., & Wang, Z. (2016). Quantifying direct and indirect carbon dioxide emissions of the Chinese tourism industry. *Journal of Cleaner Production, 126*, 586–594. https://doi.org/10.1016/j.jclepro.2016.03.177

Merk, O. M. (2020). Quantifying tax subsidies to shipping. *Maritime Economics & Logistics, 22*(4), 517–535. https://doi.org/10.1057/s41278-020-00177-0

Munday, M., Turner, K., & Jones, C. (2013). Accounting for the carbon associated with regional tourism consumption. *Tourism Management, 36*, 35–44. https://doi.org/10.1016/j.tourman.2012.11.005

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1), 1–13. https://doi.org/10.1177/1609406917733847

OECD. (2022). *OECD territorial grids. OECD Centre for Entrepreneurship, SMEs, regions and cities*. Retrieved from.

OECD, & UNEP. (2011). *Climate change and tourism policy in OECD countries*. Paris, France: Organization of Economic Co-operation and Development (OECD) and United Nations Environment Programme (UNEP).

Oklevik, O., Gössling, S., Hall, C. M., Jacobsen, S., 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.

Østli, V., Fridstrøm, L., Kristensen, N. B., & Lindberg, G. (2021). Comparing the Scandinavian automobile taxation systems and their CO2 mitigation effects. *International Journal of Sustainable Transportation*, 1–18. https://doi.org/10.1080/15568318.2021.1949763

Oswald, Y., Steinberger, J. K., Ivanova, D., & Millward-Hopkins, J. (2021). Global redistribution of income and household energy footprints: A computational thought experiment. *Global Sustainability, 4*.

Oxford Economics/CLIA. (2021). *Environmental commitment, innovation, and results of the cruise industry*. Retrieved from.

Paterson, M. (2000). Car culture and global environmental politics. *Review of International Studies, 26*(2), 253–270. https://doi.org/10.1017/S0260210500002539

Patterson, M. G., & McDonald, G. C. (2004). *How clean and green is New Zealand tourism? Lincoln: Manaaki Whenua press*.

Pearce, D. (2003). *Environmentally harmful subsidies: Barriers to sustainable development. Policy issues and challenges. OECD*.

Peeters, P., & Dubois, G. (2010). Tourism travel under climate change mitigation constraints. *Journal of Transport Geography, 18*(3), 447–457. https://doi.org/10.1016/j.jtrangeo.2009.09.003

Peeters, P. M., & Eijgelaar, E. (2014). Tourism's climate mitigation dilemma: Flying between rich and poor countries. *Tourism Management, 40*, 15–26. https://doi.org/10.1016/j.tourman.2013.05.001

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.

Peeters, P., & Landré, M. (2011). The emerging global tourism geography—an environmental sustainability perspective. *Sustainability, 4*(1), 42–71. https://doi.org/10.3390/su4010042

Peng, Y. T., Saboori, B., Ranjbar, O., & Can, M. (2022). The effects of tourism market diversification on CO2 emissions: Evidence from Australia. *Current Issues in Tourism*, 1–8. https://doi.org/10.1080/13683500.2022.2071683

Pham, T., Meng, X., & Becken, S. (2022). Measuring tourism emissions at destination level: Australia case. *Annals of Tourism Research Empirical Insights, 3*(2). https://doi.org/10.1016/j.annale.2022.100062, 100062.

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science, 360*(6392), 987–992. https://doi.org/10.1126/science.aaq0216

Possible. (2022). *Missed targets*. Retrieved from.

Pradhan, P., Reusser, D. E., & Kropp, J. P. (2013). Embodied greenhouse gas emissions in diets. *PloS ONE, 8*(5), e62228. https://doi.org/10.1371/journal.pone.0062228

Reynolds, C., Goucher, L., Quested, T., Bromley, S., Gillick, S., Wells, V. K., et al. (2019). Consumption-stage food waste reduction interventions–What works and how to design better interventions. *Food Pol., 83*, 7–27. https://doi.org/10.1016/j.foodpol.2019.01.009

Rico, A., Martínez-Blanco, J., Montlleó, M., Rodríguez, G., Tavares, N., Arias, A., et al. (2019). Carbon footprint of tourism in Barcelona. *Tourism Management, 70*, 491–504. https://doi.org/10.1016/j.tourman.2018.09.012

Robaina-Alves, M., Moutinho, V., & Costa, R. (2016). Change in energy-related CO2 (carbon dioxide) emissions in Portuguese tourism: A decomposition analysis from 2000 to 2008. *Journal of Cleaner Production, 111*, 520–528. https://doi.org/10.1016/j.jclepro.2015.03.023

Scott, D., & Gössling, S. (2022). Destination net-zero: what does the international energy agency roadmap mean for tourism? *Journal of Sustainable Tourism, 30*(1), 14–31. https://doi.org/10.1080/09669582.2021.1962890

Scott, D., Hall, C. M., & Gössling, S. (2019). Global tourism vulnerability to climate change. *Annals of Tourism Research, 77*, 49–61.

Scott, D., Peeters, P., & Gössling, S. (2010). Can tourism deliver its 'aspirational' greenhouse gas emission reduction targets? *Journal of Sustainable Tourism, 18*(3), 393–408. https://doi.org/10.1080/09669581003653542

Smith, P., et al. (2016). Biophysical and economic limits to negative CO2 emissions. *Nature Climate Change, 6*(1), 42–50. https://doi.org/10.1038/nclimate2870

Sozer, H. (2010). Improving energy efficiency through the design of the building envelope. *Building and Environment, 45*(12), 2581–2593. https://doi.org/10.1016/j.buildenv.2010.05.004

Sun, Y.-Y. (2014). A framework to account for the tourism carbon footprint at island destinations. *Tourism Management, 45*, 16–27. https://doi.org/10.1016/j.tourman.2014.03.015

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., Cadarso, M. A., & Driml, S. (2020). Tourism carbon footprint inventories: A review of the environmentally extended input-output approach. *Annals of Tourism Research, 82*, Article 102928. https://doi.org/10.1016/j.annals.2020.102928

Sun, Y. Y., Gössling, S., & Zhou, W. (2022). Does tourism development increase or decrease carbon emissions? A systematic review. *Annals of Tourism Research*.

Sun, Y.-Y., & Higham, J. (2021). Overcoming information asymmetry in tourism carbon management: The application of a new reporting architecture to Aotearoa New Zealand. *Tourism Management, 83*, 104231. https://doi.org/10.1016/j.tourman.2020.104231

Sun, Y.-Y., Lenzen, M., & Liu, B. (2019). The national tourism carbon emission inventory : Its importance, applications and allocation frameworks. *Journal of Sustainable Tourism, 27*(3), 360–379. https://doi.org/10.1080/09669582.2019.1578364

Sun, Y., Lin, P., & Higham, J. (2020). Managing tourism emissions through optimizing the tourism demand mix: Concept and analysis. *Tourism Management, 81*, Article 104161. https://doi.org/10.1016/j.tourman.2020.104161

Sun, Y.-Y., & Wong, K.-F. (2014). Stability of input—output coefficients by capacity utilization for short-term tourism demand fluctuation. *Tourism Economics, 20*(3), 509–526. https://doi.org/10.5367/te.2013.0294

Susilorini, R. M. I. R., Ismail, A., Wastunimpuna, B. Y. A., Wardhani, D. K., Prameswari, L. L. N., Amasto, A. H., et al. (2022). Tourism village carbon footprint after COVID-19 pandemic: A challenge to sustainability. *Sustainability (Switzerland), 14*(4). https://doi.org/10.3390/su14042400.

Sustainable Hospitality Alliance. (2017). *Global Hotel decarbonisation report*. Retrieved from.

Tang, M., & Ge, S. (2018). Accounting for carbon emissions associated with tourism-related consumption. *Tourism Economics, 24*(5), 510–525. https://doi.org/10.1177/1354816618754691

Tang, Z., & Huang, T. (2021). Carbon dioxide emission measurement and its spatiotemporal evolution of tourism industry in heilongjiang province, China. *Advances in Meteorology, 1458373*. https://doi.org/10.1155/2021/1458373

The Wall Street Journal. (2022). *France considers taxing private jet use in fight against climate change*. Retrieved from.

Thongdejsri, M., & Nitivattananon, V. (2019). Assessing impacts of implementing low-carbon tourism program for sustainable tourism in a world heritage city. *Tourism Review, 74*(2), 138–156. https://doi.org/10.1108/TR-04-2017-0082

Trading Economics. (2022). *Gasoline*. Retrieved from.

Tsukui, M., Ichikawa, T., & Kagatsume, M. (2017). Repercussion effects of consumption by domestic tourists in Tokyo and Kyoto estimated using a regional waste input–output approach. *Journal of Economic Structures, 6*(1). https://doi.org/10.1186/s40008-017-0061-3

The World Bank. (2022). *International tourism, expenditures*. Retrieved from: https://data.worldbank.org/indicator/ST.INT.XPND.CD.

UBA. (2021). *Klimaschutzinstrumente im Verkehr. Tempolimit auf Autobahnen*. Retrieved from.

UNFCCC. (1998). *Kyoto Protocol to the UNFCCC*. Retrieved from.

UNFCCC. (2018). *What is the Paris agreement?*. Available 1 December 2018.

UNFCCC. (2022). *NDC Registry*. Available. Retrieved from 23 July 2022.

UNWTO & ITF. (2019). *Transport-related CO2 emissions from the tourism sector*. Retrieved from.

UNWTO. (2022). *Transforming tourism for climate action*. Retrieved from 20 July 2022.

UNWTO, UNEP & WMO. (2008). *Climate change and tourism: Responding to global challenges*. Madrid: World Tourism Organization.

Van Beers, C., & de Moor, S. (2001). *Public subsidies and policy Failures: How subsidies distort the natural environment, equity and trade and how to Reform them*. Cheltenham, UK: Edward Elgar Publishing.

VisitValencia. (2019). *Carbon footprint calculation of valencia tourist activity*. Retrieved from 21 July 2022.

Visschers, V. H. M., & Siegrist, M. (2015). Does better for the environment mean less tasty? Offering more climate-friendly meals is good for the environment and customer satisfaction. *Appetite, 95*, 475–483. https://doi.org/10.1016/j.appet.2015.08.013

Wang, L., Xu, C., & Guo, X. (2021). Subsidy policies and supply chain management for emerging cruise industry. *Maritime Policy & Management, 48*(1), 91–108. https://doi.org/10.1080/03088839.2020.1757776

Westhoek, H., Lesschen, J. P., Rood, T., Wagner, S., De Marco, A., Murphy-Bokern, D., et al. (2014). Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. *Global Environmental Change, 26*, 196–205. https://doi.org/10.1016/j.gloenvcha.2014.02.004

Whittlesea, E. R., & Owen, A. (2012). Towards a low carbon future–the development and application of REAP Tourism, a destination footprint and scenario tool. *Journal of Sustainable Tourism, 20*(6), 845–865. https://doi.org/10.1080/09669582.2012.680699

Wiedmann, T., & Minx, J. (2008). A definition of 'carbon footprint'. In C. C. Pertsova (Ed.), *Ecological economics research trends: Chapter* (pp. 1–11). Hauppauge NY, USA: Nova Science Publishers.

World Bank. (2013). *Calculating the carbon footprint from different classes of air travel. Policy Research Working Paper 6471*. Available 25 July 2022.

WTTC-UNEP-UNFCCC. (2021). *Driving climate action: A net zero roadmap for travel & tourism*. Retrieved from.

WWF Germany. (2013). *Machbarkeitsstudie zum klimafreundlichen Tourisms im Wattenmeer (Feasibility study on climate-friendly tourism in the Wadden Sea)*. Retrieved from.

Yang, X., Lin, S., Li, Y., & He, M. (2019). Can high-speed rail reduce environmental pollution? Evidence from China. *Journal of Cleaner Production, 239*, Article 118135. https://doi.org/10.1016/j.jclepro.2019.118135

Yu, L., Bai, Y., & Liu, J. (2019). The dynamics of tourism ' s carbon footprint in. *Journal of Sustainable Tourism, 27*(10), 1553–1569. https://doi.org/10.1080/09669582.2019.1648480

Zha, J., He, L., Liu, Y., & Shao, Y. (2019). Evaluation on development efficiency of low-carbon tourism economy: A case study of hubei province, China. *Socio-Economic Planning Sciences, 66*, 47–57. https://doi.org/10.1016/j.seps.2018.07.003

Zhang, J., & Zhang, Y. (2020). Assessing the low-carbon tourism in the tourism-based urban destinations. *Journal of Cleaner Production, 276*, Article 124303. https://doi.org/10.1016/j.jclepro.2020.124303

Stefan Gössling is a professor of tourism at Linnaeus University, Sweden. He has worked with sustainable tourism since the mid 1990s.

Martin Balas is a research fellow at the Biosphere Reserves Institute of the University for Sustainable Development Eberswalde in Germany. His research interests are in the area of sustainable destination management, corporate social responsibility (CSR), certification and regional economic effects of tourism. His PhD research focuses on the Measurement of sustainability impacts of tourism.

Marius Mayer is professor for sustainability and destination development at the Munich University of Applied Sciences, Germany, since October 2022. His research interests cover sustainable tourism, climate change and tourism, tourism in protected areas and regional development.

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.