DETERMINING THE IMPACT OF TOURISM ON THE ENVIRONMENT BY EXTRACTING THE CARBON FOOTPRINT OF ROAD INFRASTRUCTURE IN NATURAL PROTECTED AREAS - CASE STUDY OF THE UČKA NATURE PARK

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Abstract

Purpose – The research is based on the thesis that if the impacts of tourism on the environment were reduced to a local carrying capacity of the environment, then the global impact of tourism on the environment would be fully sustainable. In this light, the purpose of this research is to measure the local impact of tourism related road traffic on the environment on the example of the Učka Nature Park.

Methodology – The carbon footprint of road traffic in the Učka tunnel was calculated using the carbon footprint methodology. The footprint was measured in the period from 2015 to 2020 on a monthly basis in order to gather database for analysing the seasonality of CO_2 emissions, taking into account the local biocapacity of the environment.

Findings – The total carbon footprint of traffic in the Učka tunnel from 2015 to 2020 is the result of an average volume of 3,204,375 vehicles per year. This amount of road traffic emitted an average of 2934.3 tons of CO_2 per year. On a yearly basis 4.45% of the total biocapacity of the Učka Nature Park or 687.9 lha is needed to absorb carbon emissions from the Učka tunnel. The share of tourism in the total carbon footprint of road traffic in the Učka tunnel during the observed period at the annual level is 30.5%.

Contribution – The paper contributes to the discussion of the local impact of tourism related to road traffic. Specifically, the paper aims to raise awareness and encourage the scientific community to research more local case studies that will measure the concrete impact of tourism on the environment. The applied contribution of the work is expressed through the measured value of the total and specifically separated tourist carbon footprint and contributes to the expansion of the database that would enable objective, measurable and sustainable spatial management.

Keywords: tourism, environmental impact, sustainable development, road traffic, carbon footprint, natural protected area.

INTRODUCTION

The impact of human activities on environmental changes is increasingly in the focus of modern scientific research on sustainable development (Mensah 2019). In the context of climate change, emissions of greenhouse gases and specifically carbon dioxide stand out in studies of human impact on the environment. Modern tourism, with its reliance on growing global mobility, plays a significant role in burdening the environment, and this is particularly visible through the influence of greenhouse gases (Lenzen et al. 2018).

The Republic of Croatia is a renowned tourist country and the County of Istria is a leading tourist region on the eastern coast of the Adriatic Sea, making them an integral part of international tourist travel. Both at the national and at the regional level tourism of the County of Istria is dominantly based on road transport (Marušić et al. 2019; Maršanić et al. 2021), and there is a variety of cause-and-effect relationships between the economic and social factors of road transport in tourism-developed destinations with characteristic seasonality (Grofelnik and Kovačić 2023).

Modern strategies of general and tourism development intensively seek to achieve sustainability, within which the element of environmental sustainability and greenhouse gas emissions is emphasized (Ali et al. 2021). The fact is that the impact on the environment, especially in the aspect of gas emissions into the atmosphere, is of a global nature. However, if the impacts of tourism on the environment were reduced to a local measure of the carrying capacity of the environment's biocapacity, then the global impact of tourism on the environment would be fully sustainable. The contemporary research focus of the scientific community is often reduced to measuring sustainability at the large scale of national or global systems (Gühnemann et al. 2021; Lenzen et al. 2018; Yang and Jia 2022). The problem with such research approach is that it does not provide reliable and comparable answers, due to differences in methodologies and the overcomplexity of the system, and therefore the impact on the environment that tends to be overly generalized. Generalizations primarily do not take into account allocated impacts, and it is difficult to distinguish which studies' results can be compiled, compared and further used.

The authors of this research are convinced that one of the possible solutions to the described gap in the research area is the implementation of a larger number of smaller, and thus simpler and comparable, case studies. If this concept would be spread globally, then we would be dealing with a sufficient database to improve the management of the impact on the environment and to accelerate the approach to an equilibrium of the environment. Since the studies dealing with local sustainability in the segment of CO_2 emissions related to tourism are few, in order to address the observed deficit in researching the measurement of local biocapacity and carbon footprint, this paper focused on the case study of one of the large and strategically important road infrastructure facilities, and measuring its impact on the environment. The specificity of this research lies in the fact that the researchers till now did not measure the carbon footprint of road traffic on the environment within protected natural areas, and especially not by singling out the impact of tourism. In this light, this research aims to measure the local carbon footprint of one of the large road infrastructural facilities on the example of a case study of the Učka tunnel, which is located within the protected area of the Učka Nature Park.

The aim of this paper is to calculate the total local carbon footprint of transit road traffic in the area of the Učka Nature Park, in relation to road traffic in the Učka tunnel, and to separate the tourist share of the carbon footprint within it. Furthermore, the research aims to determine the annual oscillations in the intensity of the impact on the environment through the carbon footprint and the participation of tourism in this burden on the environment.

Two hypotheses were tested in the research:
H-1: The carbon footprint of road traffic in the Učka tunnel is greater than the local biocapacity of the Učka Nature Park.
H-2: The carbon footprint trends of road traffic in the Učka tunnel are dominantly influenced by tourism.

The research covers the pre-pandemic and pandemic period from 2015 to 2020, and the northeastern branch of the Istrian Epsilon on which the Učka tunnel is the most significant object of strategic importance. The tunnel not only links the Istrian County and the rest of the national territory, but also connects Istria as a tourist destination with the domestic and foreign tourist markets of Central Europe and provides a supply route and logistics corridor.

1. THEORETICAL BACKGROUND

There is a rising interest in the topic of CO_2 emissions generated by road traffic, while reducing the emissions became an important part of mitigating the negative effects of climate change (Lyu et al. 2021), making it essential to monitor the GHG emissions. It is in line with the fact that transportation sector globally generates around 29% of the total GHG emissions, as well as 25% of the energy related CO_2 emissions (Zhang et al. 2019). In EU, road transport accounts for the 77% share of total transport-related GHG emissions (European Environment Agency). However, road traffic infrastructure such as tunnels supports trade, national and international (Chen and Li 2021; Donaubauer et al. 2018; Karymshakov and Sulaimanova 2021; Shen 2023).

The reduction of carbon footprint and environmental performance are becoming the key issues in designing tunnels and a part of tunnel sustainability evaluations (Phillips 2016). Tunnelling projects are perceived to have high emissions during their operational life (Guo et al. 2016; Guo et al. 2017), but those are sometimes surpassed in the construction stage (Ahn et al. 2010; Huang et al. 2015; Kalvå 2015). Tunnels impact the environment and people, but can still remain highly sustainable (Phillips 2016). Namin et al. (2014) focused on the environmental and socio-economic aspects and impacts of tunnels in all life-cycle stages pointing out the need to integrate the environmental assessment of tunnels in the tunnel design stage. The need to focus on the entire tunnel's lifecycle is confirmed by Huymajer et al. 2022.

The socio-economic impacts of road tunnels are found to be positive. Previous research has demonstrated that tunnel infrastructure has the potential to contribute to short-distance labour market (Bjarnason 2014), as well as the long-distance one by supporting the work migrations of professionals and skilled workers (Bjarnason 2021). Tunnels are also a factor of reducing travel times through better connections (Samuelsen and Grøv 2018), mitigating regional isolation and population decline (Bjarnason 2014), and employment prospects for local population (Grydehøj and Casagrande 2020). In the 40 years of its operation, the strategic, economic, political and social value of Učka tunnel for the integral national transport system continues to be demonstrated, from the point of its construction (Marinčić 2016).

2. METHODOLOGY

In the last two decades, tourism has been one of the globally significant and rapidly growing activities that influence the increase in carbon dioxide emissions (Lenzen et al. 2018). It has been proven that one of the largest shares in the total impact of tourism on the environment in terms of CO_2 emissions comes from the transport of people and goods, without which modern tourism as a global economic activity is unthinkable (Gössling and Peeters 2015). In modern research on the impact of tourism through CO_2 emissions into the atmosphere on the natural environment, as an element that absorbs CO_2, the method of determining the carbon footprint is increasingly used (Lenzen et al. 2018). Carbon footprint can be measured on a global level, according to the average biocapacity of the global ecosystem, or locally, according to the absorption biocapacity of a certain isolated area (Grofelnik 2015; Liu et al 2016). The majority of scientific research in the relevant scientific databases deals with the impacts of tourism on carbon emissions on a systemic, theoretical, global or national level (Gühnemann et al. 2021; Lenzen et al. 2018; Yang and Jia 2022).

In order to complete the observed lack of research, this paper studies a case of one of the large and strategically important road infrastructure facilities. The specificity of this paper is the separation of the local impact of the carbon footprint, which was done on the example of the Učka tunnel, located within the protected natural area of the Učka Nature Park. Therefore, in this paper, the research interest is focused on the measurement of local CO_2 emissions in relation to the local bioabsorption capacity of the forests in the protected area, and a part of the carbon footprint under the influence of tourism as a dominant activity in the wider region is specifically highlighted.

Through the research, the carbon footprint was calculated from the data on the intensity and structure of road traffic in the Učka tunnel. The footprint was measured on a monthly basis in order to enable analysing the seasonality of CO_2 emissions, taking into account that the biocapacity of the local environment. Measured data on road traffic was converted into specific values of CO_2 emissions, which were further converted into local hectares using the carbon footprint methodology.

For the purposes of the research, county and local secondary statistical data were collected in direct contact with the company BINA-Istra (concessioner of the highway Istrian Epsilon and Učka tunnel), the Tourist Board of Istria County and the Croatian Bureau of Statistics.

The analysis of input data related to the intensity of road traffic, tourist movements and carbon footprint output values was carried out at the level of monthly indicators and characteristic seasonal periods. The results of the research were interpreted based on input factors and calculated variables of the carbon footprint, bioabsorption capacity and tourist indicators that model the monthly movement of the carbon footprint in the observed period.

In order to make the data on the carbon footprint in the Učka tunnel more closer to reality the Spritmonitor.de database, that monitors the real fuel consumption of an extremely large number of vehicles, was used in the process of conversion and calculation of carbon emissions. Germany was taken as the reference base for vehicles consumption, since it is the largest emitting tourist market for the Istrian county. In the Spiritmonitor.de database, with the help of the filter function, data on the average consumption of vehicles with over 20,000 kilometres travelled was used. The database was accessed on February 8, 2023, and the average consumption was calculated based on 266,379 selected vehicles, of which 128,471 (48.23%) were powered by diesel and 137,908 (51.77%) by petrol engine (Verbrauch: Alle Hersteller - Alle Modelle - Spritmonitor.de).

From the data of the aforementioned database and in accordance with the carbon footprint calculation methodology, the individual average CO_2 emission for road vehicles was calculated:

- 18.4 kg of CO_2 per 100 km for diesel vehicles, based on an average consumption of 6.97 litres of diesel fuel per 100 km x 2.64 (conversion coefficient for diesel);
- 17.8 kg CO_2 per 100km of petrol powered vehicles, based on the average consumption of 7.63 litres of petrol fuel per 100 km x 2.33 (conversion coefficient for petrol).

The average emissions of diesel and gasoline vehicles at the overall level gives 180.9 g of CO_2 per km, which was further used to calculate the monthly and annual vehicle emissions in the Učka tunnel.

3. RESULTS

The results of measuring the intensity and structure of traffic by vehicle category and their specific CO_2 emissions were converted using the carbon footprint methodology into concrete values of the local impact on the environment with regard to the appropriate biocapacity of the environment. The footprint was analysed at monthly level (Table 1, Figure 1) in order to put the analysis of the seasonality of CO_2 emissions in relation to the changing biocapacity of the environment and tourism seasonality.

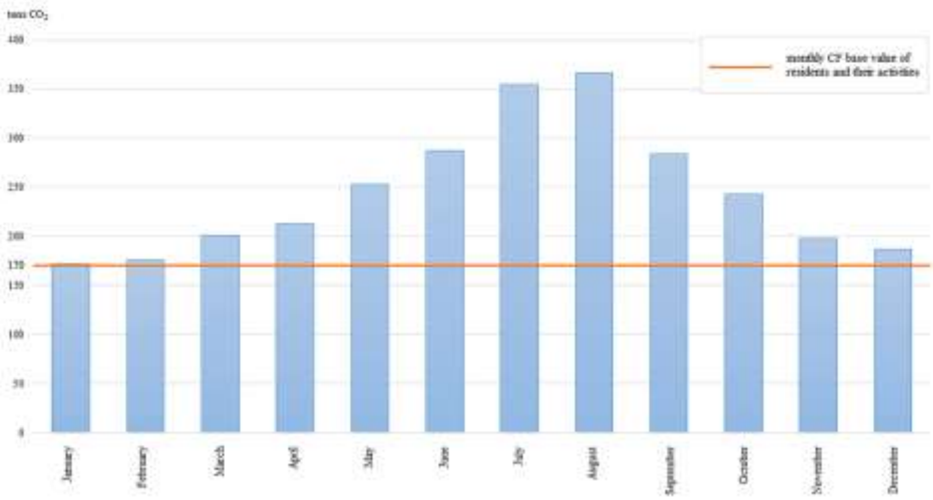
Table 1: **Carbon footprint of total road traffic in the Učka tunnel in the period from 2015 to 2020**

year	monthly CF (tons CO_2)											
	1	2	3	4	5	6	7	8	9	10	11	12
2015	145.9	143.9	181.6	205.8	234.1	254.1	320.9	335.6	258.6	209.7	179.8	176.9
2016	151.4	163.6	197.5	215.3	247.4	262.6	348.4	364.3	275.5	227.8	186.4	187.4
2017	158.5	175.6	216.9	245.2	269.6	300.4	373.1	371.2	284.4	250.4	200.3	191.1
2018	188.7	171.0	222.5	262.8	295.4	315.5	382.7	391.2	311.1	266.4	213.4	203.1
2019	189.3	195.0	242.6	270.9	294.9	332.4	391.4	407.0	319.3	280.1	220.6	213.4
2020	200.3	209.7	146.3	77.8	174.7	255.4	310.2	330.6	251.5	222.7	184.3	149.9
average	172.4	176.4	201.3	213.0	252.7	286.8	354.4	366.6	283.4	242.9	197.5	187.0

Source: author's calculation

The average annual carbon footprint of road traffic in the Učka tunnel for the period from 2015 to 2020 is 2934.3 tons of CO_2. This footprint is the result of the average annual traffic of 3,204,375 road vehicles through the Učka tunnel, in the period from 2015 to 2020.

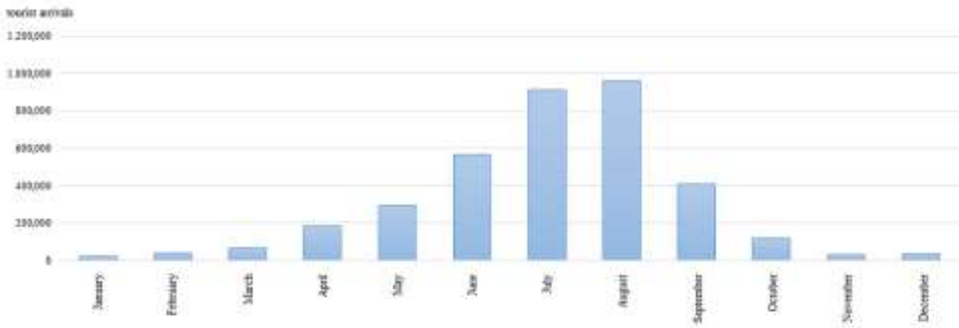
Figure 1: **Average monthly CO_2 emissions for the period 2015-2020**



Source: author's calculation

Due to acknowledging the impact of tourism on the local bioabsorption capacity of the area through the carbon footprint, data on average monthly tourist arrivals in the observed period were taken into account (Figure 2).

Figure 2: **Average monthly tourist arrivals in Istria for the period 2015-2020**



Source: Croatian Bureau of Statistics

For the calculation of the total annual biocapacity of the Učka Nature Park, areas under the categories forests and meadows and mastures (Table 2) were taken, which make up 97.0% of the area of the protected area.

Table 2: **Structure of the Učka Nature Park surfaces**

Categories of surfaces in Učka Nature Park	ha	%
Settlements	67.46	0.42
Areas of separate use (economic, tourist-hospitality, sports-recreational, quarries)	32.91	0.20
Infrastructure (roads, transmission lines, gas pipeline, telecom, water supply)	277.89	1.75
Agricultural areas	100.43	0.63
Forests	12,127.65	76.10
Medows and pastures	3331.54	20.90

Source: Turnšek et al. 2006.

For the biocapacity of the forest communities of the nature park, a value of 4.5 tons of CO_2 per hectare was taken, i.e. the level of bioabsorption of mature forests of moderate latitudes in Europe, the age of the forest is 20 to 60 years (Bernal et al. 2018). A value of 3.43 tons of CO_2 per hectare was taken for the biocapacity of the grass communities of the nature park, i.e. the level of bioabsorption of mature grass areas of moderate latitudes, age 30 years (Phillips et al. 2023). The annual biosorption capacity of the forest areas of the Učka Nature Park is 54,574.4 tons of CO_2/year, while the biocapacity of the grassy areas is 11,427.2 tons of CO_2/year. It follows that the total biocapacity of the Učka Nature Park is 66,001.6 tons of CO_2/year, while the average CO_2 emission in the Učka tunnel for the period from 2015 to 2020 was 2934.3 tons of CO_2. Therefore, the absorption of emissions from the Učka tunnel requires 4.45% of the biocapacity of the protected area or 687.9 hectares at the level of local biocapacity.

4. DISCUSSION

The results obtained from this research show the seasonal regularity of oscillations of CO_2 emissions, with a pronounced summer maximum in August and an increase in average emissions by about 113% compared to the winter minimum in January (Figure 1). The dominant economic activity in Istria for the last 60 years has been tourism, and its basic characteristics are pronounced seasonal oscillations and reliance on the road arrival of guests to the destination (Marušić et al. 2019; Maršanić et al. 2021; Ružić and Težak Damjanić 2016). The increase in the number of tourist arrivals throughout the year (Figure 2) also shows the same seasonal pattern. Given that tourism during has a very low intensity during the winter period compared to the summer (Figure 2), its contribution to the carbon footprint of road traffic is minor. The dominant role is taken by the spatial movement of residents for personal needs and movement that supports economic activities with year-round operation.

By analysing the data on a monthly basis and comparing the annual trend and intensity of monthly changes, it can be clearly seen that the minimum of both carbon footprint (Figure 1) and tourist arrivals (Figure 2) in Istria County is very similar (with a minimum in the winter and a maximum in the summer season). It is important to have in mind that carbon footprint emissions in the Učka tunnel are generated not only by tourism circulations but have a monthly and yearly amount (base value) that is generated by residents and all their other activities. If the monthly trends and intensity of changes in carbon footprint and tourist arrivals in Istria county are compared it is needed for the next step of analysis to single out the value of monthly base value that can be associated with residents and their activities. For the first step in research, it is taken the monthly base value of 170 tons of CO_2 of the carbon footprint related to the needs of residents (Figure 1), and in the second step if this base monthly amount is subtracted from the whole monthly carbon footprint the rest of the monthly footprint have almost identical trends to the monthly trends of tourist arrivals (Figure 2). It is therefore evident that tourism and its supporting activities in the area of Istria County dominantly determine changes in the intensity of environmental impact and CO_2 emission values in the Učka tunnel. If the same value (170 tons of CO_2 for the needs of the resident population and year-round economy) is taken as a base, then it can be calculated that the share of tourism and related activities in CO_2 emissions in the Učka tunnel is 30.5%.

For further improvement of the research it would be important to get more detailed insight into the seasonal oscillations of the intensity of activities that are logistically supporting tourism (e.g. transport, trade...) on one hand, and of other activities in the area of Istria County (e.g. agriculture...) on the other. These activities could have a similar annual trend of activity intensity and, consequently, the need for the spatial movement of people and goods through the Učka tunnel (the northeastern branch of the Istrian Epsilon). Also, future research should expand the spatial dimension of observing the impact of the intensity of total traffic and specifically traffic related to tourism in the area of Istrian County, bearing in mind the importance of tourist and other traffic related to the north-western branch of the Istrian Epsilon. By extracting the above mentioned aspects, more accurate results of the impact of tourism on the environment through the carbon footprint could be obtained, and make an interesting input data in the standard and alternative management models of the Istrian Epsilon and the Učka tunnel, particularly in managing crisis situations in road traffic similar to those in the spring of 2020 caused by the COVID-19 pandemic.

CONCLUSION

Large objects of road infrastructure such as road tunnels are mostly perceived negatively from an ecological point of view, although sometimes their negative environmental impact is larger in the construction phase than in the operational phase of the life cycle. Tunnels are specific because they bring numerous benefits to the connected areas, and except for the possible negative impact on the environment - which can be monitored and controlled, they have a various positive economic and social impact.

The research has isolated the part of the carbon footprint of road traffic generated within the Učka Nature Park under the influence of tourism as the dominant activity in the area of the Istrian County. The results of the research confirm distinct seasonality and connection of the impact of tourism on the environment through the generation of traffic in the Učka tunnel and the associated expressways. This research showed that tourism affects the carbon footprint of the road infrastructure, but also that it is not too large in the context of the bioabsorption capacity of the Učka Nature Park, which takes 4.45% of biocapacity to absorb the emissions from the Učka Tunnel.

The research did not confirm the H-1 hypothesis, that the carbon footprint of road traffic in the Učka tunnel is greater than the local biocapacity of the Učka Nature Park. But the results confirmed the H-2 hypothesis, that the carbon footprint trends of road traffic in the Učka tunnel are dominantly influenced by tourism.

The theoretical contribution of this paper aims towards raising awareness and encouraging the scientific community to create a larger number of case studies that will specifically measure the impact of tourism on the environment. The applied contribution of the work is expressed through the measured value of the total carbon footprint and the specifically separated tourism carbon footprint, which expands the database of specific measured impact on the environment and supports the objective and sustainable operational management of space in the near future.

The general contribution of the research could be achieved by spreading awareness of the impact of tourism and its related traffic carbon footprint in the context of the European Green Plan 2050 of the European Commission in the segment of greenhouse gas emissions. The specific contribution of the research is visible through the expansion of the database of measured environmental impact data.

The scientific contribution of the research is visible in the fact that so far no scientific work has measured the impact of tourism on the environment in the segment of the carbon footprint of large transport infrastructure facilities in protected area in the operational phase of the infrastructure's life cycle. The scientific contribution of this research is further supported by the finding that although tourism inevitably affects the carbon footprint of the road infrastructure, this impact need not be completely perceived as negative. It is demonstrated that even with high seasonal traffic volumes carbon footprint can be in accordance with the bioabsorption capacity of the natural protected area.

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