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STRATEGIC NOISE MAP FOR BELGRADE NIKOLA TESLA AIRPORT

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Abstract. *Environmental noise management is a critical aspect of public health policy, particularly within the European Union, which established Directive 2002/49/EC to standardize noise assessment and mitigation efforts across member states. Serbia has integrated the Directive's provisions through its Law on Environmental Noise Protection and accompanying by-laws. This paper presents the strategic noise mapping process for Belgrade Nikola Tesla Airport, Serbia's largest international airport, marking a significant milestone as it is the first time a strategic noise map is being developed for a major airport in Serbia. The legal framework, methodology, and results of this mapping process are discussed in detail. Utilizing the CNOSSOS-EU:2015 method and the Aviation Environmental Design Tool (AEDT) for acoustic calculations, the study defines the affected areas, noise indicators, and population exposure based on 2023 air traffic data. The results indicate that the* L_{den} *noise levels exceeding 55 dB impacted 24223 residents, while the* L_{night} *noise levels exceeding 50 dB affected 7493 residents. The analysis also includes the estimated number of dwellings, schools, hospitals, and people affected by different noise levels, providing necessary data for developing action plans aimed at mitigating noise pollution. Additionally, the study examines the potential health impacts, including population annoyance and sleep disturbance, using dose-effect relationships as defined by the European Commission. The results underline the importance of ongoing noise monitoring and the need for timely revisions of strategic noise maps and action plans to ensure compliance with both national and EU regulations. This research contributes to the broader effort of environmental noise management, offering insights into the methodologies and challenges of strategic noise mapping for airports in Serbia.*

Key words: *environmental noise, noise mapping, airport, noise indicators, aircraft noise, population exposure*

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1. Introduction

The European Parliament, as a basis for assessing and managing environmental noise, adopted Directive 2002/49/EC (hereinafter referred to as: the Directive) in 2002 [1]. The primary aim of the Directive is to define a common approach intended primarily to avoid, prevent, or reduce harmful effects due to exposure to environmental noise, including disturbances caused by noise. Serbia has implemented the provisions of the Directive through the Law on Environmental Noise Protection from 2021 [2] and the by-laws from 2010 [3,4] and 2023 [5].

Strategic noise mapping has become an essential tool for managing environmental noise across Europe, particularly in urban areas and around major transportation hubs such as airports. These maps provide a visual representation of noise exposure, allowing policymakers, urban planners, and environmental agencies to assess the extent of noise pollution and its impact on public health. In the context of airports, strategic noise maps are crucial for identifying areas where noise levels exceed acceptable limits, informing the development of mitigation strategies, and ensuring compliance with both national and European regulations. Across Europe, numerous airports have developed and regularly updated their strategic noise maps as part of broader environmental noise management plans. These efforts are essential for balancing the growth of air traffic with the need to protect communities from the adverse effects of noise.

In Serbia, the development of strategic noise maps is still in its early stages. Until now, the only strategic noise map for an airport in Serbia was developed for Niš Constantine the Great Airport, as part of the strategic noise map for the agglomeration of the City of Niš. However, this paper represents a significant milestone as it marks the first time a strategic noise map is being developed for a major airport in Serbia—Belgrade Nikola Tesla Airport. This effort reflects Serbia's commitment to aligning with European standards in environmental noise management and addressing the growing concerns related to airport noise in the country's largest urban area.

The aim of this research is to provide a comprehensive analysis of the strategic noise mapping process for Belgrade Nikola Tesla Airport, utilizing the latest methodologies and data. The study examines the legal framework governing noise management in Serbia, the specific methodologies employed in the mapping process, and the results of the noise analysis. The research is structured into several key chapters: the legal framework overview, the methodology of noise mapping, the specific case study of Belgrade Nikola Tesla Airport, and the results of the strategic noise mapping. Each chapter provides insights into the challenges and outcomes of the mapping process, contributing to the broader understanding of environmental noise management in Serbia.

2. Legal Framework

The legal regulations of the Republic of Serbia, used in the preparation and analysis of strategic noise maps, included:

- Law on Environmental Noise Protection (”Official Gazette of the RS”, No. 96/21) [2],
- Regulation on Noise Indicators, Limit Values, Noise Indicators Assessment Methods, Disturbance and Harmful Effects of Environmental Noise ("Official Gazette of the RS", No. 75/10) [3],

- Rulebook on the Methodology for Determining Acoustic Zones (”Official Gazette of the RS”, No. 72/10) [4], and
- The Rulebook on the Content and Methods of Developing Strategic Noise Map and Action Plan, the Manner of Their Development and Presentation to the Public, as well as Their Forms ("Official Gazette of the RS", No. 90/23) [5].

The obligation to report on the state and impact of noise on the population through the development of strategic noise maps is prescribed by the Directive and the legal regulations of the Republic of Serbia. This ensures the provision of information on noise exposure at local, national, and international levels and the development of action plans aimed at managing and reducing the negative impacts of noise. All information from the strategic noise maps shall be communicated to the public in a clear and accessible manner, using the most suitable information technologies.

Strategic noise maps represent data on existing and estimated noise levels, which are shown using noise indicators. A strategic noise map contains data on noise levels in a specific area for the calendar year preceding the year of the strategic noise mapping, specifically including data on: the existing, previous, or predicted state of environmental noise expressed by noise indicator values; exceedance of noise indicator limit values; the estimated number of residences, schools, and hospitals exposed to certain noise indicator values; and the estimated number of people exposed to noise in a given area.

The Republic of Serbia has mandated that strategic noise maps for agglomerations, main roads, main railways, and main airports be prepared and adopted by June 30, 2024, and revised by June 30, 2027, at the latest [2]. Environmental noise protection action plans shall be adopted no later than one year after the adoption of the strategic noise maps [2].

Strategic noise maps are used as a basis for the development of action plans and as a means of informing the public about environmental noise levels and their harmful effects.

The City of Belgrade, in accordance with legal obligations, has designated acoustic zones by Decision on the establishment of acoustic zones in the territory of the city of Belgrade ("Official Gazette of the City of Belgrade", no. 2/22). In accordance with Article 17 of the Law on Environmental Noise Protection ("Official Gazette of the RS", no. 96/21), in areas where it has not yet been implemented, the values prescribed for Acoustic Zone 5 are applied as limit values.

3. Overview of the Belgrade Nikola Tesla Airport

Belgrade Nikola Tesla Airport (IATA: BEG, ICAO: LYBE) is the largest international airport in Serbia, serving nearly 8 million passengers and handling 83,311 commercial take-off and landing operations in 2023.

It is located 19 km west of downtown Belgrade, near the settlement of Surčin. The airport covers an area of approximately 3 850 000 m². Currently, runway 12L-30R, which is 3,400 m long, is undergoing reconstruction, and these works could only commence after the construction of the new (inserted) runway 12R-30L, which is 3500 m long. After the completion of the reconstruction, the inserted runway will serve as a parallel taxiway and as a reserve runway only in case the main runway (12L-30R) is closed. Belgrade Nikola Tesla Airport currently has 18 taxiways, the airport's category is 4E, and its fire category is 8.

4. Methodology

The process of strategic noise mapping consists of seven phases, with each phase defined by the previous ones [6]. This ensures that all requirements and specifications are addressed before the development of data sets and noise models.

4.1. Phase 1 – Defining the Area for Which the Strategic Noise Map Should Be Created

The starting point for defining the area for which the noise mapping needs to be carried out for 2023 are the noise contours previously developed for Belgrade Nikola Tesla Airport. To define the area for the strategic noise mapping, the noise contours developed based on 2019 traffic data were used. By comparing the areas of these noise contours with the boundaries of the municipalities surrounding the airport, it was determined that air traffic noise above 55 dB L_{den} and/or 40 dB L_{night} affects eight municipalities: Stara Pazova, Zemun, Surčin, Novi Beograd, Savski venac, Rakovica, Voždovac, and Čukarica.

4.2. Phase 2 – Defining the Calculation Methods

For the development of noise maps for Belgrade Nikola Tesla Airport, the CNOSSOS-EU:2015 (Directive 2002/49/EC, Directive 2015/996) method was used for assessing air traffic noise [7]. The calculation program used for the computations complies with the 4th edition of ECAC.CEAC Doc 29 [8], which is required by the CNOSSOS-EU:2015 method for assessing air traffic noise.

4.3. Phase 3 – Defining the Input Data Specifications

The definition of data required for the calculations is based on the specifications of the chosen method for estimating the size of noise indicators, the process of preparing noise maps, and the area where strategic noise mapping is conducted. The data needed for the strategic noise mapping for air traffic include digital model of the observed area, air traffic data, meteorological and demographic data.

4.4. Phase 4 – Collecting and Creating Data Sets

4.4.1. Digital Terrain Model

The data for creating the three-dimensional digital terrain model in the area for which the strategic noise map is being developed were obtained from the Republic Geodetic Authority (RGA). The data were collected from the Basic Topographic Model (BTM), which was established in accordance with the Law on State Survey and Cadastre and the by-law governing topographic survey and development of topographic-cartographic products – the Regulation on Topographic Survey and Topographic-Cartographic Products.

4.4.2. Buildings

The data on facilities (buildings) in the area of strategic noise mapping were obtained from the RGA. Two sets of data were obtained. The first data set provided information on the layout position of facilities (digital cadastre). The second set, which included data on the purposes and heights of the facilities, was also obtained through the RGA, but using the alphanumeric service of eKatastar (KnWEB - web service intended for accessing real estate cadastre data). The data for 129 616 facilities were used for further work and detailed consideration.

4.4.3. Air Traffic Data

Belgrade Airport d.o.o. provided data on aircraft movements for each individual take-off and landing operation during 2023, and data from the continuous noise monitoring system for aircraft taking off and/or landing at Belgrade Nikola Tesla Airport (NTK system).

The implemented flight schedule provided by BA included 84 871 operations (commercial and non-commercial), of which 340 operations were cargo truck transport operations (not aircraft) that were not considered. Furthermore, according to the CNOSSOS-EU method [7], noise generating activities associated with airport operations that do not contribute materially to the overall population exposure to aircraft noise and associated noise contours (such as helicopters, taxiing, engine testing and use of auxiliary power-units), may be excluded. Therefore, we excluded 194 helicopter operations and 172 ultralight aircraft operations which do not significantly impact noise contours, along with the 54 military operations that are excluded by the regulation [2,7]. Finally, 84,111 were used for strategic noise mapping. For each individual take-off and landing operation in 2023, BA provided data on the aircraft type, date and time of take-off and landing, departure and arrival airport, approach and departure paths (radar data), and the runway in use. The annual average distribution of departures and arrivals during the day, evening, and night periods on the runways in use is given in the table below. For most operations, runways 12R and 12L were in use, with 64 % for take-offs and 61 % for landings.

Table 1 Number of Take-off and Landing Operations During the Day, Evening, and Night Periods on the Runways in Use

L_{den} time periods	Landings				Takeoffs			
	12L	30R	12R	30L	12L	30R	12R	30L
Day	4774	4545	10371	5990	6228	4347	12386	6299
Evening	1199	898	2193	1516	1744	1313	3250	2359
Night	2423	1188	4866	2095	1174	230	2327	396
Total	8396	6631	17430	9601	9146	5890	17963	9054

In terms of the number of takeoff and landing operations by aircraft type, the A319, AT72, and A320 collectively account for over 50% of all operations. Furthermore, the aircraft types A319, AT72, A320, A321, E195, B738, A21N, C56X, E190, C525, B38M, E170, BCS3, A332, and C550 together represent 90 % of total operations, which consisted of around 180 different aircraft types.

4.4.4. Meteorological Parameters

The meteorological parameters are obtained from the publication “Belgrade Nikola Tesla Airport Climatography” issued by the Republic Hydrometeorological Service of Serbia in 2018, covering the period from 2005 to 2017, and which was downloaded from the official RHMZ website[1]. For the period from 2018 to 2023, the meteorological parameters are based on meteorological data contained in METAR reports provided by the Serbia and Montenegro Air Traffic Services SMATSA llc (SMATSA).

4.4.5. Population

The population data for the area covered by the strategic noise map were obtained from the Statistical Office of the Republic of Serbia. The data include information about residents and dwellings, by statistical and enumeration areas based on the 2022 Census. The core area, which includes four urban municipalities (Surčin, Zemun, Novi Beograd, and Čukarica), which was the subject of further detailed analysis, comprises 2,500 enumeration areas (the smallest spatial unit for which data are recorded in the Register of Spatial Units and formed for census purposes) with a population of 610 867 and 284 911 dwellings.

4.5. Phase 5 – Development of the Acoustic Model

All collected data were processed and adapted in accordance with the requirements for their use in the computational program *Aviation Environmental Design Tool (AEDT)*, version 3f, by the American *Federal Aviation Administration (FAA)*, which was used for acoustic calculations and analysis of population exposure to noise. For the 2023 strategic noise map, all operations were modeled as if they occurred solely on the main runway at Belgrade Nikola Tesla Airport, reflecting the planned return to its exclusive use after the completion of runway reconstruction in 2024.

4.5.1. Routes and Dispersion

Analysis of radar trajectories revealed significant dispersion in arrival and departure paths. Due to considerable deviation of implemented trajectories in relation to the standard procedures for approach and departure published in the Aeronautical Information Publication, it was decided that a series of backbone tracks for arrivals and departures should be established for each runway in use, along with an assessment of the dispersion around these backbone tracks in order to examine how the aircraft deviates from the average value with the increase in distance from the airport. In total, 31 backbone tracks were defined, i.e. 175 including the dispersed sub-tracks (see Figs. 1 and 2).

4.5.2. Aircraft substitutions

In the development of the acoustic model, the predominant aircraft types operating at the airport were accurately identified using available databases. For certain aircraft types, particularly those associated with general aviation and accounting for a very small number of operations, substitutions were made. In these cases, the most similar aircraft from the same manufacturer were selected as substitutes. This approach was based on similarities in performance characteristics, size, and operational profiles, ensuring minimal impact on the accuracy of the resulting noise contours. Given the low frequency and limited contribution of these substituted aircraft to overall noise levels, their impact on the final contours is negligible.

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[1] https://www.hidmet.gov.rs/data/aerodromi/Klimatografija%20aerodroma%20-%20BEOGRAD%20-%20SURCIN.pdf - accessed on 20.02.2024

4.6. Phase 6 – Calculating Noise Levels

The basic settings in the software package during the calculation of noise indicators, in accordance with the requirements of the Directive 2002/49/EC and the legislation of the Republic of Serbia in the field of noise protection, included the following: the calculation was performed on a grid resolution 10 × 10 meters; the calculation of noise indicators was performed at a height of 4 meters above the ground; and a long-term time correction for the given meteorological data was used during the calculation with different conditions for each period of the day (L_{day}, $L_{evening}$ and L_{night}).

4.7. Phase 7 – Post-Processing and Analysis

After completing the noise level calculations, an analysis of the results was conducted to obtain summary statistics that can be reported to the Serbian and European Environment Agency. The results of the analysis are presented in the following text.

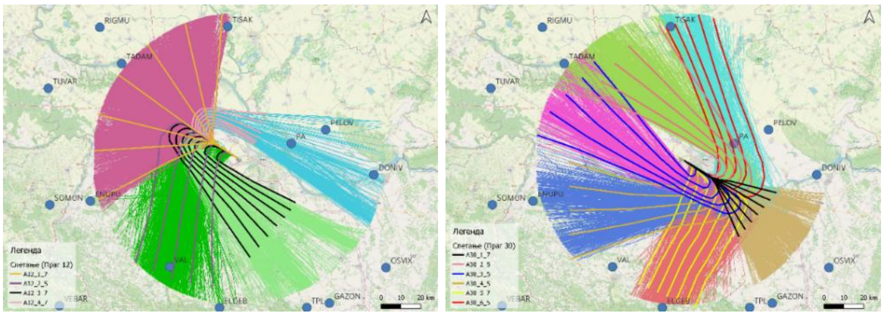

Fig. 1 Trajectory Clusters for Landings on RWY 12 (Left) and RWY 30 (Right)

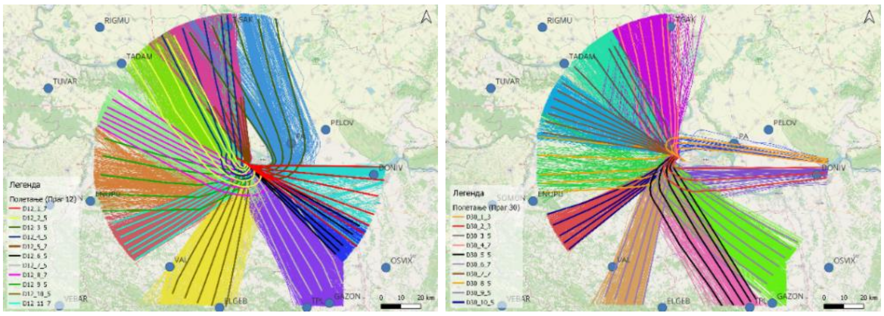

Fig. 2 Trajectory Clusters for Take-Offs on RWY 12 (Left) and RWY 30 (Right)

5. Results of Strategic Noise Mapping

The final phase in the process of strategic noise mapping involves developing maps of equal noise levels, estimating the areas, residential units, and people exposed to noise; assessing population disturbance due to noise, and determining the exceedance of noise limit values in certain areas. The graphical part of the strategic noise map for the night period (noise indicator L_{night}) is shown in Fig. 3, while the graphical part of the strategic noise map for the day-evening-night period (noise indicator L_{den}) is shown in Fig. 4.

Fig. 3 Strategic noise map for noise indicator L_{night}

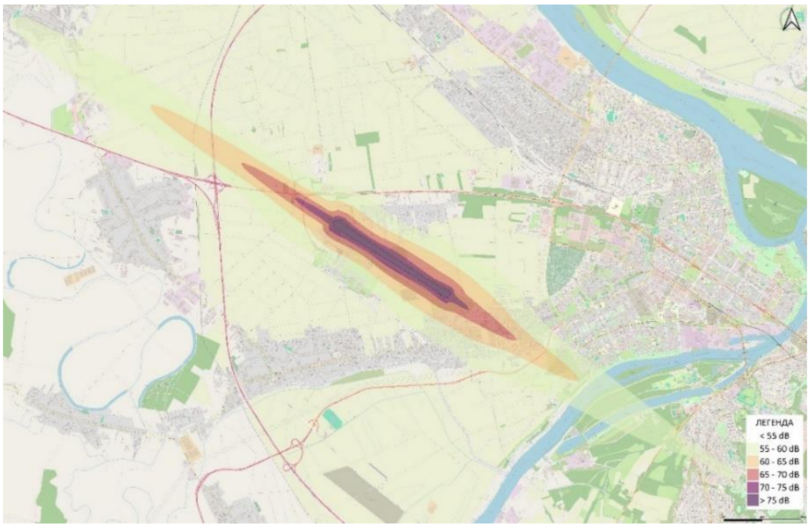

Fig. 4 Strategic noise map for noise indicator L_{den}

The results of the analysis of the area and residential units, including the estimated number of inhabitants for the strategic noise mapping for Belgrade Nikola Tesla Airport, are presented in Table 2. The results of the analysis of school buildings (preschool institutions, primary education, secondary education, and higher education) and hospital buildings (healthcare institutions providing long-term patient care) of the strategic noise mapping for Belgrade Nikola Tesla Airport are presented in Table 3.

Table 2 Analysis of Exposure of Areas, Dwellings, and People (Including Agglomerations)

Noise indicator range L_{den},dB	Exposed area in km²	Estimated number of dwellings (in hundreds)	Estimated number of inhabitants (in hundreds)
> 55	30.1	149	314
> 65	4.5	7	17
> 75	0.7	0	0

Table 3 Analysis of the Exposure of Schools and Hospitals

Noise indicator range, dB	L_{night}		L_{den}	
	Number of school buildings	Number of hospital buildings	Number of school buildings	Number of hospital buildings
< 50	422	13	416	13
50 - 54	1	0		
55 - 59	2	0	7	0
60 - 64	0	0	2	0
65 - 69	0	0	0	0
70 - 74	0	0	0	0
> 75	0	0	0	0

The data on the estimated number of people (in hundreds) living in non-agglomerated residential areas, exposed to L_{den} and L_{night} noise indicators calculated at 4 m above ground on the most exposed facade are presented in Table 4.

Table 4 Analysis of the Population Exposure Outside the Agglomerations*

Noise indicator range, dB	Population exposed to the noise ranges of indicator	
	L_{night}	L_{den}
< 50	599 760	579 511
50 - 54	7493	
55 - 59	3246	24223
60 - 64	368	5482
65 - 69	0	1651
70 - 74	0	0
> 75	0	0

* data refer to the entire area under the influence of aircraft noise

The number of people living in residential units with quiet facades, where the L_{den} value on the quiet facade is more than 20 dB lower than the facade with the highest L_{den} value, is not available due to the nature of air traffic noise. Due to the unavailability of information, it was not possible to estimate the number of people living in residential units with special sound insulation measures.

To assess the harmful effects of noise on the population during strategic noise mapping, the dose-effect relationship is used. The regulation defines the dose-effect relationship for the percentage of the affected and highly affected population based on exposure to L_{den}, as well as the percentage of the population whose sleep is disturbed and those whose sleep is highly disturbed based on exposure to L_{night}. The European Commission Directive 2020/367 dated March 4, 2020, established a new method for assessing the harmful impacts of environmental noise, which has been used for evaluating population disturbance due to environmental noise.

The number of people who may be highly affected by air traffic noise during the day-evening-night period has been estimated and is presented in Table 5. The number of people at high risk of sleep disturbance due to air traffic noise during the night period has been estimated and is presented in Table 6.

Table 5 Analysis of Population Disturbance

Noise indicator range L_{den}, dB	Population exposed to the noise ranges of indicator L_{den}	Mean value of the noise range L_{den}, dB	The percentage of the population that may be highly affected by air traffic noise	Estimated number of people who may be disturbed by air traffic noise
55 - 59	24 223	57.5	31.3 %	7584
60 - 64	5482	62.5	40.7 %	2232
65 - 69	1651	67.5	50.5 %	833
70 - 74	0	72.5	60.6 %	0
75 - 80	0	77.5	71.1 %	0
80 - 85	0	82.5	81.9 %	0
Total	31 356	--	--	10 649

Table 6 Analysis of Sleep Disturbances in the Population

Noise indicator range L_{night}, dB	Population exposed to the noise ranges of indicator L_{night}	Mean value of the noise range L_{night}, dB	The percentage of the population at high risk of sleep disturbance due to air traffic noise	The estimated number of people at high risk of sleep disturbance due to air traffic noise
50 - 54	7493	52.5	22.6%	1691
55 - 59	3246	57.5	28.8%	935
60 - 64	368	62.5	36.1%	133
65 - 69	0	67.5	44.3%	0
70 - 75	0	72.5	53.5%	0

For public information and the action plan development purposes, the strategic noise map shall include maps showing areas where noise indicator limit values are exceeded, known as conflict maps.

A conflict noise map is a noise map developed based on the strategic noise map and shows the difference between the current and/or predicted noise level expressed through the noise indicator and the limit values established by acoustic zones. It was not possible to assess the exceeding of noise limit values for L_{den} noise levels because the legal framework of the Republic of Serbia does not have defined limit values for the L_{den} noise indicator. The conflict map for the night period is presented in Fig. 5.

Fig. 5 Map disclosing the exceeding of a limit value for the night period

6. Conclusion

This research provides a comprehensive analysis of the strategic noise mapping process for Belgrade Nikola Tesla Airport, contributing to the broader understanding of environmental noise management in Serbia. The study utilized the CNOSSOS-EU method and the Aviation Environmental Design Tool (AEDT) to assess noise exposure based on 2023 air traffic data. The results highlighted the significant impact of aircraft noise on the surrounding municipalities, particularly in areas where noise levels exceeded 55 dB L_{den} and 40 dB L_{night}. The analysis identified the number of residential units, schools, hospitals, and people affected by different noise levels, providing a crucial foundation for future action plans aimed at mitigating the effects of noise pollution.

The findings from this research underscore the critical role that strategic noise maps play in environmental noise management. By providing detailed insights into the areas most affected by aircraft noise, this study lays the groundwork for the development of effective noise mitigation strategies. The strategic noise maps produced from this analysis will serve not only as a vital tool for policymakers in crafting action plans aimed at reducing noise pollution but also as an essential resource for informing the public about the levels of environmental noise and the associated risks. As required by national legislation, environmental noise protection action plans must be adopted within one year following the completion of these maps. Ensuring that these plans are timely and well-informed by accurate data is crucial for mitigating the harmful effects of noise on the community and for aligning Serbia's environmental policies with broader European standards.

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