Trends in the growth of the ecological footprint of tourism in the Mongolian and Kazakhstan Altai mountains

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Abstract. The Altai Mountains, stretching along the borders of four Central Asian countries, represent one of the most intensively visited tourism regions in the area. Snow-covered peaks, glaciers, forested landscapes, and scenic mountain environments constitute the main attractions for visitors. In Kazakhstan and Mongolia, ecotourism has been promoted as a key form of tourism in the Altai Mountains; however, numerous studies have reported its negative environmental impacts. Recent research has quantified tourism footprints, and this article presents the final results of those studies expressed in terms of greenhouse gas emissions. Environmental impacts of tourism were converted into CO_2-equivalent (CO_2eq) emissions to enable comparison, and future trends were identified based on a five-year dynamic analysis. The results indicate that tourism greenhouse gas emissions in the Mongolian Altai reached a peak and began to decline from 2024 onward. Of the total emissions, 52% originated from degraded areas, while 33% were generated by livestock concentrated due to tourism activities. In contrast, in the Kazakhstan Altai, 82% of total tourism-related greenhouse gas emissions were produced by transport. Emissions from degraded land accounted for 14%, and tourist waste contributed 2% of total emissions. Overall, these findings different from conventional practical assumptions regarding the main sources of tourism-related environmental impacts.

Keywords: Altai Mountains; Ecotourism; Greenhouse Gas Emissions (GHG Emissions); Trend Analysis.

1. Introduction

For thousands of years, the Altai Mountains have been an important transitional region between the major ecological regions of Eurasia (Caspari, 2017). The Altai Mountains are the result of a complex and contrasted history. Several periods of complete flattening of the landscape have been recorded and the current setting with archaeological sites (Zwyns, 2014). The Altai Mountains, with their beautiful nature and unique ecosystem, have now become one of the most popular tourist destinations in Central Asia. (Chlachula, 2001). These settlement patterns were closely associated with the region's distinctive natural features, including its mountainous terrain, abundant water resources, scenic landscapes, rich biodiversity, and diverse flora and fauna.

Today, the Altai Mountains renowned for their valuable archaeological heritage, well-preserved ecosystems maintained over centuries, and exceptional natural beauty have become one of the most prominent tourist destinations in Central Asia. Stretching approximately 2,000 km along the borders of four countries Russia, China, Kazakhstan, and Mongolia - the Altai constitutes a vast orographic system composed of 88 mountain sub-ranges, predominantly oriented from northwest to southeast (Beisenova, 2014), (Yakovlev, 2012). Although the Altai has historically functioned as a corridor and destination for nomads, pilgrims, explorers, and travelers, the development of modern tourism in the region began relatively recently, emerging primarily in the twentieth century (Badyelgajy, Myeirambek, 2022).

Approximately 50% of the total area of the Altai Mountains lies within Mongolia, while about 10% falls within the territory of Kazakhstan. Despite this substantial spatial coverage, tourism development in these two countries remains relatively limited compared with other parts of the Altai region. Nevertheless, the Altai Mountains rank among the most visited regions globally, and tourist arrivals across all four countries increased markedly during and following the COVID-19 pandemic (Badyelgajy, Kapsalyamov, 2023). For instance, in 2023–2024, approximately 300 million tourists visited the Xinjiang Uyghur Autonomous Region of China (Weili, 2024), of whom about 8.5 million traveled to Kanas Lake in the Chinese Altai (Xinhua, 2019). During the same period, 2.7 million tourists visited Lake Teletskoye in the Altai Republic of the Russian Federation (Filipenkova, 2024). In East Kazakhstan Region, 885 thousand tourists were recorded, including 194 thousand visitors to Katon-Karagay National Park. In contrast, Altai Tavan Bogd National Park the westernmost protected area of the Mongolian Altai received approximately 53 thousand tourists in 2023, followed by a decline to 25 thousand visitors in 2024 (Qazaqstan Ūlttyq statistika bürosy, 2024). Given that nearly 9.6 million tourists are concentrated around the Altai Mountain system annually, there is a clear and urgent need to assess the ecological footprint and environmental impacts associated with tourism activities in this region. Because tourism exerts diverse and multifaceted pressures on the environment. The negative environmental impacts of tourism are multifaceted, making it methodologically challenging to assess them using a single integrated indicator (Monz, 2021). Numerous studies examining excessive tourist concentration in various national parks have demonstrated this complexity (Mateusz, 2025; Mihalic, 2020). Consequently, research in this field has increasingly focused on developing approaches to quantify the ecological damage caused by tourism activities (Santos-Rojo, 2023). As the scientific literature consistently confirms that tourism pressure intensifies with increasing visitor numbers, the present study assesses the impacts of tourism in the Altai Mountains through the indicator of GHGs.

For this reason, many researchers have adopted GHG emissions as an integrated metric for evaluating tourism-related environmental impacts. Although previous studies have quantified GHG emissions associated with individual tourism-related activities and discussed their environmental implications, comparative assessments and trend analyses of these emissions over time remain largely underexplored. In addition, a significant body of newly emerging empirical material has yet to be systematically documented and analyzed. To address these gaps and contribute to the existing body of knowledge, the present article was developed with the aim of fulfilling these specific research objectives. Within this framework, the study sets out the following objectives:

(a) to quantify GHG emissions arising from selected tourism-related impact pathways;
(b) to integrate tourism-induced GHG emission data for subsequent dynamic analysis; and
(c) to analyze growth trends and illustrate their spatial distribution.

2. Materials and methods
2.1. Study area and selected tourism routes

Since 2018, the researchers have conducted field expeditions and investigations along the most intensively used tourism routes in the Altai Mountain Range. Consistent with previous studies, the selected study areas include two major tourism corridors: (1) the principal 1150 km tourism route leading to Katon-Karagay National Park in Kazakhstan, and (2) a 580 km tourism route covering the

western part of the Mongolian Altai within Altai Tavan Bogd National Park. The selected routes are illustrated in Figure 4. A brief description of the selected route and the reason of selection is summarized in the following table (Table 1).

Table 1. The basic definition of selected routes

Indicators	Altai Mountains of Mongolia	Altai Mountains of Kazakhstan
Reason of chosen	A trending route in Mongolia's domestic tourism since 2019. The main route with the highest tourist visitation.	A trending route in domestic tourism in Kazakhstan, after the pandemic. The main route with the highest tourist visitation.
Location	Western Mongolia, Bayan Ulgii province	East Kazakhstan, Khaton-karagai, Zaisan, and Kurshim soums.
Main attractions and destinations	Ulgii city→Khokhhotol town→Peak Tavanbogd, Potain glacier→ Lake Hoton-Hurgan→ Baga Turgen waterfall→Tsengel soum→Ulgii city	Ust-Kamenegorsk city→ Altai city → Katon-karagai→Berel museum→ Kharakol lake → Rakhan hot spring → Road of Austria → Zaisan lake → Kyin Kerish paleontological zone → 5 lake of Sibe
Length	580 km	1150 km
Duration	3-4 days	4-5 days
Type of roads	No asphalt during the route, bumpy and rough roads, travel only high-engine cars. Go by car up to 3200 m altitudes.	Asphalt road, less rough road, few muddy roads. Comfortable traveling with family
Type of activity	Nature sightseeing, praying for Tavanbogd peaks (Traditional habit)	Beautiful nature with many mountain lakes, drinking the blood of deer antlers to health
Time for travel	From June 10 to July 25	From June 10 to July 30

2.2. Estimation of Greenhouse Gas (GHG) Emissions from the Tourism Ecological Footprint

The study employed a combination of available datasets and calculated indicators to estimate GHG emissions associated with tourism activities. Pre-existing quantitative data on GHG emissions from tourist transportation in the Altai region were adopted from Badyelgajy, Doszhanov, et al (2025), while emissions originating from livestock concentrations induced by tourism activities were obtained from Source Badyelgajy, Kapsalyamov, et al (2025). Other components of tourism GHG emissions were calculated using the following methodological frameworks:

- GHG emissions from tourism solid waste were estimated based on the UNFCCC Greenhouse Gas Emissions Calculator (Document Version 02.6, 2022), following Table A-8 (UNFCCC, 2022);
- GHG emissions resulting from coal combustion at tourist accommodation facilities were calculated using the U.S. Environmental Protection Agency (EPA) Greenhouse Gas Emissions and Sinks Inventory methodology, specifically Tables A-20, A-25, A-32, and A-226 (EPA, 2014);
- GHG emissions from degraded land were estimated at the Tier 1 level in accordance with the IPCC 2006 Guidelines, applying the Grassland Chapter (Chapter 6, Tables 6.2 and 6.4), Generic Methods (Chapter 2, Table 2.3), and Other Land (Chapter 9) methodologies (IPCC, 2006).

*2.3. Comparison of Greenhouse Gas Emissions and Trend Analysis*

GHG emissions from each category were compared and trend lines were calculated using Microsoft Excel. Spatial visualization and mapping were performed using QGIS 20.3. Hypsometric

cross-sections of the selected routes were generated by Google Earth, and the final graphical outputs were processed and integrated with the calculated results using Adobe Photoshop.

3. Results

3.1. Estimation of Greenhouse Gas Emissions from the Tourism Ecological Footprint

Prior to presenting the growth trends of the tourism ecological footprint in the Altai Mountains, several preliminary calculations were required. Previous studies have determined that the average amount of solid waste generated per tourist 441 gr in the Mongolian Altai and 612 gr in the Kazakhstan Altai (Badyelgajy et al, 2023). However, these studies did not quantify GHG emissions associated with waste generation. Therefore, in the present study, GHG emissions from tourism waste were estimated using the standardized coefficients provided in the GHG Emissions calculator. The resulting emissions are illustrated in Figure 1.
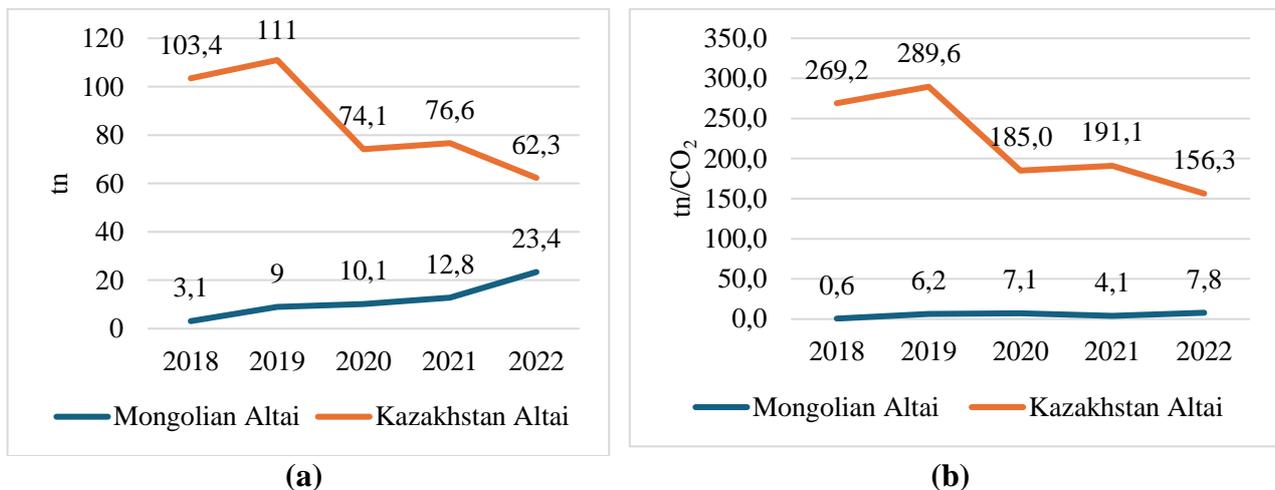
Figure 1. (a) Growth in the volume of waste generated by tourists in the Altai Mountains. **(b)** Amount of GHG emitted from the corresponding tourism waste

During the pandemic years, tourist arrivals to the Kazakhstan Altai declined, whereas an opposite trend was observed in the Mongolian Altai, where visitor numbers increased. In 2018, approximately 103.4 tonnes of solid waste were generated by 168 thousand tourists in the Kazakhstan Altai, increasing to 111 tonnes in 2019. As the volume of waste increased, corresponding GHG emissions also rose: GHG emissions increased from 269.2 t/CO_2 in 2018 to a higher level in 2019. In subsequent years, a noticeable decline in tourist numbers was accompanied by a reduction in both generated waste and associated GHG emissions.

Field-based investigations of tourism-induced land degradation in the Altai Mountains were carried out during targeted expeditions in 2021 and 2022, and the results were published in separate articles (Badyelgajy, Onerkhan, et al, 2022), (Badyelgajy, Kapsalyamov, Tussupova, 2022). However, these studies did not quantify GHG emissions originating from degraded land. Therefore, within the scope of the present article, GHG emissions from degraded areas were calculated using the IPCC 2006 Guidelines, applying the coefficients presented in Table 2. The resulting GHG emission estimates are reported in Table 3.

Table 2 – Numerical Values Used for Estimating GHG Emissions from Degraded Land

	Fixed Coefficients and Numerical Values
SOC reference (0–30 sm):	50 tC/ha (Cold temperate, dry)
Biomass (cold temperate dry):	6.5 t d.m./ha × 0.47 = 3.055 tC/ha
FMG Factors by Degradation Level	- Low → 0.98 (by linear interpolation between 1.0 and 0.95). - Meduim → 0.95 - High → 0.70 - Fully degraded or very highly degraded → 0 (Other Land; complete emission)
Loss of biomass:	biomass_loss = biomass_C × (1 − FMG)
Applied Calculation Formula	- Carbon emissions per 1 hectare = soil_loss_tC/ha + biomass_loss_tC/ha - soil_loss_tC/ha = SOCref × (1 − FMG) - biomass_loss_tC/ha = biomass_C × (1 − FMG) - Total emission: Area × (level) = tC → tCO_2 = tC × 44/12
Limitations	- The uncertainty associated with Tier 1 default values is ±75%. N_2O and CH_4 emissions were not included in the present calculations. - For areas classified as fully degraded, all carbon stocks were assumed to be completely released into the atmosphere.

Based on the degraded land areas estimated using the above values, the following results were obtained (Table 3).

Table 3 – GHG Emissions from Degraded Land, tn/CO_{2eq}

	Level of degredation	Are, ha	FMG	Soil loss, tC/ha	Biomass loss, tC/ha	Total loss, tC/ha	Total loss, tC	Total loss, tCO_2
Mongolian Altai	Low	2.7	1	1	0.1	1.1	2.9	10.5
	Meduim	120.6	1	2.5	0.2	2.7	319.9	1173
	High	66.3	0.7	15	0.9	15.9	1055.3	3869.3
	Fully degraded	104.1	0	50	3.1	53.1	5523	20251
Kazakhstan Altai	Low	78.22	1	1	0.1	1.1	83	304.3
	Meduim	595.9	1	2.5	0.2	2.7	1580.8	5796.2
	High	31.6	0.7	15	0.9	15.9	503	1844.2
	Fully degraded	0	0	0	0	0	0	0

As a result, GHG emissions amounted to 25303.945 t/CO_{2eq} in the Mongolian Altai, while 20785 t/CO_2 were emitted in the Kazakhstan Altai. According to the IPCC methodological guidelines, these estimates are based on soil organic carbon (SOC) conditions and biomass loss; therefore, they represent the total amount of carbon released during a single year as a consequence of land degradation. In the following years, these degraded areas gradually dry out, become unsuitable for vegetation growth, and their overall condition changes substantially. In addition, because annual monitoring of tourism-induced land degradation has not been conducted, the amount of carbon dioxide emissions released in other years remains uncertain.

3.2. Integration of Quantitative Data on Tourism Greenhouse Gas Emissions

Based on the calculations conducted in this study and a re-examination of previously published research, annual GHG emission estimates were compiled and integrated across different tourism sources. The aggregated results are presented in the following table. Of the five emission categories shown, the first three columns, GHG emissions from waste of tourists, accommodation facilities, and degraded land, were newly calculated within the scope of this study.

GHG emissions from tourist accommodation facilities were estimated following the Greenhouse Gas Emissions and Sinks Inventory, applying standard emission coefficients of 2.325 kg/CO_2, 274 g/CH_4, and 40 g/N_2O per short ton of bituminous coal. Because these emissions were calculated using a proportional method, the detailed derivation is not presented here.

According to the integrated dataset, a total of 49268.9 t/CO_{2eq} of GHG emissions have been released in the Mongolian Altai since 2017, whereas emissions in the Kazakhstan Altai amount to 57047.3 t/CO_{2eq} over the same period (Table 4).

Table 4. Greenhouse Gas Emissions from Tourism in the Altai Mountains, tn/CO_{2eq}

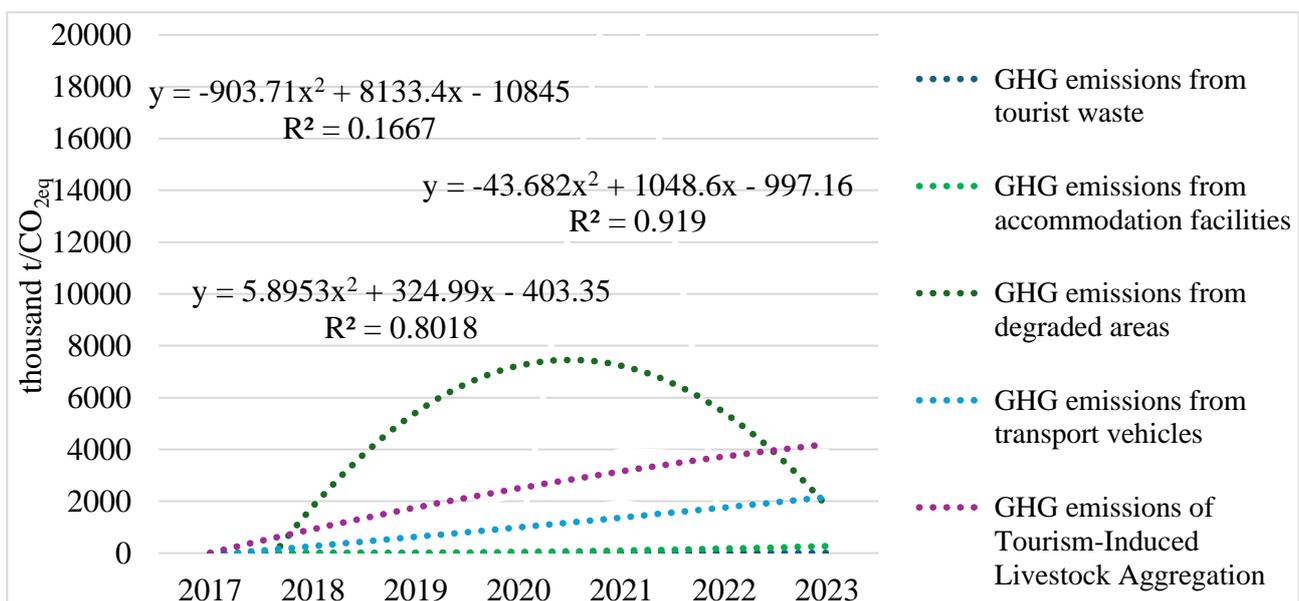| Year	GHG Emissions from Tourism Waste	GHG Emissions from Tourist Accommodation Facilities	GHG Emissions from Degraded Land	GHG Emissions from Tourist Transportation (Badyelgajy, Doshzanov, et al, 2025)	GHG Emissions from Tourism-Induced Livestock Concentration (Badyelgajy, Kapsalyamov, et al, 2025)	Total
Mongolian Altai						
2017	0	0	0	119.2	399.1	518.2
2018	0.6	0	0	124.3	531.5	656.4
2019	6.2	0	0	168.5	1418.2	1592.9
2020	7.1	0	0	1231.3	2262.6	3501.1
2021	4.1	137.9	25303.945	1969.2	3956.4	31371.6
2022	7.8	185.5	0	1241.6	3796.8	5231.7
2023	0	247.3	0	2247.6	3902	6396.9
Kazakhstan Altai						
2017	0	0	0	3915.9	35.1	3951
2018	269.2	0	0	4148	47.2	4464.4
2019	289.6	0	0	6561.7	135.5	6986.8
2020	185	0	0	2817.2	171.1	3173.3
2021	191.1	0	0	7933	183.1	8307.2
2022	156.3	0	7944.693	8325.1	200.7	16626.8
2023	0	0	0	13537.8	0	13537.8

In the Mongolian Altai, 51.4% of total greenhouse gas emissions originated from degraded land, 33% from Tourism-Induced Livestock Aggregation, and 14.4% from transportation. In contrast, in the Kazakhstan Altai, 82.8% of total greenhouse gas emissions were generated by transportation, followed by 13.9% from degraded land and 1.9% from solid waste.

4. Discussion

An analysis of growth trends in GHG emissions from multiple tourism-related sources in the Altai Mountains reveals the following patterns. In the Mongolian Altai, the largest share of GHG

emissions originates from the degradation of surface soil layers caused by tourism activities, confirming that one of the most significant negative impacts of tourism is the disturbance of vegetation cover. In recent years, however, the apparent trend in emissions from degraded land suggests a decline, primarily because no additional field surveys of disturbed surface soils have been conducted. In reality, GHG emissions from this source may be higher than currently estimated.

Comparative results further indicate that one of the most substantial negative impacts of tourism is associated with tourism-induced livestock concentration. While in many countries livestock grazing is prohibited within strictly protected areas, several studies report that livestock grazing occurs within buffer zones of protected areas in Mongolia (Navchaa, 2017; McCarthy, 2018; Wurts, 2013; Richard, 2004). In the present study, GHG emissions were estimated not for the approximately 340 thousand livestock grazing within the buffer zone of the national park, but rather for the roughly 20 thousand concentrated specifically along tourism routes. Although this represents only 5.8% of the total livestock in the area, these animals account for approximately 33% of the overall negative environmental impact attributable to tourism (Figure 2). This finding clearly highlights the need for targeted regulation and management measures.

The chart shows emissions in thousand t/CO_{2eq} (y-axis, 0 to 20000) over years 2017–2023 (x-axis).

$$y = -903.71x^2 + 8133.4x - 10845$$
$$R^2 = 0.1667$$

$$y = -43.682x^2 + 1048.6x - 997.16$$
$$R^2 = 0.919$$

$$y = 5.8953x^2 + 324.99x - 403.35$$
$$R^2 = 0.8018$$

Legend:
- GHG emissions from tourist waste
- GHG emissions from accommodation facilities
- GHG emissions from degraded areas
- GHG emissions from transport vehicles
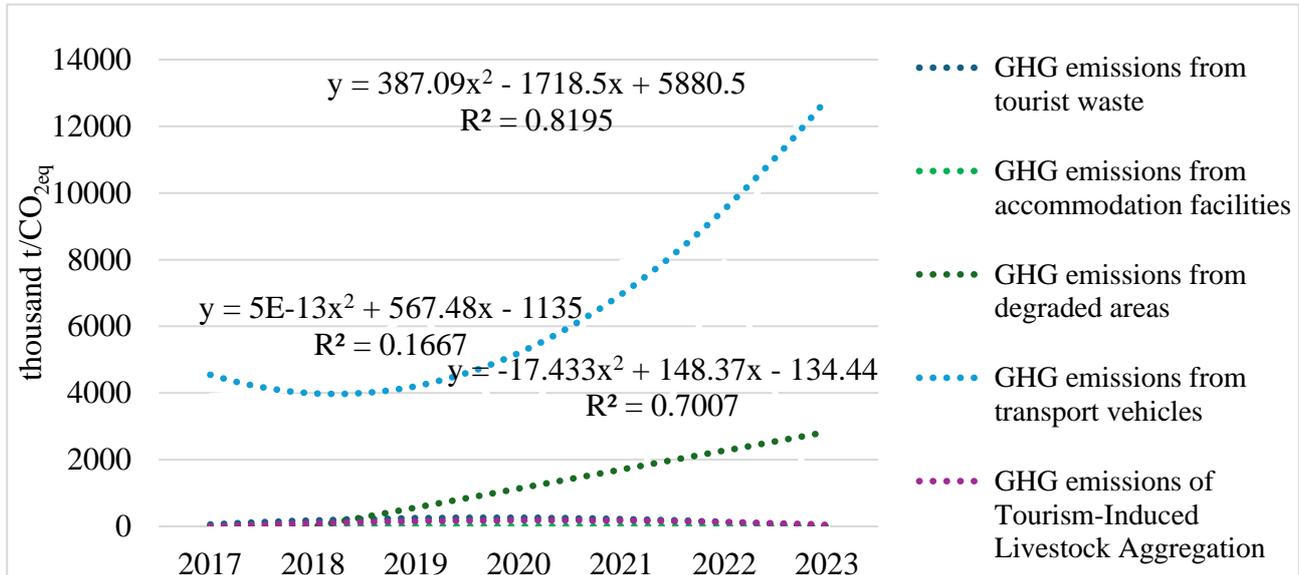- GHG emissions of Tourism-Induced Livestock Aggregation

Figure 2. Trends in GHG emissions in the Mongolian Altai Mountain

While the negative impact associated with livestock aggregation shows a continuing upward trend, GHG emissions from tourist transport vehicles demonstrate a slight declining tendency. Among the directly observable adverse effects of human presence, GHG emissions generated from tourist waste remain the lowest and are projected to decrease marginally in the future. In contrast, the negative environmental impacts of tourism in the Kazakhstan Altai exhibit a markedly different pattern. In this case, the most significant negative impact of tourism GHG emissions generated by tourist transport vehicles, which are also expected to increase sharply in the future. Although transport-related emissions account for approximately 82% of total tourism-related GHG emissions, emissions arising from degraded areas remain relatively low. This can be explained by the fact that nearly 90% of the selected routes are paved roads with well-developed infrastructure.

Looking ahead, GHG emissions associated with tourism-induced livestock aggregation and those originating from degraded (disturbed) areas are projected to decline, whereas emissions from tourist waste are expected to show an increasing trend. In contrast, GHGs emissions from accommodation facilities could not be estimated for the Kazakhstan Altai due to data limitations (Figure 3).

Although the coefficient values of GHG emissions and the trend-growth R^2 values are relatively low for several indicators, the fitted curves are considered to adequately represent the underlying

trends. The low R^2 values can be attributed to the absence of data for certain years, as well as to the fact that some indicators are based on observations from only a single year. This interpretation is further justified by the use of uniform calculation formulas for these indicators, consistent with those applied to greenhouse gas emission trends from transport vehicles and livestock, ensuring methodological comparability across all variables.

$$y = 387.09x^2 - 1718.5x + 5880.5$$
$$R^2 = 0.8195$$

$$y = 5E\text{-}13x^2 + 567.48x - 1135.$$
$$R^2 = 0.1667$$

$$y = -17.433x^2 + 148.37x - 134.44$$
$$R^2 = 0.7007$$

GHG emissions from tourist waste

GHG emissions from accommodation facilities

GHG emissions from degraded areas

GHG emissions from transport vehicles

GHG emissions of Tourism-Induced Livestock Aggregation

Figure 3. Trends in GHG emissions in the Kazakhstan Altai Mountain

In addition to analyzing the trends in GHG emissions generated by tourism, the spatial distribution of these emissions is also visualized. The following figure illustrates the selected routes and identifies the specific sections of the routes where the GHG emissions presented in the above table are most intensely generated (Figure 4).
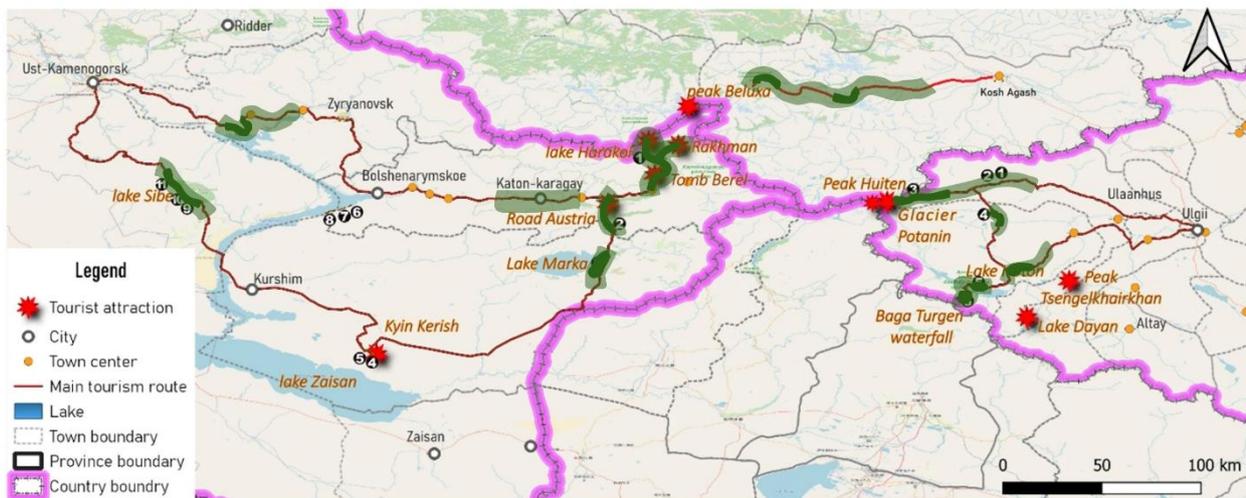
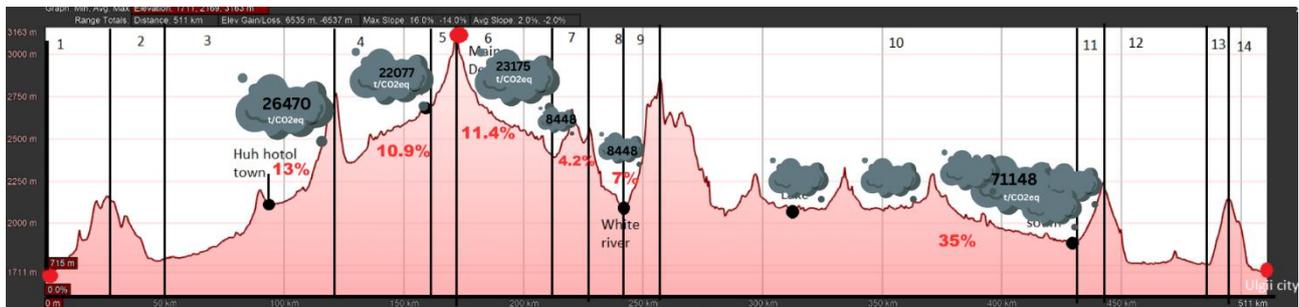**Figure 4.** Spatial distribution of GHG emissions along the selected tourist routes

As shown in Figure 4, the highest levels of GHG emissions in the Mongolian Altai are concentrated in the vicinity of the Potanin Glacier within Altai Tavan Bogd National Park, as well as around the Baga Turgen waterfall, the Khoton–Khurgan Lake valley, and the surrounding areas of

Tsengel soum. When the spatial distribution of GHG emissions presented on the map is transformed into a hypsometric cross-sectional profile, several key patterns become evident.

Approximately 22% of total GHG emissions, equivalent to 45252 t/CO$_{2eq}$, were generated along the route between the ranger station of Altai Tavan Bogd National Park and the Presidential Ovoo worship. This area is characterized by the absence of carbon-sequestering forests, sparse vegetation cover, and extensive land degradation primarily caused by tourist vehicles. In addition, heavy metal contamination of soils has been reported in this zone (Badyelgajy, Kapsalyamov, Tussupova, 2022).

A further 35% of total emissions, corresponding to 71148 t/CO$_{2eq}$, were released along the gorge road leading to Tsengel soum. At the terminal section of this gorge lies the Bayan Mountain Range, which acts as a natural orographic barrier. As a result, the emitted GHGs tend to accumulate in the vicinity of Tsengel soum, creating favorable conditions for a localized greenhouse effect, as clearly illustrated in the figure. A similar phenomenon is also observed in the low-lying areas along the riverbanks near Khökhkhotol village, where approximately 3500–4000 t/CO$_{2eq}$ of GHGs are emitted annually from tourism-related activities (Figure 5).

Although there are no major mining operations or industrial facilities in the vicinity of these settlements, the presence of a large number of coal-burning households, high livestock aggregation, and intensive vehicular activity contributes to the formation of significant local accumulations of GHGs.

Figure 5. Spatial distribution of tourism GHG emissions in the Mongolian Altai Mountain (last 7 years)
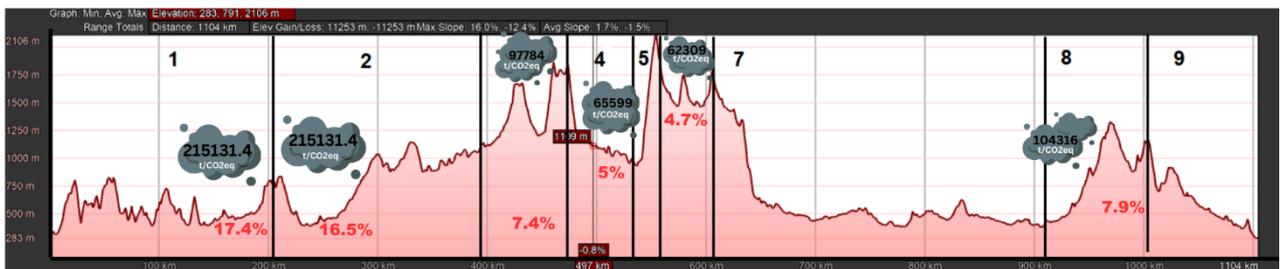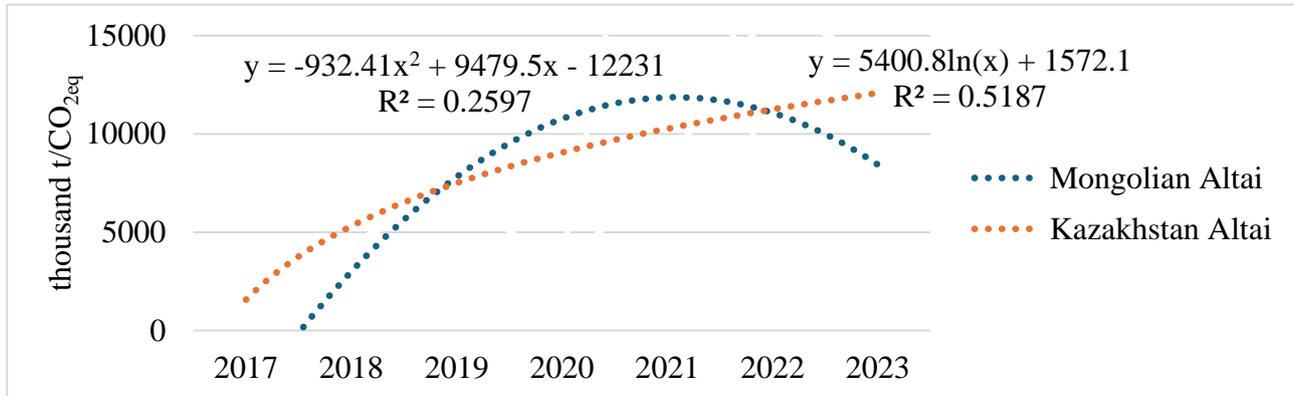

Figure 6. Spatial distribution of tourism GHG emissions in the Kazakhstan Altai Mountain (last 7 years)

In the Kazakhstan Altai, the majority of tourism GHG emissions are concentrated in the Berel village valley, the Ürel village area, the surroundings of Lake Yazovoye, and along the Bukhtarma River gorge leading toward Mount Belukha. It is clearly evident that tourism activities concentrated around the Altai (Zyryan) city area account for a substantial share of total tourism-related GHG emissions, with approximately 70000 t/CO$_{2eq}$ emitted annually on both sides of the mountain range (Figure 6).

In contrast, high-altitude lake depressions in the vicinity of Lake Yazovoye and the Rakhmanov Springs have generated a cumulative total of approximately 100000 t/CO$_{2eq}$ over the past seven years, corresponding to an annual average of around 15000 t/CO2eq solely from tourism activity. Along the route of the former Austrian Road, approximately 5% of total GHG emissions are trapped and

accumulated, while in the Markaköl Lake basin, about 4.7% of total emissions -equivalent to nearly 9000 t/CO_{2eq} per year originate from tourism.

In addition, the area surrounding the Sibiny Lakes, located near the city of Ust-Kamenogorsk, also exhibits a pronounced tourism footprint, indicating significant localized tourism-related environmental pressure. Another study conducted in Katon-Karagai National Park also reported a high level of tourism pressure (Aktymbayeva, Nuruly, et al, 2023).

Figure with equations:
$$y = -932.41x^2 + 9479.5x - 12231$$
$$R^2 = 0.2597$$
$$y = 5400.8\ln(x) + 1572.1$$
$$R^2 = 0.5187$$

Figure 7. Comparative trends in the growth of GHG emissions in the Mongolian and Kazakhstan Altai Mountains

The growth trends of tourism-related GHG emissions in the Mongolian and Kazakhstan Altai display two distinctly different patterns. In the Mongolian Altai, a decline in tourist numbers is projected in the coming years, accompanied by a corresponding reduction in GHG emissions. In contrast, the Kazakhstan Altai is expected to experience a continued period of high growth in tourism activity, resulting in a sustained increase in associated GHG emissions (Figure 7).

5. Conclusion

This study, which practically demonstrates that the environmental impacts of tourism can be quantitatively assessed using GHG emissions, covers both the western and eastern parts of the Altai Mountain. Although the research encompasses the Kazakhstan and Mongolian segments of the extensive Altai mountains system, a robust comparative analysis of the results was conducted. Given that the Altai Mountains rank among the world's prominent tourist destinations, the pressure exerted by human activities on their scenic landscapes, natural environment, endemic communities, and biodiversity is substantial. One of the major contributing factors is tourism, particularly the «ecotourism policies» actively promoted by the selected countries.

During the period of intensified tourism development in the Altai Mountains between 2017 and 2024 - overlapping with the years of the COVID-19 pandemic - tourism activity increased markedly in both the Mongolian and Kazakhstan Altai. This increase is clearly reflected in the corresponding growth of tourism-related GHG footprints.

A comparative assessment of the environmental impacts of tourism reveals that, in the Mongolian Altai, the majority of tourism-related GHG emissions originate from degraded areas, followed by emissions from transport vehicles and GHGs associated with tourism-induced livestock aggregation. Together, these sources account for more than 90% of the total tourism footprint. Notably, 22% of total emissions, equivalent to 45252 t/CO_{2eq} were generated in areas located near the glaciers of Altai Tavan Bogd National Park, confirming a direct and significant negative impact on sensitive environments. The growth of GHG emissions in the Mongolian Altai appears to have reached its peak, with a declining trend observed from 2024 onward.

In contrast, in the Kazakhstan Altai, approximately 4/5 of tourism GHG emissions are associated exclusively with transport vehicles. Emissions from degraded areas and tourist waste also contribute to the overall footprint at a moderate level.

A comparative analysis of tourism GHG footprints across the Altai Mountains indicates a strong dependence on national development levels and infrastructure conditions. In the Mongolian Altai, where selected routes are entirely unpaved, tourism GHG emissions are primarily derived from degraded land surfaces and tourism-induced livestock aggregation. Conversely, in the Kazakhstan Altai - where approximately 90% of the routes are paved - the dominant contributor to GHG emissions is transport-related activity. Overall, tourism GHG emissions are closely linked to both tourist numbers and transportation.

If these indicators were further compared with the Altai mountains of the Russian Federation and the People's Republic of China, which receive substantially higher tourist flows, markedly different results would be expected. Although total GHG emissions in those regions may be higher, the intensity and spatial characteristics of their environmental footprints are likely to exhibit contrasting patterns.

6. Supplementary Materials: Not applicable.

7. Author Contributions

Conceptualization - B.Ye., B.S.; methodology - B.Ye.; software - B.Ye.; validation - B.S., Sh.Ch; formal analysis - Sh.Ch.; investigation - B.Ye.; resources - B.Ye.; data curation - Sh.Ch.; writing - original draft preparation - B.Ye.; writing - review and editing - Sh.Ch.; supervision - B.Y.; project administration - X.X.; All authors have read and agreed to the published version of the manuscript.

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Моңғол Алтай және Қазақстан Алтай тауларындағы туризмнің экологиялық ізінің өсу үрдістері

Ербахыт Баделгажы, Чанагнянгар Шаравпүрэв, Сайханбаяр Бямбасүрэн

Аңдатпа. Орталық Азияның төрт мемлекетінің шекарасы бойымен созылып жатқан Алтай тау жоталары туристер ең көп баратын бағыттардың бірі. Қар жамылған шыңдары, мұздықтары, орманды көркем таулары туристердің негізгі қызықтайтын жәдігерлері. Қазақстан мен Моңғолияда Алтай тау жоталарында экотуризмді дамыту басым бағыт ретінде жоспарланғанымен, оның қоршаған ортаға тигізетін теріс әсерлері туралы ғылыми еңбектерде жазылған. Соңғы жылдары жүргізілген зерттеулерде туризм ізін сандық тұрғыда бағалап, өлшеген. Бұл мақалада аталған зерттеулердің қорытынды нәтижелерін парниктік газдар шығарындылары арқылы салыстыру үшін ұсынылады. Туризмнің қоршаған ортаға әсерлері CO_2-эквиваленті (CO_2eq) бірлігі бойынша әртүрлі әсер көздерін өзара салыстыра отырып,

соңғы бес жылдық динамикасына талдау жасау арқылы туризм іздерінің даму үрдістері анықталды. Зерттеу нәтижелері Моңғол Алтайында туризм саласынан бөлінген парниктік газдар көлемі ең жоғары деңгейге жетіп, 2024 жылдан бастап құлдырау үрдісі байқалғанын көрсетеді. Жалпы шығарындылардың 52%-ы зақымдалған алаңдардан, ал 33%-ы туризм әсерінен шоғырланған мал шаруашылығынан бөлінген. Ал қазақстандық Алтайда туризмге байланысты парниктік газдар шығарындыларының 82%-ы көлік құралдарынан бөлінген. Зақымдалған алаңдардан үлесі 14%-ды, ал туристік қалдықтардан бөлінетін шығарындылар 2%-ды құрайды. Бұл нәтижелер туризмнің қоршаған ортаға әсері туралы қалыптасқан дәстүрлі түсініктерден өзгеше екендігін көрсетеді.

Түйін сөздер: Алтай жотасы; экологиялық туризм; парниктік газдар; өсу үрдістері.

Тенденции роста экологического следа туризма в Монгольском Алтае и Казахстанском Алтае

Ербахыт Баделгажы, Чанагнянгар Шаравпурэв, Сайханбаяр Бямбасурэн

Аннотация. Алтайские горы, протянувшиеся вдоль границ четырёх стран Центральной Азии, являются одним из наиболее интенсивно посещаемых туристических регионов. Вечноснежные вершины, ледники, лесные массивы и живописные горные ландшафты выступают основными факторами туристической привлекательности. В Казахстане и Монголии экотуризм рассматривается как приоритетное направление развития туризма в Алтайском регионе, однако в научной литературе неоднократно отмечалось его негативное воздействие на окружающую среду. В последние годы проведён ряд исследований, в которых удалось количественно оценить туристический след. В данной статье представлены итоговые результаты этих исследований, выраженные в показателях выбросов парниковых газов. Воздействие туризма на окружающую среду было приведено к эквиваленту CO_2 (CO_2eq), что позволило сопоставить различные источники воздействия, а также определить тенденции их изменения на основе пятилетнего динамического анализа. Результаты исследования показывают, что в Монгольском Алтае выбросы парниковых газов, связанные с туристической деятельностью, достигли пикового значения и с 2024 года перешли к нисходящей тенденции. Из общего объёма выбросов 52% приходится на деградированные территории, а 33% - на выбросы от скота, сконцентрированного вследствие туристической деятельности. В Казахстанском Алтае 82% совокупных выбросов парниковых газов в сфере туризма формируются за счёт транспортных средств. При этом 14% выбросов связано с деградированными землями, а 2% - с туристическими отходами. Полученные результаты отличаются от традиционных практических представлений о структуре туристического воздействия на окружающую среду.

Ключевые слова: Алтайский горный хребет; экологический туризм; парниковые газы; тенденции роста.