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A MODEL FOR ASSESSING
THE ENVIRONMENTAL IMPACT OF TRANSPORT

Environmental effects of transport, with a particular focus on the natural environment have been discussed. The authors present methods for assessing the influence of investments in transport infrastructure on the environment, as well as the concept of a simulation model which integrates various methods and approaches used to assess the impact of such investments on the environment.

Keywords: *transport, environment, computer simulation*

1. Introduction

In the present EU economy, transport is the most dynamically growing sector, crucial in contributing to the achievement of the EU Lisbon Strategy which aims at growth in the economy and employment [12]. Unfortunately, the increasing demand for transportation services has lead to a higher concentration of traffic and, consequently, to aggravated risk to our natural environment.

For many years, the makers of a common transport policy in the EU have been seeking effective instruments to reduce the ecological effects of transport. One of its targets is to achieve sustainable transport growth, i.e. to make sure that European transportation systems meet socio-economic needs, while minimising their adverse effects on economies, societies and the environment [5–7, 23, 47, 27, 32].

The most recent EU publications and documents [13, 14, 9, 10] emphasise the important role that local and regional authorities play in taking measures to alleviate local environmental problems. Considering the fact that in the EU the majority of new

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infrastructural projects, including transport infrastructure, have to comply with the environmental impact assessment (EIA) regulations and/or environmental protection laws, the Committee of the Regions claims that the directive on the strategic environmental impact assessment [16] and the directive on the environmental impact assessment [15] are key instruments of local and regional policies for environmental protection.

The main point of the EIA is to describe the environmental impact of each investment giving consideration to all causes and effects. Due to its complexity, the EIA requires the use of many methods – from identification to forecasting and assessment. The decision concerning the choice of a method is made by experts being hired by the investor in order to prepare the documentation. These assessments are made by specialists from a range of scientific fields. Each of the specialists applies their own research instruments – either existing ones or ones created for the purpose of a given study. The choice of these methods also depends on the stage that document preparation is at, the type of investment and the ways of preparing variants (according to the differing amounts of data required for each of the methods). Therefore, the following questions arise: how to integrate various EIA approaches and methods into a single methodological system and how to present the results in a way that is comprehensible to all the actors taking part in the process.

The primary purpose of this paper is to present a concept of a model for computer simulations which allows us to integrate various approaches and methods applied in assessing the environmental impact of transport infrastructure investments.

2. The effects of investments in transport infrastructure

Authors of many publications [40, 54, 30] emphasise the close relation of transportation systems to economic, social and ecological systems. These systems influence one another and overlap. On the one hand, there are "expectations" of the economic, social and ecological systems in relation to the transportation system (the tasks resulting from needs and available resources). On the other hand, however, the transportation system influences the functioning of the other systems causing particular effects [39]. These mutual dependences and examples of their effects are presented in Fig. 1.

What follows below is a more specific description of the environmental effects of building and using transport infrastructure:

• Land is taken for building transport infrastructure.

• As a result of land disintegration, the proper functioning of the integrated and dynamic combination of various types of ecosystems that occupy specific areas is at risk, which leads to the devastation of plants and extinction of animals.

• The pollution of air, soil and water threatens people's health and life and has a destructive effect on flora and fauna.

• The emission of noise and vibrations pose threats.

• There is a risk of road accidents, as well as a risk connected with transporting dangerous goods and waste.

• Solid waste can be difficult to dispose of (e.g. car wrecks, used tyres, etc).

• Transport consumes large amounts of energy from non-renewable fuels.

• Time devouring traffic congestion causes an increase in the emission of harmful substances.
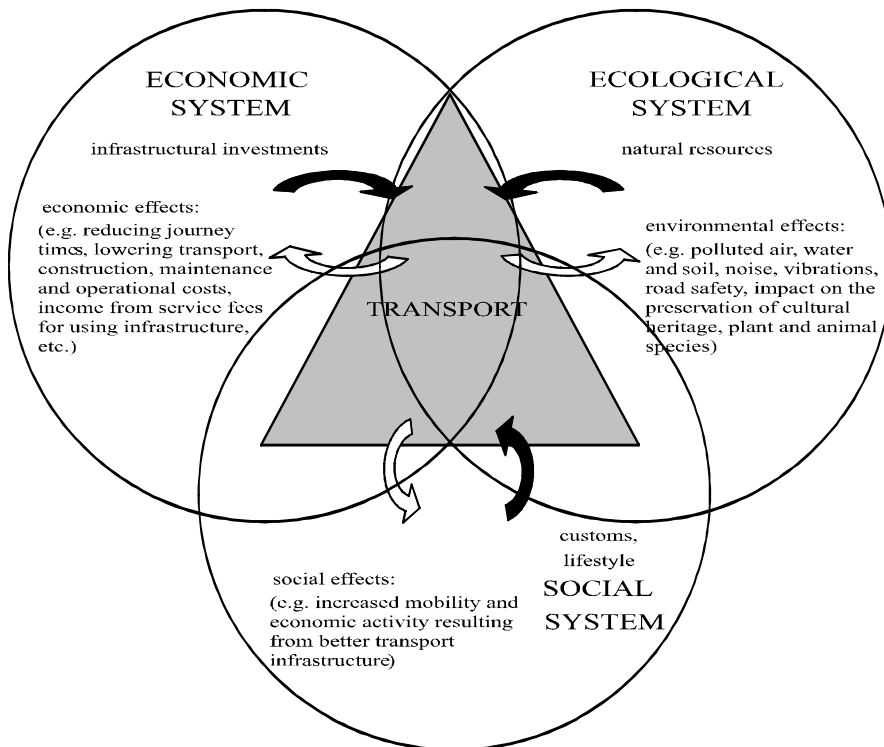

Fig. 1. Mutual influence of individual systems and examples of the impact of transport on these systems. Source: authors' own study on the basis of [37, 52]

All the above effects should be evaluated before a decision is made concerning the choice of a particular investment plan made as the result of an environmental impact assessment.

3. The procedure of environmental impact assessment

The environmental impact assessment (EIA) is a systematised mode of operation consisting of the interdisciplinary identification and assessment of the impact that

planned investments, as well as their alternatives, will have on a particular area and the processes ongoing there. The essence of the EIA is to assess the environmental impact of each investment giving specific consideration to its measurable and im-measurable environmental implications. It serves the purpose of finding solutions which will minimize the conflicts that can appear in the social-economic--environmental sphere as a result of a planned investment. The EIA also helps to make a decision concerning the implementation of an investment project. Such an assess-ment should be complex, suggest alternative solutions with a view to avoiding risks and, finally, contain an analysis of local and global effects, non-reversible changes, as well as of the long-term impact [1].

The EIA is performed according to a procedure consisting of three main stages: identification, forecasting and assessment. At each of these stages, the application of specific methods and tools is required (Fig. 2).
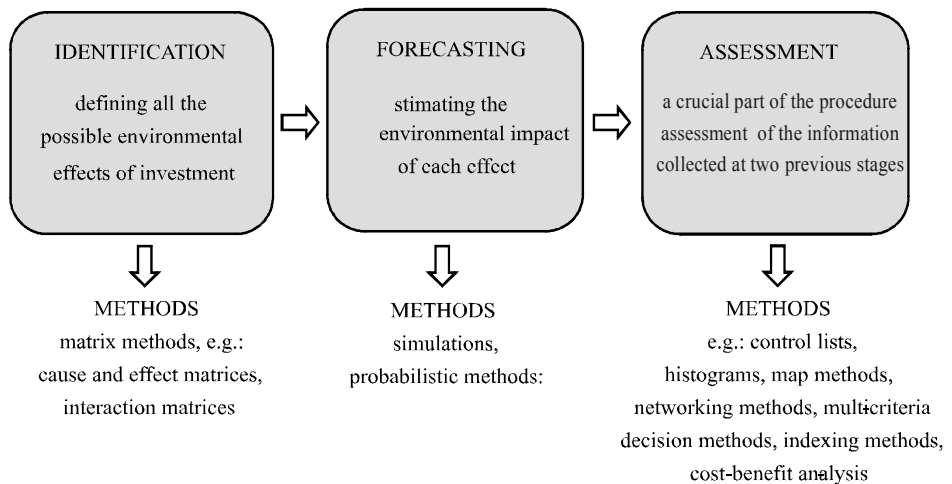

Fig. 2. The stages of environmental impact analysis (EIA).
Source: authors' own study

At the stage of identification, all the possible effects on the environment are de-fined. Each factor is associated with affected spheres. Due to the large number of fac-tors and impacts at this stage, matrix methods are used, for which cause and effect matrices or interaction matrices are constructed.

The forecasts carried out at the second stage of EIA concern the parameters describ-ing the condition of the environment. They are carried out on the basis of simulating the course of a given environmental impact or by means of probabilistic methods, which help define the probability of each possible future state of a given element of the envi-ronment. The decision regarding the choice of a method or methods is made by the ex-perts who prepare the documentation. The forecasts are made by specialists representing

different scientific fields. There are experts who study the impact of a project on atmospheric pollution, others examine its effects on surface and ground water or soil, on the acoustic climate and nature, etc. What is more, each expert uses different research tools – existing ones or ones created specifically for the sake of a given study.

The assessment, i.e. the essential part of the procedure, covers the integration of the data collected at the two previous stages and is performed by means of various methods and techniques [17]:

• comparative breakdown of the impacts of planned investments on particular elements of the environment expressed in various, often incomparable, units (e.g. dB, mg/m^3, etc.),

• qualitative and quantitative characteristics of all the environmental impacts of an investment,

• a relatively objective proposal of the investment plan that likely to be the least harmful to the environment.

Overall assessments can be performed by means of the following methods: control lists, histograms, map methods, networking methods, multi-attribute utility theory, multi-criteria decision methods, indexing methods, as well as cost-benefit methods.

It should be noted that the integration of information is a substantial problem in EIA which occurs at two levels. The first one concerns single components of the environment which can be affected by numerous factors (e.g. pollution, noise, etc.). The forecasted effect on a given component of the environment is described by means of many different parameters that are often interrelated. The second level relates to the choice of components of the environment to be assessed, as it is also necessary to define the mode of integrating the assessments of the effects on individual components, which eventually leads to an overall assessment of the impacts [26].

Additional complications result from the fact that the assessment of the impact of any transport infrastructure investment must simultaneously cover such aspects as the spatial range of environmental effects, the long-term nature of an investment and its long-term operation, as well as uncertainty [39].

All in all, the assessment of the influence that transport has on the environment is a methodically complicated process, which involves many experts using plenty of methods and techniques, as well as dedicated IT tools, a list of which is presented in the next part of this article.

4. Computer-aided assessments of the environmental impact of transport

IT aided EIA is most often performed at the stage of forecasting the impact of a given enterprise on the environment. At the identification stage, geographic information systems (GIS) are common for data collection and processing [8, 24, 38, 25, 35, 3].

IT tools are seldom used for overall assessment – mainly for preparing investment variants where multi-criteria decision methods are applied.

Table 1. Review of computer tools aiding EIA

No.	Tool	Land use and disintegration[a]	Pollution emissions		Noise emissions	Road safety
			Air	Water and soil		
1	CALINE 3	–	+	–	–	–
2	COPERT III	–	+	–	–	–
3	COPERT IV	–	+	–	–	–
4	OpaCal3m	–	+	–	–	–
5	OPERAT FB package for Windows	–	+	–	–	–
6	SAMOCHODY module of OPERAT-FB	–	+	–	–	–
7	EK100W	–	+	–	–	–
8	AERO 2010	–	+	–	–	–
9	INFRAS	–	+	–	–	–
10	EDMS, ALAQS, ADMS	–	+	–	–	–
11	NMPB-Routes 96	–	–	–	+	–
12	RMR (SRM II)	–	–	–	+	–
13	ECAC.CEAC	–	–	–	+	–
14	SoundPLAN	–	+	–	+	–
15	SON2	–	–	–	+	–
16	IMMI	–	+	–	+	–
17	VISUM	–	+	–	–	+
18	Vissim	–	–	–	–	+
19	Geographic Information System (GIS)	+	+	+	+	+

[a]Land use and disintegration means e.g. impact on landscape, impact on plant and animal species. Source: authors' own study based on [48, 21, 22, 20].

Table 1 presents examples of IT tools that can be applied at the forecasting stage in relation to some of the aforementioned environmental impacts of transport. It can be easily noticed in the table that most of the tools refer simultaneously to two effects with the exception of GIS-type tools that, unfortunately, do not allow us to show forecasted effects on the time axis, which is crucial in the case of effects that accumulate over time.

Therefore, it is necessary to develop such an IT tool that would allow simultaneous analysis of all the above EIA issues. This tool should offer an opportunity to provide complex data concerning all the expected effects using a dynamic and spatial approach [36]. It should also help to present secondary effects resulting from the inner

dynamics of the examined system (such as the transportation system) in relation to the environment. A model for computer simulations which integrates various methods applied in the EIA process into a single methodological system enabling parallel estimation of all the considered effects in a dynamic approach could be a good approach.

Computer simulation is a numerical method used for experimenting on certain types of mathematical models that describe the long time behaviour of complex systems [46, p. 21]. According to Małek [41, p. 54], such methods are better than the traditional methods applied to the analysis of transportation systems, because it allows us to analyse the complex processes taking place in the system examined and its environment both in time and space. A similar view concerning complex systems (such as the system of interactions between transport and the environment) was expressed by Forrester [19, p. 88], who said that "the effective reflection of the behaviour of a complex system lies beyond the boundaries of traditional mathematical methods". He regarded computer simulation as the only effective instrument in this matter. Cempel [11] is of an almost identical opinion and claims that "in our cognition of complex systems the simulation, being able to manipulate the space-time continuum, is the only tool offering the chance to express and understand the cause and effect relations that are distant in time and space and linked by many feedbacks".

It is important to choose a detailed technique of formalising the proposed simulation model which will enable us to construct a complex, dynamic and coherent model for examining the influence of the development of infrastructure on the environment. On the basis of the reference literature, a hypothesis can be drawn that the system dynamics (SD) developed by Forrester and his colleagues from the Massachusetts Institute of Technology [18] is a good choice for this particular purpose.

This method was created on the basis of several scientific disciplines, so its very origin shows that it combines numerous methods (including conventional analytical ones) into a single methodological system. For instance, there are industrial models built in the convention of system dynamics working in Input-Output systems, linear programming, system dynamics [33] or energy models, such as ZENCAP-D developed at ETH Zürich [31] or models of transport systems [4]. SD has been successfully used both for long-term forecasts by the Club of Rome [42, 43, 44] and for biocybernetic experiments assessing the social effects of industrial or transport growth [53]. SD is also commonly used for integrated assessment of various strategies of transport policy (see: [55, 34, 51, 2, 50]).

5. The concept of a model for computer simulations

A general structure of the proposed model is presented in Fig. 3. The model consists of modules, thanks to which it enables integration of all the effects of investments
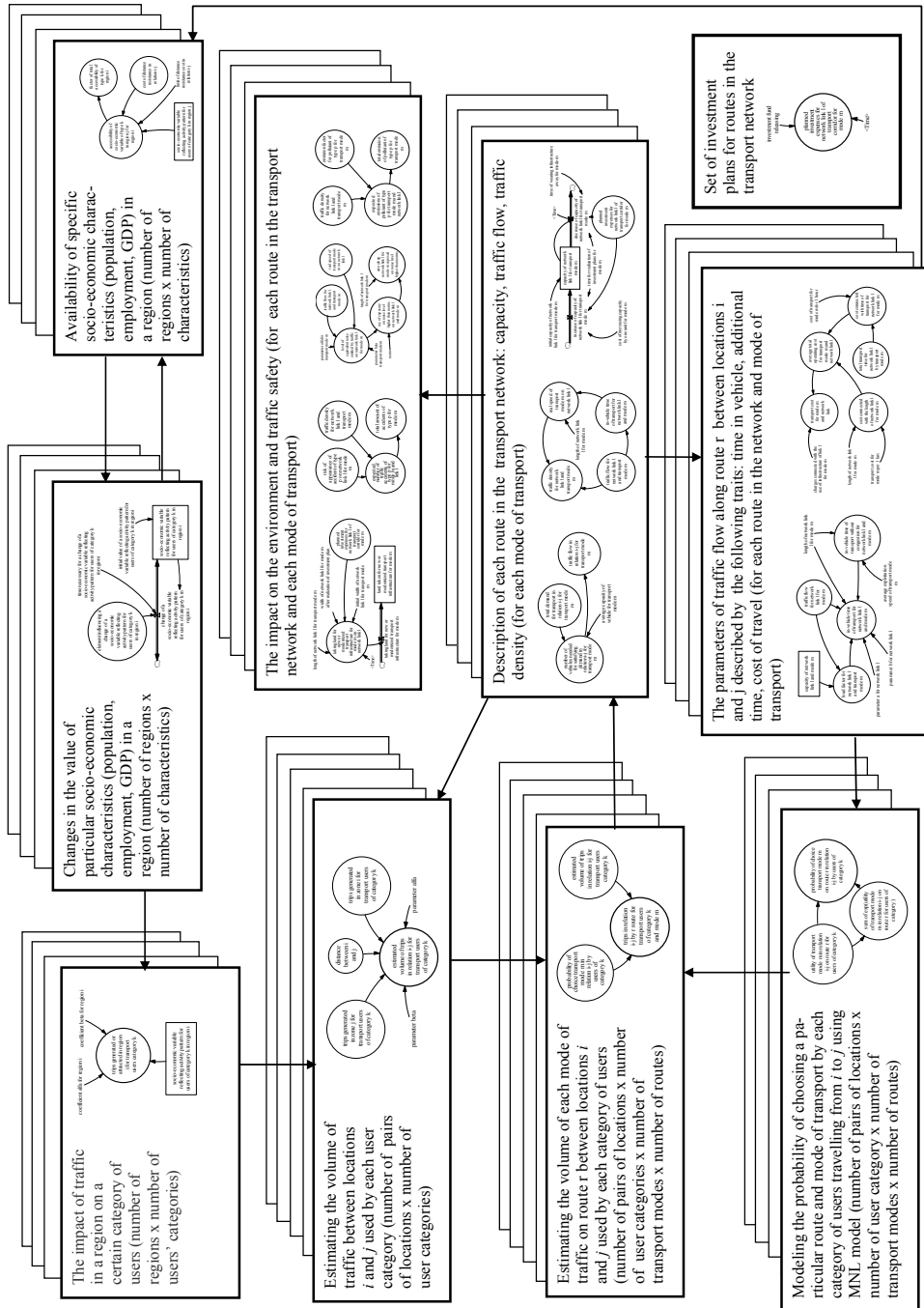
Fig. 3. The general structure of the model for simulating the environmental impact of transport. Source: authors' own study

in transport infrastructure that can be observed both on its environment and the transport system as a whole, as well as on social and economic systems. What is more, the authors take into consideration the feedback between the modelled effects in a dynamic way.

The model contains not only modules connected with the effects on the environment, but also ones that facilitate assessment of the long-term future level of traffic on the infrastructure under construction or modernisation. The modules related to the natural environment make use of information coming directly from the modules responsible for determining: average traffic speed, descriptive elements of the transport network (mainly traffic congestion and flow) which in turn require data calculated in other modules, as well as information about planned investment variants contained in a separate module.

The modules are composed using elements of system-dynamic notation (levels, streams, ancillary variables, parameters) and instructions in the formal language of simulation (DYNAMO, VENSIM, Powersim, IThink, etc.). The modules are building materials for constructing a target model, as well as being able to act as models themselves. For instance, the modules used for forecasting the environmental impact of an investment in transport infrastructure are often related to biophysical models based on the laws of physics and chemistry.

Table 2 lists the effects of transport infrastructure investments that are most commonly taken into consideration in EIA with examples of models used for their estimation. The corresponding models are presented in system-dynamic notation in Fig. 4.

Table 2. Impact of transport infrastructure on chosen environmental quality indices

Effect	Example of a simple model	Ref.
Road safety [No. of accidents/year]	$$N_{p,m} = \sum_{1} r_{p,l,m} k_{l,m} g_m$$ where: $N_{p,m}$ – expected number of type p accidents for means of transport m, $r_{p,l,m}$ – odds ratio of type p accidents on route l for means of transport m, $k_{l,m}$ – traffic congestion on edge l for means of transport m, g_m – mean load capacity of means of transport m	[28]
Land use [km^2]	$$T_m = \sum_{1} \left(w_{k,m,l} - w_{p,m,l} \right) L_{m,l}$$ where: T_m – total area of land intended for the construction or modernisation of transport infrastructure for means of transport m, $w_{k,m,l}$ – width of route l for means of transport m after the investment has been completed, $w_{p,m,l}$ – initial width of route l for means of transport m, $L_{m,l}$ – total length of route l for means of transport m	[49]

| Climate change: – changes in CO_2 emissions [t/year] Acidity – changes in SO_2 emissions [t/year] – changes in NO_2 emissions [t/year] Air quality: – volume of VOC, SO_2, NO_2, CO emissions [t/year]	$$E_{p,m} = \sum_l k_{l,m} e_{p,m}$$ where: $E_{p,m}$ – total emissions of the type p pollutant, $k_{l,m}$ – traffic congestion along route l for means of transport m, $e_{p,m}$ – emission rate of the type p pollutant for means of transport m	[29]
Noise – changes in the noise level in the examined area: [km^2 below 55 dB(A)]	$$L_{l,m} = \alpha + \beta \lg v_m + 10 \lg q_{l,m}$$ where: $L_{l,m}$ – level of noise emitted along route l by means of transport m in dB(A), $q_{l,m}$ traffic flow along route l for means of transport m, v_m mean speed of means of transport m, α,β function parameters for means of transport m	[45]

Source: authors' own study.
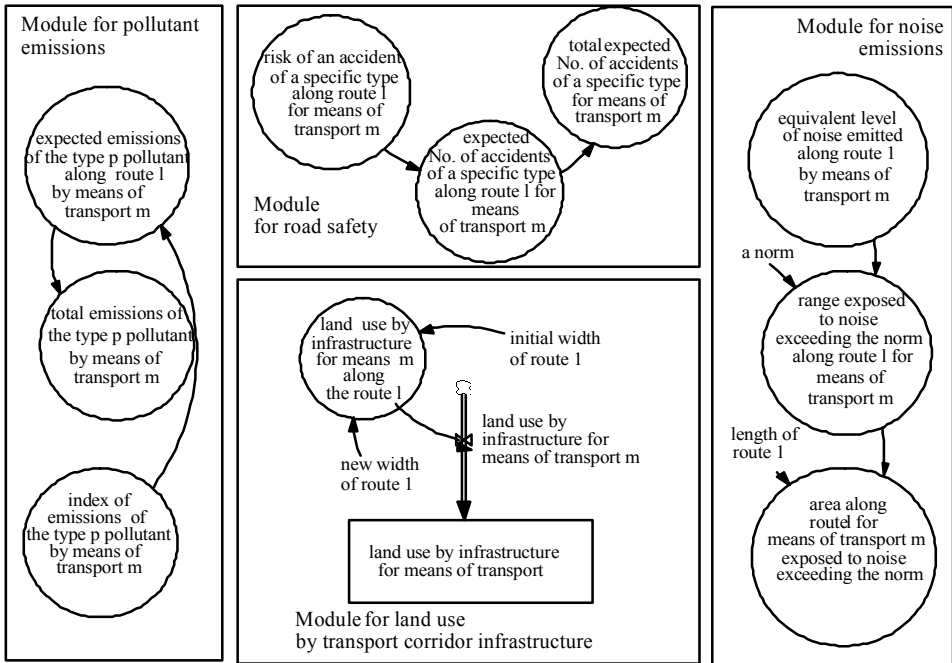
Fig. 4. Structure of the model for the sectors of the natural environment
and road safety. Source: authors' own study

A full set of the modules of the proposed model includes all the elements presented in Fig. 3. This set can be extended as new dependences are discovered in the course of observations and further improvements to the theory concerning the examined system are made.

Thanks to its module structure, the model for computer simulations allows the integration of various methods and models applied for assessing the environmental impact of transport. What is more, this concept makes fast and easy, as well as efficient and effective, creation and modification of the model possible, due to the ready-made modules deriving solutions that have been already tested.

6. Further studies

Based on the concept presented above, studies are being carried out on a model adapted to the case study *The Construction of a Ring Road in Stargard Szczecinski as a Segment of Route 10*. This investment includes the construction of a ring road, repair of the local road network and existing infrastructure, as well as the construction of facilities reducing the negative impact of road traffic on the environment. This model will cover some of the effects of the investment on the following elements of the environment evaluated ex ante and presented in the report on the environmental impact of the investment: the acoustic climate, atmospheric air, surface water and soil, wildlife, cultural assets, landscape, geological and hydrological conditions, ground water and mineral resources, the population's health and living conditions. The validation of the model will be based on data from post-investment monitoring.

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