Tourism climatic conditions of Hungary – present situation and assessment of future changes

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Abstract—This paper provides insight into the tourism-related outcomes of the Hungarian CRiGiS project, which was conducted in 2015. Based on tourism climatic indicators, this study aims at assessing the exposure of tourism sector to climate change. The widely known Tourism Climatic Index (TCI) is applied for the quantification of the climatic potential in Hungary in its original and modified form. This adjusted index version is suitable to reflect the seasonally different thermal perception patterns of Hungarian residents. These indicators were calculated based on past observations, and on the other hand, they rely on the outputs of regional climate model projections. The spatial distribution of the index values in Hungary is presented on a monthly basis and on district level, which is an administrative territorial unit in Hungary. The results indicate that, according to both versions of TCI, tourism climate conditions will likely to improve in the shoulder seasons and deteriorate in summer, remaining still at least acceptable for outdoor tourism purposes. The project outcomes are available for public use in the National Adaptation Geo-information System (NAGiS) developed in Hungary.

Key-words: climate change, tourism climatic potential, Tourism Climatic Index, spatial pattern, subjective thermal perception, districts of Hungary
1. Introduction

Climate constitutes an essential natural resource for tourism industry – it can promote or constrain certain tourist activities and tourism development (de Freitas, 2003; Gómez Martín, 2005; Scott and Lemieux, 2010; Scott et al., 2012). Climate is an important driver of tourist motivation (Crompton, 1979; Morgan et al., 2000; Kozak, 2002; Hübner and Gössling, 2012) as well as of destination choice and other decision-making mechanisms, either before trip or under holiday (Hamilton and Lau, 2005; Gössling et al., 2006; Scott et al., 2008, 2012; Moreno, 2010; Scott and Lemieux, 2010). In addition, climate has a significant impact on overall attractiveness of a target area (Hu and Ritchie, 1993; Kozak, 2002; Moreno, 2010). Tourism industry and destination products are highly sensitive to climate variability and climate change. The impacts of climate change are expected to vary geographically and seasonally (IPCC, 2014).

Climate change will directly affect tourism sector by altering the temporal and spatial distribution of climate resources for tourism, and thus, the main domestic and international tourism flows and expenditures (Scott et al., 2004, 2012; Rutty and Scott, 2014). Climatic resources – considering their global level distributions – are projected to shift towards higher latitudes. Namely, northern parts (of Europe and America) are expected to improve of climate conditions, while southern regions (Mediterranean and Caribbean) are likely to become ‘too hot’ in summer. On the other hand, spring and autumn months will likely to improve in the latter case. As a result, northern European tourists might stay in their home country or neighboring areas in summer due to climate change. These features were emphasized or concluded by many research studies in the field of tourism climatology (Morgan et al., 2000; Scott and McBoyle, 2001; Scott et al., 2004; Hamilton et al., 2005; Amelung and Viner, 2006; Amelung et al., 2007; Nicholls and Amelung, 2008; Hein et al., 2009; Perch-Nielsen et al., 2010; Amengual et al., 2012; Amelung and Moreno, 2012). However, some studies have questioned these results, because they have not considered what tourists perceive to be thermally unacceptable for their activities.

According to Rutty and Scott (2010), it is unlikely that the above mentioned southern regions will become ‘too hot’ for coastal tourism for the next decades. They concluded this assertion according to a survey of university students conducted in northern Europe, which examined their climate preferences for beach and urban tourism concerning the Mediterranean region. Moreno and Amelung (2009) similarly concluded that relatively modest shifts in climatic attractiveness will likely to be found over the coming 50 years, and the Mediterranean region is likely to remain Europe’s prime region for summer vacation. They used the Beach Climate Index of Morgan et al. (2000), which was developed by using interviews with tourists. Using questionnaires with northern travellers, Moreno (2010) found that large majority of tourists would
still travel to the Mediterranean even if ideal coastal weather conditions were occur in their home country as a result of climate change.

These are only three examples, which question the main research opinion – i.e., the tourist activities may decrease in the Mediterranean because of the projected warming tendencies –, subjective reactions of people actually may not follow the projected trends concluded from purely objective investigations. In fact, direct consultation with travellers on their climate assessments (perception, preferences, and tolerances) is more important than ever, as emphasized by a large number of studies (e.g., Gómez Martín, 2005, 2006; de Freitas et al., 2008; Scott et al., 2008; Gössling et al., 2012). These investigations, with focusing on human assessments, allow us on the one hand to explore tourists perception and preferences of weather parameters, to define the ‘ideal’ or ‘unfavorable’ climatic conditions and to determine the perceived importance of different climate parameters, or even to explore the role and importance of climate (or climate change) as a destination attribute. On the other hand, several studies analyse tourism climate potential of destination areas with climate evaluation tools (indices, rating systems). Travellers’ assessment patterns should be incorporated into these tools.

Understanding the way climate change affects tourism industry and the subjective assessments and behavioral reactions of tourists remains limited. Effectiveness of adaptation to climate change and adaptive capacity of tourists remain largely unexplored as well (Scott et al., 2009, 2012; Gössling et al., 2012). By identifying the quantitative impacts of climatic conditions and climate change on tourism, we can facilitate the development of objective strategies, decision-making processes, and planning for climate change adaptation. Several tourism climatological evaluation tools have been developed to quantify the climate potential and climate change impacts on tourism sector; however, they are most regardless of local residents’ or tourists’ climatic assessments. It is widely accepted in the field of tourism (bio)climatology that the tourism climate evaluation tools should be adjusted to the local residents’ or tourists’ subjective assessments (de Freitas, 2003; Scott et al., 2004, 2008; de Freitas et al., 2008). To prepare targeted and sustainable adaptation strategies in response to climate change, it is indispensable to reveal climate potential with empirically tested approaches.

This study provides insight into the results related to tourism climate potential of the project ‘Vulnerability/impact studies with a focus on tourism and critical infrastructures’ (CRIGiS, 2016). This project was conducted in 2015, with the main aim to develop methodologies that could be used to objectively quantify the effects of climate change in exposure, vulnerability, and adaptation capacity for various sectors in Hungary. In the frame of the project, the exposure of the tourism sector to the climate change was quantified. For this purpose, we applied the widely used Tourism Climatic Index in its original form (TCI; Mieczkowski, 1985) and in its modified form that is adjusted to the Hungarians’
subjective thermal assessments \( (mTCI; \text{Kovács} \text{ et al., } 2016) \), as well as the recently developed so-called second generation tourism climatic index – Climate Index for Tourism \( (CIT; \text{de Freitas} \text{ et al., } 2008) \). In this paper, we present some outcomes on the basis of \( TCI \) and \( mTCI \) patterns.

2. Methods

2.1. Tourism Climatic Index

\( TCI \) is a widely used measure that evaluates the suitability of a particular climate for general outdoor tourism activities like sightseeing and shopping or other light physical activities \( (\text{e.g., Mieczkowski, } 1985; \text{Scott} \text{ et al., } 2004; \text{Amelung} \text{ and Viner, } 2006; \text{Amelung} \text{ et al., } 2007; \text{Farajzadeh} \text{ and Matzarakis, } 2009; \text{Hein} \text{ et al., } 2009; \text{Perch Nielsen} \text{ et al., } 2010; \text{Amelung} \text{ and Moreno, } 2012; \text{Amelung} \text{ and Nicholls, } 2014; \text{Roshan} \text{ et al., } 2016) \).

In Hungary, \( TCI \) has been used only by a few studies so far. \text{Németh} (2013) quantified climate potential for Lake Balaton Region for the climate normal periods 1961–1990, 1971–2000, and 1981–2010. \text{Kovács} \text{ et al., } (2015) analyzed the annul course of \( TCI \) for Budapest (the capital of Hungary) and Siófok (the main resort on the shore of Lake Balaton) for the period 1996–2010. \text{Hódos} (2014) presented first time the spatial distribution of \( TCI \) in the region of Hungary. She determined \( TCI \) per month for the Carpathian Region (44–50°N and 17–27°E) for the normal periods 1961–1990, 1971–2000, 1981–2010, and 2001–2010. The changes between the periods 1981–2010 and 1961–1990 were also analyzed. The study region covered the target area of the CarpatClim project, which final outcome was a 0.1° spatial resolution, quality controlled, homogenized, cross border harmonized, and gridded dataset on daily scale for several basic meteorological variables and derived climate indicators from 1961 to 2010 \( (\text{Szalai} \text{ et al., } 2013) \). For homogenization the MASH (Multiple Analysis of Series for Homogenization; \text{Szentimrey, } 2011), for interpolation the MISH (Meteorological Interpolation based on Surface Homogenized data basis; \text{Szentimrey and Bihari, } 2007) procedure were applied; both of them were developed at the Hungarian Meteorological Service.

The original form of the \( TCI \) consists of five sub-indices, which in turn are based on monthly values of seven basic climate parameters \( (\text{Table 1}) \). From the seven basic parameters, three ones – monthly precipitation sum, daily sunshine duration, and daily mean wind speed – are rated in itself with different score values, from zero (unfavorable) to five (optimal), forming sub-indices \( R, S, \) and \( W, \) respectively \( (\text{Table 1, Fig. 1}) \). In the case of \( R \), the rating system is monotonically decreasing with the increase of precipitation sum \( (\text{Fig. 1a}) \), while the score values of \( S \) ascend monotonically as the number of sunshine hours increases \( (\text{Fig. 1b}) \). In the case of \( W \), four distinct rating systems were introduced by \text{Mieczkowski} (1985) depending on specific air temperature ranges \( (\text{Fig. 1c}) \).
Table 1 The sub-indices of Tourism Climatic Index, their rating score ranges, and their weights (based on Mieczkowski, 1985)

<table>
<thead>
<tr>
<th>Monthly values of basic climate parameters</th>
<th>TCI sub-indices</th>
<th>Scores</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>daily maximum temperature (°C)</td>
<td>daytime effective temperature (°C)</td>
<td>Cl – daytime comfort index</td>
<td>-3 to +5</td>
</tr>
<tr>
<td>daily minimum relative humidity (%)</td>
<td>daytime effective temperature (°C)</td>
<td>Ca – daily comfort index</td>
<td>-3 to +5</td>
</tr>
<tr>
<td>daily mean temperature (°C)</td>
<td>daily mean relative humidity (%)</td>
<td>R – precipitation index</td>
<td>0 to +5</td>
</tr>
<tr>
<td>monthly precipitation sum (mm)</td>
<td>daily sunshine duration (hour)</td>
<td>S – sunshine duration index</td>
<td>0 to +5</td>
</tr>
<tr>
<td>daily mean wind speed (km/h)</td>
<td>daily mean wind speed (km/h)</td>
<td>W – wind speed index</td>
<td>0 to +5</td>
</tr>
</tbody>
</table>

For wind speed above 8 km/h, wind chill nomogram should be used (see Mieczkowski, 1985)

Fig. 1. Rating score systems for each sub-index in the Tourism Climatic Index (based on the rating systems of Mieczkowski, 1985).
The remaining two sub-indices of TCI were designated to describe the thermal comfort conditions – one of them refers to the whole day (CIa – daily comfort index), while the other characterizes the thermal conditions at the warmest period of the day (CId – daytime comfort index). Correspondingly, CIa is derived from the daily mean values of air temperature and relative humidity, while CId rates the combined effect of the daily maximum air temperature and minimum relative humidity (Table 1) (Mieczkowski, 1985). In fact, the rating system of CIa and CId relies on one of the earliest thermal indices, the so-called Effective Temperature (ET). ET is a simple empirical index, which expresses the combined effect of air temperature and relative humidity on thermal comfort (Houghten and Yaglou, 1923). Mieczkowski (1985) defined the ET range of 20–27 °C as optimal zone with a rating score of five; then reduced the points gradually on both sides of the optimal zone according to an arbitrarily assigned set of ordinal values (Fig. 1d).

It is worth noting that in contrast to the score values of R, S, and W, Mieczkowski (1985) assigned minus score points to the lowest ET values (i.e., to the coldest environmental conditions) (Fig. 1) in the case of CIa and CId.

Finally, each sub-index is weighted with certain factors that express their relative importance within the overall climate evaluation (Table 1). The value of TCI is obtained as the weighted sum of the sub-indices (Mieczkowski, 1985):

\[
TCI = 2(4CId + CIa + 2R + 2S + W).
\]  

The TCI measures the climate’s overall suitability for tourism activities on a scale of minus twenty to hundred, with higher values indicating more favorable climate potentials for outdoor activities (Mieczkowski, 1985; Table 2).

<table>
<thead>
<tr>
<th>TCI scores</th>
<th>Descriptive categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 – 100</td>
<td>ideal</td>
</tr>
<tr>
<td>80 – 89</td>
<td>excellent</td>
</tr>
<tr>
<td>70 – 79</td>
<td>very good</td>
</tr>
<tr>
<td>60 – 69</td>
<td>good</td>
</tr>
<tr>
<td>50 – 59</td>
<td>acceptable</td>
</tr>
<tr>
<td>40 – 49</td>
<td>marginal</td>
</tr>
<tr>
<td>30 – 39</td>
<td>unfavorable</td>
</tr>
<tr>
<td>20 – 29</td>
<td>very unfavorable</td>
</tr>
<tr>
<td>10 – 19</td>
<td>extremely unfavorable</td>
</tr>
<tr>
<td>−20 – 9</td>
<td>impossible</td>
</tr>
</tbody>
</table>

Table 2. Tourism climatic index rating system (Mieczkowski, 1985)
2.2. Modified form of Tourism Climatic Index

Although TCI has been the most widely applied tourism climate index over the past 30 years (Scott et al., 2012), a number of limitations have been identified or emphasized by several research studies (e.g., Scott et al., 2004; Amelung and Viner, 2006; de Freitas et al., 2008; Farajzadeh and Matzarakis, 2009; Moreno and Amelung, 2009; Perch-Nielsen et al., 2010; Kovács and Unger, 2014a). The modified form of TCI used in CRIGiS project overcomes two of the major shortcomings of the index.

One of the main limitations of the index is that its thermal components are theoretically unsound according to the recent human thermo-physiological knowledge. In fact, the thermal comfort sub-indices, Clid and Cla, rely on ET, which is based on air temperature and humidity data only. However, several biometeorological studies have indicated that the thermophysiological effect of the atmospheric environment on the human body depends on the combination of four climate parameters (air temperature, air humidity, wind velocity, and thermal radiation) and on personal factors, such as clothing and human activity (Jendritzky, 1993; Matzarakis and Mayer, 1996; Höppe, 1999; Mayer, 2008). Several studies have proposed modification of the TCI’s thermal comfort sub-indices (Scott and McBoyle, 2001; Scott et al., 2004; Amelung and Viner, 2006; Perch-Nielsen et al., 2010). Instead of using effective temperature, Kovács et al. (2016) proposed the integration of the Physiologically Equivalent Temperature (PET) into the thermal comfort sub-indices of the TCI. The advantage of the biometeorological index PET is that it considers the physiological effect of both climate and human factors (Höppe, 1999; Kántor et al., 2016a).

The other essential shortcoming of TCI is that the rating and weighting schemes of each of its sub-indices are arbitrary – they were defined according to Mieczkowski’s personal expert opinion, which was based on former, obsolete (biometeorological) literature. These rating systems had never been tested empirically against the perceptions and preferences of real tourists (Mieczkowski, 1985; Scott et al., 2004; Amelung and Viner, 2006; de Freitas et al., 2008; Farajzadeh and Matzarakis, 2009; Moreno and Amelung, 2009; Perch-Nielsen et al., 2010).

Adaptation of some tourist climate evaluation tools has already begun in Hungary. The process focused mainly on the adjustment of the thermal parts of TCI by incorporating PET (Kovács and Unger, 2014a, 2014b) and making the score-system suitable to express the subjective thermal assessment patterns of the Hungarian population (Kovács et al., 2016).

From the different aspects of subjective thermal evaluation, in this paper we are focusing on the most evident assessment – the thermal perception (thermal sensation). A new PET rating system is developed and integrated into the thermal sub-indices of the TCI, which reflect the thermal perception patterns of Hungarian residents. This modification improves the credibility of the
thermal rating scores of TCI, and thus, enhances the potential of TCI to evaluate the thermal aspect of climate.

In order to reveal the subjective thermal assessment patterns, we used questionnaire surveys and simultaneous meteorological measurements in open air urban environments. We utilized data from a 3-year-long outdoor thermal comfort campaign, conducted on 78 days in 2011, 2012, and 2015 in six public spaces of Szeged, Hungary. Corresponding to the outdoor activities of people in this climate zone, the interviews and the meteorological measurements were carried out during spring, summer, and autumn. (More information on the Hungarian thermal comfort surveys is available in Kántor et al., 2011, 2012, 2016b; Kovács et al., 2016; Kántor, 2016.)

In frame of the surveys we recorded the thermal perception of people on a 9-point scale (thermal sensation vote, TSV). The applied TSV scale ranged from −4 to 4, corresponding to the perception of very cold to very hot. Then the thermal sensation votes were paired with the measured atmospheric parameters according to the exact time when the TSV data were recorded. From the meteorological data (air temperature, relative humidity, wind velocity, and mean radiant temperature), PET values were calculated with the RayMan software (Matzarakis et al., 2010). Then we used the obtained 5805 TSV–PET datapairs to reveal the subjective thermal sensation patterns of Hungarians in different seasons.

In order to develop a new PET rating system, at first, TSV responses were plotted against PET. Instead of the usage of the actual TSVs, mean thermal sensation votes (MTSV) were used, which were calculated according to 1°C-wide bins of PET values (Fig. 2). It should be emphasized that MTSVs were weighted with the number of cases per PET-bin, similarly to the method of Nakano and Tanabe (2004) and Yang et al. (2013). Then, we performed regression analyses between the subjects’ MTSVs and PET. The analyses were implemented separately for each evaluated season. The number of data pairs were 2792 in spring, 1097 in summer, and 1916 in autumn.

In every season, statistically significant regression equations (p = 0.000) were obtained, and quadratic model was found to increase the value of determination coefficient (R²) compared to linear regression. Thus, we present only the quadratic functions in this study and use them for further analysis. The slope of the regression lines represents the ‘thermal sensitivity’ of subjects against the changes of PET. All of the obtained equations indicate that Hungarians react more sensitively to one unit increment of PET in the cooler parts of the PET-scale, than in the warmer end, revealing an enhanced heat tolerance (Fig. 2).

The presented seasonal MTSV vs. PET quadratic regression functions formed one of the main pillars of the next step of our study, that is, the development of a PET-based rating system for TCI. Beside the regression equations, we defined a new relationship, where sub-index rating scores from
zero (unfavorable) to five (optimal) were assigned to \( PET \) values. For providing full details on the conceptual and methodological aspects of the modification and adjustment of \( TCI \), see Kovács et al. (2016).

\[ \text{Fig. 2. Quadratic regression between the mean thermal sensation votes of Hungarians vs. the physiologically equivalent temperature (PET) in spring, summer, and autumn.} \]

\[ \text{Fig. 3 illustrates the derived seasonal relationships between PET and the rating scores. Each PET value takes a score between zero and five. These relationships} \]
are utilized in the new $C_{Id}$ and $C_{Ia}$ thermal comfort sub-indices to rate $PET$ values (instead of to rate the $ET$ values with the scores in the case of the original $TCI$, see Fig. 1). In practice, the new $C_{Id}$ and $C_{Ia}$ sub-indices are derived utilizing daytime maximum and daytime average $PET$ values. The rating systems of the precipitation ($R$), sunshine ($S$), and wind speed ($W$) sub-indices were not modified and are used in accordance with the rating methods of Mieczkowski (1985) (Fig. 1).

![Fig. 3. The derived $PET$ rating scores for the thermal sub-indices ($C_{Id}$ and $C_{Ia}$) of modified $TCI$ in different seasons based on the thermal sensation votes of Hungarians.](image)

2.3. Quantifying the impact of climate change on tourism potential

The CRIGiS project, which constitutes the base of the present study, was the part of a broader program called ‘Adaptation to Climate Change’ (ACC, 2016). Beyond establishing assessment methodologies, the program aimed at installing a system providing reliable database for supporting development of domestic adaptation activities to climate change. The implementation of the program started with the establishment of the National Adaptation Geo-information System (NAGiS) (NAGiS, 2016). The NAGiS aimed at supporting strategic planning and decision-making on the adaptation to climate change through development and operation of a multipurpose, geo-information database, which could merge several data sources derived from diverse sectors, such as hydrology, agriculture, and natural ecosystems. The CRIGiS project was initiated to extend the NAGiS with new data layers to further sectors. This extension includes indicators of exposure, sensitivity, and adaptive capacities in the tourism sector, as well as in the critical infrastructure sectors. One of the main goals of the tourism-related part of CRIGiS was to allow the outcomes usable for analyses aiming to estimate the effects of climate change on tourism potential. Such investigations can contribute to help in impact assessments and
resilience tests related to climate change in tourism sector. Ultimately, the results can be usable promoting sustainable tourism development.

The new, tourism-related data layers (i.e., original and modified TCI) were established for different time periods. First of all, based on observational data, they were calculated for the period of 1961–1990. On the other hand, future values of these indices were obtained from regional climate model projections for the periods of 2021–2050 and 2071–2100. The observational data were derived from the database used in CarpatClim project (as well as in Hódos, 2014), homogenized and interpolated with the methods MASH and MISH. However, the target area was extended to the whole area of Hungary (covering 45.8–48.6°N and 16–27°E). The climate projections were provided by the ALADIN-Climate, a regional climate model (RCM) applied at the Hungarian Meteorological Service (Csima and Horányi, 2008). The model run relied on A1B emission scenario described in the Special Report on Emissions Scenarios (SRES; Nakicenovic et al., 2000), which concerns average future changes in socioeconomic conditions and population.

The climate projections did not contain information about the future values of sunshine duration, which are, however, required to calculate TCI and mTCI. Thus, sunshine duration was obtained from daily cloud cover data according to the method suggested by Monteith (1965) and adopted by several studies calculating TCI from climate model data (Amelung, 2006; Perch-Nielsen et al., 2010; and Mailly et al., 2014).

The original TCI values were determined according to the rating schemes and formula of Mieczkowski (1985) (see Section 2.1.). For the modified TCI, daily values of the observational and model data were applied instead of monthly values; moreover, calculation of PET required daily averages of total cloudiness as well. We determined daily PET values from air temperature, relative humidity, wind velocity, and cloud cover data by utilizing RayMan. For the new CId sub-index of TCI (which relies on daily maximum PET), the daily maximum temperature, daily minimum relative humidity, daily average wind speed, and daily average cloud cover data were used. For the new CIa sub-index (which relies on daily average PET), daily average temperature, relative humidity, wind speed, and cloud cover data were used. From the daily maximum PETs, daily average PETs, and the other necessary variables (precipitation, sunshine duration, and wind speed), monthly averages were taken and then monthly mTCI values were calculated.

For future exposure analysis, the so-called delta-method was applied. This means that the changes between the modeled future outcomes (2021–2050, 2071–2100) and the past model data (1961–1990) were determined, and the differences between them were added to the observational data (1961–1990). The reason for using delta method was to filter the systematic errors of model results. It should be emphasized that this method was used not for the raw model results but for the exposure assessment outcomes (i.e., for TCI and mTCI data).
The outcomes, therefore, combined past ‘exposure observations’ and changes occurring in the ‘exposure’ (Fig. 4).

![Fig. 4. Process of determining tourism climate indicators based on observations and model data.](image)

The climate indicators were calculated on a 0.1°×0.1° (about 10 km) horizontal resolution grid of the observational and climate model data, for a total of 1104 grid points in Hungary. In order to display of tourism climate indices on maps, district averages were calculated from the grid point data as this provides more beneficial results for the users, such as tourists and tourism professionals. The district is an administrative territorial unit in Hungary. The spatial distribution of $TCI$ and $mTCI$ are presented on a monthly basis and on district level.

### 3. Results

In this paper, the results of the middle months of the seasons, April, July, and October are presented. We classified $TCI$ and $mTCI$ values according to the rating categories in Table 2, with the only exception of $TCI$ values below 40, which were merged into a category ‘unfavorable’, if at all.

First, the results based on observational data are presented for the two indicators (Figs. 5a–10a). In April, according to original $TCI$, some western and northern districts are characterized with acceptable conditions (range of 50–59), while in the other parts of the country, including the whole Great Hungarian Plain, good conditions occur (60–69) (Fig. 5a). Modified $TCI$ indicates more favorable conditions, generally by two categories: very good (70–79) conditions are found in Transdanubia and the northern regions, while the climate potential is excellent (80–89) in most parts of the Great Plain (Fig. 6a). Almost every district are characterized with at least excellent climatic conditions in July according to $TCI$, moreover, in most parts of the Great Plain, the climatic conditions reach the ideal category (90–100) (Fig. 7a). The $mTCI$ pattern
usually signals less pleasant conditions by two categories, and its distribution is slightly more diverse. It is worth mentioning that this means still good or very good circumstances (Fig. 8a). October shows similar results as April concerning both the category level and the spatial distribution of TCI and mTCI (Figs. 9a–10a).

Turning our attention for future assessments through climate model results, considerable changes will not be probable for the mid-century according to TCI in April (Fig. 5b). For the end of the century, most parts of the country will likely to be characterized with good conditions; only some mountainous districts remain acceptable, while in a few districts in the Great Plain, very good conditions are displayed (Fig. 5c). In the case of mTCI, only a slight redistribution will be probable for the mid-century (Fig. 6b). However, for the end of the century, large parts of the country may experience an improvement in climatic circumstances, that is, the conditions in Transdanubia and the northern districts may become excellent like in the Great Plain (Fig. 6c).

Fig. 5. Spatial distribution of TCI categories in April by districts for 1961–1990 (a), 2021–2050 (b), and 2071–2100 (c).
Fig. 6. Spatial distribution of $mTCI$ categories in April by districts for 1961–1990 (a), 2021–2050 (b), and 2071–2100 (c).

The tendencies are similar for the future periods in the case of both indicators in July. Both of them indicate considerable changes but for unfavorable direction (Figs. 7–8). According to $TCI$, ideal conditions may not occur at all, and the ratio of excellent areas may decrease for the mid-century (Fig. 7b). At the end of the century, very good conditions are probable in the northern part of the country, while good conditions are displayed in the Great Plain and southwestern part of Transdanubia (Fig. 7c). According to $mTCI$ patterns, the ratio of the very good conditions may decrease for the mid-century, and good conditions may dominate in most parts of the country. Moreover, in the southwestern part of Transdanubia, acceptable conditions are displayed (Fig. 8b). For the end of the century, $mTCI$ pattern indicates acceptable conditions in greater parts of the country, mainly in the whole southwestern part of Transdanubia and southern Great Plain (Fig. 8c). The spatial pattern of $mTCI$ categories at the end of the century is similar to the case of $TCI$ but they indicate less favorable conditions for light outdoor activities.
Fig. 7. Spatial distribution of TCI categories in July by districts for 1961–1990 (a), 2021–2050 (b), and 2071–2100 (c).

Fig. 8. Spatial distribution of mTCI categories in July by districts for 1961–1990 (a), 2021–2050 (b), and 2071–2100 (c).
In October, according to TCI, more remarkable improvement in climate potential is probable than in April, which already refers to the mid-century period (Fig. 9b). For this period, most parts of the country will likely to be characterized with good conditions, moreover, a remarkable part of the Great Plain may become very good. The improvement continues to the end of the century, moreover, at this time excellent conditions will be probable in a few southeastern districts of the Great Plain (Fig. 9c). The mTCI patterns indicate unchanged conditions or an improvement by a category (Fig. 10). Here, in the mid-century, already excellent conditions are indicated in most parts of the country, which was not the case in April.

*Fig. 9.* Spatial distribution of TCI categories in October by districts for 1961–1990 (a), 2021–2050 (b), and 2071–2100 (c).
4. Summary and concluding remarks

The study presented some tourism-related outcomes of the CRIGiS project based on the original $TCI$ as well as on a modified form of $TCI$, that was adjusted to the subjective thermal assessment of Hungarian residents. According to the district-based spatial patterns of $TCI$ and $mTCI$ through observational data, the following outlines can be drawn for the three selected months:

- In the shoulder months (April and October), the Great Hungarian Plain as well as some northern and eastern parts of Transdanubia have more favorable climatic conditions by a category than the other parts of the country according to both indices. The $mTCI$ pattern indicates more pleasant conditions than that of $TCI$ generally by two categories.

- July has more favorable conditions than April and October according to $TCI$, however, $mTCI$ indicates less pleasant circumstances in July compared to the shoulder months.

According to the climate model outcomes, the tourism climate potential changes for the end of the century are as follows:
In April, the climatic conditions in Transdanubia and the northern parts of the country will likely to improve by a category and may become the same as in the Great Plain concerning both indices. The conditions may remain unchanged in most parts of the Great Plain.

October shows an improvement by a category according to TCI, moreover, some southeastern districts in the Great Plain may expect two TCI categories improvement. According to mTCI patterns, the climatic conditions in Transdanubia and the northern parts may improve by a category and become the same as in the Great Plain.

In July, most parts of the country may become less favorable for tourism. Both indices signal that climatic conditions are likely to deteriorate mostly at the southwestern part of the country and at the southern part of the Great Plain. The climatic conditions will still remain at least acceptable even from the Hungarian assessment point of view.

It should be borne in mind when considering the results, that the tourism climate potential of an area is associated with the features how tourism sector is affected by the present and future climatic circumstances. However, the competitiveness and economic success of tourism businesses and destinations are highly influenced by several socioeconomic mechanisms and factors (e.g., budget, accessibility and distance, presence of markets) and by natural or cultural landscape elements affecting tourist decision-making (e.g., geology, hydrology, vegetation, historical monuments, celebrations) as well (de Freitas, 2003; Gómez Martín, 2005).

Since one of the most important objectives of project CRIGiS was to develop a methodology for impact and vulnerability assessments, they were based on the outputs of a single regional climate model (RCM) simulation. Nevertheless, in a further step, the investigations have to be repeated using more RCM results to quantify the uncertainties of the projection for the users (in the absence of this, outcomes of any impact study cannot be properly interpreted).

In order to accomplish the other comprehensive goal of the project, i.e., to install a geo-information system providing reliable database, the datasets (i.e., TCI and mTCI data layers) were prepared to be compatible with the NAGiS system. Thus, the outcomes could be established in the datasets of NAGiS to be ready for use. The results are available for public use since May, 2016 (NAGiS, 2016).

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References


