Interactive comment on “Suitability Analysis of Ski Areas in China: An Integrated Study Based on Natural and Socioeconomic Conditions” *by* Jie Deng et al.

Daniel Scott

daniel.scott@uwaterloo.ca

Received and published: 11 April 2019

This review commentary will build on the insightful comments of Carlo Maria Carmagnola and not repeat the questions and suggested areas of revision previously identified.

The objective of the analysis is clear and builds on a similar type of analysis in a much smaller study area of the United States that is characterized by very different climateology (particularly natural snow resources).

The approach to include both natural conditions and the socioeconomic factors that can influence the feasibility and competitiveness of ski area operations is essential. The selection of indicators and how they are operationalized (including data sources) is well explained.

Response: We appreciate Dr. Daniel Scott for his constructive comments on our manuscript.

Before going further, we would like to point out that the ski industry in China is very different from that in major skiing countries (e.g., the United States), not only in terms of climatic conditions but also the development status of the ski market. As described in our manuscript, China's ski industry is still at the stage of rapid development. Due to the lack of strategic plan and effective regulation, the chaotic market has caused serious environmental problems and waste, which hampers the sustainable development of the ski industry. Therefore, we would like to restate the significance of our work considering the results that provide timely advice and guidance to sustainable development of the ski market based on natural and socioeconomic conditions in China.

In summary, this study was designed to 1) provide a scientific metric for future development of ski market at the national scale and 2) evaluate the current situation of the ski resorts, which is definitely lacking and most-needed in the nation. Additionally, a more sophisticated and object-oriented method should be further developed when considering a specific resort (such as the snowmaking), which, indeed, can be derived and modified based on the current method.

We have carefully addressed all the issues raised by the Reviewer and modified our manuscript accordingly. Detailed responses (marked in blue font) are summarized in the following sections with the original comments (marked in black font). The revised manuscript is attached with changes marked in red font.

There are two important limitations to the study as currently conducted: First, the equal weighting of the indicators is problematic. The set of indicators are not equal, as some are essential (must be achieved) and others are useful to improve competitiveness or a higher quality ski experience. Consultation with industry stakeholders in China could have been used to determine which indicators are essential to business operations and profitability. Expert weightings could also have been used. For example, without sufficient cold temperatures and water supply for snowmaking, ski operations are not feasible in most of China (which has a dry season in winter and very limited natural snow). Other natural and socio-economic factors cannot overcome the inability to produce and maintain a reliable, quality snowpack at operational depths.

Response:

(1) First, we would like to address the question regarding the weights of indicators. We agree with the Reviewer that the weights of indicators are not equal. Therefore, in this study, a common method based on entropy weight theory was used (Bian et al., 2018; Bednarik et al., 2010; Srdjevic, Medeiros, and Faria, 2004; Tang, 2015) to determine the weights based on both statistics and expert knowledge. Indeed, calculations of the index weights are divided into two groups: One is determined by the knowledge and experience of experts or individuals (including the stakeholders mentioned by the Reviewer), named the subjective weight; the other is based on statistical properties and measured data, named the objective weight. The entropy weight method belongs to the latter as one of the objective methods to determine weight weighting coefficients. It has been commonly used in the fields of sustainable development evaluation and social economy (Vranešević et al., 2016). The weight coefficients of each indicator were calculated based on the sample of 116 existing ski areas established before 2012 (see Table 3). As the reviewer mentioned, the evaluation results obtained by the entropy weight method, relying on the objective data, may be slightly deviated from the expert's understanding. However, it is commonly subjective to determine the weights according to the expert experiences. In a word, we believe that both methods have their values even we chose to use the objective method for our weights in this study. Nevertheless, we incorporated government report and field surveys of 35 ski resorts including questionnaires and interviews with managers and staff, which, though, not used in the weights calculation, but could be served as complementary information to evaluate our results. In the revised manuscript, we added more explanations of the entropy weight method as follows (Page 9, Line 28 to Page 10, Line 3):

"The weight coefficients were calculated by an objective method based on the theory of information entropy, which has been widely employed for the determination of weights of evaluating indicators. (Bian et al., 2018; Bednarik et al., 2010; Srdjevic, Medeiros, and Faria, 2004; Vranešević et al., 2016). The concept of information entropy originally came from thermodynamics and indicates the extent of disorder in the system status (Bednarik et al., 2010). Generally, if the dispersion of data is high, the value of information entropy is low, which means that more information will be provided. Correspondingly, the greater the influence of the index on the evaluation, the higher its weight (Tang, 2014). Therefore, the entropy weight method can be used to calculate the objective weights of the index system and avoid bias caused by subjectivity to a certain extent (Pourghasemi, Mohammady, and Pradhan, 2012)."

According to the results of the weight coefficients (Table 3), we also added the following sentences in the end of Sect. 2.3 (Page 10, Line 26-28):

"The results show that the total weight of natural suitability (0.52) is higher than that of socioeconomic suitability (0.48), which indicates that natural conditions have a greater impact on the development of ski areas than socioeconomic conditions."

Table 3. Weight coefficients for the evaluation indexes.

Indexes		Weight coefficients
Natural suitability		0.52
	Snow cover	0.36
	Air temperature	0.19
	Topographic conditions	0.32
	Water resources	0.04
	Vegetation	0.09
Socioeconomic suitability		0.48
	Economic conditions	0.37
	Distance to a city	0.29
	Accessibility of transportation	0.18
	Distance to a tourist attraction	0.16

(2) Then we would like to discuss our results in China compared with other developed countries. In European and American countries, people pursue high-quality skiing experience, so natural factors are crucial to the operation of ski resorts. The Reviewer may be surprised by the results of weight coefficients in Table 3, which show such high weights of socioeconomic indicators. To help explain the results, we plot spatial distributions of natural suitability and integrated suitability in the existing ski areas. As shown in Fig. S1 (supplementary information), in the eastern and southern of China, natural conditions are relatively modest. A large number of small-size ski areas are located in such areas with better socioeconomic conditions. The results indicate that, in the developing country like China, socioeconomic conditions are still very important factors for the operation of a ski area at present.

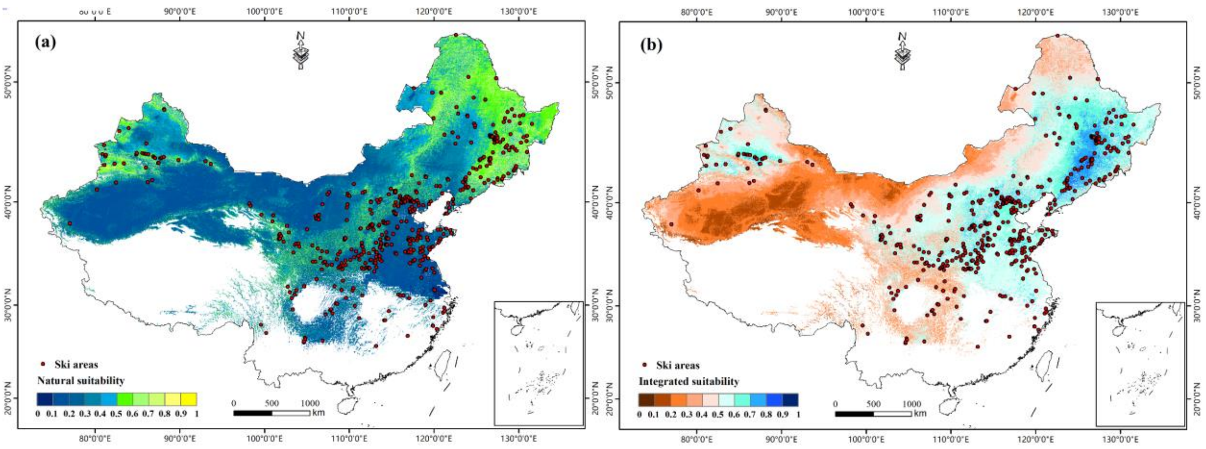

Figure S1. The distribution of existing ski areas in China. (a) Natural suitability map; (b) Integrated suitability map.

However, with social and economic development, these ski areas are threatened with closure, causing further environmental problems. Therefore, when making an investment on a new ski area, not only the integrated suitability but also the driving factors (see Sect. 3.3) should be considered. In the discussion section, we have also pointed this out as:

"In total, 84.23% of the ski areas were located in areas with an integrated suitability value greater than 0.5, while 15.77% of the ski areas were located in areas with integrated suitability values less than 0.5, which are almost all distributed in socioeconomic-driven areas. Notably, the ski areas in socioeconomic-driven areas are more prone to environmental problems due to the decreased natural suitability, and these enterprises may soon face the challenges of dismal prospects." (Page 13, Line 26-30)

"In socioeconomic-driven areas, the ski area markets are determined by local visitors. According to the situation of local socioeconomic development, an appropriate number of small ski areas are advised to be built for recreational sports to expand the influence of snow sports. However, a large number of small-size ski areas with poor facilities have been established in the economically driven areas, and these ski areas are unsafe and provide skiers with low-quality ski experiences. Therefore, in socioeconomic-driven areas, the number of ski areas should be limited, and enterprises should enhance their competitiveness by improving the quality of the ski area." (Page 14, Line 25-30)

(3) To further illustrate the reliability of the results, the following figures are presented as supplementary information that were not included in the manuscript. As we can see, the higher the grade of the ski area is, the better its locational integrated suitability (Fig. S2). Further, we also analyzed the locational integrated suitability and the ski season lengths of ski areas. As shown in Fig. S3, the ski season length varies widely from 60 to 182 days. With the increase of locational suitability, the snow season lengths in ski areas is getting longer. The low determination coefficient between ski season length and integrated suitability is due to the fact that some ski areas are still operated even under the condition of poor snow quality.

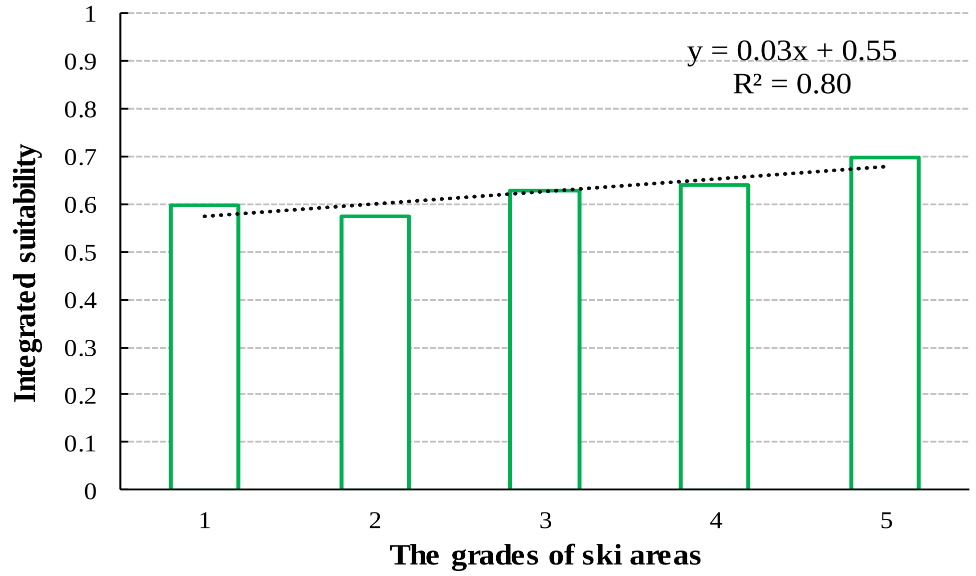

Figure S2. Locational integrated suitability versus the grades (ski areas that were investigated).

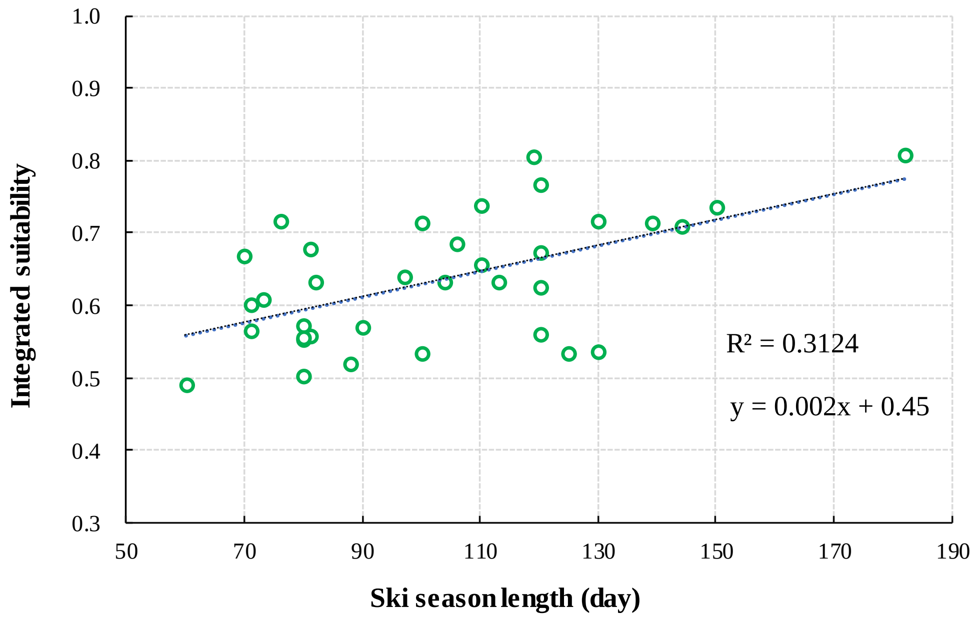

Figure S3. Locational integrated suitability versus the ski season lengths (ski areas that were investigated).

Second, while the range of indicators included is a strength of the study, some of the indicators used are problematic. The study should consult Steiger et al (2017) for a summary of limitations of studies in the literature that result in the mis-represention of climate variability/climate change risks for the ski industry. This study suffers from two of these limitations: (1) the use of inappropriate performance indicators and (2) the lack of an indicator that accurately represents the combined natural-technical snowpack, and therefore does not represent the current operational realities of ski areas in China.

Response: We appreciate the Reviewer for recommending Steiger et al. (2017). We carefully read the paper and found that this work is very interesting, which provided a critical review of studies on the risk of climate change on ski tourism. However, in this study, we mainly analyzed the current suitability for development of ski areas in term of natural and socioeconomic conditions, not considering the potential influence of climate/environmental changes. Our future research will focus on the impact of climate change and socioeconomic development on ski market, which has been discussed in the revised manuscript (Page 16, Line15-24):

"The results of the weight coefficients indicate that snow resources, air temperature and topographic conditions are major natural factors that influence ski area development. In the context of global warming, it is necessary to evaluate the vulnerability of a ski area to future climate change (Steiger et al., 2017). With the increase in winter temperatures and the decrease in snowfall in the next few decades (Ji and Kang, 2012; Wang and Wang, 2012), the natural suitability values for southern and eastern China will decrease, and small midlatitude and low-elevation ski areas will be the first to close due to poor snow conditions (Bark and Colby, 2010; Gilaberte-Búrdalo et al., 2017). Additionally, with social and economic development, people's living standards will greatly improve. Thus, the socioeconomic suitability in northwestern and northeastern China may increase. As a result, northwestern and northeastern China may become popular markets and central places for ski tourism. To more thoroughly study the future of ski tourism in China, future research is needed to evaluate the locational suitability of ski areas in relation to climate change and socioeconomic development."

The paper states that, "Therefore, in this study, an SCD [snow cover day] larger than 100 days is taken as the optimal value." Snow cover days are not an suitable indicator of ski seasons. Snow cover is measured as 1 inch/2.5cm and is not sufficient for ski operations, and therefore provides no meaningful information on whether skiable conditions were present on a day with 'snow cover'.

The indicator needed to define a ski season is how many days with sufficient snow depth for ski operations (usually a minimum of 30 cm is used in the literature, but this varies based on terrain). In every regional market in the world, this operational depth must be calculated as the combined snowpack of natural snow and machine-made snow, because there is no regional market where at least some ski areas / ski terrain utilizes snowmaking. This is particularly the case in China, much of which has a dry winter climate.

The study identifies a snow depth threshold that is common in the literature, but provides no measure of how many days this threshold is achieved with natural snow, because "small-scale snow properties (~1 km) cannot be obtained due to the low resolution of passive microwave products." Furthermore, the study does not physically model the snowpack with snowmaking, but rather uses proxies of potential snowmaking days.

It is not clear what is meant in the statement that, "Therefore, SD is only taken as a reference for the index of snow cover." However, as indicated, snow cover is not a meaningful indicator for ski area operations and cannot be used as a proxy for operational snow depth. Because the study does not provide a robust and meaningful analysis of snow resources (natural or with the additional capacity of snowmaking) that are fundamental to ski operations, publication cannot be recommended.

Response: We appreciate the Reviewer's feedback. Overall, this study was designed to provide a scientific metric for the development of ski market at the national scale. Therefore, the choice of indicators is useful for the evaluation in large scale. We considered snow conditions from two aspects of natural snow and machine-made snow, in which the machine-made snow was reflected by the air temperature conditions. We agree that there are limitations in the processing of snow cover index and the treatment of machine-made snow. Snow model, which integrates natural and machine-made snow, can better reflect local snow conditions for specific ski area (Scott, McBoyle, and Mills, 2003; Hennessy et al., 2008; Spandre et al., 2017). But it is difficult to apply the site-scale model to a large scale. For future study, we plan to select several typical ski areas to develop a more sophisticated and object-oriented method.

a. First, we would like to respond to the comments on performance indicators. On the one hand, as suggested by the Reviewer, snow cover day may not be a suitable indicator on skiable conditions. In this study, snow cover day is considered as an indicator of climate suitability (temperature and precipitation) and the measure of aesthetic value. On the other hand, since the areas in China with natural snow depths greater than 30 cm are very few, we did not used this measure. Instead, the average snow depth (SD) was considered in this study.

   In the revised manuscript, the following two sentences:

   "Therefore, SD is only taken as a reference for the index of snow cover." and "small-scale snow properties (~1 km) cannot be obtained due to the low resolution of passive microwave products." have been rephrased as follows (Page 4, Line 17-28):

   "Natural snow cover is a crucial resource for ski areas. Skiers may cancel trips when there are poor snow conditions (Scott et al., 2003; Steiger and Abegg, 2018). Tervo (2008) analyzed the viability of nature-based winter tourism enterprises and declared that 90–120 skiable days are adequate for making a profit. In fact, a ski area is profitable if the snow reliability period is greater than 100 days per season, which is known as the 100-day rule and is the most common indicator of snow reliability (Steiger, 2012). Additionally, Scott, McBoyle, and Mills (2003) defined a skiable day as a day with a snow depth greater than 30 cm on ski runs. However, the snow depth in China is much lower than that in North America and Europe, and the areas with natural snow depths greater than 30 cm are extremely rare (Mudryk et al., 2015). Therefore, we did not use the indicator of the number of days with a natural snow depth greater than 30 cm. As a supplement for the snow depth on ski runs, the average snow depth (SD) during a ski season was considered in this study. In addition, the number of snow cover days (SCD), which is total number of days (can be discontinuous) with snow cover in an area during the ski season, was considered as an indicator of climate suitability (temperature and precipitation) and a measure of the aesthetic value of a site given that many ski areas have snow cover on only the ski runs."

b. Second, we agree with the Reviewer, that the conditions of snowmaking are the important factor for ski destination choice. In the revised manuscript, the following sentence has been added to the end of the section of **Snow cover** (also was suggested by Reviewer #1):

"This index was for natural snow only, and machine-made snow was taken into account by the index of air temperature." (Page 5, Line 9-10)

We reclassified the daily mean temperature into 11 regimes. Among them, the air temperature between -2 ℃ and -5 ℃ are were taken as optimal conditions in regard to efficient snowmaking.

We added some more explanation in the section of **Air temperature** (also was suggested by Reviewer #1):

"The 11 temperature regimes and their corresponding scores were designed as a trade-off between the cold temperatures needed to preserve the snowpack and to produce machine-made snow and the warm temperatures needed by skiers." (Page 5, Line 28-30)

In this study, we did not physically model the snowpack with snowmaking, but used proxies of potential snowmaking days. Therefore, we added the relevant discussions in a new section:

"The first limitation of our study is related to machine-made snow. For the index of snow cover, only natural snow has been considered. As mentioned in Sect. 2.1.1, machine-made snow was considered in the index of air temperature, which may have imperfectly represented the snowmaking conditions. The exact number of skiable days cannot be captured by using our method. Some studies have focused on modeling machine-made snow processes, and these models have been used to calculate the length of the ski season at specific ski destinations (Scott, McBoyle, and Mills, 2003; Hennessy et al., 2008; Spandre et al., 2017). The main barrier that arises when addressing snow models over large-scale regions is associated with the difficulty in obtaining data with high spatial and temporal resolution. It is also difficult to apply the site-scale model in a large scale. However, since the aim of this study was to provide the guidelines for the ski market at the national scale rather than define whether a specific resort will be viable, we believe that using the air temperature to reflect the snowmaking conditions is acceptable over large-scale regions." (Page 15, Line 5-14)

"The method of this work attempts to identify the suitability patterns of the main ski areas in China, but a more detailed and refined analysis based on local data will be necessary before deciding to invest (or not) in a new ski area. Based on previous studies, machine-made snow, air temperature and wind should be addressed in future studies on specific ski areas." (Page 15, Line 28-30)

The associated discussion also was added in the conclusion section:

"This study can pave the way for more detailed and refined analyses based on local data and other sources of information, which represents the next necessary step to promote investments in new ski areas." (Page 16, Line 12-14)

References

Bednarik, M., Magulova, B., Matys, M., and Marschalko, M.: Landslide susceptibility assessment of the Kralovany–Liptovsky Mikulaš railway case study, Phys. Chem. Earth, 35, 162–171, doi.org/10.1016/j.pce.2009.12.002, 2010.

Bian, Z., Xu, Z., Xiao, L., Dong, H., and Xu, Q.: Selection of optimal access point for offshore wind farm based on multi-objective decision making, Int. J. Electr. Power Energy Syst., 103, 43–49, doi:10.1016/j.ijepes.2018.05.025, 2018.

Hennessy, K. J., Whetton, P. H., Walsh, K., Smith, I. N., Bathols, J. M., Hutchinson, M., and Sharples, J.: Climate change effects on snow conditions in mainland Australia and adaptation at ski resorts through snowmaking, Clim. Res., 35, 255–270, doi:10.3354/cr00706, 2008.

Srdjevic, B., Medeiros, Y. D. P., and Faria, A. S.: An Objective Multi-Criteria Evaluation of Water Management Scenarios. Water Resour. Manag., 18, 35–54, doi:10.1023/b:warm.0000015348.88832.52, 2004.

Scott, D., McBoyle, G., and Mills, B.: Climate change and the skiing industry in southern Ontario (Canada): Exploring the importance of snowmaking as a technical adaptation, Clim. Res., 23, 171–181, doi:10.3354/cr023171, 2003.

Spandre, P., Morin, S., Lafaysse, M., George-Marcelpoil, E., Fran¸cois, H., and Lejeune, Y.: Determination of snowmaking efficiency on a ski slope from observations and modelling of snowmaking events and seasonal snow accumulation, The cryosphere, 11, 891-909, doi:10.5194/tc-11-891-2017, 2017.

Steiger, R., Scott, D., Abegg, B., Pons, M., and Aall, C.: A critical review of climate change risk for ski tourism, Curr. Issues Tour., 1-37, doi.org/10.1080/13683500.2017.1410110, 2017.

Tang, Z.: An integrated approach to evaluating the coupling coordination between tourism and the environment, Tour. Manag., 46, 11–19, doi:10.1016/j.tourman.2014.06.001, 2015.

Vranešević, M., Belić, S., Kolaković, S., Kadović, R., and Bezdan, A.: Estimating Suitability of Localities for Biotechnical Measures on Drainage System Application in Vojvodina, Irrig. Drain., 66, 129–140, doi:10.1002/ird.2024, 2016.