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SPATIAL ASSESSMENT OF INFRASTRUCTURE PROJECTS

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The aim of the study is to improve the soundness of decisions on the choice of infrastructure development areas by taking into account spatial factors when evaluating infrastructure projects (IPs). The article analyzes the properties and features of such projects and the known methods of their evaluation. It is noted that existing methods are laborious, complex, and based on large amounts of data. This limits the benefits of their use, leads to a decrease in project efficiency and sustainability. The uniqueness of IP complicates design work, although most of them are regulated by current building codes. Astudy of the content of some of them confirms the need to take into account the spatial features of the area where IPis implemented. The examples show that the involvement of spatial analysis methods in the assessment already in the initial phases of the IP life cycle increases the thoroughness and accuracy of the initial project estimates (parameters, budget, timing), and further simplifies and accelerates the implementation of some project works, contributes to the achievement of sustainable development goals, and helps the public better understand the concept of IP and its features.

Introduction

In the context of prolonged martial law, the importance of the country's regions to ensure its sustainable and secure development increases significantly, and there is a need to build their potential and create infrastructure prerequisites for their growth. In these circumstances, infrastructure becomes a driver of socio-economic growth, affects the quality of life of the population and the satisfaction of their needs in accordance with the concept of sustainable development, develops existing infrastructure, stimulates certain sectors of the economy, and creates new jobs. The proper functioning of infrastructure, as well as the creation of new infrastructure facilities and the modernization of existing ones, are achieved through infrastructure projects (IP) [1, 2].

Infrastructure projects (e.g., construction of water supply, sewerage, transport and energy facilities, residential and social development, etc.) that implement strategic efforts to achieve social, economic, and environmental sustainability goals are aimed at solving long-term problems; they become a means of defining, creating, and realizing values with long-term consequences for the environment and society [1, 3].

The concept of sustainable development defines sustainability as the practice of meeting the needs of the current generation without affecting the ability of future generations to meet their needs. Thus, it is intended to maximize social and economic benefits while minimizing environmental damage [4]. Therefore, for such infrastructure to be considered sustainable, it must be planned, designed, constructed, operated, and decommissioned in a way that promotes economic, social, and environmental development at every stage of its life cycle [5]. Traditionally, however, IP performance is assessed mainly by economic indicators, while ignoring environmental and social arguments, despite their significant impact on sustainable environmental development. The well-known "iron triangle" of cost, time, and quality in project management, which traditionally determines project success, refers to the formation of a technologically efficient product within budgetary and time constraints, providing for the creation of certain technical specifications at a lower price without much attention to the environmental and social value of projects [3]. However, IP implementation takes a long time, these projects are capital-intensive, require significant investment and labor, which is significantly complicated in the context of the financial crisis and budget shortages and requires, first of all, careful justification. Such projects are expensive, controversial, and difficult to manage, requiring mandatory assessment of their impact on natural resources, ecosystem services, and access to social services to prevent social conflicts, cost overruns, and reputational losses of the administration, ensuring project sustainability [2]. Therefore, an integrated approach to the formation of project performance indicators that combines methods for assessing its various environmental impacts with traditional cost, time, and quality assessments is becoming necessary.

Features of comprehensive assessment of infrastructure projects

Unlike other projects, IP (Table 1) is a long-term strategic initiative that determines the competitiveness of the territory, its sustainable and balanced development, aimed at building, reconstructing or modernizing infrastructure facilities, improving the quality of services provided to consumers, and improving the socio-economic situation in the territory [6]. The analysis of the properties and features of these projects (Table 1) once again emphasizes that even the formation of their feasibility studies within the framework of a contradictory process to achieve different interests and goals of numerous influencing bodies (local governments, businesses, the state, local residents, etc.) requires careful preliminary justification, analysis, and consideration of a set of not only economic factors. Although infrastructure improvements are necessary, the possible negative environmental impact of the project should be carefully investigated, which requires focusing on (Fig. 1) [5–7]:

– technical aspects of the project, the components of which lead not only to economic changes, but also to environmental and social disruptions in the environment;

– dynamic development of the project with the introduction of new technologies and construction methods, in compliance with health and safety rules, building codes, legal aspects and legal features related to the industry, etc.

Table 1

Properties and features of IP

IP Properties		IP Features
Objective:	improving the competitiveness of the territory and its sustainable development;	Uniqueness and innovation
Targets:	infrastructure objects that have a significant impact on the industry, or on the quality of services provided to consumers, or on improving the socio-economic and/or environmental situation in the territory;	Technical complexity
Life cycle:	long economic planning horizon; prolongation of the design phase due to the need to develop innovations; possible overlap between the design and implementation phases of the project;	Long-termism
Scale:	a large project with a significant amount of work;	Multi-channel supply
Participants:	state authorities and governments, a significant number of companies, including foreign ones;	Organizational complexity
Organizational structure:	takes into account the specifics of a particular infrastructure sector and provides a mechanism for interaction between the parties;	Availability of a unified information space
Resources:	attracting unique resources (highly qualified specialists, materials, devices, etc.); the possibility of financing the project from various sources; availability of schemes for replacing some financial obligations under the project with others;	Long period of investment return
Risks:	possible changes in scale, investment attractiveness, and goals during design and implementation, which reduces the reliability of the initial technical and economic information;	Adaptability in management High risks
Relationships:	various organizational, legal and financial interactions between numerous participants.	Complex interaction system

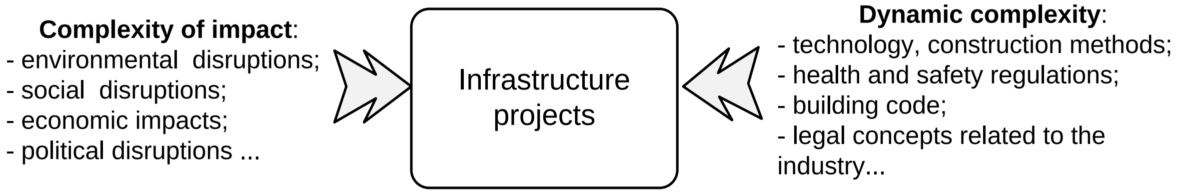


Fig. 1. IP features in the context of forming a comprehensive assessment

Under these circumstances, the importance of economic assessments is shifting in favor of sustainability, which is becoming a key factor in IP decision-making throughout their life cycle; environmental impact assessments are becoming increasingly important at both the state and local levels (given the long-term environmental impact of project decisions) [7, 8].

The environmental impact assessment of a project is often carried out using the Life-Cycle Assessment (LCA) method, one of the well-known EU environmental management tools designed to assess the environmental, economic, social and environmental impacts of projects. The versatility of this method contributes to its use in almost all industries where IP is appropriate, including transportation, healthcare, construction, traditional and alternative energy, waste management, etc.

In the LCA method, life cycle assessment is defined as "...a systematic set of procedures for collecting and analyzing all material and energy flows of a project, taking into account their environmental impacts throughout the life cycle of a project product and/or process... [9]". The method is unified in a series of international standards ISO 14040 – 14043 (Fig. 2), which define an iterative procedure for continuously analyzing the results of each phase of the project and adjusting the results obtained, when the experience gained at the next stage is considered as feedback that can change the previous stages of the assessment process. The purpose of such an assessment is to obtain a thorough assessment of the project’s environmental impacts to make economic, technical, and social decisions without solving direct environmental problems [9].

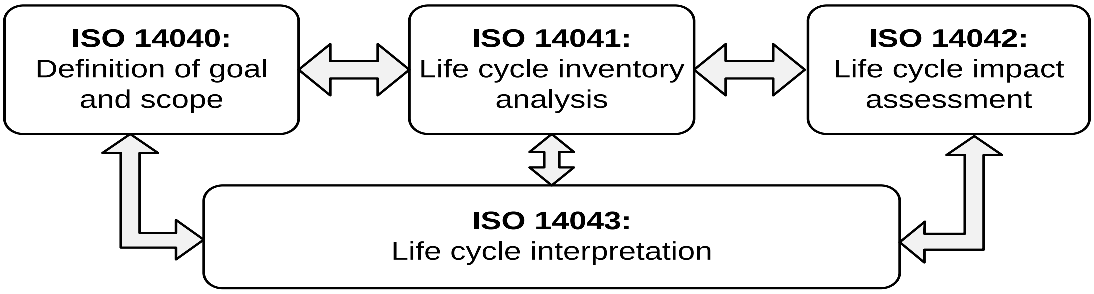


Fig. 2. The structure of the LCA method
in the context of forming a comprehensive IP assessment

According to ISO 14041, life cycle inventory analysis is the longest and most costly stage, where data on input and output flows are analyzed and appropriate project environmental impact assessments are generated. However, this procedure is time-consuming and complex, and experts face the problems of lack of data of the required volume and quality, subjectivity in characterizing and determining its consequences, inadequate definition of the project's environmental impact and assumptions about its duration [10]. Therefore, LCA is usually performed at the end of the design stage, when, on the one hand, all the necessary information is available, and on the other hand, the design decisions with the most negative environmental impact have already been made, and therefore it is almost impossible to take into account its environmental impact when making IP decisions [8, 10]. In these circumstances, there is a gap between environmental impact assessment and other aspects of the project, which complicates the process of ensuring the environmental sustainability of IP and makes it impossible to improve it.

Such a fragmented assessment process is one of the reasons for the formation of ambiguous public opinion on IP [10, 11]. On the one hand, local residents understand the benefits of IP, as it is aimed at creating new jobs and public services. On the other hand, in the event of an emergency or an accident with environmental pollution, local residents may become potential victims. Therefore, the local population often organizes active opposition to the implementation of IP, given that their interests may be harmed.

It should be noted that the general public is not subject to the influence of IP stakeholders, but it is very interested in its economic and environmental performance, and public discussion is becoming an important element of the political life of society. That is why these opinions and comments are increasingly considered more objective and unbiased, forming a holistic assessment of the entire project [11, 12], and are increasingly taken into account when determining environmental assessments of IP, developing an individual environmental trajectory for its implementation, and encouraging the public to protect the environment.

Thus, the scale and complexity of IPs, the ambiguity of their environmental impact, and the significant social resonance require new approaches to project evaluation at the initialization and planning stages, ensuring the sustainable development of society as a whole. Increasing the number of infrastructure facilities, improving their quality, and balancing quantity and quality in terms of achieving sustainable development goals is possible only if a systematic approach to infrastructure development is implemented, taking into account a combination of factors [11, 13].

Remote sensing is a modern source of data for IP valuation

The justification, design, and evaluation of IP at the national, regional, or local level is carried out in accordance with applicable law. Depending on the area of implementation, this procedure is prescribed in the relevant State Building Codes, which are legal acts approved by the authorities on construction, urban planning, and architecture. According to the portal https://dbn.co.ua/, the Building Code covers all sectors of the national economy, regulates activities in various spheres of human life, and therefore becomes the legal basis for the valuation of any IP.

As a rule, the requirements of completeness of assessment and comprehensive consideration of the environmental impact of an object are the main requirements of the Building Code, which implement a systematic approach regardless of the scope of application. At the same time, the uniqueness of IP leads to the complexity of design work, requires original design solutions, and creates special requests during design, which are usually taken into account by Building Codes focused on certain types of construction projects. However, the content of the Building Code also includes general categories aligned with the goals of sustainable development that are inherent in any type of facility (Table 2).

Analyzing the data in Table 2, we note that the combination of these factors focuses on the geographical aspects of the IP location and, when making a decision, requires taking into account its spatial features and even the spatial configuration of the existing transport and communication network, settlement structure, etc. Usually, this data is obtained based on the results of comprehensive engineering surveys. Their volume directly depends on the available instrumentation and technical base, the complexity of the survey conditions, and the culture of assessment and decision-making. Usually, they are obtained on a "come and see" basis using traditional geodetic instruments, which is quite labor-intensive, time-consuming, and the measurements obtained during these surveys are point measurements obtained in pre-selected locations. In some cases, compliance with the principle of data completeness is limited by the impossibility of conducting comprehensive engineering surveys on the ground due to their high cost, which further reduces the accuracy of calculations of project parameters, estimates of its budget, timing, etc. Moreover, due to the peculiarities of IP (Table 1), they are often started without clearly defined goals and without detailed knowledge of how the project will develop or what results will be achieved [15].

Therefore, to increase the effectiveness of survey results and ensure the objectivity of the initial data for IP planning, it is possible to combine well-known project evaluation methods, such as the LCA method, with new advanced methods, such as remote Earth sensing (RES) and geographic information technologies (GIS) [13, 15, 16].

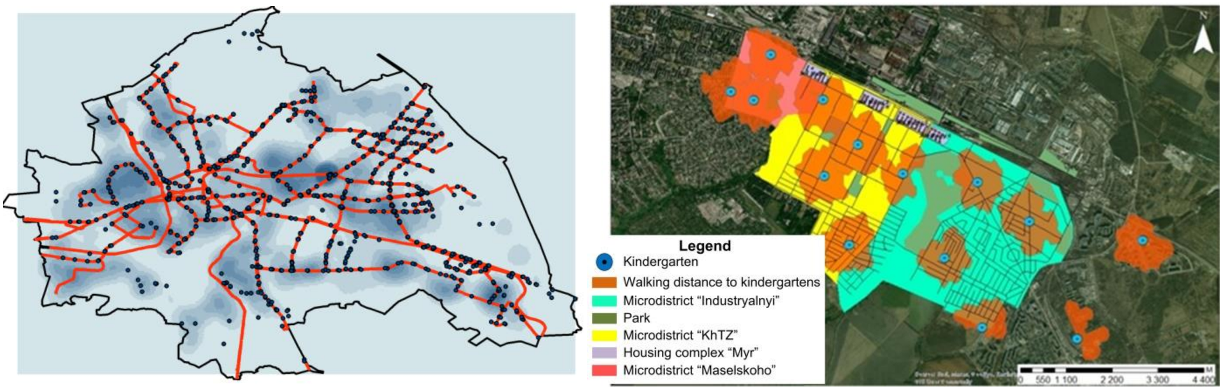
Table 2

Building Code requirements for the most common IP applications

General requirements	Building Code from the field of:		
	Transportation infrastructure design (B.2.3-4-2015)	Waste management (B.2.4-4:2010)	Construction of social objects (Б 2.2.-12:2019)
Regulates the distance:	– to the elements of the power grid; – does not allow crossing with pipelines; – takes into account animal passage routes, etc.	– to airports; – to the boundaries of settlements; – to resort facilities and nature reserves; – to fish farms; – to water bodies, etc.	for objects: – daily maintenance – within 15 minutes of pedestrian accessibility, at a distance of up to 500 m – periodic maintenance – within 30 minutes of transport accessibility, etc.
Geodesic and geologic parameters (acceptable value):	– slope of the territory – no more than 10% (for simple conditions); – special design solutions in the presence of slopes, swamps, weak soil foundations, etc.	– slope of the territory – no more than 1%; – groundwater depth is more than 20 meters, etc.	– the slope of the territory reduces the standard distance, ensuring the necessary accessibility; – special design solutions for settlements with difficult terrain, etc.
Location:	special design solutions are required within valuable lands, nature reserves, etc.	– land not suitable for agricultural use; – non-agricultural land, etc.	depends on the location of transport, social and engineering infrastructure elements.

In our opinion, engineering surveys are the main element of the conceptual phase of IP; they are usually carried out in two stages: the first one is to justify the choice of a site for the implementation of IP by options, and the second one is to obtain initial data for the development of the necessary project documentation. Of course, the uniqueness of IP requires an individual approach to organizing and implementing surveys, but even in less complex projects, one can see the benefits of using RES and GIS [13, 16]. For example, at the first stage, when justifying the directions of development of social or transport infrastructure, it is necessary to study its existing elements, thoroughly analyze existing problems, and identify possible improvement steps [13, 17]. Unfortunately, more applicable practices in this case are expert methods [15], which are becoming less and less effective in the context of urbanization and the distribution of such structures. RES and GIS make it possible to assess the feasibility of modernization, reconstruction or expansion of existing infrastructure, for example, taking into account changes in the settlement structure and existing trends in the development of settlements.

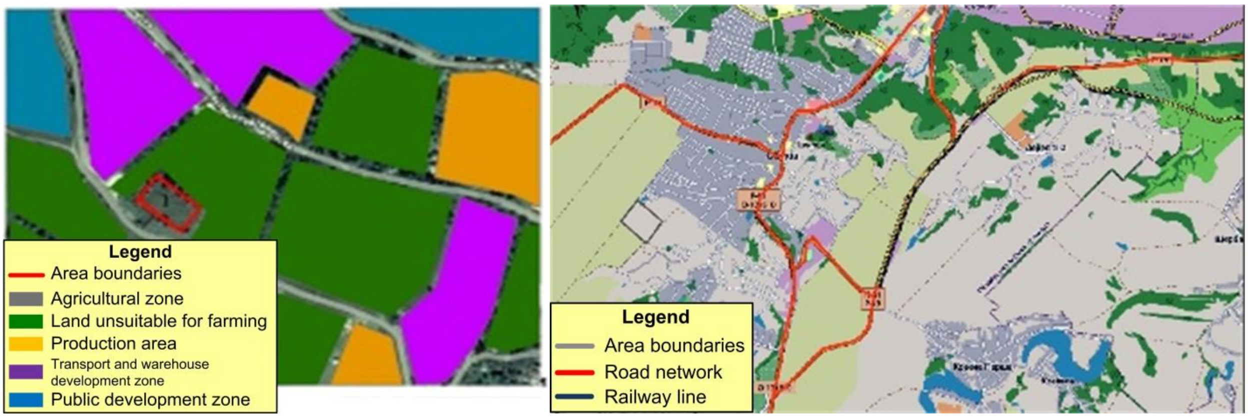
Fig. 3 shows examples of spatial analysis of the city's public transportation infrastructure (Fig. 3, a) and the infrastructure of kindergartens in the city's neighborhoods (Fig. 3, b). The flexibility inherent in GIS makes it possible to combine several layers and obtain different results, helping to draw important practical conclusions. For example, in Fig. 3, a combination of layers of the city's settlement structure, public transport routes, and available stops makes it possible to find hard-to-reach areas of the city, optimize transport routes, and equip stops in accordance with the requirements of current legislation [3].



a) b)

Fig. 3. Spatial analysis of transport and social infrastructure elements of the city:
a) to improve the network of public transport stops;
b) to improve the network of kindergartens in the neighborhood

Based on the definition of IP, we note that the project product should "fit" into the existing zoning structure of the territories, become an element of the existing electrical, communication network, and engineering infrastructure [6]. Given the specificity and fragmentation of these data, as well as possible problems with their updating, there is a significant difficulty in forming a "single picture" and assessing the effectiveness of IP and the consequences of its implementation. RES and GIS are becoming an effective tool for solving such problems: satellite data provide information on remote and hard-to-reach areas, GIS and spatial analysis methods ensure its fast processing, visualizing the results.Fig. 4 illustrates a study of the spatial planning organization of the territory where IP is supposed to be implemented in order to explore possible options for expanding the waste management system. Using GIS, cartographic models of the zoning of the analysis area (Fig. 4, a) and the existing transport network (Fig. 4, b) were built to support decision-making on the justification of possible IP implementation sites [16].



a) b)

Fig. 4. Study of the spatial and planning organization of the territory where IP is supposed to be implemented:
a) spatial analysis of the functional zones of the study area;
b) analysis of the existing transport network near the place of possible IP implementation

Of course, the study of the relief features of the territory where the IP will be implemented is a central element of any construction-related projects. This is the most costly part of engineering surveys, the results of which directly affect the cost of the project, its efficiency, and sometimes its feasibility [7, 13]. The use of RES data obtained using photogrammetric methods of earth surface surveying, for example, models obtained from the results of a radar topographic mission – SRTM, becomes promising here.

The effectiveness of SRTM data is confirmed by their wide application in the scientific environment [18]: they cover about 80% of the earth's surface from 560 south latitude to 600 north latitude, and can be used to study objects that are large in area, with a significant elevation difference, with complex terrain (hollows, valleys, gullies, erosion, etc.), different vegetation, water bodies, etc. Processing this data in GIS, overlaying several layers allows to obtain a composition (overlay) of spatial objects, the topology of this composition, and its attributes (Fig. 5).

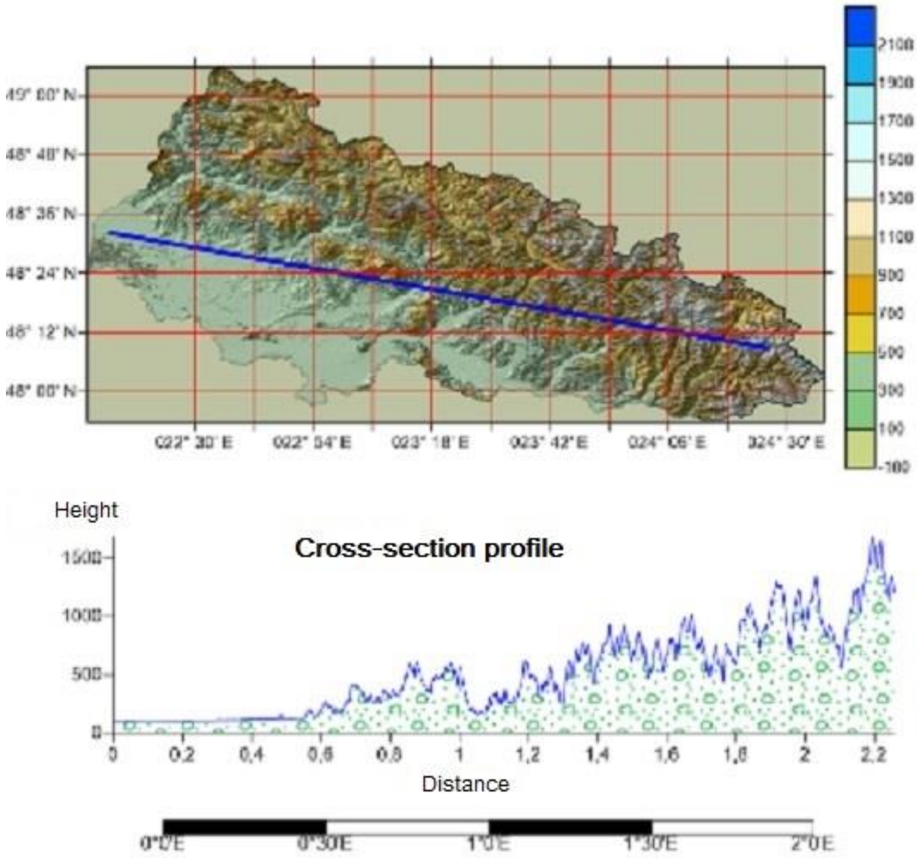


Fig. 5. Study of the relief features of the territory where IP is supposed to be implemented using RES and GIS tools

The obtained digital data become the basis for many topographic and geodetic IP materials, in particular, taking into account the peculiarities of the relief and geometry, they determine the sectors for topographic and geodetic survey of the site and plan the sequence of its implementation. In conditions where project implementation takes place in areas with complex terrain, these data become the only source of accurate information, because without them, work related to the calculation of excavation and/or soil fill, the required amount of construction materials, etc. is based on generalized recommendations with little accuracy [8, 13, 16]. This increases the accuracy of obtaining the geometric parameters of the site, reduces the direct time spent on surveying, creates the basis for design and survey work, development of land management documentation necessary for the implementation of IP, for calculating the amount of work on the construction site, reducing the total project costs, etc.

Thus, the involvement of spatial analysis methods in IP assessment at the initial stages of the life cycle increases the thoroughness and accuracy of initial project assessments, and further simplifies and accelerates the implementation of some project activities, contributing to the achievement of sustainable development goals.

Conclusions

The complexity and uniqueness of IPs and their focus on achieving sustainable development goals require new approaches to project performance evaluation and planning. Focusing on the LCA method and combining it with modern RES and GIS tools in solving these problems provides good results that have been experimentally confirmed. Digital data, combined with RES materials, facilitates effective communication between stakeholders, helps to store all project data, making it accessible to all participants, ensuring interaction at all stages of work without delays and data loss. At the same time, the accuracy of the project results increases: mapping and digital models make it possible to identify errors and inaccuracies during design and later during construction, providing protection against additional costs due to errors and inconsistencies. The resulting digital models of the IP product clearly illustrate and explain what the project results will look like, helping the public to better understand its concept or design. As a result, professionals from various fields involved in IP can design, plan, evaluate, and build infrastructure facilities more effectively.

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