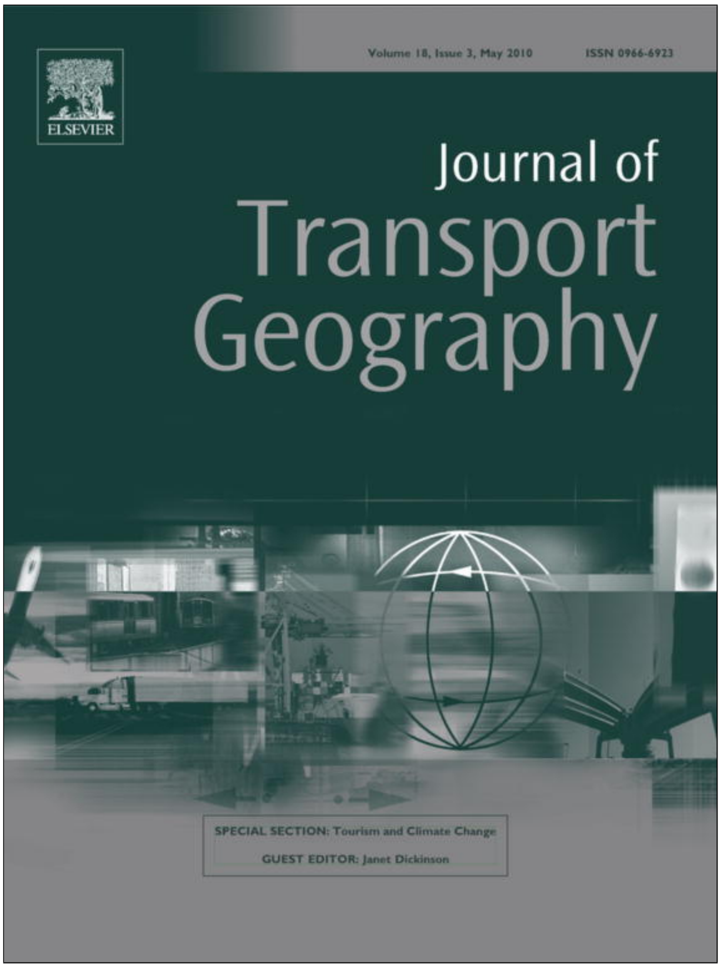
Volume 18, Issue 3, May 2010
ISSN 0966-6923
ELSEVIER
Journal of Transport Geography
SPECIAL SECTION: Tourism and Climate Change
GUEST EDITOR: Janet Dickinson

Journal of Transport Geography 18 (2010) 447–457

Contents lists available at ScienceDirect

Journal of Transport Geography

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

Tourism travel under climate change mitigation constraints

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ARTICLE INFO

Keywords:
Tourism
Transport
Climate change
Mitigation
Scenarios
Backcasting

ABSTRACT

The paper first describes an inventory for 2005 giving the tourism related CO_2 emission caused by global tourism, and presents a 30-year projection and a 45-year simulation. The study found that tourists cause 4.4% of global CO_2 emissions. Also these emissions are projected to grow at an average rate of 3.2% per year up to 2035. This increase is problematic as globally a reduction of emissions by 3–6% is required to avoid 'dangerous' climate change. Using contemporary scenario techniques it appeared difficult to find a future tourist travel system consistent with CO_2 emission reductions of up to 70% by 2050 with respect to 2005. Based on the model underlying the 30-year projection, 70 scenarios are presented in a 'landscape' graph exploring the effect of opportunities to reduce the emissions, but this attempt did not reach the large reductions envisaged. We therefore explored automated scenario generation as a way to define backcasting scenarios that both reach the emission reduction target and retain the highest possible economic value for the sector. The main contributions made by this study are (1) in comparing the value of different ways to approach a (desired) future and (2) giving insight into the kind of structural changes required within tourism and tourism transport in case very strong emission reductions are required. Finally the model showed signs of 'complex' behaviour.

1. Introduction

The fourth Assessment report of the Intergovernmental Panel on Climate Change (IPCC) forecasts that a post-industrial temperature rise is very unlikely to stay below 1.5 °C and likely to rise above 2 °C (IPCC, 2007c). A change in temperature of over 2 °C is considered to be at a 'dangerous' level, meaning it may destabilise the climate system (Hansen et al., 2006; Schellnhuber et al., 2006). Temperature rise projections for 2100 range from 1.5 °C to as much as 6.4 °C. To avoid 'dangerous' climate change, current emissions will have to be reduced by between 3% (Hansen et al., 2006; Parry et al., 2008b) and 6% per year from 2015 onwards (Parry et al., 2008a). In our paper we will show that current tourism development is unsustainable with respect to climate change as its emissions are projected to grow at over 3% per year, and, if unrestricted, may even become larger than the global emission allowance within four decades. Both the sector and governments need to assess the risks and opportunities associated with future climate change and climate policies. So there is a clear need for thorough examination of the future of tourism and tourism transport.

Scenario development is one of the major tools to inform the policy building process (Bradfield et al., 2005). This is especially true in IPCC reports, heavily dependent on scenario studies (IPCC, 2000) to deliver data on global greenhouse gas emissions or on climate change impacts. Global tourism scenarios are scarce, with only four studies found (Bosshardt et al., 2006; Nordin, 2005; TUI UK, 2004; WTO, 2000). Only Bosshart and Frick (2006) and Nordin (2005) mention climate change, but their studies are limited to the impacts of climate change on tourism. On a regional level, very few studies deal with tourism's contribution to climate change (e.g. for the EU by Peeters et al., 2007 and for France by Dubois and Ceron, 2007). Scenarios for global transport and climate change are more common (e.g. Åkerman, 2005; Azar et al., 2003; Boeing, 2007; Hawksworth, 2006; Kelly et al., 2007; Moriarty and Honnery, 2004; Olsthoorn, 2001; Schafer, 1998; Schäfer and Jacoby, 2005, 2006; Schafer and Victor, 2000; Vedantham and Oppenheimer, 1998; Wiederkehr, 1999), but none of these studies deal specifically with tourism transport. Global emission inventories are published by the IPCC (IPCC, 2000, 2007b, 2007c). These inventories are unsuitable to extract the impact of tourism as these inventories

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doi:10.1016/j.jtrangeo.2009.09.003

are based on contemporary economic sectors, while tourism is not such a sector in itself but a composite of parts of other sectors (e.g. transport, leisure industry, hospitality, ITC). This clearly illustrates the need for both specific emission inventories and scenarios for tourism.

In 2007 the UN World Tourism Organisation (UNWTO), UNEP and the World Meteorological Organisation (WMO) issued a report about tourism and climate (UNWTO-UNEP-WMO, 2008). For this report the authors developed an emission inventory and 2005–2035 emission scenario (published in Chapter 11 and Section 2.5). In this paper we describe this inventory and these scenarios. However, scenarios, being narrative or model-based (Raskin et al., 2005), often are problematic as they are subject to bias towards the ordinary (MacKay and McKiernan, 2004). Scenario builders reject the more remote scenarios or those perceived to be unlikely and generally have difficulties in introducing discontinuities, which hampers the ability to assess risks (van Notten et al., 2005). A specific way out of these problems is to develop systematic sets of 'landscapes' of scenarios reaching all extremes regardless of probability (see e.g. Lempert et al., 2003). A more general solution is to use automated techniques of scenario building, avoiding the many arbitrary or subjective choices to be made when developing just a small number of scenarios.

The first objective of this paper is to fill gaps in knowledge about current and future greenhouse gas emissions caused by global tourism. The second objective is to show what tourism could look like in the case of very strong emission reduction goals. The third objective is to explore methods beyond the classical scenario method using automated backcasting. For the 2035 projection and landscapes, the Global Tourism and Travel Model, basic version ($GTTM^{bas}$) was developed. This model assumes constant annual growth of its input variables projecting tourism and transport volumes and CO_2 emissions. For automated backcasting scenario generation, this model has been re-programmed using Powersim Studio 7 system dynamic modelling software into the advanced $GTTM^{adv}$.

Section two briefly discusses the scenario method and the position of our global scenarios within this theory. It also describes the assumptions and methods used for the inventories and the model versions. Section three presents the results of the 2005 emissions inventory, the projections and the backcasting scenarios. Finally, section four discusses the limitations of the methods presented to explore the future and presents some conclusions.

2. Methods

2.1. The scenario method

The scientific literature gives a wide range of definitions of scenarios (Bradfield et al., 2005; Schwartz, 1996). We have adopted the definition given by the IPCC for climate scenarios: "A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. Scenarios are not predictions or forecasts but are alternative images without ascribed likelihoods of how the future might unfold" (IPCC, 2007a, p. 145).

The range of scenario types is broad, and scenarios are often divided into different groups. One commonly used division distinguishes four groups by dividing scenarios into combinations of exploratory ↔ normative and quantitative ↔ qualitative projections (Gordon, 1992; Prideaux et al., 2003 and, in other terms, van Notten et al., 2003). Exploratory (plausible) scenarios generally extrapolate trends or are forms of forecasting, while normative (desirable) scenarios first define a desired future and use backcasting to find a way to get to this future (Prideaux et al., 2003, p. 476). The technique of backcasting is useful for studies exploring sustainable development of complex systems, where a specific future situation is desired that deviates strongly from continuation of current trends (e.g. Dreborg, 1996). Quantitative scenarios use a range of methods (e.g. models, simulations) to describe the future and determine underlying relationships, while qualitative scenarios depend on expert judgement (e.g. the Delphi method, brainstorms, narratives). Our 2035 tourism and tourism transport projection is quantitative and explorative and uses the exponential growth $GTTM^{bas}$ model. The 2050 backcasting simulation with the $GTTM^{adv}$ is quantitative and normative as it uses a well-defined future target for tourism and tourism transport CO_2 emissions. Furthermore the backcasting exercise differs from the landscape method as we used wider ranges for the input variables, we tested the model against four different economic and demographic background scenarios and we extended the scenario period by 15 years to 2050.

Future studies are empirical and output-oriented comprising a multitude of techniques, the choice of which depends on the objectives of the study. In the field of transport quantitative results are often required (Ceron and Dubois, 2007), for example to plan new infrastructure, while in tourism qualitative results are indispensable, such as the type of societal change. Ideally, a scenario exercise should try to integrate both needs (Raskin et al., 2005): coherent and plausible quantitative results embedded within qualitative storylines and policy pathways. A challenge for our backcasting exercise is to define a tool allowing a transparent and rigorous exploration of a future situation satisfying several targets (e.g. a certain GHG emission reduction, while maximising tourism revenues), for a complex set of variables and factors of change (e.g. technology, infrastructure, the tourism markets, demographics, international context). Contemporary scenarios are often developed in working groups, but present severe limitations:

- At best, if at all, they allow for quantification through laborious manual iterations with simple models, consuming large amounts of time.
- The complex interactions and feedbacks within many systems hamper experts to fully comprehend/control which is a source of inconsistency and plain errors.
- More importantly, for such long term scenarios (2050, or even 2100, frequently used in the field of climate change), experts and scientists tend to ignore strong discontinuities or trends perceived to be unlikely, thus censoring themselves while venturing at 'terra incognita'.
- Finally, the experts may introduce some moral limitations in the process blurring the broader picture (e.g. reducing growth of domestic travel in developing countries as a possible solution, but dismissed on grounds of equity when done manually).

Therefore, instead of first exploring narratives and qualitative pathways of change for tourism and then quantifying the most promising ones, we chose to explore first quantitative automated backcasting optimisation. We run this optimisation model thousands of times to find the set of input parameters (growth of markets, technological development) that satisfies the goal (a certain reduction of CO_2 emissions) and objective (maximum total tourist revenues). In this way we may inform policy makers about structural changes of the tourism sector required to reach the emission goal. The next step – to be developed in a follow-up to this paper – will go back to explore and describe the qualitative pathways and policies to reach this desired future.

2.2. The 2005 emissions inventory

Tourism is defined as 'the activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year' (UNWTO, 2008a, Annex-21). So 'tourism' includes both 'tourists' (i.e. overnight visitors) and 'same-day' visitors. This means that not only are holidaymakers included, but also business and visiting friends and relatives tourists, as well as a share of the leisure daytrips outside the usual environment. Unfortunately this broad definition of tourism is confusing. In most publications tourism is defined as overnight visitors and even often restricted to leisure based trips, thus excluding business travel. Same-day visitors are ignored in this study because their levels are measured by national statistical offices that use different and often incomparable definitions. Furthermore, in spite of the very large numbers of same-day visitors, they contribute only about 10% to all tourism related emissions.

Tourist- and tourism transport-related CO_2 emissions are derived by multiplying emission factors by volumes of transport (passenger-kilometre per transport mode), guest-nights and activities. For the purpose of the 2035 Baseline Scenario, we created, in collaboration with the World Tourism Organisation's Department of Statistics and Economic Measurement of Tourism (UNWTO-DSEMT), a database for trips (i.e. not arrivals, as is common practice in most UNWTO statistics, because one international trip may account for several arrivals when more than one country is visited in one trip), and guest-nights, from data published by UNWTO, IATA and ICAO. Three main markets are distinguished – international, domestic within developed countries (OECD90, see in IMAGE-team, 2006 for a full list) and domestic within other (non-OECD90) countries, as well as three transport mode groups – air, car and other. The database gives estimates of the number of passenger-kilometres (pkm) and trips per transport mode (air, car, other) and tourist market, as well as the number of guest-nights per market. The modal split measured in number of trips of surface tourism-related transport divided into car and other (public transport modes like rail, coach and ferries) and distance per trip were derived as follows:

- For international trips, UNWTO-DSEMT shows 70% of surface trips to be by car.
- For domestic tourism we estimated that for 90% of all surface trips within OECD90 and 30% within non-OECD90 countries the car is used (based on data from Gössling, 2002).
- Average distances for car and other (surface) transport modes for international and domestic markets within OECD90 countries were taken from the MuSTT study (Peeters et al., 2004).
- Distances travelled for domestic trips within non-OECD90 countries are simply not available. We assumed the averages to be 20% less with respect to the OECD90 value because the infrastructure in non-OECD90 countries have much higher shares of unpaved roads and thus will allow for lower speeds as compared to OECD90 countries (based on data from International Road Federation, 2008) and average travel time budgets per country are supposed to be equal (e.g. see Schafer, 1998; Schafer, 2000; Schafer and Victor, 1999; Schafer and Victor, 2000).

The CO_2 emission factors are based on a European scenario study (see Peeters et al., 2007). For cars in non-OECD90 countries, however, the average seat occupation was raised from two per car to three per car, assuming that low incomes would lead to more efficient use of transport. This assumption is backed by data for 16 OECD90 and 10 non-OECD90 countries. From this an average seat occupation of 1.7 appeared for OECD90 and 2.4 for non-OECD90 countries (International Road Federation, 2008) was found. We have rounded these to 2 and 3 for tourism purposes respectively as commuting tends to show much lower occupation rates compared to leisure.

The emission factors for air transport were chosen such that the total amount of emissions for tourism corresponds to the most recent air transport emission inventories (Eyers et al., 2004; Kim et al., 2005 (upd. 2006), Kim et al., 2007). For the model we need to subtract the share of emissions allocated to air freight transport. For this we first defined a conversion factor of 160 kg freight as equivalent to one passenger by comparing full payload capacity of passenger and freight versions of the same Aircraft (Peeters et al., 2005; Wit et al., 2002). Interpolation of data for 1997 and 2010 shows that 19.5% of all aviation transport volume (i.e. revenue ton kilometres) was freight (Pulles et al., 2002).

The emission factors for international and OECD90 domestic market accommodations are based on various recent publications (Becken, 2002b; Bohdanowicz and Martinac, 2007; Gössling, 2000; Gössling, 2002; UK CEED, 1998). For non-OECD90 domestic trips, we use a much lower figure because most (domestic) tourists in non-OECD90 countries stay at the homes of friends or family and the emissions per head caused by households in non-OECD90 countries are very low (see Watkins, 2006). The assumption of high shares of domestic tourists staying at private addresses is backed by the large difference between the number of domestic trips in the largest domestic market, China, of 1.2 billion trips in 2005 (National Bureau of Statistics of China, 2007) and the number of domestic nights in hotels and similar establishments, which was only 0.3 billion nights. This means at least 70% of domestic tourist-nights were not spent at commercial tourist accommodation.

The emissions for tourist activities at the destination (local transport and leisure activities) were determined by average length of stay for the three groups of tourists (international, domestic within OECD90 and domestic within non-OECD90 countries) and data from the literature (i.e. emissions from Becken, 2002a; Gössling, 2002 and types of tourism from UNWTO, 2006). Table 1 gives an overview of all emission factors.

2.3. The basic Global Tourism and Transport Model ($GTTM^{bas}$)

The $GTTM^{bas}$ is an Excel-based model which projects tourism and transport volumes and CO_2 emissions in 2035 by extrapolating the 2005 Emission Inventory data using constant growth rates for the number of trips, average distance per trip, length of stay (LOS) and emission factors. All these rates are assumed to be constant for the whole period 2005–2035 and described by:

$$V_n = (1+\delta)^n \cdot V_0 \tag{1}$$

with V_n the volume or emission factor in year n, δ the annual growth factor (fraction of the volume) and V_0 the volume or emission factor in the base year (in this study 2005). Table 6 in Section 3.2 shows

Table 1
Generalised emission factors for transport. Sources: transport (adjusted from Peeters et al., 2007), accommodation (based on Becken, 2002a; Bohdanowicz and Martinac, 2007; Gössling, 2000; Gössling, 2002; UK CEED, 1998; Watkins, 2006; see full description in section A2.2.3 of UNWTO-UNEP-WMO, 2008) and activities (Becken, 2002a; Gössling, 2002; see also Section 11.1.3 of UNWTO-UNEP-WMO, 2008).

Transport mode (kg CO_2/pkm):	Emission factor
Air (international)	0.124
Air (domestic)	0.137
Car (international)	0.133
Car (dom. OECD90)	0.133
Car (dom. non-OECD90)	0.089
Other	0.025
Accommodation (kg CO_2/night):	
International	19
Domestic OECD90	19
Domestic non-OECD90	4
Activities (kg CO_2/trip):	
International	27.0
Domestic OECD90	11.3
Domestic non-OECD90	2.8

the growth rates δ for transport distances (pkm) and tourist volumes (nights and trips).

The δ's are kept constant for the whole 2005–2035 period. The GTTM^{bas} therefore has two limitations: the time horizon and the consistency of the results. It is felt the 30-year period for the 2035 Baseline Scenario represents the maximum time span for assuming constant growth factors. Countries like China or India, for example, have recently shown very high tourism growth rates (National Bureau of Statistics of China, 2007), but these growth rates will most likely fall to much lower levels within 30 years (e.g. Yeoman, 2008, p. 48).

Regarding the second issue, data consistency, problems arise specifically when combining growth rates for the number of trips and those for transport volume (passenger-kilometres), as a difference in these rates will change the average distance per trip, without a consistent change in infrastructure or travel speed. Therefore, growth rates not given by the literature have been chosen in such a way that the average distances will change in consistent ways for the 2035 Baseline Scenario.

2.4. The advanced Global Tourism and Transport Model (GTTM^{adv})

The GTTM^{bas} model described above is programmed in Excel, which made it a convenient tool for assessing scenarios manually. We have re-programmed the GTTM^{bas} into the GTTM^{adv} using Powersim Studio 7 software (SR 10). Powersim Studio 7 includes an evolutionary optimisation module, which allows the user to find sets of input values (the growth factors for trips, LOS, transport volume and energy efficiency) for a given goal (in this paper, the goal is a predefined target for CO_2 emissions while maximising the tourism economy). This module is based on a Co-Variance Matrix (CMA) evolutionary algorithm (see Hansen, 2006; Hansen and Ostermeier, 2001). Furthermore we added a more advance trip generation module to the model.

2.4.1. Trip generation

Deviating from the original GTTM^{bas}, the GTTM^{adv} does not make use of constant exponential growth factors for tourism growth, but uses a 'trip generation model'. This model is based on the assumption that there is a positive continuous linear relationship between GDP per capita and the annual number of trips per capita (T_C) up to a certain maximum (see e.g. Mulder et al., 2007). This works out as:

$$T_C = \min\left(T_{C_{\max}}, C_{cy} + \alpha_{cy} \cdot \overline{GDP_{cap}}\right) \quad (2)$$

In this equation C_{cy} gives the number of trips at GDP = €0 and α_{cy} the number of trips per € GDP/cap. From the data we used for this model it appeared that C_{cy} is small but not zero at zero GDP, as might be expected. Most likely the relation between GDP and trip numbers is non-linear at very low GDP's.

Now we arrive at the following equation for the total number of trips:

$$V_t = \sum_{n=1}^{n=3}\left(\frac{LOS_{2005_n}}{LOS_{t_n}} \cdot P_n \cdot T_{C_n}\right) \quad (3)$$

where V_t is the total number of tourist trips for t, P_n is the population for the tourism segment n and T_{C_n} is the number of trips per capita per year as found with Eq. (2). LOS_{2005_n} and LOS_{t_n} denote length of stay (in 2005 and year t respectively, both for tourist segment n). The population and tourism segments are:

- International market, global population ($n = 1$).
- Domestic within OECD90 countries market with OECD90 population ($n = 2$).
- Domestic within non-OECD90 countries market, non-OECD90 population ($n = 3$).

The factor LOS_{2005_n}/LOS_{t_n} is necessary to correct for changes in length of stay over time since the data given by Mulder et al. (2007) refer to a constant number of trips for a given GDP per capita, while the literature points to a stable travel time (see for example Hupkes, 1982; Kölbl and Helbing, 2003; Schafer and Victor, 2000). In Fig. 1, the 2005 and 2035 scenario points are second and third from the left respectively. Compared to a similar relationship published previously our estimated number of trips per capita is slightly more shallow (compare Bigano et al., 2004).

The 2035 Baseline Scenario data used are presented in Table 2. These coefficients have been determined by fitting the 2005 and 2035 points to the results of the GTTM^{bas} using the SRES A1F scenario population and GDP per capita data (Bouwman et al., 2006; IMAGE-team, 2006; IPCC, 2000).

2.4.2. Decisions

'Decisions' are equivalent to the input of the model, i.e. the variables the model user at normal manual use may change to generate one projection. The Powersim Studio 7 optimisation module automatically changes the values of decision variables to reach a set of objectives. The GTTM^{adv} optimisation has been based on decisions for technological development (the constant rate of change of emission coefficients for accommodation, activities, air transport, cars and other transport modes), rate of change of LOS (length of stay), and transport mode and market specific trip generation. For each decision variable a minimum and maximum value was defined to keep the model within perceived reasonable bounds. The technological rate of change was kept between 0% and −4% per year (−6% for other transport modes, where a change to green electricity might accelerate change). The rate of change of LOS was kept between −1% and +1% per year. The modes may increase additionally with −5% to +5% per year. Finally trip generation is changed through multiplying the default number of trips α_{cy} by a coefficient (one for each market) between 0.6 and 1.1.

2.4.3. Objectives

The objective of the GTTM^{adv} backcasting runs is to find a set of decision values that fulfils the predefined target, i.e. a reduction of the CO_2 emissions by 70% at the highest possible contribution of

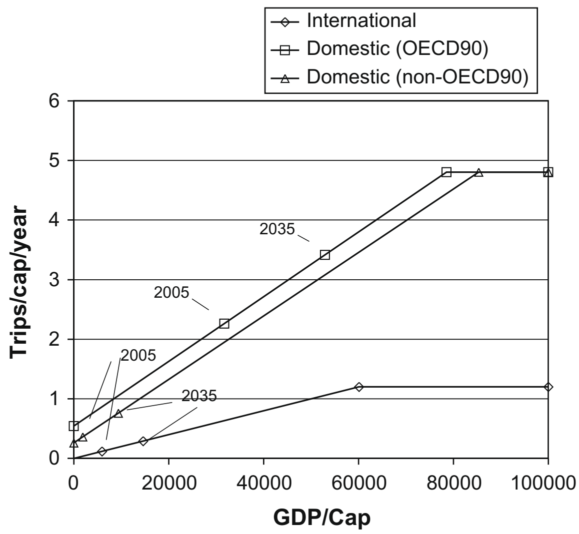

Fig. 1. The number of trips/cap/year as based on UNWTO scenarios (UNWTO-UNEP-WMO, 2008) and TNS NIPO maximum (Mulder et al., 2007).

Table 2
Baseline values for the parameters determining trip generation.

Tourism market	C_{cy}	α_{cy}	T_{max}
International	−0.0042	0.00002003	1.2
Domestic OECD90	0.5382	0.00005427	4.8
Domestic non-OECD90	0.2544	0.00005326	4.8

the tourist industry to the world economy. The net contribution to the economy is defined by the sum of tourism and tourism transport revenues and CO_2 abatement costs.

Revenues per tourist-night differ for the three market segments and the three transport modes. In addition, the length of stay has some impact on revenues per day, as generally the daily spending of tourists decreases with increasing LOS. This has been modelled as follows:

$$R_i = LOS_i \cdot (r_{0_i} + \alpha_{r_i} \cdot LOS_i) + \sum_{m=1}^{3} r_{m_i} \cdot \bar{d}_{m_i} \quad (4)$$

and

$$R = V_t \cdot \sum_{i=1}^{3} r_i \quad (5)$$

with r_i the revenues per tourist for market i, r_{0_i} the revenues for a one night trip, α_{r_i} the rate of change of revenues per extra night, r_{m_i} the revenues for transport mode m (1 = air, 2 = car, 3 = other), $\bar{d}_{m_i}$ the average return distance per transport mode and market i and LOS_i the length of stay for market i. R represents the total revenues of the global tourist industry. Values for r_{0_i} and α_{r_i} are based on data from the 2005 Dutch Continuous Holiday Survey (CVO), while revenues for transport per passenger-kilometre were defined using data from UNWTO, World Bank, IATA and other sources (e.g. IATA, 2008a; IATA, 2008b; UNWTO, 2008a, 2008b; World Bank Group, 2008a, 2008b, 2008c).

The net revenues are equated by subtracting the emission abatement cost from the revenues as found with Eq. (4). Nordhaus suggests the general abatement cost development has the form of an 'allometric power curve' (see Nordhaus, 2008, p. 205):

$$C = a + b \cdot \mu^c \quad (6)$$

In this equation μ is the reduction of the emission factor as a fraction of current emission factor (between 0 and 1) and C is the abatement cost in US$ per ton of CO_2. We used Findgraph (software version 1.942, Vasilyev, 2004) to estimate the parameters *a, b* and *c* using data on 2030 net (societal) costs per ton and absolute emission reduction potentials published by IPCC (2007b). The average costs are calculated by integrating (6), dividing by the value of μ, and solved using a standard integral solution:

$$\bar{C} = a + \frac{b}{c+1} \cdot \mu^c \quad (7)$$

The total abatement cost at year T is the average cost per ton of avoided emissions times total amount of avoided emissions. Hence, based on Eq. (7) and assuming E_t the total emissions at time t, the following expression for total abatement costs is found:

$$C = \bar{C} \cdot E_i \cdot \left(\frac{\mu}{1-\mu}\right) \quad (8)$$

The literature gives abatement costs in US$ for 2005, which have been converted to 2005 € using an average conversion rate of 0.80379 €/$ (based on UNWTO, 2008a, Annex-25). Table 3 gives the values for the coefficients of Eq. (7) for accommodation, activities and transport; 'activities' are assumed to be equal to car transport.

Table 3
Coefficients *a*, *b* and *c* of Eq. (7) for calculating abatement costs per ton of CO_2 emission reduction (based on net societal costs given by IPCC, 2007b).

	a (€/ton CO_2)	*b* (€/ton CO_2)	*c* (–)
Accommodation	−123.9	318.8	1.455
Activities	0.0	246.8	2.585
Car	0.0	246.8	2.585
Air	0.0	346.8	1.552
Other (electric part)	0.13	77.7	10.390
Other (non-electric part)	0.0	246.8	1.552

3. Results

3.1. The 2005 inventory

Table 4 shows the number of arrivals and trips for worldwide international and domestic tourists (excluding same-day visitors). The table also shows that the global share of air transport in all tourist trips is relatively small (17%). However for individual market segments like inter-regional travel between Europe, the Americas, Asia, the Pacific, Africa and the Middle East, air travel accounts for 92% of tourist trips. Globally, these long haul trips account for just 2.5% of all tourist trips (domestic and international, all transport modes). Another important finding is that domestic tourism trips outnumber international trips by more than a factor 5. This finding is based on a range of national statistics. For OECD90 countries domestic tourism has been extrapolated from data for the EU (Peeters et al., 2007), USA (UNWTO, 2006) and Australia (Australian Bureau of Statistics, 2007) for all countries. For non-OECD90 countries data for the main domestic markets (Indian Tour Operators Promotion Council, 2009; Ministry of Culture and Tourism, 2005; Ministry of Tourism, 2004; National Bureau of Statistics of China, 2007; Prom Perú, 2004a; Prom Perú, 2004b; Tourism Authority, 2006; UNWTO, 2007) were used as a base to estimate all domestic tourism within this part of the world.

CO_2 emissions amount to 1170 Mton CO_2 for global tourist trips (thus excluding same-day visitors), which equal 4.4% of total human CO_2 emissions in 2005 (7.2 Gton C according to IPCC, 2007c, or 26,400 Mton CO_2). Total 2005 CO_2 emissions for tourism (thus including same-day visitors) is estimated at 1302 Mton, which is almost 5% of global emissions. Table 5 shows that most tourist emissions are caused by transport (72%). Also, air transport alone produces 43% of total CO_2 emissions but is only used in 17% of the total number of tourist trips.

Table 4
Approximate tourism and transport volumes 2005. The number of trips and nights for domestic tourism are coincidentally equally divided over OECD90 and non-OECD90 countries. Source: UNWTO Department of Statistics and Economic Measurement of Tourism (UNWTO-UNEP-WMO, 2008, Annex 1).

	Total	Of which:		
		International	Domestic	
			OECD90	Non-OECD90
Nights (bln)	19.87	6.17	6.85	6.85
Trips (bln)	4.75	0.75	2.00	2.00
Car	2.32	0.29	1.46	0.57
Air	0.82	0.34	0.38	0.10
Other modes	1.61	0.12	0.16	1.33
Share for air (%)	17	45	19	5
Distances (bln pkm)	7908	3077	2841	1990
Car	2462	344	1605	513
Air	3924	2585	1058	281
Other modes	1522	148	178	1196
Share for air (%)	50	84	37	14

Table 5
Emissions from global tourism in 2005 (excluding same-day visitors).

CO_2 emissions (metric Mton)	Transport				Accommodation	Activities	Total
	Total	Air	Car	Other			
International	370	320	46	4	117	20	507
Domestic (OECD90)	363	146	213	5	130	23	516
Domestic (non-OECD90)	114	39	46	30	27	6	147
Total	847	504	305	38	275	48	1170

3.2. The 2035 Baseline Scenario

The future growth of tourist-related CO_2 emissions depends upon three major parameters. First, the *number of tourists* is projected to grow exponentially over the next two decades. According to Vision 2020 (WTO, 2000) and more recent reports (e.g. UNWTO, 2008a, p. 77, showing actual development to be close to the Vision forecasts), the number of international tourist arrivals will reach 1.56 billion by 2020, an increase of 95% compared to 2005 levels (about 800 million arrivals). Current growth rates in domestic tourism in India and China, the two most important non-OECD90 markets, have been up to 10% per year in recent years (Indian Tour Operators Promotion Council, 2009; National Bureau of Statistics of China, 2007).

Second, the Vision 2020 project (WTO, 2000) also shows that the *number of trips of long haul tourism* is growing by a factor 2.6 between 1990 and 2020, which is much faster than global international tourism growth (1.95 times) found in the same study. Therefore, average trip distance is increasing, as shown in the EU, where the number of trips is projected to grow by 57% between 2000 and 2020, while the distances travelled are expected to grow by 122% (Peeters et al., 2007).

Third, there is a trend for more *frequent holidays for a shorter length of stay*. Consequently, guest-night numbers are likely to grow at a slower pace than the number of trips, distances travelled and corresponding CO_2 emissions. These three trends translate to the growth factors given in Table 6.

The 'expert estimates' were made in such a way that the results were consistent with the known growth rates from the literature. For example the distance growth of OECD90 domestic tourism by 'other modes' was constrained to a narrow band of reasonable average distances in the future for air and car transport and the total number of trips. The average distances are assumed not to change very much because these are limited by the average speed of the transport system and travel time budget limitations.

Table 7 shows the assumed changes of emission factors. For air transport a reduction of 27% in 2035 as compared to 2005 has been used (based on Peeters and Middel, 2007), which translates to just over 1%/year. For cars, a moderate 1% reduction for OECD90 and international tourists has been assumed. Better technology and the desire for higher performance partly counterbalance each other (e.g. Sprei et al., 2008). In non-OECD90 domestic travel, the rate is estimated at 2%/year, higher because it is assumed that the average age of cars will reduce in these countries. In the accommodation and activities domain, two trends may counterbalance each other: better energy efficiency will reduce emissions, while higher luxury standards will increase them. It has been assumed that emissions per night will not change for international and domestic tourism in OECD90 countries, but will grow by 2% per year in non-OECD90 domestic tourism, mainly due to a strong shift of private home stays to commercial accommodations with much higher additional CO_2 emissions per night. For activities the improved technological efficiency is also more than balanced by increased use of energy consuming leisure devices.

In the 2035 Baseline Scenario, the extrapolations show tourist-related CO_2 emissions may reach 3059 Mton by 2035, up from 1170 Mton in 2005 (see also Fig. 2). The number of trips is projected to grow by 179%, guest-nights by 156%, passenger-kilometres by 222% and CO_2 emissions by 161%. The proportion of emissions related to aviation may increase from 43% in 2005 to 53% by 2035. The share of transport-related CO_2 emissions slightly decreases from 75% to 69% of all tourism emissions according to these extrapolations.

Table 6
Model assumptions: tourist arrivals and transport volume growth rates (%/year).

	Transport volume (pkm)			Accommodation	Tourism volume
	Air	Car	Other	Nights	Trips
International	5.3[a]	2.3[b]	2.0[d]	4.0[b]	4.5[c]
Domestic (OECD90)	3.0[a]	1.5[b]	3.7[b]	1.8[b]	2.3[d]
Domestic (non-OECD90)	8.1[a]	6.0[b]	0.0[d]	3.5[d]	4.0[d]

[a] Boeing (2006).
[b] Peeters et al. (2007).
[c] WTO (2000).
[d] Expert estimate.

Table 7
CO_2 emission efficiency changes.

	International	Domestic (OECD90)	Domestic (non-OECD90)
Air transport (overall reduction between 2005 and 2035 in %)	27	27	27
Specific energy use car transport (% change per year)	−1	−1	−2
Other transport (% change per year)	−1	−1	−1
Accommodation (% change per year)	0	0	2
Activities (% change per year)	1	1	2

3.3. Landscapes

The main purpose of this section is to find "physical changes" to the tourism transport system that might reduce emissions, ignoring policy measures that may be put in place to bring about these 'low emissions futures' or the likeliness of such changes to emerge. Physical changes are divided into two groups. The first includes improvements in energy efficiency through technological development (see Table 8). The second group concerns changes in tourist flows, modal shifts, destination shifts and length of stay (the Volume changes, see Table 9). In these latter changes we kept the number of nights equal to the 2035 Baseline Scenario except in changes 1 and 9. This is the first step in a strategy which ultimately allows us to assess the effectiveness of policies, and how tourism

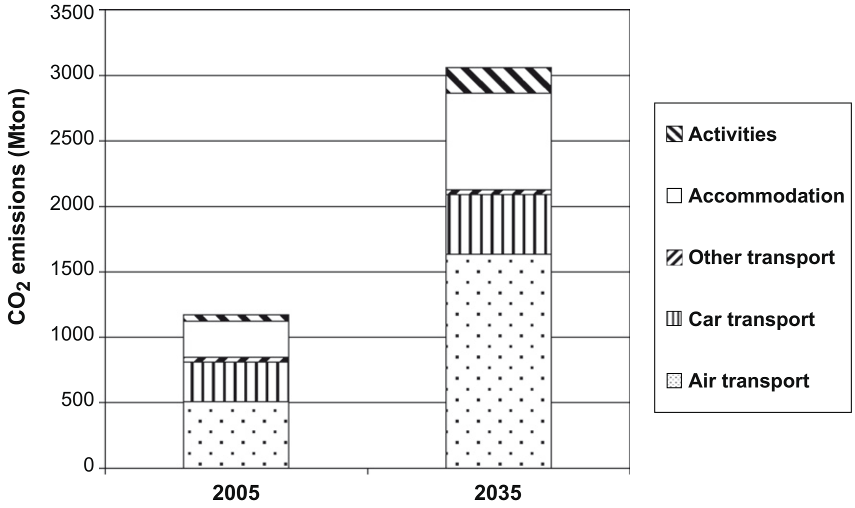

Fig. 2. CO_2 emissions caused by global tourism (excl. same-day visitors).

Table 8
Energy efficiency (Tech changes) improvement assumptions (the numbers give the *additional* reduction of energy consumption per year with respect to the 2035 baseline (e.g. in Tech_1 for air transport the 1% per year is raised to 1.0 + 1.3 = 2.3% reduction).

	Air	Car	Other	Accommodations	Activities
Tech_0	0	0	0	0	0
Tech_1	1.3	0	0	0	0
Tech_2	0	2.0	0	0	0
Tech_3	0	0	2.0	0	0
Tech_4	0	0	0	2.0	2.0
Tech_5	1.3	2.0	2.0	0	0
Tech_6	1.3	2.0	2.0	2.0	2.0

has to develop to become sustainable. Working on the likeliness and consistency of pathways is a future step.

Table 10 shows the 70 scenarios[2] which result when combining all Tech and Volume strategies. Only the combination of the two strongest changes reduces the amount of tourist CO_2 emissions to below pre-2005 levels (by 16%, highlighted dark grey and boldly lined). Only four scenarios come close to keeping CO_2 emissions more or less at 2005 levels (highlighted dark grey and thinly lined). Most combinations fail to prevent even a doubling of the 2005 emissions (26 combinations highlighted in light grey).

Table 10 makes clear that, considering issues of probability and ignoring the details of policy measures, it is almost impossible to find a tourism future that is physically able to reduce its CO_2 emissions without challenging the current growth of tourism volume. At the same time, all sectors need to reduce emissions by 50–80% before 2050 to avoid dangerous climate change (Hansen et al., 2006; Parry et al., 2008b).

3.4. Automated backcasting

The objective of the simulations is to find the right set of coefficients of the exponential functions defined in the GTTM^{adv} to reach a predefined objective for CO_2 emissions in 2050. We extended the time horizon because it is better in line with emission reduction targets avoiding 'dangerous' climate change and because the trip generation engine of the model is now attached to the long term IPCC SRES scenario's economic and population projections and thus no longer a simple exponential growth extrapolation.

We used Powersim Studio 7's evolutionary optimisation module to automatically find the optimised set of coefficients. This module needs a target and an optimisation parameter. The target was set to a 70% reduction of CO_2 emissions in 2050 with respect to 2005 levels. The optimisation parameter used was to maximise total net revenues (i.e. tourism plus transport revenues minus abatement costs). The runs were performed for four different assumptions regarding global economic and demographic developments (scenarios, see Table 11). The simulation limits for the decision variables were kept constant for all four runs. Compared to the landscapes we set these limits wider because the landscapes were developed for UNWTO, UNEP and WMO, whose referees limited the changes to within perceived politically feasible values. However, the limits are comparable with our earlier manual backcasting (Dubois et al., in press). In all cases the simulation reached the 70% reduction target.

Fig. 3 shows the growth rates for the 2035 Baseline Scenario found for the four backcasting scenarios each based on one of the four background growth scenarios. From the figure the following observations can be made:

- All four scenarios will have lower growth rates of number of trips than in the 2035 Baseline Scenario.
- All scenarios show a choice for extended technology, even though we attached a price (the abatement costs) to this. Still technological change did not reach the limiting values we assumed.
- For all scenarios the non-OECD90 domestic growth is more or less the same, but OECD90 domestic growth equals the Baseline case for Low Growth & Very Crowded (A2) and Medium Growth & Medium Crowded (B2), while it is much lower in the two other cases.
- As far as growth for different transport modes is concerned, the figure shows a dividing for Medium and High Crowded (A2 and B2) and the Less Crowded scenarios (A1 and B1). In A1 and B1 car transport is increased at the cost of air transport, while 'other modes' remain constant. In the cases A2 and B2 however, car use is strongly reduced for the benefit of keeping current air transport volumes and a very strong growth for 'other modes'.

The left graph of Fig. 4 shows the modal split for 2005 data and the four resulting scenarios. Air transport drops from 17% of total

[2] There are 7 Tech scenarios and 10 Volume scenarios; when all combined this is 7 ∗ 10 = 70, of which 1 is the Baseline scenario 2035 (the combination of Tech_Scen_0 and Volume_Scen_0).

Table 9
Volume related change assumptions (the numbers give the factor of change per year; the first row designated with a '_0' gives the 2035 Baseline Scenario assumptions).

	Growth rate of total distance travelled									Number of trips	Nights/trip
	International			Domestic OECD90			Domestic non-OECD90			Trips	LOS
	Air	Car	Other	Air	Car	Other	Air	Car	Other		
Volume_0	1.053	1.023	1.020	1.030	1.015	1.037	1.081	1.060	1.000	1.000	0.995
Volume_1	1.026	1.023	1.035	1.026	1.015	1.035	1.026	1.060	1.035	1.000	0.995
Volume_2	1.053	1.023	1.020	1.030	1.015	1.037	1.038	1.038	1.038	1.000	0.995
Volume_3	1.053	1.023	1.020	1.000	1.015	1.072	1.081	1.060	1.000	1.000	0.995
Volume_4	1.053	1.023	1.020	1.030	1.000	1.072	1.081	1.060	1.000	1.000	0.995
Volume_5	1.025	1.023	1.077	1.030	1.015	1.037	1.081	1.060	1.000	1.000	0.995
Volume_6	1.045	1.045	1.045	1.023	1.023	1.023	1.040	1.040	1.040	0.937	0.995
Volume_7	1.053	1.023	1.020	1.030	1.015	1.037	1.081	1.060	1.000	0.862	1.005
Volume_8	1.026	1.023	1.020	1.015	1.015	1.037	1.040	1.060	1.000	1.000	1.005
Volume_9	1.000	1.023	1.050	1.000	1.015	1.040	1.000	1.060	1.024	1.000	1.005
Volume_10	1.053	1.000	1.040	1.030	1.000	1.072	1.081	1.000	1.039	1.000	0.995

Table 10
Results of the ratio of 2035 CO_2 emissions to 2005 emissions for the 70 scenarios. The last two columns give the ratio for total number of trips and nights with respect to the 2035 Baseline Scenario.

	Tech_0	Tech_1	Tech_2	Tech_3	Tech_4	Tech_5	Tech_6	Trips	Nights
Volume_0	2.61	2.17	2.44	2.60	2.25	1.98	1.62	1.00	1.00
Volume_1	1.80	1.58	1.62	1.76	1.49	1.37	1.07	1.00	0.92
Volume_2	2.42	2.04	2.27	2.39	2.06	1.85	1.49	1.00	1.00
Volume_3	2.50	2.10	2.32	2.48	2.14	1.90	1.54	1.00	1.00
Volume_4	2.55	2.11	2.41	2.53	2.19	1.95	1.59	1.00	1.00
Volume_5	2.12	1.84	1.94	2.09	1.76	1.64	1.28	1.00	1.00
Volume_6	2.14	1.87	1.96	2.11	1.78	1.66	1.29	1.02	1.00
Volume_7	2.10	1.78	1.97	2.09	1.76	1.63	1.29	0.75	1.00
Volume_8	1.80	1.60	1.63	1.79	1.47	1.41	1.07	0.79	1.01
Volume_9	1.45	1.35	1.28	1.43	1.14	1.15	0.84	1.00	0.81

Table 11
Overview of GDP and population assumptions (the data and scenario codes are taken from the four SRES scenarios; IMAGE-team, 2006).

Scenario name	Global economy	Equity	Population	Poverty
A1: High Growth and Less Crowded	Max	Max	Min	Min
A2: Low Growth and Very Crowded	Min	Min	Max	Max
B1: Medium Growth and Less Crowded	Medium	Medium	Min	Min
B2: Medium Growth and Medium Crowded	Medium	Medium	Medium	Medium

trips to about 2% in A1 and B1 and 7% in A2 and B2. Differences between the scenarios are mainly determined by the split between car and 'other' transport modes, as the right graph shows. High trip growth (A2, B2) results in more public transport use ("other"), while lower trip growth leads to an increase in car use.

The right graph also shows that total net revenues grow by a factor of about 2.5 in all four scenarios, though this growth is obtained with different structures (increased length of stay in the two low growth scenarios).

4. Conclusions and discussion

This paper had three objectives: (1) describe the current and future CO_2 emissions caused by global tourism, (2) show what tourism would look like in the case of very strong emission reduction goals and (3) explore methods beyond the classical scenario method using automated backcasting. To do so, we first developed an emission inventory for 2005, as well as a 30-year projection. Based on the model underlying the projection (basic Global Tourism and Transport Model, $GTTM^{bas}$), 70 scenarios were presented in a 'landscape' graph. Finally, a derivative model ($GTTM^{adv}$) was developed with the ability to optimise the tourism system towards a predefined emission constraint while maximising net revenues. This model allowed us to develop four automated backcasting scenarios. Both landscape and backcasting scenarios describe just what tourism would look like in a carbon emission restricted future in terms of revenues, number of trips and modal split. No policy pathways or measures are attached to these scenarios.

The study found that overnight tourism represents 4.4% of global CO_2 emissions (including all motives and transport, accommodation and activities; for all tourism – also including same-day trips – this is 4.95%). If we are to avoid dangerous climate change, global CO_2 emissions must be reduced by 3–6% per year. However the 2035 Baseline Scenario yields 3.2% growth in tourist-related CO_2 emissions between 2005 and 2035, a growth rate that surpasses the IPCC's expectations for global CO_2 emissions in the highest SRES growth scenarios (2.5% for CO_2 emissions between 2000 and 2030; IPCC, 2007b, p. 4). Therefore current tourism sector development is at odds with serious climate change mitigation policies and objectives.

The second finding is that we did not achieve the target emission reduction with the (manual) landscape scenario method. This finding is based on a set of 70 scenarios using a linear growth (i.e. constant growth rates) model for tourist trips, tourist-nights and differential growth of the transport volume for the three transport modes, and assuming mitigation by (1) reducing emission factors

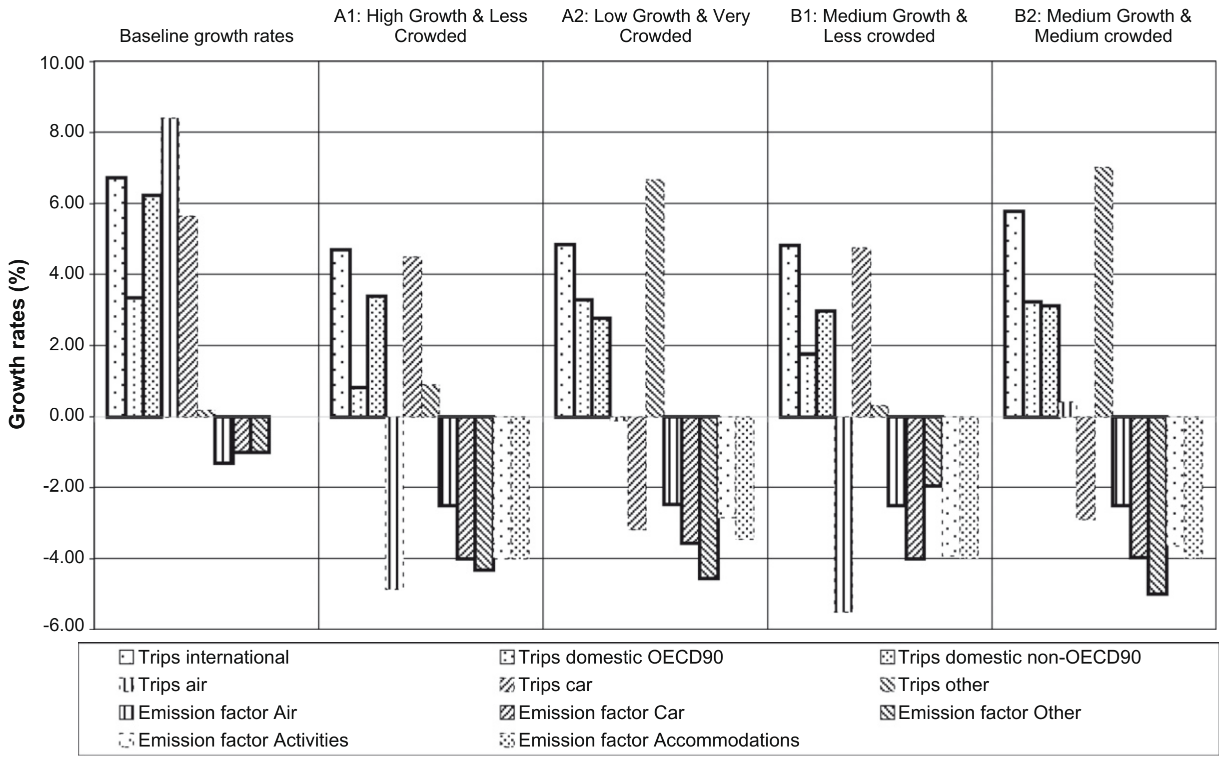

Fig. 3. Solutions for the four backcasting optimisation runs with GTTM^{adv}, given as growth rates in %/year for the number of trips per tourism market and per transport mode and for the emission reductions (i.e. the amount of technology applied). Note 1: for the growth rates of number of trips the average value between 2005 and 2050 is given as these are non-linear. Note 2: in all scenarios the CO_2 emissions have been reduced by 70% with respect to the emissions in 2005.

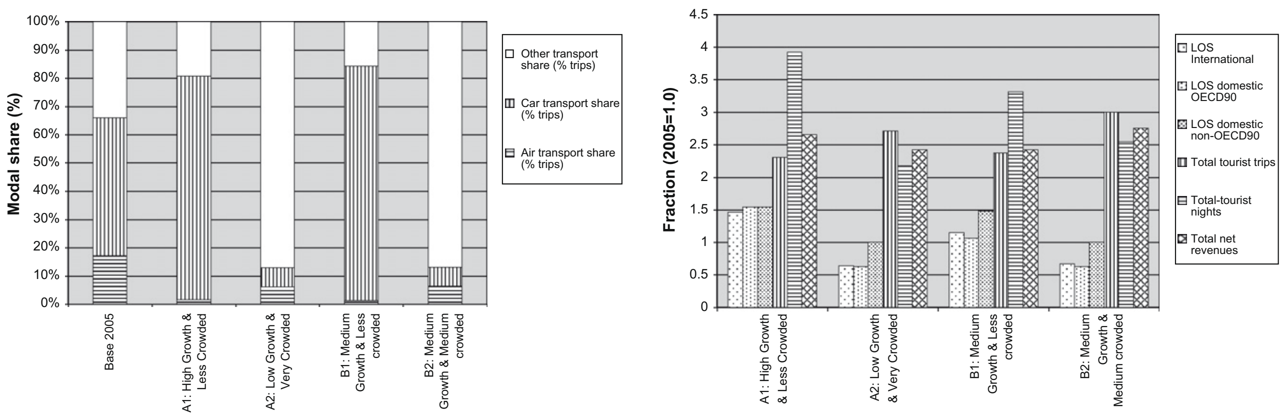

Fig. 4. Scenario results for modal split (left figure) and LOS, trips, nights and net revenues (right figure).

and (2) changes in modal split, number of trips and length of stay. Only one scenario reached an absolute reduction of emissions in 2035 with respect to 2005, but none showed the goal of reducing emissions by two-thirds. Also in a previous exercise (Dubois et al., in press), using the GTTM^{bas} to manually develop backcasting scenarios, we did not succeed in reaching the target of reducing emissions by 67% in 2050 compared to 2005. Theoretically there is no reason why manual backcasting or landscaping could not reach an optimum solution, but the radical changes required combined with the issue of author perceived acceptability and practical limits of model run-time prevented the authors to find the input that would satisfy the same optimum solution.

The third finding is that without radical shifts, it seems impossible to find a future tourist travel system consistent with the strong CO_2 emission reductions required to avoid dangerous climate change. This finding is based on the automated backcasting we performed with GTTM^{adv}, that shows the radical changes in modal split and distribution of tourists over destinations required and on par with current trends. The backcasting simulation approach appears to be promising for future work on sustainable tourism development. Interestingly the relatively simple model used shows 'chaotic' behaviour typical for complex systems as it is "non-linear, (...) deterministic and unstable in that it displays sensitivity to initial conditions" (Smith, 2007, p. 16).

The findings have important implications for the sustainable development of tourism. Improvements in technology alone are insufficient if we want to reach sustainability targets for CO_2

emissions. To reduce CO_2 emissions to the level required to avoid dangerous climate change, major shifts in transport modes and destination choice (less far away) are necessary. Given tourism's current contribution to CO_2 emissions and growth rates in CO_2 emissions from tourism and tourism transport, the problem cannot be solved globally by relying on the reductions made by all other sectors (e.g. Bows et al., 2009).

The results describe how a sustainable tourism system might look in the future. It does not give directions for policies that implement this situation. The four backcasting scenarios show no easy solutions. A larger than business-as-usual investment in technology seems efficient in any case. Furthermore, the four scenarios are characterised by either a very strong reduction of current air transport or a simultaneous reduction of car use and increase of other modes like rail and coach, while keeping air transport at current levels (i.e. no growth). Both are politically and socially not easy to achieve. However, as the impacts of climate change become more and more severe and the disastrous character of 'dangerous' climate change gains more widespread acceptance, a sense of 'emergency' may lead to much stronger policies not yet considered feasible. An example is the modal split of all passenger transport in the USA during World War II. At the start of the war public transport captured just 10% of all traffic, but in 1943–1944 this increased to 40% (Gilbert and Perl, 2008, p. 29), because of strong patriotic communication by the government (e.g. driving alone was likened to 'driving with Hitler').

The main contribution made by this study is in comparing the value of different ways to approach the future. In this case, for example, futures that deviate significantly from the current situation are required. Contemporary forecasting scenarios may cause people to 'lock-in' to the problem, rather than search for a solution ('it has been forecasted so we cannot escape it'). Explorative techniques using qualitative scenarios avoid this problem, but seem more vulnerable to subjective considerations of likeliness or probability and may lead, to a lesser extent, to the same kind of lock-in. Backcasting (normative) scenarios are shown to be a more useful way to explore problems, as they are solution-oriented and may help avoid lock-in, and if the scenario input parameters are allowed a sufficiently large range.

The next step of this research will be to include policy and sector investment measures and feedback that controls human and corporate behaviour. The target can be economic (net tourism revenues), but also social (access to tourism). Decision variables include pricing policies, emission caps, innovation policies and investments in infrastructure (investment by governments and corporations). Human behaviour will be modelled using generalised rules. Candidates are travel time and financial budgets (e.g. Schafer and Victor, 2000), the relation between tourist number of nights and average income, and a general latent urge to travel to 'exotic' places. This will result in a system dynamics version of the model – $GTTM^{dyn}$ – which can be used for evolutionary policy approaches.

Acknowledgements

We extend our grateful thanks to UNWTO, UNEP and WMO for their support and data that helped us create the emission inventory and 2035 Baseline scenario. Also we are very grateful for the critical but constructive comments by Wil Thissen (Delft University of Technology, the Netherlands) Jaap Lengkeek (Wageningen University and Research, the Netherlands), Stefan Gössling (Lund University, Sweden), Jean-Paul Ceron (CRIDEAU Université de Limoges, France) and two anonymous reviewers. Finally we are grateful for the help by Rhonda Campbell and Sue Jordan with our struggle to write proper English. Still we take full responsibility for the text and contents of this paper.

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