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The vulnerability of beach tourism to climate change—an index approach

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Abstract The attractiveness of a region for touristic activities depends strongly on the local weather and climate. This paper analyses the vulnerability of the beach tourism sector towards climate change by means of an index approach on a country level. A vulnerability framework for the tourism sector is developed and on its basis, indicators are defined for exposure, sensitivity and adaptive capacity. A transparent index approach, including a robustness analysis with multiple transformation methods and weighting sets, yields an assessment of the overall relative vulnerability of the beach tourism sector in 51 countries. Aggregate results on an annual level are presented as a starting point for a more detailed comparison of countries based on the individual indicators. The important limitations regarding the availability of accurate indicators as well as the concept of vulnerability itself are discussed. Despite these limitations, the present study contributes to integrating the numerous direct as well as indirect effects climate change may have on beach tourism.

1 Introduction

Since many types of tourism depend directly on weather and climate, the current and future changes in climate have a strong potential to affect the tourism sector. In spite of this, the influence of climate (change) on tourism has only been investigated in few studies, while other affected economic sectors such as agriculture and the insurance services have received far more attention (IPCC 2007a). Such underrepresentation is not justified. Climate and tourism are closely linked: climate has been identified

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as one of the most important factors in destination choice (Hamilton and Lau 2006). In addition, tourism is an important economic sector, generating approx. 3.6% of the Gross World Product, and forming the very backbone of the economy in many small island nations (WTTC 2007). Although research on this topic has gained some momentum in recent years (Scott et al. 2005), overall the influence of climate change on tourism remains poorly understood.

It is surprising that vulnerability, as one of the key concepts in climate impact research, has so far not been explicitly studied for the tourism sector. Implicitly, the vulnerability of the tourism sector has naturally been investigated, mostly by studies on one of the three dimensions of vulnerability: exposure, sensitivity, and adaptive capacity. The exposure of the tourism sector to climate change has for instance been analysed by research on the suitability of future climate for tourism (Amelung et al. 2007; Scott et al. 2004) or on possible changes in snow cover (e.g. Abegg 1996; Harrison et al. 1999; Whetton et al. 1996). The sensitivity has been addressed by using statistical methods to determine how sensitive tourism demand is to climate (Bigano et al. 2006; Lise and Tol 2002; Maddison 2001) or by asking tourists how they would react to specific climate-related changes in a destination (Behringer et al. 2000; Braun et al. 1999; Scott et al. 2007a). Also adaptation has been the subject of a number of studies (Becken 2005; Behringer et al. 2000; Scott and McBoyle 2007). Finally, a few studies have combined different vulnerability dimensions to project changes in tourism flows (Hamilton et al. 2005; Hamilton and Tol 2007) or in ski season length (Scott et al. 2003, 2007b).

This paper analyses the vulnerability of the beach tourism sector towards climate change by means of an index approach. Indicators are defined for the exposure, sensitivity and adaptive capacity on a country level and the relative vulnerability of the beach tourism sectors in 51 countries is compared. The choice of beach tourism is a deliberate one. A specific type of leisure tourism is selected because climatic preferences differ between tourism activities (Crowe et al. 1977; Lise and Tol 2002; Yapp and McDonald 1978). Beach tourism is selected because the associated activities of sunbathing and swimming are more strongly linked to specific weather conditions than other tourism activities.

The chosen approach of using an index to estimate relative vulnerability has a number of advantages. The notion of a relative metric—relative vulnerability—takes into account that climate change is expected to change the pattern of tourism flows rather than aggregate numbers of tourists (Hamilton et al. 2005) and therefore the relative performance is more important than the absolute one. In addition, the approach allows to explicitly address all three vulnerability dimensions and to integrate direct as well as indirect effects of climate change (e.g. changes in the suitability of climate for beach tourism as well as changes in coral reefs). This is particularly important in a comprehensive assessment, as direct and indirect consequences of climate change are both important for tourism and can have opposing effects (Scott et al. 2007a). These advantages of this approach regarding integration are however achieved at a price: indices run the risk of oversimplifying and their development is fraught with uncertainties, making a transparent and sound method an absolute necessity.

The basis for this analysis is a conceptual framework for vulnerability described in Section 2. The selection of indicators for each vulnerability dimension, their transformation and weighting, and the data used are explained in Section 3. Subsequently in

Section 4, resulting countries' vulnerability profiles are presented and discussed. The robustness of the approach as well as lists of the most and least vulnerable countries are presented in Section 5 followed by an overview of limitations in Section 6 and conclusions in Section 7.

2 Development of a conceptual framework

Vulnerability has emerged as a key concept for the human-environment interface and during the last decade, its use in the scientific literature has experienced a sharp increase (Janssen et al. 2006). Vulnerability describes the degree to which a system "is likely to experience harm due to exposure to a hazard" (Turner II et al. 2003, p. 8074). or is "susceptible to [...] adverse effects" (IPCC 2007b, p. 883). While such broad definitions of vulnerability are by and large undisputed, the conceptualization of the term is very diverse across different research branches. A number of fields have adopted and developed the term vulnerability (see overviews and examples in Adger 2006; Kasperson et al. 2001; Kelly and Adger 2000; Patt et al. 2005; Schröter et al. 2005), resulting in different concepts and terminologies presented in a number of conceptual frameworks (Brooks 2003; Cutter 1996; Ford and Smit 2004; Luers 2005; O'Brien et al. 2004; Turner II et al. 2003). Which of all these is the 'right' conceptualization? Füssel (2007) argues that there is none, as different assessment contexts have different requirements. He thus stresses the need to clearly specify the applied vulnerability concept.

As a basis for the present study, the conceptualization provided by the IPCC Forth Assessment Report is adopted, which defines vulnerability as a function of a system's exposure to climate change, its sensitivity, and its adaptive capacity (IPCC 2007a). Exposure is the "nature and degree to which a system is exposed to significant climatic variations" (IPCC 2001, p. 987). Sensitivity means "the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise)"(IPCC 2007a, p. 881). Adaptive capacity refers to "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2007a, p. 869).[1]

The vulnerability concept provided by the IPCC is designed to be applicable to a large variety of assessments and is thus very broad. In order to derive indicators it is therefore necessary to elaborate the general framework and mould it on the beach tourism sector. For this purpose, the three dimensions exposure, sensitivity and adaptive capacity were combined in a matrix with different mechanisms by which climate change might affect the tourism sector directly or indirectly. In Table 1, the seven important mechanisms identified are presented: changes in mean climate, extreme events, sea level rise, biodiversity, water availability, snow and mitigation measures.

[1] In the terms of the framework provided by Füssel (2007), this means that two types of the four possible "vulnerability factors" are addressed in this analysis: the exposure to climate change is an external biophysical factor, the sensitivity and adaptive capacity are internal socio-economic factors.

Table 1 Framework for the vulnerability of the tourism sector to climate change

Mechanisms dimension	Mean climate	Extreme events	Sea level rise	Biodiversity	Water availability	Snow	Mitigation measures
Exposure	Change in suitability of climate for the type of tourism present	Change in frequency and intensity of extreme events relevant to tourism	Rise in sea level	Changes in composition of flora & fauna	Changes in precipitation, evaporation and factors that affect water consumption	Change in snow security	Policies to reduce greenhouse gas emissions
Sensitivity	Dependence on tourism that relies on current climate	Proximity of tourism infrastructure and resources to extreme events	Proximity of tourism infrastructure and resources to the maximum shoreline	Dependence on tourism relying on existing biodiversity	Water consumption of tourism industry	Dependence on tourism relying on snow	Elasticity of current tourism demand
		Value of tourism infrastructure and resources at risk	Value of tourism infrastructure and resources at risk	Attractiveness of new flora & fauna	Competing water consumers	Existing snowmaking facilities	Dependence on long-haul tourists
		Robustness of tourism infrastructure and resources towards extreme events (hazard resistant building, etc)	Dependence on coastal tourism			Existence of other attractions	Extent of new potential short-haul tourists
		Availability of insurance and other loss sharing systems					Carbon intensity of current tourism
Adaptive capacity	Economic resources available to tourism to adapt Innovation potential of tourism entrepreneurs Technologies available to tourism to adapt Knowledge within the tourism sector on climate change and its potential impacts Existence and effectiveness of institutions relevant for the tourism sector						

For each matrix element one or more vulnerability factors were identified and listed. The sensitivity factors regarding extreme events are based on Smith (2001) and the five general determinants of adaptive capacity were adopted from the IPCC (2001, p. 895–897) and are listed generically across all seven mechanisms.

The framework presented in Table 1 is developed for the tourism sector in general and can be used as the basis to derive indicators for different types of tourism (winter sports, nature-based tourism, coastal tourism) and different scales (destination, region, nation). For the specific case of beach tourism on a national level in this study, indicators were derived for the first four mechanisms. Snow reliability is obviously of no relevance while water availability as well as mitigation measures were very hard to quantify and thus left to future research.

3 Method and data

Indices are sets of weighted and aggregated indicators. In general, their strength lies in their ability to summarize a large amount of information in a format that is simple and understandable. They have been widely applied to synthesize economic, social, environmental and technological concepts (OECD 2003) with different purposes such as raising awareness, comparing between countries, monitoring progress and prioritizing action (Brenkert and Malone 2005; Kaly et al. 2003). Also in the field of vulnerability, composite indices have been developed (Downing et al. 2001; UNEP 2002).

Despite their usefulness, caution is also warranted in the use of indices. Their construction poses a number of challenges, especially the selection and weighting of indicators is fraught with uncertainties. Indices pose the risk of oversimplifying or misrepresenting the targeted process. Therefore, transparency regarding the process, the methodology and data used is of paramount importance (Eriksen and Kelly 2007; Esty et al. 2006; OECD 2002). In this study, the guidance issued by the OECD (2002) was generally followed and the method for each of the steps is documented transparently: the scope of the analysis, the selection of indicators, their transformation, weighting and aggregation as well as robustness analysis.

3.1 Temporal and geographical scope

The time frame chosen is two-fold and thus represents a hypothetical situation: the sensitivity and adaptive capacity of the *current* system (~2000) and *future* climate change (exposure by the 2050s) is analyzed. This is due to the very different nature of the underlying systems. While climate change can be reasonably well projected into the far future given an emission scenario, the development of the tourism sector cannot, as it underlies countless and mostly unpredictable influences such as economic and demographic growth, the global sense of security, rapidly changing trends, leisure time budgets, etc. The initial goal for sensitivity as well as adaptive capacity was to generate a time series yielding valuable insights into the past development of vulnerability. However, the lack of time series for many of the selected indicators restricted the analysis to one point in time.

Indicators were collected for a total of 177 coastal countries worldwide. However, results are presented only for the 51 countries for which all indicators were available and in which tourism is 'relevant'. 'Relevant' was defined as displaying either a high relative share or high absolute contribution of the tourism and travel industry to the gross domestic product (GDP). As a cut-off, the 50 highest scoring countries in each of these categories were selected based on data by the World Travel and Tourism Council (2004a).

3.2 Selection of indicators

The selection of indicators is the most critical step in the development of composite indicators, as it inevitably involves subjective choices. An important means of reducing overall subjectivity is robustness testing (see Section 3.8). However, there are also possibilities to reduce subjectivity within this first selection step by: (1) deriving indicators from a sound theoretical framework; (2) using a proxy; and (3) selecting indicators on the basis of a set of criteria. In this study, use was made of the first and last option to the extent possible.

Regarding the theoretical framework, the indicators were selected on the basis of the factors presented in Table 1, which in turn builds on the coarse vulnerability framework by the IPCC. However, this option for reducing subjectivity was limited, as so far no well-founded theory on the vulnerability of an economic sector to climate change has been developed, let alone of the tourism sector in particular.

For the second option, the possibility of using a proxy was not considered applicable to the present case. Largely, the approach consists in correlating a large number of potential indicators to a proxy variable for vulnerability and selecting those as final indicators that correlate significantly (for an application to vulnerability, see Brooks et al. 2005). The weakness of such an approach is that selecting a benchmark against which to test "is somewhat paradoxical since the very need for vulnerability indicators is because there is no such tangible element of vulnerability" (Adger and Vincent 2005, p. 404).

Finally, a set of criteria for indicator selection was derived from the literature (see Table 2). It proved challenging to find indicators for all vulnerability factors listed in Table 1, due to the common problem of data availability and quality. As the

Table 2 Set of criteria for the selection of indicators (based on Atkins et al. 1998; Esty et al. 2006; Kaly et al. 2003; OECD 2002)

	Criterion	Explanation
Validity	Well-founded	Based on a tested theoretical framework
	Accurate	Really measuring what it should
	Non-ambiguous	Agreement on the direction of influence between the indicator and vulnerability
Use	Comprehensible	Relatively easy for users to understand
Type	Relevant	Applicable to many geographic and economic conditions
	Responsive to changes	Can be influenced by action
	High information content	No yes/no indicators, and preferably actual performance data instead of model-based data
Data	Available	Data that is publicly and easily available
	Homogenous and periodical data	Data that is collected homogeneously, making it suitable for international comparisons

indicators considered could not satisfy all of the criteria listed, the set of criteria was applied as guidance and not as a requisite for the selection of the indicators. Often, criteria were conflicting, for instance the accuracy of the indicator might conflict with its data availability or also its comprehensibility.

The indicators selected are described in the following subsections. An overview is given in Table 3. The second column lists the mechanism as well as the factor within this mechanism that the indicator represents.

3.3 Exposure indicators

3.3.1 Mean climate

The exposure indicator for mean climate should reflect the change in climate from the perspective of beach tourism. A widely used index that measures the suitability of climate for tourism is the Tourism Climatic Index (TCI) developed by Mieczkowski (1985). It combines different climatic aspects relevant for tourism: daytime comfort, daily comfort, sunshine, precipitation and wind. These aspects are transformed from their specific unit onto a scale from −3 to 5 (or 0 to 5 for sunshine and wind, and up to 5 for precipitation). The scores are then multiplied by a weighting factor (most weight given to daytime comfort) to produce the index that ranges from approx. −30 to 100. This index suffers from several shortcomings. The most important one is the fact that the ratings of climate variables is attributed based on expert judgement and is not verified empirically. In addition, there are many indications that tourist climate preferences are neither constant over time nor across different countries (Besancenot 1990; Lise and Tol 2002; Morgan et al. 2000). Nevertheless, such an index is deemed more accurate than the use of for instance temperature alone. Calculations were carried out on the basis of the original paper. However, as the original TCI is designed for light sightseeing activities, in this study two subindices have been adapted for beach tourism. Of the four different wind rating scales used by Mieczkowski the 'normal' system was used for all cases, as it best reflects beach visitor preferences reported by Scott et al. (2008). For sightseeing, Mieczkowski defined optimal thermal comfort between 20°C and 27°C effective temperature. Based on stated preferences (Scott et al. 2008), this optimum was shifted to 24°C to 31°C effective temperature. As the number of sunshine hours were not directly available from climate models, they were derived from cloud cover data as suggested by Amelung (2006). An alternative calculation method using solar radiation data (Yorukoglu and Celik 2006) was rejected, as it performed very poorly at high latitudes. When applied to beach tourism, an important limitation of the index is that water temperature is not taken into account.

For the indicator, the projected average annual B-TCI for 2041–2070[2] was subtracted from the past average B-TCI (1970–1999). The socio-economic scenario SRES A2 was chosen as it was the only scenario for which data was available for all exposure indicators. The data processed were monthly averages from the three models GFDL_CM2.1, MIROC3.2 (medres) and ECHAM5/MPI-OM, provided by the Program for Climate Model Diagnosis and Intercomparison (PCMDI). The

[2]For the ECHAM5/MPI-OM model, the time span was 2045–2065, as some of the necessary data was only available for these 20 years.

Table 3 List of vulnerability indicators used for the analysis

	Mechanism: factor	Indicator	Units	Years	# Countries	Distribution ($\alpha = 5\%$)[a]	Source
Exposure	Mean climate: suitability of climate for the type of tourism present	Change in modified tourism climatic index	Scale from 0 to 100	1970–1999 vs. 2041–2070	218	Normal/uniform	Calculated from 3 GCMs
	Extreme events: frequency and intensity of extreme events relevant to tourism	Change in maximum 5-day precipitation total	mm	1961–1990 vs. 2041–2070	218	None	Calculated from 3 GCMs
		Change in fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for wet day amounts	%	1961–1990 vs. 2041–2070	218	None	Calculated from 3 GCMs
	Biodiversity: strength of climate change that might affect flora & fauna current climate	Required adaptation of corals to increased thermal stress	°C	1980–1999 vs. 2050–2059	218	Lognormal	Donner et al. (2005)

Sensitivity	Mean climate: dependence on tourism that relies on	Share of arrivals for leisure, recreation and holidays	% of total arrivals	2000–2002 (1996–2004)	158	Normal/uniform	UN-WTO (2006)
	Extreme events: robustness of beach tourism infrastructure and resources towards extreme events (hazard resistant building, etc)	Number of people totally affected by meteorological extreme events	% of population	1995–2004	188	None	EM-DAT (2006)
	Sea level rise: proximity of tourism infrastructure and resources to the maximum shoreline	Number of people additionally inundated once a year given a sea level rise of 50 cm	People per million inhabitants	2000	206	None	Hoozemans et al. (1992)[b]
		Length of low lying coastal zone with more than 10 persons/km^2	km per 1,000 km coastline	1990	210	None	IPCC Response Strategies Working Group (1990)
		Beach length to be nourished in order to maintain important tourist resort areas	km per 1,000 km coastline	1990	216	None	IPCC Response Strategies Working Group (1990)

Table 3 (continued)

	Mechanism: factor	Indicator	Units	Years	# Countries	Distribution ($\alpha = 5\%$)[a]	Source
Adaptive capacity	Economic resources available to tourism to adapt	GDP per capita. purchasing power parity	2000 USD per capita	2000–2002	218	Normal/uniform/ lognormal	CIA (2001–2003)
	Technologies available to tourism to adapt	Internet users	% of population	2000–2002 (1999–2004)	200	None	ITU (2006)
	Knowledge within the tourism sector on climate change and its potential impacts	Total gross enrolment	% of population of respective age group	2000–2002 (1999–2004)	191	None	UNESCO (2006), UNDP (2005)
	Existence and effectiveness of institutions within the tourism sector	Regulatory quality	−2.5 to 2.5	2000–2002	197	Normal	Kaufmann et al. (2005)
	Importance of tourism	GDP generated by the travel and tourism industry	% of GDP	2005	181	Lognormal	WTTC (2004b)

[a] Four possible distributions were tested with a one-sample Kolmogorov-Smirnov test at a significance level of 0.05: normal, lognormal, uniform, exponential

[b] Coastal population density 1990 was adjusted to 2000 by assuming same growth as average national growth

calculation of TCI values were carried out on the original grids. Then, linear interpolation of grids was performed and an average of the three models was taken. For the country averages, grid cell results were area-weighted.

3.3.2 Extreme events

How extreme events that are relevant to tourism will change in frequency and intensity is difficult to summarize in indicators, as the spatial scale of general circulation models (GCMs) is quite coarse—too coarse for some extreme events (e.g. tropical cyclones). In addition, indicators that capture very rare events do not provide the statistical robustness needed for the analysis (Frich et al. 2002). Frich et al. (2002) thus defined ten indicators that are robust but as a tradeoff measure less extreme events such as number of frost days or growing season length. Of these ten, some are either already covered by the B-TCI while others are not relevant for beach tourism and were not included. However, two indicators stand for more extreme precipitation events and are thus chosen as flood indicators: the relative change in the maximum 5-day precipitation total of the year and the absolute change in the fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for wet day amounts. As above, data from A2 projections for 2041–2070 were used. Due to data restrictions, the comparison period was changed to 1961–1990. The indicators did not have to be calculated but were already provided on PCMDI. The three models used were GFDL_CM2.1, MIROC3.2 (medres) and PCM. For the averaging on country level, see Section 3.3.1 above.

3.3.3 Sea level rise

For the mechanism of sea level rise there is no exposure indicator. The obvious indicator, the projected eustatic rise for each coastline, could not be used as a result of high uncertainty: locally differentiated projections of sea level rise currently show strongly differing patterns depending on the model chosen (Meehl et al. 2007). The alternative of using the global average rise is also of no value as an indicator, as it is naturally the same for each country.

3.3.4 Biodiversity

Corals can be of great importance to beach destinations (Uyarra et al. 2005) and are expected to be damaged by increasing sea surface temperatures. Donner et al. (2005) assessed coral bleaching globally and determined the rates of adaptation required for survival under climate change. These rates were considered a first proxy for the exposure of beach tourism to biodiversity changes as indirect effects of climate change. The specific indicator selected is the “increase in thermal tolerance required to ensure bleaching occurs only once every five [...] years” (Donner et al. 2005, p. 2257) such that the corals can recover. The data are based on the HadCM3 model and the same scenario (A2) and similar time periods as above (2050–2059 versus 1980–1999). As grid cells could not be attributed to countries with the usual country boundaries, data of the ‘Exclusive Economic Zone’ seazone boundaries was taken from the Maritime Boundaries Geodatabase (Vlaams Instituut voor de Zee 2005).

3.4 Sensitivity indicators

For the sensitivity indicators, averages were generally calculated from the years 2000 to 2002 where possible in order to smooth out short-term effects in single years. For countries where no data was available for these years, averages were taken from those years noted in brackets in Table 3 that were available.

3.4.1 Mean climate

As an indicator for the dependence on beach tourism, the share of arrivals visiting for leisure purposes (UN-WTO 2006) was selected. It is assumed that tourists visiting for business purposes or to see friends and relatives are less sensitive to changes in climate (Fagence and Kevan 1997). It is a very coarse metric, but more specific tourism type indicators were not available on a global level.

3.4.2 Extreme events

Of the four sensitivity factors listed for extreme events, only a very rough proxy could be found for the ‘robustness of beach tourism infrastructure and resources towards climatic extreme events’. As no such tourism specific indicators were available, it was approximated by the percent of population annually affected by meteorological extreme events (EM-DAT 2006). This indicator provides information on how well a country can cope with extreme events in general. Unfortunately, it represents not only the country’s sensitivity, but also its current exposure and these two facets cannot be separated. For this indicator, the average of 10 years was taken in order to account for the low frequency of extreme events.

3.4.3 Sea level rise

Of the three sensitivity factors listed for sea level rise, indicators were found for the ‘proximity of tourism infrastructure and resources to maximum shoreline’. The ‘km of beach length to be nourished in order to maintain important tourist resort areas’ (IPCC Response Strategies Working Group 1990) is generally a very suitable indicator for this purpose. However, as the estimation was a very rough one, conducted on country level but intended for aggregation to a regional level, the indicator is not very accurate. In addition, the data are 20 years old which seriously limits their ability to reflect tourism sensitivity today. Therefore, two additional indicators were added to make the results more robust and less dependent on a single figure. From the same study, the length of low lying coastal zone with more than 10 persons/km^2 was added as a general indicator for sensitivity of the coast. Additionally, the number of people that would be additionally inundated once a year given a sea level rise of 50 cm was taken from the Global Vulnerability Assessment by Hoozemans et al. (1992). More recent assessments (Nicholls et al. 1999; Nicholls and Tol 2006) could have been used, but these are all also based on the original work by Hoozemans et al. (1992).

3.5 Adaptive capacity indicators

The indicators for adaptive capacity (also Table 3) could not be adapted to the (beach) tourism sector specifically due to the lack of data but had to be chosen on a more generic level. Such generic indicators for adaptive capacity towards climate variability and change on a national level have been developed by Brooks et al. (2005). However, their set of indicators was rejected as it refers specifically to mortality due to climate-related disasters. In the following, the indicators selected for the present study are presented. The same temporal range as that of the sensitivity sector was applied to these indicators (averages from 2000 to 2002 where possible, averages from the years noted in brackets where not).

For economic resources, gross domestic product (GDP) per capita adjusted for purchasing power parity (CIA 2001–2003) was selected. A number of other indicators considered, such as debt repayments, external debt, foreign direct investment and indices for income distribution equity, proved to be less adequate as well as less available, especially for small island countries.

No indicator could be found for the factor 'innovation', as even moderately accurate and homogenous data are not available (see Volo 2005). Many potential available indicators were considered, such as patent applications, trademarks, royalty and licensee fees, scientific journal articles etc. Apart from the fact that a number of such traditional innovation indicators are not collected homogeneously, they are not meaningful in the context of service industries. In these, innovation is often immaterial, cannot be protected and thus cannot be measured by patents or trademarks (OECD 1996). Innovation in the tourism industry is connected more to entrepreneurs than to scientists and research laboratories.

A wide variety of technologies might be useful for adapting to climate change. Indicators used for technological adaptation in other studies were rejected: 'investment in research and development' (Brooks et al. 2005) for reasons mentioned above regarding innovation and 'GDP' (Brenkert and Malone 2005) as it already represents the economic adaptive capacity. As a first approximation, the relative number of internet users (ITU 2006) was selected.

For the factor know-how, the indicator of total gross enrolment including all levels except preprimary (UNDP 2005; UNESCO 2006) was preferred to the literacy rate, as the latter is not able to distinguish between most developed countries. In these, literacy rates are assumed to be 100% and thus not collected anymore.

For the existence and effectiveness of institutions in the tourism sector, the six governance indicators reported by Kaufmann et al. (2007) were evaluated as proxies: control of corruption, voice and accountability, government effectiveness, regulatory quality, political stability, rule of law. Although most of the indicators can be considered relevant in some way, regulatory quality was deemed to be the most adequate for tourism as an economic sector, as it represents "the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development" (Kaufmann et al. 2007, p. 4).

As the above indicators are not tourism-specific, an additional indicator was included to build this bridge. The indicator represents the importance of tourism for a country. The rationale behind this additional indicator it is that the larger share the tourism industry contributes, the more weight and lobbying power it has to gear the adaptive capacities available towards tourism. Again, numerous indicators were screened, including number of tourists or stays divided by the population or expenditures of tourists divided by GDP. The share of GDP generated by the travel and tourism industry (WTTC 2004b) was selected as the most adequate to depict the importance of the tourism sector and additionally was also available for a large number of countries. The factor ‘importance of tourism’ exemplifies very well how the indicators chosen depend on the perspective of the analysis. From the perspective of a country, one could argue that a very high importance of tourism is damaging, as it inevitably also stands for a high dependence on a single sector, making the country very vulnerable to changes in international tourism choices. However, from the perspective of the sector itself, this issue is much less important. The community perspective would be yet a different one.

3.6 Transformation of indicators

Since the individual indicators are expressed in different units (e.g. US dollars or percentage of population) they have to be transformed in order to enable comparison and aggregation. There are a number of transformation methods, each with specific advantages and disadvantages (OECD 2003). The selected indicators are partially not very precise as data collection or calculation methods are not identical for each country. In addition, they showed very diverse and mostly irregular distributions (see column “distribution” in Table 3). Therefore, a coarse transformation method was chosen that is less sensitive to such data and does not feign more accuracy than actually present. It divides the data into quintiles and assigns a score from 1 to 5 (see below tr0 for standard method of transformation). For robustness testing, three additional methods were selected with a general focus on robust methods (tr1 to tr3).

tr0	categorical scale	divided into quintiles -> score 1 to 5
tr1	standardisation (z-transformation)	$x_i^{trans} = (x_i - \bar{x}) / s$
tr2	adapted standardisation	$x_i^{trans} = (x_i - m) / iqr$
tr3	share of sum[3]	$x_i^{trans} = 1000 \bullet x_i / \sum_{a=1}^{n} x_a$

(s = stand deviation, m = median, iqr = interquartile range, n = number of observations/countries)

The first alternative method (tr1) is standardisation, an approach commonly used in indicator construction, consisting of standardising the variables by deducting the mean and dividing by the standard deviation. The second method (tr2) applies the same principle but uses the interquartile range and the median. The third method (tr3) divides a value through the sum of all values, rendering the result less sensitive to irregular data distributions.

In order to make data comparable, transformation also needs to render values that are oriented in the same direction, meaning that higher values consistently represent better performance for each and every indicator (or worse performance for each indicator, of course, depending on the definition). However, high sensitivity and high adaptive capacity have opposing effects on vulnerability. Would both be given high values, they could not be added to each other in aggregation. In order to prevent such confusion, in this study the distinction is always made between ‘favourable’ and ‘unfavourable’. High values are thus given to the direction that is ‘favourable’ i.e. representing *low* vulnerability, *low* exposure, *low* sensitivity but *high* adaptive capacity. The equations listed above achieve this goal for indicators that consist of

[3]The multiplication with 1,000 is merely in order to make the resulting numbers more readable.

positive values only and for which higher values represent better performance to start with. For indicators that consisted of positive and negative values and/or for which lower values represented better performance (e.g. number of people affected by extreme events), the equations were adapted.

3.7 Weighting of indicators and aggregation

Weighting is a critical step in the process for the same reason as the selection—it is nigh on impossible to avoid subjectivity. The proxy approach being ruled out (see Section 3.1), statistical methods such as principal component analysis could be used to derive weights. However, in that case the weights would simply be determined by the indicators selected—which again have been chosen subjectively. Therefore in this study alternative weighting sets were chosen to use in robustness testing (see Table 4).

Table 4 Different weighting sets (in rounded percentages)

Dimension	Mechanism	Indicator(s)	wei0 (%)	wei1 (%)	wei2 (%)	wei3 (%)
Exposure	Mean changes	Change in B-TCI	33	50	25	25
	Extreme events	Maximum 5-day precipitation total fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for wet day amounts	33	25	25	50
	Biodiversity	Required adaptation of corals to increased thermal stress	33	25	50	25
Sensitivity	Mean changes	Share of arrivals for leisure, recreation and holidays	33	25	20	50
	Extreme events	Number of people totally affected by meteorological extreme events	33	25	40	25
	Sea level rise	Number of people additionally inundated once a year given a sea level rise of 50 cm Length of low lying coastal zone with more than 10 persons per km^2 Beach length to be nourished in order to maintain important tourist resort areas (all three equal weights)	33	50	40	25
Adaptive capacity	Economic	GDP per capita. Purchasing power parity	14	20	14	43
	Knowledge	Total gross enrolment	14	20	14	14
	Technology	Internet users	14	20	14	14
	Institutions	Regulatory quality	29	20	14	14
	Tourism importance	GDP generated by the travel and tourism industry	29	20	43	14

For exposure and sensitivity, the main weighting set ('wei0' in Table 4) assumes all three mechanisms to be equally important. The three alternative weightings are named wei1 to wei3 and each give most weight to one of the three factors. For the indicators for adaptive capacity, the main weighting set gives institutions and tourism importance double weight, as high tourism importance might channel all other factors towards tourism and a high regulatory quality has a similar effect by giving local as well as foreign investors the possibility to advance tourism. Alternative weighting wei1 assumes an equal set of weightings, while wei2 and wei3 gives triple weight to tourism importance and financial resources, respectively.

The last hurdle before aggregation is to define how to deal with missing values. The indicators were only aggregated to an index for countries where all indicators are available. Of the 88 countries where tourism is 'relevant', this approach yielded 51 countries with full data sets (of the overall 177 coastal countries 91 have complete data sets).

For the aggregation to a subindex, the transformed and weighted scores can subsequently simply be summed. For the aggregation to the overall vulnerability score, the arithmetic mean of the three subindices was taken. The arithmetic mean was chosen over the geometric mean, as the latter cannot be applied to negative values as obtained by two of the transformation methods. In addition, a comparison of arithmetic and geometric mean for the two other transformation methods showed that they were very highly correlated in any case (97–99% depending on the weighting).

3.8 Robustness analysis and identification of the most and least vulnerable countries

The term 'robustness testing' is used in this study instead of the more common 'sensitivity testing' in order to avoid the confusions that might arise from using this latter term in connection with the vulnerability dimension 'sensitivity'. As stated above, different transformation methods and different weighting sets were applied in order to test the robustness of the results towards different transformation methods as well as weighting choices. Calculating all possible combinations yields 256 vulnerability indices. Note that indices from different transformation methods cannot be directly compared to one another, as they have different units. In order to still be able to compare all 256 indices, all indices were transformed into simple ranks. Boxplots of these 256 indices per country give an impression on how robust the ranks are. To define the most and least vulnerable countries over all 256 indices, the approach of using quintiles applied by Brooks et al. (2005) was followed: Countries were defined as being most and least vulnerable if they were in the highest and lowest quintile in at least 100 out of 256 index variants (or 12 out of 16 variants for the individual dimensions, respectively).

4 Vulnerability profiles and patterns

4.1 Results

Figure 1 presents the results of the index calculations with the main weighting set and transformation method (categorical scale from 1 to 5). The three individual dimensions as well as the overall vulnerability index are shown.

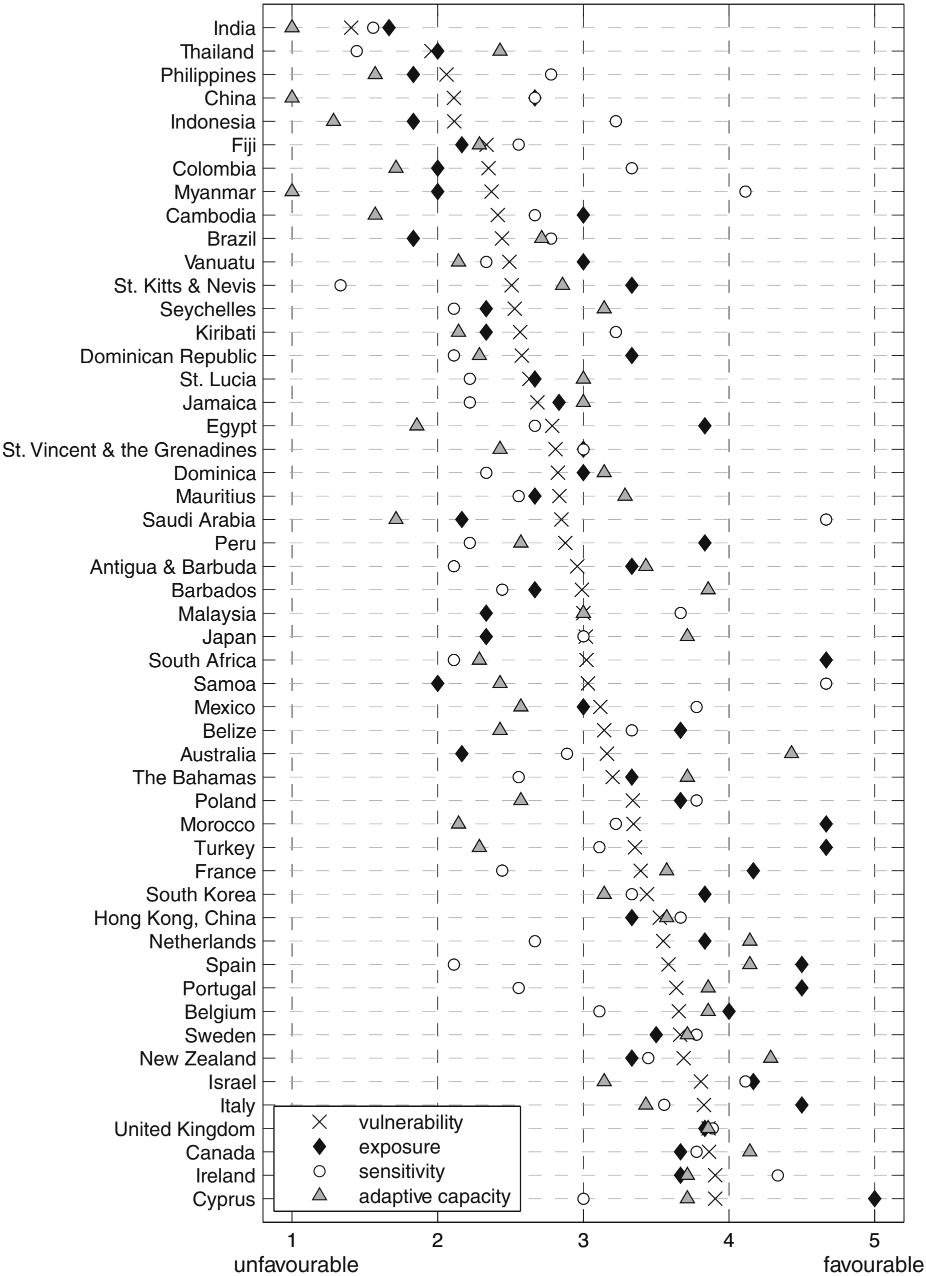

Fig. 1 List of countries showing the relative vulnerability of beach tourism to climate change. Results for exposure (♦), sensitivity (○), adaptive capacity (△) and all combined (×) are shown for the standard transformation and weighting

It is important to recall that the results presented do not refer to the countries' vulnerability but to the countries' beach tourism sectors' vulnerability. However, in order to simplify the language, in the following reference is made to the countries.

From a bird's eye view of Fig. 1 it becomes apparent that nearly all vulnerability scores (marked with x) lie between 2 and 4. The fact that the extreme ranges are not occupied show that no country has very high—or very low—vulnerability in all three dimensions. The notable exception is India, which scores extremely low on adaptive capacity but also very unfavourable on the other two dimensions. The most of the following very vulnerable countries are—like India—of a medium development status and are also all very populous. In the range of the low to medium vulnerability many small island states are to be found, together with a heterogeneous group of countries including Egypt, Peru, Malaysia and Japan. The least vulnerable countries are developed countries of high latitudes such as Canada, New Zealand, and Ireland, as well as Mediterranean countries including Cyprus, Italy, and Portugal.

There is quite a diverse composition of vulnerability with different subindex scores producing the same overall ranking. For instance South Africa and Samoa display nearly the same level of vulnerability, while the sensitivity and exposure scores are diametrically opposed. Similar patterns are displayed by Belize and Australia or Mauritius and Saudi Arabia. The overall score of the most vulnerable countries is based primarily on low adaptive capacity and high exposure while the sensitivity of some countries (especially Myanmar) is comparatively favourable. Several countries have strongly opposing subindex scores such as Myanmar, Saudi Arabia, Morocco, and Spain, making their overall vulnerability result very dependent on the weight given to each dimension. Others score equally favourable or unfavourable on all dimensions such as India, Fiji, Sweden and the UK.

A more systematic way of comparing different vulnerability patterns is presented in Fig. 2 below: Sensitivity and adaptive capacity are together (arithmetic mean)

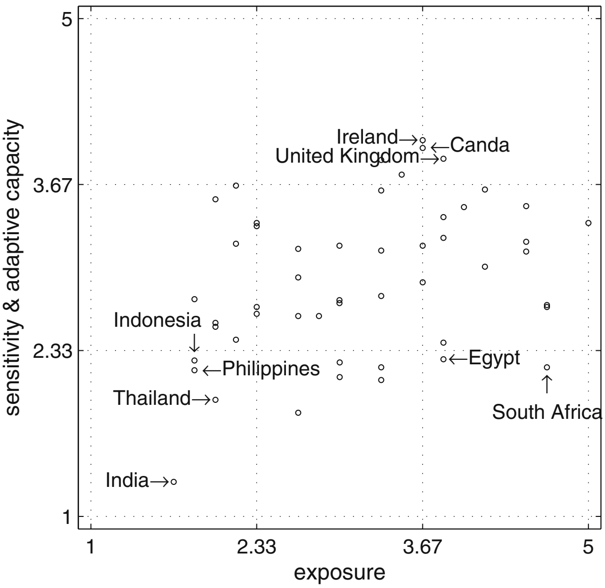

Fig. 2 Comparison of the arithmetic mean of sensitivity and adaptive capacity versus exposure. The units used are a scale from 1 to 5 representing unfavourable to favourable, respectively

plotted against exposure. The lower left square represents overall high vulnerability (India, Indonesia, the Phillippines, and Thailand), the top right one for overall low vulnerability (United Kingdom, Canada, and Ireland). The bottom right corner stands for countries that have a favourable exposure but have an unfavourable combination of sensitivity (high) and adaptive capacity (low) (South Africa and Egypt). The top left corner stands the reverse situation but contains no countries.

4.2 Discussion

For the interpretation of the results it is crucial to keep in mind that the scores are of relative nature. The scaling between 1 and 5 does not provide any information whether the vulnerability of all countries together is very low or high on an absolute scale. This is both a weakness—it provides no notion of absolute scale—and a strength, as destination choice depends strongly on (relative) differences between competitors (Hamilton et al. 2005). For instance India scores a straight 1 for adaptive capacity, which means it has the lowest adaptive capacity score of all countries included. 'Included' in this case means all countries in which tourism is 'relevant' (see 3.1), and for which all data is available. The first criterion rules out a large number of African countries that would score lower on adaptive capacity as defined here. The average adaptive capacity of all countries included is thus probably not equal to the world average.

It is also important to remember that a comparatively low vulnerability—despite the negative connotation to the word 'vulnerability'—can actually denote favourable conditions for the beach tourism sector of a country. Most of the indicators for exposure allow for both improvement and deterioration: the suitability of the climate for beach tourism as well as the frequency of strong precipitation events may increase or decrease. Only the indicator for corals does not allow for improvement but only for more or less (or no) damage.

With this in mind the results can be discussed. While it is generally assumed that small island states are among the most vulnerable regarding tourism, in Fig. 1 it is populous countries that head the list, only then followed by small island countries in the lower and medium ranges. The populous countries' high vulnerability is not based on high sensitivities but on low adaptive capacity combined with high exposure. The small island states in contrast, display a range of adaptive capacities and exposures but all display a rather high sensitivity. However, these results have to be taken with a grain—if not rather a whole handful—of salt because the indicator approach does not lend itself well to large countries. For instance in China, the maximum 5-day precipitation is projected to increase by approx. 10%. This number hides a very large variability within the country: on a grid basis the change projections range from −7 to + 47% (for the GFDL_CM2.1 model). Aggregating climatic, natural or socio-economic conditions over such a large area yields results that are near to meaningless on a local level.

This problem is not so relevant for the small island states. Their vulnerability scores are generally composed of a high sensitivity, although not as high as could have been expected as some are not so low-lying, others not so dependent on leisure tourists and others again have not been affected by meteorological extreme events in the past. The exposure of island states is generally unfavourable with corals strongly affected and a slight decrease in climate suitability. However, in some countries this is somewhat compensated by a projected decrease in heavy precipitation events. Mostly, their adaptive capacity is in the medium ranges, which to a small degree can be ascribed to the fact that 'importance of tourism' is one of the indicators. In addition, it seems to show that a high tourism share has led to a certain level of development or, the reverse, i.e. that the growth of tourism requires a minimum level of development.

It does not come as a surprise that many developed countries of the high latitudes are amongst the least vulnerable countries. Their high development status accounts for the medium to high adaptive capacity and their sensitivity is comparatively low—with tourists visiting for leisure but also business purposes and the countries having been able to reduce sensitivity to meteorological extreme events. As there are no coral reefs in these regions, there is no potential loss; and a general increase in climate suitability has been expected (Amelung et al. 2007). In general, this assessment also holds true for the Mediterranean countries. At first sight this might seem to be in contradiction to projections of the Mediterranean becoming too hot for beach tourism (Rotmans et al. 1994). However, these refer to summer conditions whereas the present analysis uses the average suitability across the year, which is projected to increase. This points to a limitation of the indicator for climate suitability, i.e. that it is on a coarse temporal scale and does not account for institutional seasonality. Long summer holidays are standard in the most important origin countries of Mediterranean tourism, which would mean that an increase in climate suitability in summer is worth more than an increase in, for instance, winter. Another weakness is the fact that a 10-point increase of the suitability indicator is always equally rated. However an increase from 60 to 70 (from 'good' to 'very good') could be considered more favourable that one from 20 to 30, where both ratings are quite unfavourable and would probably mean that beach tourism is still not possible for the masses in any month of the year. In this context it is important to keep in mind that the present analysis is only concerned with beach tourism. An increase in climate suitability for beach tourism can go hand in hand for instance with an increase or a decrease of the suitability for more active types of tourism such as sightseeing. The index does not provide any information on that.

Regarding the diverse composition of vulnerability, it can be instructive to compare two countries in more detail. South Africa and Samoa are nearly equally ranked but have very different profiles. Samoa is ranked as one of the least vulnerable small island states, which is primarily due to its extraordinarily—and maybe somewhat surprising—low sensitivity. Only 33% of arrivals to Samoa visit for 'leisure, recreation and holidays', most are for 'other reasons'. This is due to the fact that many Samoans live in New Zealand and return for weddings and other celebrations and to visit friends and relatives. Moreover, its sensitivity to extreme events is estimated to be low as no meteorological disasters were reported in the time span considered (1995–2004). However, if the investigated time span would have been 1991–2000, the percent of population affected once in 10 years would have been 49% instead of 0%, yielding a transformed score of 1 instead of 5. This highlights the sensitivity of this particular indicator to the time period chosen. Samoa's exposure, on the other hand, is quite high especially regarding coral bleaching and climate suitability. In contrast, climate suitability in South Africa increases, heavy precipitation events do not increase and as there are no coral reefs, they cannot be negatively affected by bleaching. In turn, South Africa has a high sensitivity, as it has been strongly affected by extreme events (mostly droughts) and most tourists visit for leisure purposes.

It is difficult to compare overall findings with other research. Comparisons with other global-scale assessments (Amelung et al. 2007; Hamilton et al. 2005) are of limited value as these do not focus on beach tourism and in addition include only one aspect of climate change (changes in temperature or a tourism climate index). A verification with studies carried out on national level (Becken 2005 for Fiji; Céron and Dubois 2005 for France; and Uyarra et al. 2005 for Bonaire and Barbados) is also futile, as these do not include all three vulnerability dimensions either and do not assess vulnerability from a relative perspective.

5 Robustness analysis

The results of the robustness testing are presented in Fig. 3. For each country, its 256 possible rankings (see method section) are displayed in the form of a boxplot. In general, the possible rankings per country are very wide. While individual countries like India may have very low ranges (three ranks), the average range lies at approx. 21 ranks—a very high value when compared to the total of 51 countries investigated. There are also cases, in which the range is extremely wide as for instance the Seychelles, Antigua &Barbuda, or the extreme case of Belgium, which nearly spans the complete width of ranks. The average interquartile range, which comprises 50% of observations, is six ranks.

These analyses show that the general features are robust while the exact rankings are not. However, the question must be raised whether a higher robustness is unambiguously a favourable feature of the index. A comparison of the subindices exemplifies this issue: the subindex for adaptive capacity is more robust (ranks varies less) than that for exposure. This is due to the fact that the indicators for adaptive capacity correlate quite highly with each other, which makes them less sensitive to different weighting sets. However, this does not necessarily make this subindex better than the other—it simply reflects the fact that correlating (i.e. in this case similar) aspects are being measured. In the exposure subindex, the different indicators correlate less or not at all, as for instance coral bleaching and 5-day precipitation maxima. However, both these indicators represent important aspects of the overall vulnerability. Kaly et al. (2003) emphasize this point in their work on the Environmental Vulnerability Index and select indicators that are as uncorrelated as possible in order to reduce redundancy. In this sense a very robust index could indicate that only one aspect is being repeatedly measured. It is evident that in an index approach if (1) different aspects are measured and (2) different weighting sets are applied, aggregated results inevitably vary. In the present case, it is precisely the aim of the vulnerability index to capture and combine several and different aspects of vulnerability. The variety of possible ranking then partially reflects how differently vulnerability can be perceived depending on individual priorities.

Figure 3 also underlines the importance of analysing the robustness of the results: In the case of Belgium it shows that results vary so widely that it makes most sense to compare this country to others by using the indicators themselves and not the aggregated indices. Relying on the result of one specific transformation and

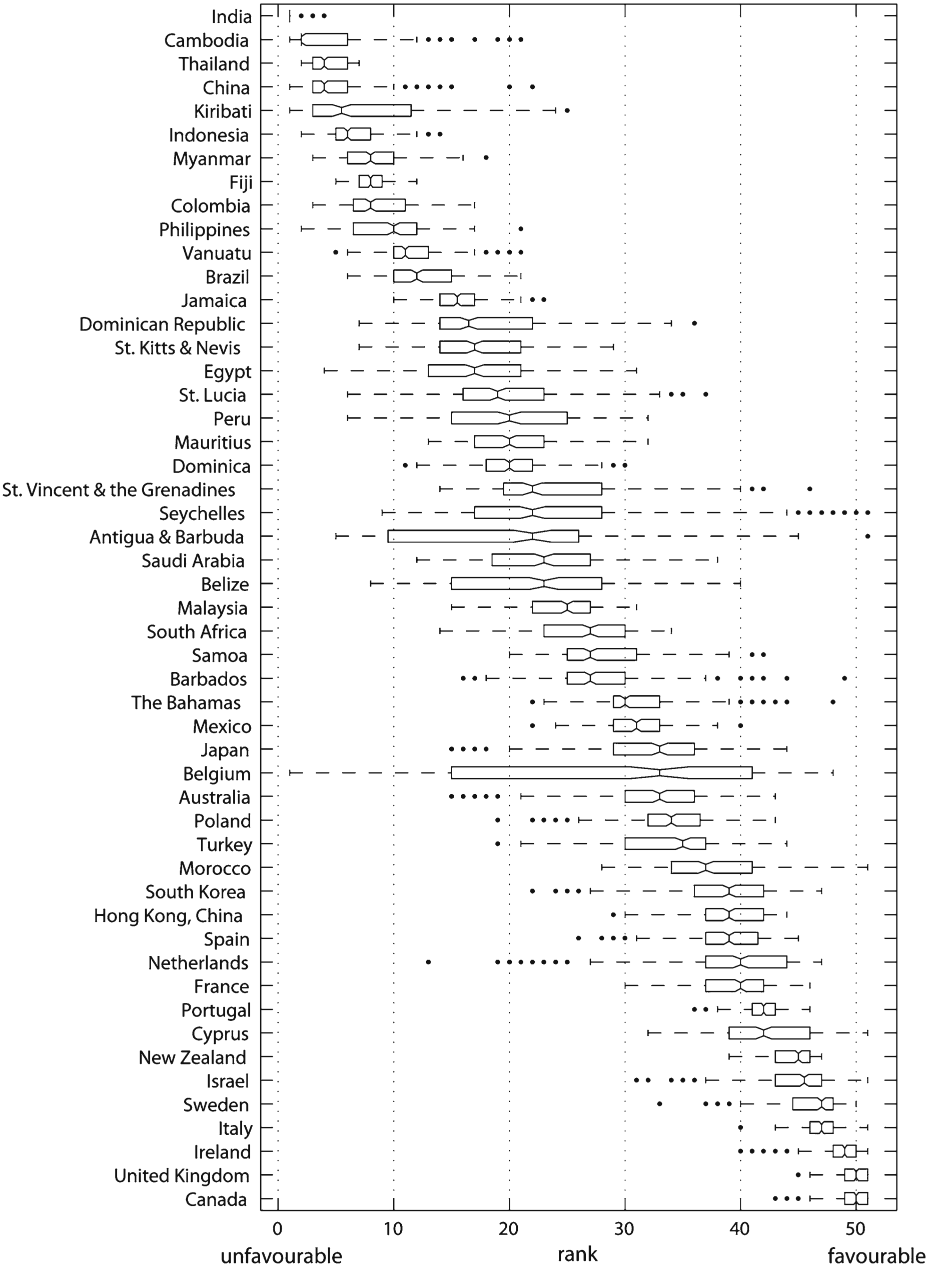

Fig. 3 Robustness analysis of vulnerability country ranking: Boxplot for each country based on the 256 country rankings. *Boxes* denote lower and upper quartiles and have notches at the medians. Maximum whisker length is 1.5 times the interquartile range. Outliers are shown with points. High ranks denote lower vulnerability

Table 5 Least and most vulnerable countries. Determined as resulting in the lowest/highest quintile in at least 12 out of 16 index variants (for individual dimensions), resp. 100 out of 256 index variants for all combined

	Vulnerability	Exposure	Sensitivity	Adaptive capacity
Unfavourable	India, Thailand, Fiji, China, Cambodia, Indonesia, Myanmar, Colombia, Kiribati, Philippines, Vanuatu	India, Colombia, Brazil, Marshall Islands, Maldives, Nauru, Tuvalu, Thailand, Indonesia, Bahrain, Micronesia, Philippines, Myanmar	India, Thailand, Antigua & Barbuda, St. Kitts & Nevis, Cambodia	India, China, Cambodia, Indonesia, Myanmar, Colombia, Iran, Russia, Philippines, Morocco, Kiribati, Saudi Arabia
Favourable	United Kingdom, Canada, Italy, Ireland, Sweden, New Zealand, Israel, Portugal, Cyprus, Netherlands	Cyprus, Morocco, Turkey, South Afria, Greece, Israel, Jordan, Italy, Portugal, France, Germany, Malta, Belgium, Croatia, Virgin Islands	United Kingdom, Ireland, Myanmar, Mexico, Malaysia, Saudi Arabia, Samoa	Netherlands, Australia, Denmark, Finland, Iceland, United States, Canada, New Zealand, Sweden

weighting would be unsound. But how does such a large variability come about? A contributing factor is the combination of very unfavourable and very favourable aspects within the same subindex that are each given high weight in one of the weighting sets: Belgium has a high GDP but a low 'importance of tourism' and each of these indicators is given triple weight in one weighting set. A second important reason are data outliers that produce different results depending on the transformation method chosen. Outliers are smoothed by categorization from 1 to 5 but can have very strong effects in the standardisation methods: Belgium has a much higher share of inhabited low lying coastal zone than all other countries investigated, it lies approx. 19 interquartile ranges away from the median of the distribution. This value is so extremely unfavourable that it can compensate all other (rather favourable) sensitivity indicators, yielding an unfavourable overall score. Finally, the calculation of many possible rankings allows to identify the most and least vulnerable countries in a more robust way (see Section 3). They are listed in Table 5 below.

6 Limitations

The selection of indicators, the interpretation and discussion of results as well as the robustness analysis have revealed a number of difficulties and limitations to the index approach. An important limitation is the subjective selection and weighting of indicators. This was to the extent possible addressed by basing it on a framework, carrying out a robustness analysis and above all reporting all steps transparently. A number of additional shortcomings are related to data constraints. The limited availability of data lead to (1) the scale of the analysis being national, with a consequently strongly diminished relevance of results for large countries; (2) some vulnerability factors not being very accurately represented by their indicators (see limitations of individual indicators in the method section); (3) some vulnerability factors not being represented at all, as for instance issues of water availability; and (4) the exclusion of certain poorly documented countries leading to a bias, which is particularly relevant in a relative analysis as the one presented here. As a consequence, the results presented in this study should be seen only as a starting point for a more in-depth analysis.

An aspect that went beyond the scope of this study are the relationships between the indicators (Eriksen and Kelly 2007). The simple averaging of (transformed and weighted) indicators has a very important implication: it means that the different aspects can compensate each other: more suitable climate can compensate for sea level rise, less GDP can be compensated by less heavy precipitation events. Tol and Yohe (2007) have shown that this assumption is valid for some but by no means all types of vulnerability. From a conceptual perspective, the resulting exposure indicators have raised doubts whether the notion of vulnerability is indeed suitable for the tourism sector. While sensitivity includes the possibility of a system to be beneficially affected and adaptive capacity comprises the ability to take advantage of opportunities, the concept of vulnerability allows only for damage, not for benefit or gain. For the analysis in the tourism sector—and perhaps others as well—it would be valuable to devise a broader concept and terminology.

7 Conclusions

This paper has presented a beach tourism vulnerability index on a national level as a new method of looking at the possible effects of climate change on tourism. A framework of the vulnerability of the tourism sector towards different aspects of climate change has been developed. Based upon this an index approach has been applied transparently, including a robustness analysis with multiple transformation methods and weighting sets. The analysis was carried out for 177 coastal countries worldwide but aggregated results are presented for 51 countries in which tourism is most important and for which full data sets were available. Aggregate results on an annual and national level indicate that, regarding beach tourism, large developing countries might be among the most vulnerable due to high exposure and low adaptive capacity. Small islands states are also vulnerable, especially due to their high sensitivity towards climate change. Developed high latitude countries as well as the Mediterranean are amongst the least vulnerable countries. However, the aggregated index should not be seen as a country ranking but only as a starting point for a more detailed comparison of individual indicators including local knowledge for the countries of interest. This caution in interpretation is warranted due to a number of limitations of the index approach. An important limitation is the lack of accurate and relevant indicators. Another drawback is the fact that for large countries, results on a national scale have very little relevance on the specific local level because a national indicator hides all geographical variability present. These two aspects could be addressed by applying the presented method on a destination instead of national level. The general framework developed could for instance be used to derive local indicators and compare competing beach destinations. If data for indicators were collected for each destination, the lack of accurate and relevant indicators would be less serious. Future research should also investigate the relationships between the different indicators and scrutinize the implicit assumption that a favourable rating in one indicator can compensate for an unfavourable rating in another. More generally, the study has revealed a key weakness of the vulnerability concept itself and points to the need for a broader concept and terminology.

The effect of climate change on tourism is not a simple one-dimensional relationship but involves complex interactions of direct and indirect effects as well as possibilities of responding to these. The merit of the presented approach lies in the integration of direct as well as indirect effects as well as explicitly addressing all three vulnerability dimensions, exposure, sensitivity and adaptive capacity. National level vulnerability assessments such as the one presented are still in a pioneering phase (Eriksen and Kelly 2007). It is hoped that this assessment has contributed to the development in this field and will encourage further exploration of methods to integrate different elements of the climate change–tourism interface.

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