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Energy Consumption and Greenhouse Gas Emissions Resulting From Tourism Travel in an Alpine Setting

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Tourism—with its social, economic, and ecological dimensions—can be an important driver of sustainable development of alpine communities. Tourism is essential for local people's incomes and

livelihoods, but it can also have a major impact on the local environment, landscape aesthetics, and (mainly through tourist transport) global climate change. A project currently underway is developing the Austrian mountain municipality of Alpbach into a role model for competitive and sustainable year-round alpine tourism using an integrated and spatially explicit approach that considers energy demand and supply related to housing, infrastructure, and traffic in the settlement and the skiing area. As the first outcome of the project, this article focuses on the development of the Model of Alpine Tourism and

Transportation, a geographic information system-based tool for calculating, in detail, energy consumption and greenhouse gas emissions resulting from travel to a single alpine holiday destination. Analysis results show that it is crucial to incorporate both direct and indirect energy use and emissions as each contributes significantly to the climate impact of travel. The study fills a research gap in carbon impact appraisal studies of tourism transport in the context of alpine tourism at the destination level. Our findings will serve as a baseline for the development of comprehensive policies and agendas promoting the transformation toward sustainable alpine tourism.

Keywords: Tourism transport; energy; greenhouse gas emissions; climate change; GIS-based carbon impact appraisal; Austria.

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Introduction

Tourism, in particular ski tourism, significantly contributes to the national economy of Austria; 25% of all tourism spending occurs in the province of the Tyrol. In 2014, the direct added value of tourism in Tyrol was US\$ 4.5 billion, representing 18% of the Tyrolean gross domestic product (Tirol Werbung 2014). Such numbers highlight the economic importance of tourism in mountainous regions like Tyrol as well as its social importance for local communities and its ecological function of sustaining attractive natural and cultural landscapes that are, in turn, the foundation of tourism. Anthropogenic climate change has the potential to significantly disturb this economically vital sector (Dawson and Scott 2013). Alpine tourism has been repeatedly identified as one of the industries most vulnerable to climate change (UNWTO et al 2008; Dawson and Scott 2013).

Tourism itself contributes significantly to global greenhouse gas (GHG) emissions, summing up to 12.5% of

total global emissions, including the secondary atmospheric impacts caused by aviation, measured as “radiative forcing” (Scott et al 2010). Transport accounts for 72% of tourism's CO₂ emissions (UNWTO et al 2008; Peeters and Dubois 2010; Scott et al 2010; Peeters 2013), followed by accommodation (24%) and recreational activities (4%) (Peeters and Dubois 2010). Of the transport-related carbon emissions, 60% are caused by only 17% of trips, those made by plane. Car travel accounts for 36% and all other forms for 4% (Peeters and Dubois 2010).

Numerous studies have estimated tourism-related GHG emissions at the national and regional level (Høyer 2000; Becken et al 2003; Chenoweth 2009; Dwyer et al 2010; Hoque et al 2010; Perch-Nielsen et al 2010), all of them identifying transportation as the major driver of GHG emissions. Only a few attempts have been made to assess tourism-related energy consumption and GHG emissions at the destination level. Case studies have been undertaken using national emission factors and data from visitor surveys asking about distances traveled, modes of

transport, and number of members in a group (Gössling et al 2005; Kelly and Williams 2007; Lin 2010). Kelly and Williams (2007) found that origin-to-destination transport (ODT) accounts for 80% of the energy consumption and 86% of the GHG emissions of Whistler, Canada, with over 70% of GHG emissions caused by air travel (Kelly and Williams 2007). Studies by the Mountain Riders Organization (2015) indicated that 57% of all GHG emissions of French mountain resorts are related to ODT.

While GHG emissions are a global problem that can only be solved in global agreements, progress must be made at the destination level if effective improvements are to be achieved (Gössling 2009). Therefore, destination-specific baseline scenarios are needed to provide local destination planners with an in-depth view of the dimensions and relations of emissions caused by different modes of ODT. To model energy consumption and GHG emissions on a local scale, emissions factors have to be carefully defined, as these may differ substantially by region, depending on preferred modes of transport, fuel types, load factors (numbers of passengers per vehicle), and types of air travel (short and long haul) (Becken et al 2003; Gössling et al 2005; Becken and Patterson 2006; Peeters et al 2007; Peeters and Dubois 2010; Filimonau et al 2013).

In this article, we present a GIS (geographic information system)-based tool for calculating energy consumption and GHG emissions for tourist transport to and from a single destination, using emissions and demographic data from different sources. The Model of Alpine Tourism and Transportation (MATT) was developed as part of a study that aims to develop the mountain municipality of Alpbach, Austria (47°23'55"N, 11°56'40"E, Figure 1) into a role model for sustainable year-round alpine tourism. The study's objectives are to analyze Alpbach's energy demand and GHG emissions patterns and the potential of renewable energy in the region, and to initiate the development of an optimized and autonomous energy supply system, pursuing the concept of a "carbon neutral destination" as elaborated by Gössling (2009). The study contributes to Future Earth's research theme, Global Sustainable Development (Future Earth 2014), as it supports decarbonization of the tourism industry, which is crucial for many mountainous regions.

From a systems analytical approach, Alpbach as a tourist destination can be described as a system with 3 major elements: skiing and recreation, transport, and housing (including accommodation). For these sectors, the status quo of energy consumption and GHG emissions can be assessed, and pragmatic (best practice) as well as normative (self-sufficiency) scenarios of energy development can be simulated. This article focuses on the transport part of the system and shows how a carbon impact appraisal can be conducted at the destination level in a mountain area.

The Model of Alpine Tourism and Transportation (MATT)

ODT's energy consumption and GHG emissions are a function of round-trip travel distance, travel mode, load factor, and specific energy consumption and emissions factors. To develop the MATT, we relied on an electronic tourist register administrated by the local tourism association, which is part of a mandatory nationwide registration system in which data such as the accommodation's identity, the number of visitors, their places of origin, and their arrival and departure dates are recorded—hence our study does not account for same-day visitors at this stage.

We used the ArcGIS World Geocoding Service (ESRI 2016) to geocode place-of-origin data for the 2014–2015 winter season (November to April). After determining whether a geocoded data point was actually located within its respective country borders, 16,985 (about 45%) of 37,658 original entries yielded valid address points. Although the correctly geocoded share was relatively small, we consider the dataset to be representative, as the country-of-origin distribution within the 2 datasets was similar (Figure 2).

We used QGIS, an open-source GIS, to create a density raster (heat map) of the geocoded visitor address points. Heat maps are based on kernel density estimation and allow a quick identification of hot spots and point clusters.

On this basis, 235 visitor-sending hot spots or hubs were defined, which made it possible for us to generalize and calculate journey distances (Figure 3). In order to connect the visitor home addresses with associated hubs, ellipsoidal distances were calculated, resulting in a shapefile containing the attributes from the address layer and the number of geocoded visitors per hub as well as the spatial information. This was exported to a PostgreSQL/PostGIS spatial database for further calculations. As only 45% of the visitor data were captured, the number of geocoded visitors associated with each hub was extrapolated to the statistical population using the equation

$$Visitors_{hub} = \frac{Visitors_{geocod_hub} \times Visitors_{ori_co}}{Visitors_{geocod_co}} \quad (1)$$

where $Visitors_{hub}$ is the statistical population, $Visitors_{geocod_hub}$ is the number of geocoded visitors assigned to the hub, $Visitors_{ori_co}$ is the total number of visitors from the specific country of origin, and $Visitors_{geocod_co}$ is the total number of geocoded visitors from the specific country of origin.

Estimating person kilometers traveled per transportation mode

To estimate energy consumption and GHG emissions resulting from overnight visitor travel to and from

FIGURE 1 Location of Alpbach and the 2 nearest airports, Munich and Innsbruck. (Map by Rainer Unger)



Alpbach, we calculated the total amount of person kilometers traveled (PKT), based on the distances from the visitor hubs to Alpbach, for 4 modes of travel (private vehicle, bus, train, and airplane).

Tourism travel to and from Alpbach is well dominated by private vehicles (75%). The high proportion of British tourists in Alpbach in winter raises aviation's share to 13%, whereas air travel constitutes only 5% of tourism travel in the province of the Tyrol as a whole. Another 7% of visitors come by bus and 5% by train (Rauch et al 2010; Manova 2014).

Based on these data, we assumed that all holiday makers from Austria and neighboring countries travel by private car, train, or bus. We used the Google Maps routing tool to calculate round-trip road distances between the hubs in these countries and Alpbach, assuming equal distances for all 3 modes of travel. For all other countries, we assumed that visitors come by plane and looked up round-trip distances from the hubs based on the ICAO carbon emissions calculator (ICAO 2015).

Calculating the overall PKT took multiple steps. We used the following equation for overland travel:

$$PKT_{overland} = \sum_{hub=1}^n Visitors_{hub} \times RRD_{hub} \quad (2)$$

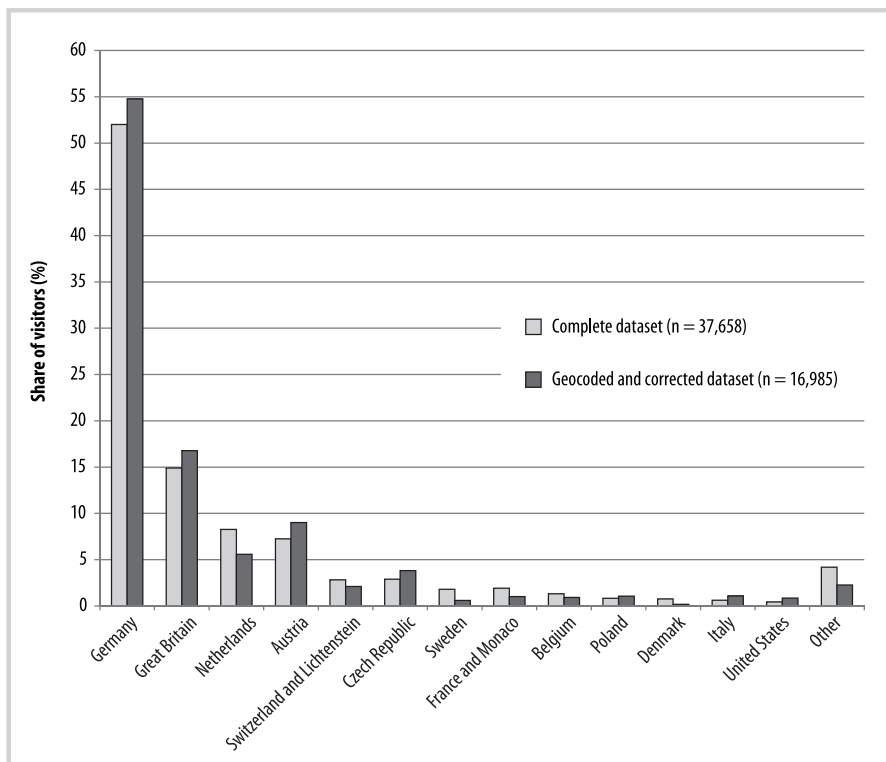
where $PKT_{overland}$ is the total number of person kilometers traveled overland (not differing between modes and not accounting for a "last mile" between the railway station and the destination), $Visitors_{hub}$ is the number of visitors associated with each hub, and RRD_{hub} is the round-trip road distance between hub and destination.

To estimate PKT for airplane travel, we added a "first mile" and "last mile" to the flight distances (calculation based on the emissions factors for car travel). The first mile concept refers to the person's entry into the transportation network, that is, the distance from the home address to the airport. The same principle applies to the last mile. Therefore, we used the following equation:

$$PKT_{air} = \sum_{h=1}^n Visitors_{hub} \times (RFD_{hub} + D_{fm} + D_{lm}) \quad (3)$$

where PKT_{air} is the total PKT by airplane, RFD_{hub} is the round-trip flight distance from each hub assumed to be a departure airport; D_{fm} is a 150 km radius from each home airport (fm = first mile); and D_{lm} is the last mile from either Innsbruck (60 km) or Munich (169 km) to the destination.

To calculate the total number of kilometers traveled to the destination and return, $PKT_{overland}$ and PKT_{air} were

FIGURE 2 Corrected and uncorrected data from the electronic tourist register.

added to PKT_{total} (Table 1). Kilometers traveled in each transportation mode were then calculated based on the modal split derived from recent visitor survey data, as mentioned earlier (Rauch et al 2010; Manova 2014). Energy consumption and GHG emissions were eventually calculated by multiplying PKT_{total} by the energy and emissions factors described in the next section.

Deriving energy and emissions factors

Energy consumption for each mode of transport was calculated as direct energy (the consumption of fossil fuel and electricity during transport) and cumulative energy (which includes the energy used during the entire production process (exploration, extraction, transport, and production of fuels). Both were measured in kWh/PKT.

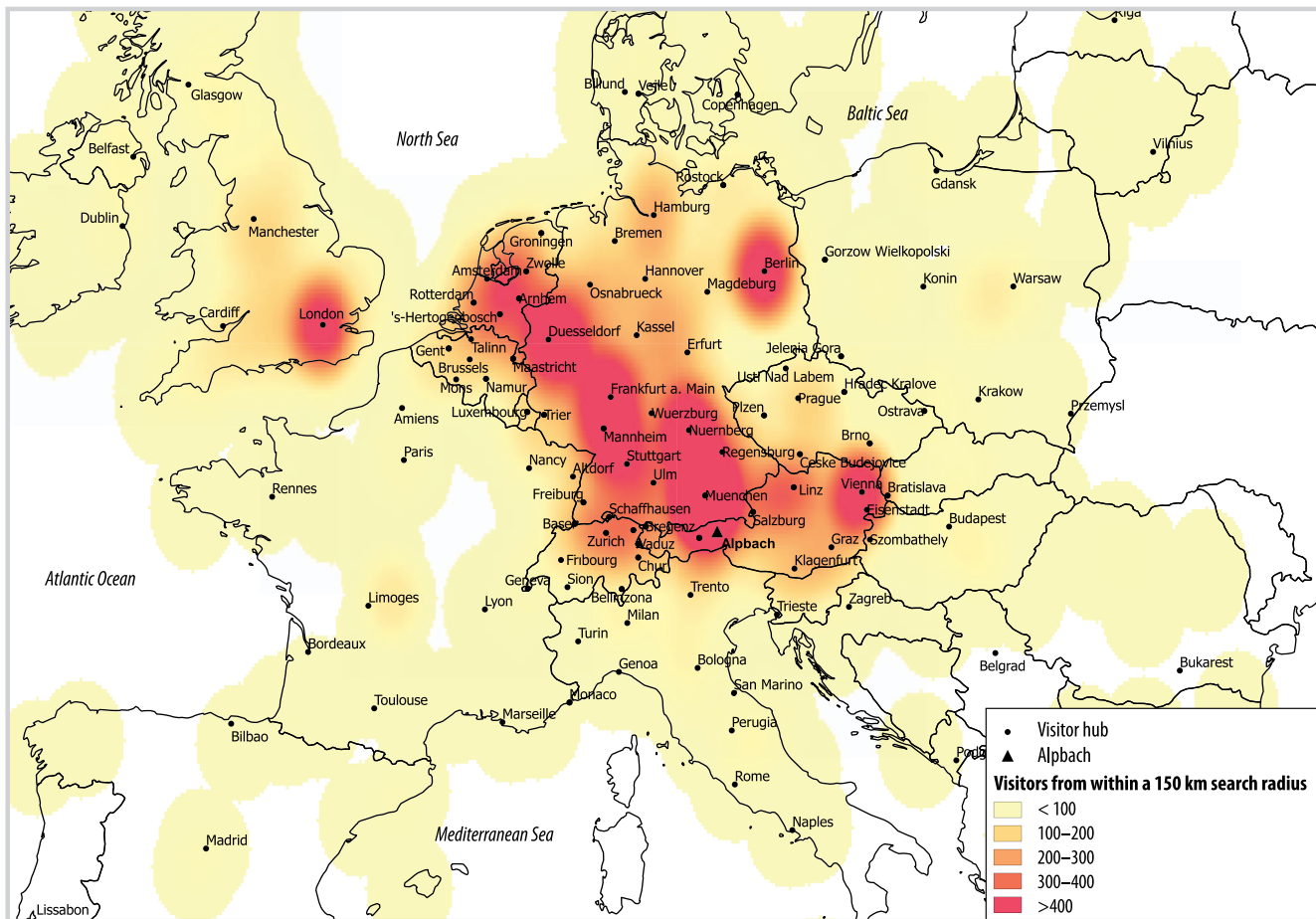
Emissions were calculated as a carbon dioxide equivalent (CO_2e) to account for the full GHG potential of emissions from burning fossil fuel. We distinguished between direct CO_2e , which is produced at the location of energy conversion, and cumulative CO_2e , which takes into account the entire production process (exploration, extraction, transport, and production of fuel).

Values for energy consumption and GHG emissions of private vehicles were derived from the open-source database GEMIS 4.94—Global Emissions Model for Integrated Systems (IINAS 2015). Fuel consumption and CO_2e for diesel- and gasoline-driven medium-class

passenger vehicles were calculated as average values due to the fact that the mean market share of diesel vehicles in EU-28 has oscillated between 45% and 55% since 2005 (ICCT 2015). GEMIS data do not account for car age structure but relate to specific reference years; this study used the data for 2010.

To calculate energy and emissions values per PKT, we assumed a load factor of 3 persons per car based on a local transportation study (Rauch et al 2010) and a visitor survey in winter 2015–2016 that was part of this project; the load factor for buses was derived from GEMIS 4.94 data (IINAS 2015). The values for all means of transport considered in the study are given in Table 1.

Estimates of energy and emissions values for railways were based on Germany's national fuel-production mix. Energy consumption and emissions data were taken from the Transport Emission Model, version 5.41 (Knörr et al 2012), and are published online by the German Federal Environmental Agency (UBA 2014). Direct CO_2e emissions per passenger were calculated by downscaling the cumulative CO_2e emissions for German trains (UBA 2014) using an energy efficiency factor of 0.353 (Knörr and Hüttermann 2015)—that is, the relation of direct energy to cumulative energy (BMVI 2014). This method was considered to be appropriate since Germany's mix of electricity production is still dominated by fossil fuels (Knörr and Hüttermann 2015).

FIGURE 3 Heat map (density raster) of the main visitor source markets. (Map by Rainer Unger)

To estimate mean CO₂e and energy consumption per PKT for air travel, we used data on great-circle distances, kerosene consumption, and total direct CO₂ emissions between the various hubs and either Innsbruck or Munich. This was derived by querying the online International Civil Aviation Organization Carbon Emissions Calculator (ICAO 2015).

ICAO only accounts for direct CO₂ emissions by burning aviation fuel and quantifies neither the CO₂

emissions of preproduction processes of kerosene nor the full GHG potential of emissions in terms of radiative forcing or global warming potential. The latter is because the CO₂e can only be calculated for GHG with a lifetime of more than 10 years (Herold 2003). As a consequence, emissions from aviation (NO_x forming tropospheric ozone, methane, and water vapor forming contrails and cirrus clouds) are difficult to compare because they are short-lived and not well mixed in the atmosphere

TABLE 1 Load factors and energy and emissions factors for different modes of tourism transport to Alpach.

Mode of transport	Fuel type	Load factor (persons per vehicle)	Energy consumption (kWh/PKT)		CO ₂ e emissions (g/PKT)	
			Direct	Cumulative	Direct	Cumulative
Private vehicle ^{a)}	Diesel/gas mix (50:50)	3	0.22	0.28	53.08	65
Bus	Diesel	30	0.13	0.16	31.54	38.10
Train	Electric	Not specified ^{b)}	0.07	0.19	15.05	43
Airplane	BP Jet A-1 (kerosene)	131	0.35	0.43	107.86 ^{c)}	233.12

^{a)} Includes cars, motorcycles, and recreational vehicles.

^{b)} based on German national average emission data

^{c)} CO₂ only based on ICAO Carbon Emissions Calculator (ICAO 2015)

TABLE 2 Calculation of emission factors for aviation

	Short haul (<1500 km)	Medium haul (1500–2500 km)	Long haul (>2500 km)	Weighted average
Number of visitors	7071	199	713	7983
Round-trip travel distance (km)	52,330	26,392	938,274	1,016,996
Fuel burn rate (kg/km)	3.6	3.46	6.57	3.86
Average load factor ^{a)}	122	169	216	131
Final energy consumption (kWh/PKT)	0.36	0.25	0.36	0.35
Cumulative energy consumption (kWh/PKT)	0.43	0.3	0.44	0.43
CO ₂ (g/PKT)	111.78	83.19	75.8	107.86
CO ₂ e (g/PKT)	241.6	179.82	163.84	233.12

^{a)} Based on the assumption that 77% of available seats are filled.

(UNWTO et al 2008). We added a preproduction factor of 0.51 to the emissions factor of 3.16, as suggested by Myclimate (2015), and a multiplier that is supposed to account for non-CO₂ effects of aviation that affect global warming (Gössling and Upham 2009; Kollmuss and Crimmins 2009; Lee, Fahey et al 2009; Lee, Pitari et al 2009; Myclimate 2015). Aware that scientific knowledge about radiative forcing is still incomplete, we integrated a conservative multiplier of 2 to include the full GHG potential of air travel, as recommended in recent publications (Kollmuss and Crimmins 2009; Azar and Johansson 2012). The multiplier was only applied to CO₂ emissions directly from fuel combustion in the air and not to preproduction of kerosene. The CO₂e (in g/pkm) for air travel was calculated for every route as follows:

$$CO_2e = \frac{CO_2 \text{ per passenger}}{3.16} \times (3.16 \times 2 + 0.51) \quad (4)$$

where 3.16 is the constant emissions factor representing the number of tons of CO₂ emitted by burning a tons of aviation fuel (ICAO 2015).

As 89% of all Alpbach tourism-related flights are short haul, the CO₂e was calculated separately for different distance classes (short, mid, and long haul). Fuel burn rates are thus weighted averages based on the aircraft typically used in the different distance classes (Myclimate 2015). Average values of CO₂ and CO₂e were weighted by the number of visitors traveling in a given distance class, giving the short-haul distance class a higher weighting. The weighted average load factor is 131 persons per aircraft.

The amount of direct energy consumed by air travel (kWh/pkm) was calculated as follows:

$$E_{direct} \left(\frac{kWh}{pkm} \right) = \text{fuel per passenger kilometer} \left(\frac{kg}{pkm} \right) \times 12 \quad (5)$$

where fuel per passenger kilometer is the fuel burn rate divided by the average load factor for each distance class, and the specific energy of kerosene is 12 kWh/kg for aviation fuel (Air BP 2000).

To compute the cumulative energy consumption of aviation fuel, we used the 83% energy-efficiency factor given by Knörr and Hüttermann (2015):

$$E_{cumulative} \left(\frac{kWh}{pkm} \right) = \frac{E_{direct}}{0.83} \quad (6)$$

Table 2 provides an overview of the calculation of emissions factors for aviation.

Results

For aviation, direct CO₂e (GHG) emissions per PKT were double those of vehicles, and cumulative CO₂e emissions were 3.6 greater. The most environment-friendly transportation option in terms of direct CO₂e emissions was the train; in terms of cumulative CO₂e, it was the bus. Bus travel also had the lowest cumulative energy consumption score of all travel modes (Table 2).

Under current transportation patterns (same-day visitors excluded), the lion's share of cumulative energy was consumed by private vehicles, which also produced over half of total CO₂e emissions. Air transport accounted for only a small proportion of tourism visits but a slightly larger share of energy consumption and a much larger share of CO₂e emissions. Bus and train travel combined brought almost as many tourists to Alpbach as air travel, while using much less energy with much lower CO₂e emissions (Table 3).

Seen in terms of a single average visitor, a visit by plane produced almost 4 times the GHG emissions of a visit by car, while a visit by bus emitted the least GHG (Table 4).

Discussion

This article's objectives were to present a new GIS-based, bottom-up approach to high-resolution analysis of energy consumption and GHG emissions patterns in transport to

TABLE 3 Energy consumption and GHG emissions for different modes of tourism transport to Alpbach.

Mode of transport	% of total transport	Total PKT	Energy consumption			CO ₂ e emissions		
			Direct	Cumulative		Direct	Cumulative	
			Total (MWh)	Total (MWh)	%	Total (tons)	Total (tons)	%
Private vehicle ^{a)}	75	48,135,354	10,380	13,678	73.73	2555	3129	58.12
Bus	7	4,492,633	574	715	3.86	142	171	3.18
Train	5	3,209,024	214	606	3.27	48	138	2.57
Airplane	13	8,343,461	2947	3551	19.14	900	1945	36.13
Total	100	64,180,472	14,115	18,550	100	3645	5383	100

^{a)} Includes cars, motorcycles, and recreational vehicles.

and from a single alpine tourism destination and to show ODT's direct and cumulative energy-use and emissions patterns.

The model's approach is based on round-trip distance calculations between the place of origin of each visitor (represented by the closest hub), as given in the electronic tourist register, and the destination. Based on heat map analysis, we defined 235 hubs, which enabled us to achieve much more detailed insight into actual travel distances than would have been possible with only 1 hub defined per country of origin. The method therefore allows a much more reliable approximation of kilometers actually traveled by visitors and thus of GHG emissions than other methods. This is particularly important when the results are meant to serve as a baseline scenario for monitoring future planning strategies.

However, finding robust energy and emissions factors is challenging, as they depend heavily on a number of factors, including load factor, vehicle type, fuel type, and type of air travel (short versus long haul). Nevertheless, with some fine-tuning, the model can be adapted to other tourism destinations in similar geographical contexts, as long as detailed tourist data are available, including the visitors' hometowns and travel mode. The emissions factor used in this study for car, bus, and train transport was

based on German data and thus should be reconsidered if there is a different source market. For example, the German mix of electricity production (relevant for train travel) has a low share of renewable energies.

Traveling on a bus produces more direct GHG emissions than traveling by train. However, the picture changes when the focus is on cumulative GHG emissions. In Germany's context of fossil-fuel-dominated power, travel by bus appears to be more efficient than travel by train. However, the CO₂e factor is very different for Austrian railways, for which 92% of the power comes from renewable energies, mainly hydro power (OEBC 2013).

Aviation's contribution to ODT's overall GHG emissions is striking, as only 13% of visitors produce more than 36% of GHG emissions. This could represent an opportunity to significantly reduce emissions while affecting only a relatively small part of the tourism economy. GHG emissions from air travel are the key environmental challenge of tourism and one of the greatest challenges of climate change response in general (Becken 2007; Barr et al 2010; Scott 2011; Cohen et al 2013). However, in Alpbach, car transport dominates, accounting for three-quarters of tourist ODT and over half of total GHG emissions; train and bus travel make up only a small share of ODT and an even smaller share of GHG emissions.

Thus, to reduce GHG emissions, we recommend promoting a shift from car to train or bus transport by offering incentives—such as providing a complete chain for luggage transport (ie pickup at home and drop-off at the accommodation), climate-friendly local transportation, or reduced local travel times (for example by offering pickup service from the train station), combined with a marketing focus on short-haul rather than long-haul source markets, the promotion of longer stays (eg Peeters and Schouten 2006; Filimonau et al 2013), and on-site awareness campaigns for local stakeholders and tourists.

The latter could be challenging. Recent research has concluded that, while there is growing public awareness of

TABLE 4 Per-capita energy consumption and GHG emissions for different modes of tourism transport to Alpbach.

Mode of transport	Energy consumption (kWh/visitor)		CO ₂ e emissions (kg/visitor)	
	Direct	Cumulative	Direct	Cumulative
Private vehicle ^{a)}	367.51	484.28	90.46	110.77
Bus	217.85	271.38	53.76	64.93
Train	113.62	321.92	25.65	73.28
Airplane	601.99	725.29	183.82	397.30
Total	374.82	492.59	96.79	142.94

^{a)} Includes cars, motorcycles, and recreational vehicles.

environmental issues, including climate change, this has not significantly affected tourism-related transport choices (Barr et al 2010; McKercher et al 2010; Miller et al 2010; Higham et al 2013; Cohen et al 2016). Therefore, soft mobility approaches to transportation, which are environment-friendly but do not involve a trade-off in comfort and flexibility, might be a key to mitigating the local climate impacts of tourism. This approach has already been recognized as a marketing instrument by the Alpine Pearls network of 25 communities across the Alpine area of Central Europe (Alpine Pearls 2016).

Conclusion

MATT demonstrates a bottom-up approach that allows a highly detailed analysis of the energy consumption and GHG patterns of ODT to a specific tourism destination, including its cumulative carbon footprint. Therefore, it fills a research gap in carbon impact appraisal studies on the destination level.

With some constraints and required adaptations, the model is transferable to other destinations in a similar geographical context. It is still limited as it does not consider same-day visitors, intracommunity transport, or

employee commutes. The outcomes of existing carbon impact appraisal studies at the local scale are difficult or impossible to compare as methods for assessing GHG emissions vary substantially, and only a few studies have accounted for the indirect share of transportation's carbon footprint. The latter can make a significant difference; for instance, in our study, taking cumulative emissions and energy-use values into account reversed the comparative climate-efficiency ratings of bus and train travel. Knowing the specific gasoline/diesel market share and the national mix of power production is crucial.

MATT covers an important part of a destination's energy consumption and carbon footprint, but it is only the first module of a project aiming to transform an alpine tourism destination into a future role model for sustainable tourism. To achieve this goal, sociocultural, institutional, and political barriers have to be overcome. To this end, a detailed, holistic, and in-depth view of a tourism destination's energy consumption and GHG emissions patterns, on different spatial and temporal scales and for different sectors, is essential to communicate the need for transformative change to stakeholders, local residents, and visitors.

REFERENCES

- Air BP.** 2000. *Handbook of Products*. Hertfordshire, United Kingdom: Air BP.
- Alpine Pearls.** 2016. *Holidays in Eco-Motion*. <http://www.alpine-pearls.com/en/home.html>; accessed on 5 September 2016.
- Azar C, Johansson DJA.** 2012. Valuing the non-CO₂ climate impacts of aviation. *Climatic Change* 111:559–579.
- Barr S, Shaw G, Coles T, Prillwitz J.** 2010. “A holiday is a holiday”: Practicing sustainability, home and away. *Journal of Transport Geography* 18:474–481.
- Becken S.** 2007. Tourists' perception of international air travel's impact on the global climate and potential climate change policies. *Journal of Sustainable Tourism* 15:351–368.
- Becken S, Patterson M.** 2006. Measuring national carbon dioxide emissions from tourism as a key step towards achieving sustainable tourism. *Journal of Sustainable Tourism* 14:323–338.
- Becken S, Simmons DG, Frampton C.** 2003. Energy use associated with different travel choices. *Tourism Management* 24(3):267–277.
- BMVI.** 2014. *Daten und Fakten zum Energieverbrauch des Schienenverkehrs*. Research Information System of the Federal Ministry of Transport and Digital Infrastructure. <http://www.forschungsinformationssystem.de/servlet/is/342234/>; accessed on 1 February 2016.
- Chenoweth J.** 2009. Is tourism with a low impact on climate possible? *Worldwide Hospitality and Tourism Themes* 1:274–287.
- Cohen SA, Higham J, Gössling S, Peeters P, Eijgelaar E.** 2016. Finding effective pathways to sustainable mobility: Bridging the science–policy gap. *Journal of Sustainable Tourism* 9582:1–18.
- Cohen SA, Higham JES, Reis AC.** 2013. Sociological barriers to developing sustainable discretionary air travel behaviour. *Journal of Sustainable Tourism* 21:982–998.
- Dawson J, Scott D.** 2013. Managing for climate change in the alpine ski sector. *Tourism Management* 35:244–254.
- Dwyer L, Forsyth P, Spurr R, Hoque S.** 2010. Estimating the carbon footprint of Australian tourism. *Journal of Sustainable Tourism* 18:355–376.
- ESRI.** 2016. *ArcGIS REST API: World Geocoding Service*. ArcGIS for Developers. <https://developers.arcgis.com/rest/geocode/api-reference/overview-world-geocoding-service.htm>; accessed on Feb 3 2016.
- Filimonau V, Dickinson J, Robbins D.** 2013. The carbon impact of short-haul tourism: A case study of UK travel to Southern France using life cycle analysis. *Journal of Cleaner Production* 64:628–638.
- Future Earth.** 2014. *Future Earth Strategic Research Agenda 2014*. Paris, France: International Council for Science.
- Gössling S.** 2009. Carbon neutral destinations: A conceptual analysis. *Journal of Sustainable Tourism* 17:17–37.
- Gössling S, Peeters P, Ceron JP, Dubois G, Patterson T, Richardson RB.** 2005. The eco-efficiency of tourism. *Ecological Economics* 54:417–434.
- Gössling S, Upham P,** editors. 2009. *Climate Change and Aviation: Issues, Challenges and Solutions*. London, United Kingdom: Earthscan.
- Higham J, Cohen SA, Peeters P, Gössling S.** 2013. Psychological and behavioural approaches to understanding and governing sustainable mobility. *Journal of Sustainable Tourism* 21:949–967.
- Hoque S, Forsyth P, Dwyer L, Spurr R, Van Ho T, Pambudi D.** 2010. *The Carbon Footprint of Queensland Tourism*. Queensland, Australia: CRC For Sustainable Tourism.
- Hoyer KG.** 2000. Sustainable Tourism or Sustainable Mobility? The Norwegian Case. *Journal of Sustainable Tourism* 8:147–160.
- ICAO [International Civil Aviation Organization].** 2015. *ICAO Carbon Emissions Calculator Methodology*, Version 8. Montreal, Canada: ICAO.
- ICCT [International Council on Clean Transportation].** 2015. *European Vehicle Market Statistics*. Pocketbook 2015/16. Mock P, editor. Berlin, Germany: International Council on Clean Transportation Europe (ICCT Europe).
- IINAS [International Institute for Sustainability Analysis and Strategy].** 2015. *GEMIS—Global Emissions Model for Integrated Systems*. Darmstadt, Germany: IINAS.
- Kelly J, Williams PW.** 2007. Modelling tourism destination energy consumption and greenhouse gas emissions: Whistler, British Columbia, Canada. *Journal of Sustainable Tourism* 15:67–90.
- Knörr W, Heidt C, Schacht A.** 2012. Aktualisierung “Daten- und Rechenmodell: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960–2030” (TREMOS, Version 5.3) für die Emissionsberichtserstattung 2013 (Berichtsperiode 1990–2011). *Endbericht*. Heidelberg, Germany: Institut für Energie- und Umweltforschung.
- Knörr W, Hüttermann R.** 2015. *EcoPassenger. Environmental Methodology and Data*. UHeidelberg, Germany: Institut für Energie- und Umweltforschung.

- Kollmuss A, Crimmins AM.** 2009. Carbon Offsetting & Air Travel. Part 2: Non-CO₂ Emissions Calculations. SEI Discussion Paper. Stockholm, Sweden: Stockholm Environment Institute (SEI).
- Lee DS, Fahey DW, Forster PM, Newton PJ, Wit RCN, Lim LL, Owen B, Sausen R.** 2009. Aviation and global climate change in the 21st century. *Atmospheric Environment* 43:3520–3537.
- Lee DS, Pitari G, Grewe V, Gierens K, Penner JE, Petzold A, Prather MJ, Schumann U, Bais A, Berentsen T, Iachetti D, Lim LL, Sausen R.** 2009. Transport impacts on atmosphere and climate: Aviation. *Atmospheric Environment* 44:4678–4734.
- Lin T-P.** 2010. Carbon dioxide emissions from transport in Taiwan's national parks. *Tourism Management* 31:285–290.
- Manova.** 2014. T-Mona (Tourism Monitor Austria): Visitor Survey Alpbach, Winter 2013/14. Vienna, Austria: Österreich Werbung Wien.
- McKercher B, Prideaux B, Cheung C, Law R.** 2010. Achieving voluntary reductions in the carbon footprint of tourism and climate change. *Journal of Sustainable Tourism* 18:297–317.
- Miller G, Rathouse K, Scarles C, Holmes K, Tribe J.** 2010. Public understanding of sustainable tourism. *Annals of Tourism Research* 37:627–645.
- Mountain Riders.** 2015. Eco Guide to Mountain Resorts. 7th ed. Chambéry, France: Mountain Riders.
- Myclimate.** 2015. The Myclimate Flight Emission Calculator. Zurich, Switzerland: Myclimate.
- OEBB [Österreichische Bundesbahnen].** 2013. Wir bewegen Österreich. Sustainability Report 2012. Vienna, Austria: OEBB.
- Peeters PM.** 2013. Developing a long-term global tourism transport model using a behavioural approach: Implications for sustainable tourism policy making. *Journal of Sustainable Tourism* 21:1049–1069.
- Peeters P, Dubois G.** 2010. Tourism travel under climate change mitigation constraints. *Journal of Transport Geography* 18:447–457.
- Peeters P, Schouten F.** 2006. Reducing the ecological footprint of inbound tourism and transport to Amsterdam. *Journal of Sustainable Tourism* 14:157–171.
- Peeters PJ, Szimba E, Duijnsveld M.** 2007. Major environmental impacts of European tourist transport. *Journal of Transport Geography* 15:83–93.
- Perch-Nielsen S, Sesartic A, Stuckl M.** 2010. The greenhouse gas intensity of the tourism sector: The case of Switzerland. *Environmental Science & Policy* 13:131–140.
- Rauch F, Peck S, Ebner V.** 2010. Zusammenschluß der Skigebiete Alpbach und Wildschönau-Auffach. Verkehrsuntersuchung (Vorabzug). Internal Report. Innsbruck, Austria: Available from the corresponding author of the present article.
- Scott D.** 2011. Why sustainable tourism must address climate change. *Journal of Sustainable Tourism* 19:17–34.
- Scott D, Peeters P, Gössling S, Stefan G, Gössling S.** 2010. Can tourism deliver its “aspirational” greenhouse gas emission reduction targets? *Journal of Sustainable Tourism* 18:393–408.
- Tirol Werbung.** 2014. Tirol Tourism Research. The Economic Relevance of Tourism: Internationally, in Austria & in Tyrol. <http://ttr.tirol.at/content/impressum/>; accessed on 20 March 2016.
- UBA [Umweltbundesamt].** 2014. Emission data 2012. <https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten>; accessed on 1 February 2016.
- UNWTO [United Nations World Tourism Organization], UNEP [United Nations Environment Programme], and WMO [World Meteorological Organization].** 2008. *Climate Change and Tourism - Responding to Global Challenges*. Madrid, Spain: World Tourism Organization and the United Nations Environment Programme.