Toolkit for ICT Infrastructure Co-Deployment with Road Transport and Energy Infrastructure

Part II

Asia-Pacific Information Superhighway (AP-IS) Working Paper Series

UNITED NATIONS ESCAP
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Executive Summary

As more of the world becomes digital, broadband access becomes more important than ever, including in rural and remote areas. National programmes to develop the information and communications technology (ICT) infrastructure and reduce the digital divide are recognized as essential to the achievement of national socioeconomic development plans.

However, for telecom operators, laying fibre-optic cables in sparsely populated regions is not always economically viable, and the existing telephone network in many regions is not adapted to provide broadband access to the Internet. The economic cost and resources used to deploy the ICT infrastructure could be optimized through co-deployment, which is defined as the concomitant deployment of ducts and/or fibre-optic cables during the construction of infrastructure such as new roads, highways, railways, power transmission lines and oil/gas pipelines.

In response to the needs of member States, the Secretariat of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) has taken significant steps to develop human capital and create a package of useful knowledge products and tools to promote an enabling environment for ICT infrastructure co-deployment with transport and energy infrastructure. This capacity building toolkit has been developed as part of the in-depth national studies on ICT infrastructure co-deployment with road transport and energy infrastructure in Kazakhstan and Kyrgyzstan,[1] in consultation with policymakers of Kazakhstan and Kyrgyzstan in October 2019 in Almaty, Kazakhstan.[2]

This capacity building toolkit proposes methodologies and tools for assessing and planning the economic and organizational aspects, and technical aspects of ICT infrastructure co-deployment with road transport and energy infrastructure.

[1] Find all resources at https://www.unescap.org/our-work/ict-disaster-risk-reduction/asia-pacific-information-superhighway/resources.

[2] ESCAP, "Addressing 2030 Agenda through Regional Economic Cooperation and Integration in Asia and the Pacific: Kazakhstan Expert Consultations", October 2019. Available at https://www.unescap.org/events/addressing-2030-agenda-through-regional-economic-cooperation-and-integration-asia-and.

One of the proposed methodologies is to determine the compatibility potential of ICT infrastructure co-deployment with road transport and energy infrastructure. This potential is defined through an evaluation of key parameters for the operation of infrastructure elements that have fundamental importance for co-deployment. The key parameters to identify whether infrastructures are compatible for co-deployment are proposed and categorized by technical, geographical, organizational and socioeconomic factors. These parameters are assessed and compared using a scoring system of either points or percentages. To demonstrate the application of this methodology, an evaluation of several promising ICT, road transport and energy infrastructure projects in Kazakhstan and Kyrgyzstan are conducted using the proposed parameters to see if the various infrastructure projects are compatible for co-deployment.

The parametric model of ICT infrastructure co-deployment with road transport and energy infrastructure assesses the cost difference between separate deployment of infrastructure (ICT, road transport or electricity) and their co-deployment. The parametric model considers parameters such as design costs, cost of obtaining permits, direct and indirect material costs, payroll for personnel, and other expenses.

The proposed methodology for assessing the economic efficiency of ICT infrastructure co-deployment with road transport and energy infrastructure is based on the comparison of an indicator of the speed of a specific increment in value for cases of co-deployment and separate deployment of the corresponding infrastructures. The indicator of the speed of a specific increment in value is the ratio of net cash flow to the product of the billing period from the start of the project to its end and the volume of investment for the current year. A special calculator tool (in *.xlsx format) using this methodology for assessing economic efficiency is available at https://owncloud.onat.edu.ua/index.php/s/jL200B8MsjBQryZ.

The active and widespread development of road transport and energy infrastructure in developing countries has led to the emergence of multiple opportunities that ICT infrastructure operators could consider for expanding the national fibre-optic network through co-deployment. However, choosing a specific road transport infrastructure or energy infrastructure project for co-deployment with the ICT infrastructure is not easy. To determine the most worthwhile project, a methodology based on hierarchy analysis is proposed. This consists of calculating a weighted indicator based on point estimates of several criteria and their weight coefficients, calculated by pairwise comparison. A special calculator tool (in *.xlsx format) using this methodology is available at https://owncloud.onat.edu.ua/index.php/s/CKdtBXuIOcPzq08.

To help ICT infrastructure designers plan co-deployment projects with the road transport or energy infrastructure, a typical design process with a set of procedures is outlined. It includes form templates for collecting initial data that is essential for the design of infrastructure co-deployment projects, and some modern technology options for laying the fibre-optic network along different types of environments (road, railway, tunnel, power transmission line, etc.). It also includes the project documentations needed that will be critical to the successful implementation of ICT infrastructure co-deployment with the road transport or energy infrastructure.

One of the main aspects that need to be strengthened for successful co-deployment is the coordination and cooperation of organizations, including the infrastructure owner of the road transport or energy infrastructure and the telecom operator, as well as relevant public and private organizations involved in the co-deployment process. To promote coordination and cooperation, the development of a single information portal is recommended.

It is envisaged that the portal includes information about all existing and planned engineering works that could potentially co-deploy fibre-optic cables. From the portal, online representatives of organizations, government agencies, potential investors and telecom operators would be able to find partners for the co-deployment of the ICT infrastructure with road transport or energy infrastructure, as well as post their information on priority areas for current investment. Using this portal, all interested parties would be able to exchange documents, make changes and receive information on the status of the fulfilment of certain requests, as well as access and use the methodologies and tools developed in this toolkit.

This proposed single information portal could potentially increase competitiveness and provide access to relevant information based on equality and transparency, which in turn would minimize corruption.

As a way forward, the proposed set of methodologies and tools in this capacity development toolkit should be further tested through multidisciplinary and multisectoral efforts by planners in a real case-scenario along a transport or energy corridor, requiring the ICT infrastructure. The results gathered through this test would be instrumental in the decision-making process. These results of feasibility study should be reviewed and recorded by experts and peers for futher decision-making process.

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Glossary of Basic Terms

Active infrastructure sharing: Sharing of common antenna, feeder cable, Node B, radio access network and transmission system (source: https://www.computerhope.com).

Broadband access: Wide bandwidth data transmission that transports multiple signals and traffic types within access network built with a different medium, like coaxial cable, optical fibre, radio or twisted pair (source: Wikipedia).

Cash flow: The net amount of cash and cash-equivalents being transferred into and out of business (source: https://www.investopedia.com).

Co-deployment (infrastructure): Concomitant deployment of ducts and/or fibre-optic cables during the construction of infrastructure such as new roads, highways, railways, power transmission lines and oil/gas pipelines (source: ESCAP).

Communications highway: Digital communications systems and the Internet telecommunications network (source: Wikipedia).

Compatibility potential: The availability of necessary and sufficient opportunities for co-existence (work, development, deployment, etc.) under given conditions (source: author).

Corporate telecommunications network: Sets of equipment that are located at geographically dispersed locations and are interconnected to provide networking services to a defined group of users (source: ITU Terms and Definitions Database).

Design process: Common series of steps that engineers use in creating network design projects (source: Wikipedia).

Discount coefficient: Coefficient used for discounting, that is, bringing the amount of cash flow at the n-th step of a multi-step calculation of the effectiveness of an investment project to a moment called the moment of reduction. The discount coefficient shows the capital received taking into account the time and risk factors and the reduction of cash flow in the n-th year, based on the given discount rate (source: http://1-fin.ru/?id=281&t=341).

Dispatch communications: Telecommunications using private or public radio or fixed systems, allowing the dispatchers to communicate directly with field workers, police officers, emergency personnel and others in order to coordinate their activities (source: Wikipedia).

Electric pylon: Tall structure, usually a steel lattice tower, used to support an overhead power line (source: Wikipedia).

Electricity infrastructure / electrical grid: An interconnected network for delivering electricity from producers to consumers (source: Wikipedia).

Energy infrastructure: An organizational structure that enables the large-scale transportation of energy from producer to consumer, as well as the directing and managing of energy flow. It includes, but is not limited to the oil and gas infrastructure and electricity infrastructure (source: https://www.designingbuildings.co.uk).

Fibre-optic communications line: Fibre-optic system consisting of passive and active elements, designed to transmit information in the optical range (source: Wikipedia).

Fixed communications: Telecommunications using fixed terminal equipment (source: https://zakon.rada.gov.ua/laws/show/1280-15).

ICT infrastructure: The information and communications technology (ICT) infrastructure and systems, including software, hardware, firmware, networks and websites (source: https://www.lawinsider.com).

Indicator of the speed of a specific increment in value: The ratio of net cash flow to the product of the billing period from the start of the project to its end and the volume of investment for the current year (source: Wikipedia).

Inflation level: Sustained increase in the general price level of goods and services in an economy over a period of time (source: Wikipedia).

Internet access: The ability of individuals and organizations to connect to the Internet using computer terminals, computers and other devices; and to access services such as email and the World Wide Web (source: Wikipedia).

Internet penetration: The percentage of the total population of a given country or region that uses the Internet (source: https://www.internetworldstats.com).

Method of hierarchy analysis: A structured technique for organizing and analysing complex decisions, based on mathematics and psychology (source: Wikipedia).

Mobile communications: Telecommunications using radio technology during which end equipment of at least one subscriber can be moved freely within all terminals of the telecommunications network, keeping the unique identification number of the mobile station (source: https://zakon.rada.gov.ua/laws/show/1280-15).

Net present value: The difference between the present value of cash inflows and the present value of cash outflows over a period of time. This is used in capital budgeting and investment planning to analyse the profitability of a projected investment or project (source: https://www.investopedia.com).

Parametric model: A model that allows the establishment of a quantitative relationship between the functional and auxiliary parameters of the system (source: author).

Passive infrastructure sharing: Sharing of fibres, fibre links, physical sites, buildings, shelters, towers, power supply and battery backup (source: https://www.computerhope.com).

Pricing policy: The policy by which a company determines the wholesale and retail prices for its products or services (source: http://www.businessdictionary.com).

Project risk: Probable event, as a result of which the decision-maker loses the ability to achieve the planned results of the project or its individual parameters having a temporary, quantitative and cost estimate (source: author).

Right of way: The legal right, established by usage or grant, to pass along a specific route through grounds or property belonging to another (source: Wikipedia).

Road transport infrastructure: The road network and associated physical infrastructure, such as signage, lighting and vehicle refuelling service (source: https://iea-etsap.org).

Sharing (infrastructure): Sharing of real estate and fixed assets comprising land, conduits, chambers, ducts, manholes and handholes, base station sites, AC power, backbone, radio links, and other resources in order to avoid infrastructure duplication and reduce costs (source: author).

Transport corridor: Generally linear area that is defined by one or more modes of transportation like highways, railroads or public transit that share a common course (source: Wikipedia).

Abbreviations and Acronyms

AP-IS	Asia-Pacific Information Superhighway
CF	Cash Flow
CU	Currency Unit
ESCAP	Economic and Social Commission for Asia and the Pacific
ICT	Information and Communications Technology
IS	Indicator of the Speed of a Specific Increment in Value
NPV	Net Present Value
ONAT	Odessa National Academy of Telecommunications
PPP	Protective Polyethylene Pipe

1. Introduction

As more of the world becomes digital, broadband access becomes more important than ever, including in rural and remote areas. National programmes to develop the information and communications technology (ICT) infrastructure and reduce the digital divide are recognized as essential to the achievement of national socioeconomic development plans.

However, for telecom operators, laying fibre-optic cables in sparsely populated regions is not always economically viable, and the existing telephone network in many regions is not adapted to provide broadband access to the Internet. The economic cost and resources used to deploy the ICT infrastructure could be optimized through co-deployment, which is defined as the concomitant deployment of ducts and/or fibre-optic cables during the construction of infrastructure such as new roads, highways, railways, power transmission lines and oil/gas pipelines. Co-deployment and sharing of infrastructure could be organized among telecom operators and between operators of various infrastructure networks.

The main factors stimulating the co-deployment and sharing of infrastructure are economic benefits and requirements for the efficient use of limited resources. Economic benefits encourage operators of different infrastructure networks to cooperate in deployment or sharing of a joint infrastructure due to potential cost savings or accelerated market entry.

In response to the needs of member States, the Secretariat of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) has taken significant steps to develop human capital and create a package of useful knowledge products and tools to promote an enabling environment for ICT infrastructure co-deployment with transport and energy infrastructure. This includes organization of relevant consultations and training workshops, as well as cross-country and in-depth national studies.

This capacity building toolkit has been developed as part of the in-depth national studies on ICT infrastructure co-deployment with road transport and energy infrastructure in Kazakhstan and Kyrgyzstan,[3] in consultation with policymakers of Kazakhstan and Kyrgyzstan in October

[3] Find all resources at https://www.unescap.org/our-work/ict-disaster-risk-reduction/asia-pacific-information-superhighway/resources.

2019 in Almaty, Kazakhstan.[4] This toolkit proposes methodologies and tools for assessing and planning the economic and organizational aspects (Section 2) and technical aspects (Section 3) of ICT infrastructure co-deployment with road transport and energy infrastructure. The toolkit is comprised of the following methodologies and tools:

- Methodology for determining the compatibility potential of ICT infrastructure co-deployment with road transport and energy infrastructure. This potential is defined through an evaluation of key parameters using a scoring system of either points or percentages (Section 2.1);
- A parametric model of ICT infrastructure co-deployment with road transport and energy infrastructure. This model assesses the cost difference between separate deployment of infrastructure (ICT, road transport or electricity) and their co-deployment (Section 2.2);
- Methodology for assessing the economic efficiency of ICT infrastructure co-deployment with road transport and energy infrastructure. This methodology is based on the principle of comparing an indicator of the speed of a specific increment in value for cases of co-deployment and separate deployment of the corresponding infrastructures (Section 2.3);
- Methodology for identifying road transport and energy infrastructure projects that could include ICT infrastructure co-deployment. This methodology is based on hierarchy analysis, which consists of calculating a weighted indicator based on point estimates of several criteria and their weight coefficients, calculated by pairwise comparison (Section 2.4); and
- Content of a typical design project together with initial data form templates for the design of ICT infrastructure co-deployment with road transport and energy infrastructure (Section 3).

[4] ESCAP, "Addressing 2030 Agenda through Regional Economic Cooperation and Integration in Asia and the Pacific: Kazakhstan Expert Consultations", October 2019. Available at https://www.unescap.org/events/addressing-2030-agenda-through-regional-economic-cooperation-and-integration-asia-and.

2. Economic and Organizational Aspects of ICT Infrastructure Co-Deployment with Road Transport and Energy Infrastructure

This section examines the economic and organizational aspects of ICT infrastructure co-deployment with road transport and energy infrastructure. In Section 2.1, a methodology for determining the compatibility potential of ICT infrastructure co-deployment with road transport and energy infrastructure is explained. A parametric model (in Section 2.2) and methodology to calculate the economic efficiency of ICT infrastructure co-deployment with road transport and energy infrastructure (in Section 2.3) is described. Based on the proposed methodology, an efficiency calculator has been developed. Section 2.4 provides the methodology for identifying road transport and energy infrastructure projects that could include ICT infrastructure co-deployment.

2.1 Methodology for Determining the Compatibility Potential of ICT Infrastructure Co-Deployment with Road Transport and Energy Infrastructure

The determination of the possibility of ICT infrastructure co-deployment with road transport and energy infrastructure is based on defining their compatibility potential. This potential could be defined through an evaluation of parameters for the operation of infrastructure elements that have fundamental importance for co-deployment.[5] As a result of this evaluation, it is possible to draw conclusions on the appropriateness or inappropriateness of co-deployment up to the design stage.

The procedures for this evaluation include the following:

- Identify key factors that affect co-deployment, such as technical, legal, environmental, social, organizational, geographical, economic, marketing and other factors;
- Evaluate each key factor according to a system that involves the scoring of parameters. For example, the technical factor can be evaluated using parameters such as the

[5] The methodology has been developed specifically for this toolkit. The approach used is based on the principles published in the articles of scientists of O.S. Popov Odessa National Academy of Telecommunications (Ukraine) that are available at http://soskin.info/ea/2015/7-8-2/201511.html and http://www.ej.kherson.ua/journal/economic_10/60.pdf.

dependency of infrastructure on the availability of electricity and the service life of infrastructure. An evaluation table that presents the scoring of parameters is created; and

- Assess and compare the parameters using points or percentages.

The methodology to assess and compare the parameters by points or percentages is explained in turn below.

Point Assessment

The assessment using points is based on calculation of the permissible deviation of the average values (ΔKF). The average value gives an average indication of the compatibility of the infrastructure projects while levelling out possible incompatibility or low compatibility for certain parameters. To do this, the average estimation of the key factor (AEKF) is determined using the following formula:

$$AEKF = \sum_{i=1}^{n} (a_i) / n$$

Where a_i is the estimation of factor by using a parameter with index i ($1 \leq a_i \leq 10$); and n is the number of parameters within the factor.

The total deviation of the average values of key factors that is used to determine the compatibility potential can be calculated using the following formula:

$$\Delta KF = \sum_{k=1}^{M} | RTAEKF_k - ICTAEKF_k | / M,$$

Where $RTAEKF_k$ is the average estimation of the key factor with index k for the road transport or energy infrastructure; $ICTAEKF_k$ is the average estimation of the key factor with index k for the ICT infrastructure; and M is the total number of factors.

If during the comparison $\Delta KF > 2$ (Pareto Principle), there is a lack of compatibility potential between the ICT infrastructure and the road transport or energy infrastructure projects.

An example of calculating the average estimation of the key factor is given in Table 1.

Table 1: Example of calculating the average estimation of the key factor

№	Factor	Parameter	a_{ij} example (10-point system)
1	Technical	Parameter 1 Parameter 2 Parameter 3 Parameter 4 … Average estimation of the key factor	7 5 9 6 6.75
2	Geographical	*As above*	
3	Organizational	*As above*	
4	Socioeconomic	*As above*	

An example of calculating the projects' compatibility potential is given in Table 2.

Table 2: Example of calculating the projects' compatibility potential

Factor	Project 1	Project 2	Maximum deviation
Technical	6.75	5.4	6.75 – 5.4 = 1.35
Geographical	7.8	8.4	8.4 – 7.8 = 0.6
Organizational	9.1	9.5	9.5 – 9.1 = 0.4
Socioeconomic	---	---	---
ΔKF			**0.78**

The example from Table 2 shows that, on average, the projects are compatible (based on geographical and organizational factors), but according to technical factors, there are certain challenges that will be visible when the parameters are detailed.

Percentage Assessment

In the assessment of parameters in percentages, for each pair of similar parameters of various projects, a compatibility assessment (O_{pi}) is given: $O_{pi} = 0 \div 1$ (step – 0.1).

Next, a parametric model of compatibility (formalized description of the communicative behaviour of a combination of factors, parameters and signs) is formed by which the co-deployment is carried out.

The value "1" in the cell at the intersection of parameters means full compatibility of the parameters, "0" means complete incompatibility, and intermediate values mean partial compatibility, which requires additional financial and/or organizational costs to enhance the compatibility of the ICT infrastructure and the road transport or energy infrastructure projects.

In accordance with this approach, projects can be considered acceptable for implementation when the average rating of compatibility of parameters outweighs the given level (for example, 75-80 per cent):

$$O_{\sum} = \sum^{n}_{i=1} (O_p) / n \text{ (number of assessments), where } O_{\sum} \geq 0.75 \text{ (75 per cent).}$$

An example of this approach is given in Table 3.

Table 3: Example of an assessment of parameters in percentages

Factors and Parameters		T		G		O		SE		
		T1	**T2**	**G1**	**G2**	**O1**	**O2**	**SE1**	**SE2**	**SE3**
T	**T1**	0.8								
	T2		0.5							
G	**G1**			0.45						
	G2				0.8					
O	**O1**					1				
	O2						0.8			
SE	**SE1**							1		
	SE2								0.6	
	SE3									0.6

Notes: T = technical factor; G = geographical factor; O = organizational factor; SE = socioeconomic factor; T1, T2 = parameters within technical factor; G1, G2 = parameters within geographical factor; O1, O2 = parameters within organizational factor; and SE1, SE2, SE3 = parameters within socioeconomic factor.

Using the example in Table 3, the average rating of compatibility is calculated as follows:

$$O_{\sum} = \sum^{n}_{i=1} (O_p) / n = 6.55 / 9 = 0.72 \text{ (or 72 per cent).}$$

At 72 per cent, the assessment shows that the projects are not compatible, since $O_{\sum} < 0.75$ (75 per cent).

Thus, for given compatibility values, project parameters can be considered poorly compatible. The given parametric model makes it possible to determine separately those parameters that are compatible to one degree or another.

Table 4 proposes some key factors and parameters that can be used to determine the compatibility potential of ICT infrastructure co-deployment with road transport and energy infrastructure.

Table 4: Proposed key factors and parameters to determine the compatibility potential of ICT infrastructure co-deployment with road transport and energy infrastructure

№	Parameter	Description
		Technical factor
1	Dependency of infrastructure on the availability of electricity	In the electrification of the road or railway transport infrastructure, it is possible to organize a maintenance-free amplification station for signal regeneration in the fibre-optic link (using electricity). Thus, if the railway is electrified or the highway is built along power lines, the probability of co-deployment success is higher. If the transport infrastructure is not electrified, the distance between the points of presence of power lines (e.g., railway stations) is essential. If it is less than the length of the regeneration section of the fibre-optic link, co-deployment is possible. If not, this will lead to a significant increase in the cost of building the fibre-optic infrastructure due to the need to organize power supply to the amplification points. When the synergy between the various types of infrastructure is higher, the level of dependency on the availability of electricity is also higher.
2	Service life of infrastructure	The service life of the infrastructure determines when reconstruction or even decommissioning is required. The synergy between various types of infrastructure is higher when there is less difference between the maximum service life of their operation.
		Geographical factor
3	Extent to which the various infrastructure routes coincide	In case of separate construction, the route of a highway and fibre-optic cable, for example, can be radically different even if both infrastructure routes must begin and end at the same geographical location. Generally, the route of the road or railway infrastructure is more demanding on the terrain than the route of the fibre-optic cable. Despite significant technological restrictions on one type of infrastructure, some sections of the route may coincide even when they are independently designed and built.
4	Influence by climatic and weather conditions, geodetic, and other features on infrastructure	Each project should design the specifics of paving, placement of supports for electrification and base stations of mobile communications by considering temperature conditions, the frequency and amount of precipitation, rock density, terrain, etc. The optimal route for the road

	construction and operation	infrastructure may differ from the optimal placement of base stations for mobile communications or the route for the fibre-optic cable. For example, the presence of a water or mountain obstacle is not a problem for the construction of base stations for mobile communications and pillars for electrification, but for road construction, it requires the construction of a bridge or tunnel, respectively, which results in additional costs for the project.
	Organizational factor	
5	Regulatory support for infrastructure co-deployment	The process of design, construction and operation of infrastructure is regulated by various regulatory acts and rules. The synergy between various types of infrastructure is higher when regulations explicitly promotes and supports co-deployment.
6	Number of approvals required for infrastructure co-deployment compared with separate deployment	In the process of designing and building the infrastructure, a sufficiently large number of coordination procedures are required. In instances where procedures overlap, this reduces the total time and cost of seeking approvals in case of their co-deployment.
7	Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	The development of human potential in ICT infrastructure co-deployment with transport and energy infrastructure is important and is the focus of many international, state and private organizations. However, co-deployment remains poorly understood and is often not considered in the design or business planning processes due to the lack of specialists in infrastructure project teams with knowledge and skills in co-deployment. The synergy between various types of infrastructure is higher in the presence of specialists with knowledge and skills in co-deployment.
8	Form of ownership (public or private) of the planned infrastructure project	Often, the form of ownership (public or private) impacts the project management approach used in infrastructure projects. Despite the importance of public-private partnerships, synergy is often higher for facilities that have the same form of ownership (private and private, or public and public).
9	Level of complexity in infrastructure management	When the level of complexity between the management of infrastructures for co-deployment are similar, the synergy is higher.
	Socioeconomic factor	

10	Level of difficulty in the technological process of addressing terrain challenges	The type of infrastructure, the planned route and type of terrain that the planned route passes through (marshes, rivers, mountains, etc.) determine the level of difficulty of the construction process based on technological or regulatory restrictions. When the level of technological difficulty in addressing terrain challenges between the infrastructures is lower, the synergy is higher.
11	Social or military (defence) significance of the infrastructure	In some cases, the construction of infrastructure may not only be associated with commercial feasibility but is also determined by sociopolitical requirements in a particular geopolitical region. If the goals of the infrastructure projects are similar in terms of social or military (defence) significance, the synergy is higher.
12	Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	This parameter determines the capabilities of one type of infrastructure when using another type of infrastructure to develop new services that create additional value for the first type of infrastructure. For example, along the roads, it is possible to create an intelligent transport system using fibre-optic cables, and gas stations and other establishments being built along the highway can become additional consumers of the ICT infrastructure. In addition, in case of co-deployment, a kind of synergistic effect may occur, which can lead to a mutual increase in the quality and/or reputation of the transport corridor (e.g., providing a percentage coverage of mobile communications over the entire length without dead zones; full electrification and the presence of electric vehicle charging stations; and rational placement of gas stations, markets, motels, etc.).

Table 5 shows the principles for assessing infrastructure facilities in the context of the proposed parameters in Table 4.

Table 5: Principles for assessing the compatibility potential of ICT infrastructure co-deployment with road transport and energy infrastructure

№	Parameter	Principles for assessing the transport or energy infrastructure	Principles for assessing the ICT infrastructure
Technical factor			
1	Dependency of infrastructure on the availability of electricity	If the infrastructure is more electrified, the score for this parameter is higher. For example, the maximum score will be on an electrified railway or on a highway along which a power line already exists or will be built.	If the technology of building fibre-optic links is more tied to the presence of electricity (the less the length of the regeneration section), the higher the score for this parameter. The fibre-optic line that does not require regeneration along the entire route (i.e., independent of electricity) will have a minimum score.
2	Service life of infrastructure	The score for this parameter is inversely proportional to the difference between the service life of the road transport or energy infrastructure and the ICT infrastructure.	
Geographical factor			
3	Extent to which the various infrastructure routes coincide	The score for this parameter is directly proportional to the ratio of the length of the part of road transport or energy infrastructure that coincides with the part of ICT infrastructure, in relation to the total length of the road transport or energy infrastructure.	The score for this parameter is directly proportional to the ratio of the length of the part of ICT infrastructure that coincides with the part of road transport or energy infrastructure, in relation to the total length of the ICT infrastructure.
4	Influence by climatic and weather conditions, geodetic, and other features on infrastructure construction and operation	The score for this parameter is directly proportional to the number of additional engineering structures that must be built along the route of the road transport or energy infrastructure to compensate for the influence of climatic and weather conditions, as well as geodetic and other features.	The score for this parameter is directly proportional to the number of additional engineering structures that must be built along the route of the ICT infrastructure to compensate for the influence of climatic and weather conditions, as well as geodetic and other features.
Organizational factor			

5	Regulatory support for infrastructure co-deployment	If the building rules for co-deployment and sharing are more detailed, the score for this parameter is higher. In the absence of regulatory documents for co-deployment, the score is minimal.	
6	Number of approvals required for infrastructure co-deployment compared with separate deployment	The score for this parameter is directly proportional to the ratio of the number of matching approval procedures for the road transport or energy infrastructure and for the ICT infrastructure in relation to the total number of approval procedures required for the construction of the road transport or energy infrastructure.	The score for this parameter is directly proportional to the ratio of the number of matching approval procedures for the ICT infrastructure and for the road transport or energy infrastructure in relation to the total number of approval procedures required for the construction of the ICT infrastructure.
7	Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	If the number of people in the team responsible for the design and construction of road transport or energy infrastructure is familiar with the advantages of co-deployment with ICT infrastructure (for example, they have received relevant training), the score for this parameter is higher.	If the number of people in the team responsible for the design and construction of ICT infrastructure is familiar with the advantages of co-deployment with road transport or energy infrastructure (for example, they have received relevant training), the score for this parameter is higher.
8	Form of ownership (public or private) of the planned infrastructure project	The maximum score for this parameter is given if the form of ownership of the created infrastructure is private. For public ownership the score is decreased by one point.	
9	Level of complexity in infrastructure management	Points are awarded for each element or process in the management system that requires coordination with higher or third-party organizations and cannot be resolved in the operational management process. Points are also awarded for each element that leads to a review of management principles and procedures in order to simplify them or reduce decision-making time.	
Socioeconomic factor			
10	Level of difficulty in the technological process of	The score for this parameter is directly proportional to the ratio of the estimated cost of building the road transport or energy infrastructure in difficult terrain,	The scores for this parameter is directly proportional to the ratio of the estimated cost of building the ICT infrastructure in difficult

	addressing terrain challenges	and the estimated cost of building the same infrastructure without passing through difficult terrain.	terrain, and the estimated cost of building the same infrastructure without passing through difficult terrain.
11	Social or military (defence) significance of the infrastructure	If the social and military (defence) significance of the road transport or energy infrastructure is higher, the score for this parameter is higher. Infrastructures that are built exclusively as commercial projects receive the lowest score.	If the social and military (defence) significance of the ICT infrastructure is higher, the score for this parameter is higher. Infrastructures that are built exclusively as commercial projects receive the lowest score.
12	Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	If ICT infrastructure co-deployment with the road transport or energy infrastructure leads to more new services, the score for this parameter is higher.	If ICT infrastructure co-deployment with road transport or energy infrastructure leads to more potential customers, the score for this parameter is higher.

Using the methodology described above, an evaluation was conducted on the compatibility of road transport or energy infrastructure with the ICT infrastructure for several promising projects in Kazakhstan and Kyrgyzstan. Detailed parameter-by-parameter assessment of the compatibility of the infrastructures is given in Annex 1 for infrastructure projects in Kazakhstan and Annex 2 for infrastructure projects in Kyrgyzstan.

Prospective road transport infrastructure projects in Kazakhstan are given in Table 6, and prospective ICT infrastructure projects in Kazakhstan are given in Table 7.

Table 6: Prospective road transport infrastructure projects in Kazakhstan

Project ID	Project title	Link to detailed information
R1	Reconstruction of the road section Almaty – Tashkent – Termez	http://mvd.gov.kz/portal/page/portal/mvd/kdp_page/kdp_news/mobile_kdp_news_country/D1EE05E2994A45CEE044002655122E6A
R2	Construction of the highway Uralsk – Taskala – Ozinki	https://www.arnapress.kz/uralsk/life/70485

Table 7: Prospective ICT infrastructure projects in Kazakhstan

Project ID	Project title	Link to detailed information
T1	Fibre-Optic Cable Line Almaty – Kordai	https://zakupki.kz/tender/element.php?ID=22142253
T2	Fibre-Optic Cable Line Uralsk – Ozinki	http://buitelecom.kz/index.php/ru/nashi-ob-ekty.html

The calculation results for Kazakhstan in Table 8 show that projects R1 and T1 are incompatible. This is due to dissimilar route design for the road and the fibre-optic network, and the complexity of the terrain. As a result, the social benefits from implementing the projects together are unclear. A recommendation here is significant route adjustment. On the other hand, projects R2 and T2 are compatible. The compatibility is observed across all technical, economic and social parameters. Therefore, projects R2 and T2 can be recommended for co-deployment.

Table 8: Compatibility of prospective projects for ICT infrastructure co-deployment with the road transport infrastructure in Kazakhstan

Road transport infrastructure project ID	ICT infrastructure project ID	
	T1	T2
R1	ΔKF = 2.05 (incompatible)	–
R2	–	ΔKF = 0.9 (compatible)

Prospective road transport and energy infrastructure projects in Kyrgyzstan are given in Table 9, and prospective ICT infrastructure projects in Kyrgyzstan are given in Table 10.

Table 9: Prospective road transport and energy infrastructure projects in Kyrgyzstan

Project ID	Project title	Link to detailed information
R1	North-South Alternative Highway Project	http://piumotc.kg/ru/p1861900/
R2	The project of the internal railway Balykchi – Kara-Keche	https://www.unescap.org/sites/default/files/Kyrgyzstan_8.pdf
E3	500 kV electric line Datka (Kyrgyzstan) – Hujant (Tajikistan)	http://www.casa-1000.org

Table 10: Prospective ICT infrastructure projects in Kyrgyzstan

Project ID	Project title	Link to detailed information
T1	Fibre-Optic Cable Line along the North-South Alternative Highway	http://www.ict.gov.kg/index.php?r=site%2Fproject&cid=25
T2	Fibre-Optic Cable Line along the route of 500 kV electric line Datka (Kyrgyzstan) – Hujant (Tajikistan)	http://www.casa-1000.org

The calculation results for Kyrgyzstan in Table 11 show that the most compatible projects are R1 and T1, and E3 and T2. For these projects, compatibility is observed across all technical, economic and social parameters, therefore, these projects can be recommended for co-deployment. The least compatible projects are R2 and T2. This is due to incompatibility in technologies, complete geographical mismatch and economic inappropriateness and, as a result, the social benefits from implementing the projects together are unclear. Recommendations for improving compatibility include changing the technology for deploying fibre-optic cables and significant route adjustment.

Table 11: Compatibility of prospective projects for ICT infrastructure co-deployment with the road transport and energy infrastructure in Kyrgyzstan

Road transport or energy infrastructure project ID	ICT infrastructure project ID	
	T1	T2
R1	ΔKF = 0.625 (compatible)	ΔKF = 2.135 (not compatible)
R2	ΔKF = 2.55 (not compatible)	ΔKF = 2.625 (not compatible)
E3	ΔKF = 2.05 (not compatible)	ΔKF = 0.9175 (compatible)

2.2 A Parametric Model of ICT Infrastructure Co-Deployment with Road Transport and Energy Infrastructure

The parametric model of ICT infrastructure co-deployment with road transport and energy infrastructure is shown in Table 12. This model assesses the cost difference between separate deployment of infrastructure (ICT, road transport or energy) and their co-deployment. The coloured parts highlight those costs that are common to all types of infrastructure and therefore, can be reduced in case of co-deployment.

Table 12: Parametric model of ICT infrastructure co-deployment with road transport and energy infrastructure

Road transport or energy infrastructure	ICT infrastructure	Co-Deployment
1. Design costs		
1.1 Cost to develop design documentation	1.1 Cost to develop design documentation	1.1 Cost to develop design documentation
1.2 Cost to develop construction estimates	1.2 Cost to develop construction estimates	1.2 Cost to develop construction estimates
1.3 Specific for roads or electricity, additional costs at the design stage (e.g., creating a road layout)	1.3 Specific for ICT, additional costs at the design stage (e.g., access network design)	1.3 Specific for co-deployment, additional costs at the design stage, as well as additional costs for the specific of roads or electricity, and ICT
2. Cost of obtaining permits		
2.1 Cost of preparing a package of documents	2.1 Cost of preparing a package of documents	2.1 The cost of preparing a package of documents
2.2 Legal costs	2.2 Legal costs	2.2 Legal costs
2.3 Cost of taxes, state duties and other obligatory payments	2.3 Cost of taxes, state duties and other obligatory payments	2.3 Cost of taxes, state duties and other obligatory payments
2.4 Cost of obtaining specific permits for road transport or energy infrastructure	2.4 Cost of obtaining specific permits for ICT infrastructure	2.4 Cost of obtaining specific permits for co-deployment, as well as cost of obtaining specific permits for the road transport or energy

		infrastructure and ICT infrastructure
3. Direct material costs		
3.1 Cost of materials in accordance with the estimate	3.1 Cost of materials in accordance with the estimate	3.1 Cost of materials in accordance with the estimate
3.2 Cost of material reserves	3.2 Cost of material reserves	3.2 Cost of material reserves
3.3 Cost of machinery and equipment	3.3 Cost of machinery and equipment	3.3 Cost of machinery and equipment
4. Indirect material costs		
4.1 Rental of transport and special equipment	4.1 Rental of transport and special equipment	4.1 Rental of transport and special equipment
4.2 Shipping costs	4.2 Shipping costs	4.2 Shipping costs
4.3 Cost of garbage and other construction waste	4.3 Cost of garbage and other construction waste	4.3 Cost of garbage and other construction waste
4.4 Fuel for own transport	4.4 Fuel for own transport	4.4 Fuel for own transport
4.5 Other indirect material costs specific for roads or electricity	4.5 Other specific indirect material costs for ICT	4.5 Other indirect material costs specific for co-deployment, as well as additional costs for the specific of roads or electricity and ICT
5. Payroll fund for personnel involved in the construction of infrastructure		
5.1 Preparatory work remuneration fund	5.1 Preparatory work remuneration fund	5.1 Preparatory work remuneration fund
5.2 Payroll fund for specialists in the construction of road transport or electricity infrastructure	5.2 Payroll fund for specialists in the construction of ICT infrastructure	5.2 Payroll fund for specialists in case of co-deployment
5.3 Payroll fund for social workers and administrative staff	5.3 Payroll fund for social workers and administrative staff	5.3 Payroll fund for social workers and administrative staff
6. Contributions to social funds and insurance		
7. Electricity costs		
8. Overhead, including project administration costs		
9. Other unaccounted expenses		

9.1 Social expenses (workwear, protective equipment, food)	9.1 Social expenses (workwear, protective equipment, food)	9.1 Social expenses (workwear, protective equipment, food)
9.2 Labour protection costs	9.2 Labour protection costs	9.2 Labour protection costs

2.3 Economic Efficiency of ICT Infrastructure Co-Deployment with Road Transport and Energy Infrastructure

The basis for assessing the economic efficiency of ICT infrastructure co-deployment with road transport or energy infrastructure is the comparison of an indicator of the speed of a specific increment in value (IS) for cases of co-deployment and separate deployment of the corresponding infrastructures.

We will consider that co-deployment is more profitable than separate deployment if the condition is fulfilled. That is, the speed of the specific increment in value in case of ICT infrastructure co-deployment with road transport or energy infrastructure is more than the average speed of similar indicators for separate deployment:

$$IS_{co\text{-}deployment} > (IS_{ICT} + IS_{transport}) / 2$$

- $IS_{co\text{-}deployment}$ is the indicator of the speed of a specific increment in value for ICT infrastructure co-deployment with road transport or energy infrastructure;
- IS_{ICT} is the indicator of the speed of a specific increment in value for separate deployment of the ICT infrastructure; and
- $IS_{transport}$ is the indicator of the speed of a specific increment in value for separate deployment of the road transport or energy infrastructure.

To calculate the indicator of the speed of a specific increment in value for any of the three options, the following formula is used:

$$IS = NPV / (n \times I)$$

- NPV is the net present value, currency unit (cu);
- n is the estimated period from the start of the project to its completion, years; and
- I is the investments of the current year, cu.

The NPV can be calculated using the following formula:

$$NPV = CF_{disc} – K$$

- CF_{disc} is the value of the discounted cash flow (CF), cu; and
- K is the capital costs (investments) calculated as the sum of costs according to Table 12 for the corresponding infrastructure, cu.

In this case, the discounted CF can be calculated using the following formula:

$$CF_{disc} = CF \times k_j$$

- CF is the cash flow, cu; and
- k_j is the discount coefficient, which is calculated using the formula: $k_j = 1 / (1 + K_{disc})^j$, where Kd_{isc} is based on the project risk level, inflation level, national bank refinancing rate, etc., and j is the time period (j = 1 .. n), years.

In turn, to calculate the CF, the following formula is used:

$$CF = NP + D$$

- NP is the net profit from the project for one year, cu; and
- D is the depreciation of fixed assets for one year, cu.

To calculate net profit (as the difference between profit and income tax), the following formula is used:

$$NP = P \times (1 - Tax)$$

- P is the expected annual profit from the project, cu; and
- Tax is the income tax rate (from 0 to 1).

The annual profit is calculated using the following formula:

$$P = AI – P_{oper}$$

- AI is the net annual income, cu; and
- P_{oper} is the amount of annual operating costs associated with the implementation of the project.

In turn, the net annual income can be defined as:

$$AI = EP – VAT$$

- EP is the expected amount of annual revenues from the operation of the ICT, transport or energy infrastructure, or from their co-deployment, cu; and
- VAT is the amount of value-added tax payable, cu.

The sequence of calculation for the expected amount of annual revenues from operation of the ICT infrastructure is given in Table 13.

Table 13: Sequence of calculation for the expected amount of annual revenues from operation of the ICT infrastructure

Indicator	Formula
Potential constant demand from the local population (PCDlp)	$PCDlp = d_t \times A_i \times d_{lps} \times P_r$ • d_t is the proportion of the population’s expenses for communications services; • A_i is the average incomes of the population (in national or other currency); • d_{lps} is the proportion of the solvent population (age 18 to 65 years); and • P_r is the region’s population.
Potential probable demand from the local population (PPDlp)	$PPDlp = d_t \times A_i \times d_{lps} \times P_r \times (1 + K_{di})$ • K_{di} is the possibility of increasing demand.
Coefficient considering the demand for ICT services from children supported by parents (Kch)	$Kch = d_{ch} \times P_r \times (1 - P_b) \times d_t \times A_i$ • d_{ch} is the proportion of children aged 7-18 years; • P_r is the region’s population; • P_b is the proportion of content not received by children due to parental control; • d_t is the proportion of the population’s expenses for communications services; and

	• A_i is the average incomes of the population (in national or other currency).
Coefficient considering the demand for ICT services from the older age group (Kold)	$Kold = d_{old} \times P_r \times P_{old} \times d_t \times A_i$ • d_{old} is the proportion of the population over 65 years old; • P_r is the region's population; • P_{old} is the average share of content used by this age category compared to base group content; • d_t is the proportion of the population's expenses for communications services; and • A_i is the average incomes of the population (in national or other currency).
Coefficient considering the presence of regular demand from tourists (Kt)	$Kt = Qt \times Ec$ • Qt is the number of tourists; and • Ec is the average cost of communications services for this category of users.
Competitive factor (Co)	$Co = Scc \times d_t \times A_i + 0.5Scs \times d_t \times A_i$ • Scc is the proportion of users who use the services of competitors (or alternative forms of communications) and do not plan to change operator; • Scs is the proportion of users who simultaneously use the services of several operators (based on the ratio of costs for communications services 50/50); • dt is the proportion of the population's expenses for communications services; and • Ai is the average incomes of the population (in national or other currency).
Expected amount of annual revenues (EP)	$EP = 12\ (PPDlp + Kch + Kold + Kt - Co)$

The sequence of calculation for the expected amount of annual revenues from operation of the road transport or energy infrastructure is given in Table 14.

Table 14: Sequence of calculation for the expected amount of annual revenues from operation of the road transport or energy infrastructure

Indicator	Formula
Traffic revenue (R_{tr})	$R_{tr} = R_{tr}^{av} \times L_i$ • R_{tr}^{av} is the average revenues per kilometre of road from traffic; and • Li is the length of the road.
Potential constant demand from the local population (PCDlp)	$PCDlp = d_t \times A_i \times H$ • d_t is the proportion of household expenses for transport and electricity services; • A_i is the average incomes of the population (in national or other currency); and • H is the number of households in the region.
Potential ongoing demand for transport and electricity services from businesses (PCS_B)	$PCS_B = \sum_{i=1}^{n} QE_i \times E_i$ • QE_i is the business unit; • E_i is the average monthly expenses of the i-th business unit for transport and electricity services; and • n is the number of business units.
Coefficient considering the presence of regular demand from tourists (Kt)	$Kt = Qt \times Ec$ • Qt is the number of tourists; and • Ec is the average cost of transport and electricity services for this category of users.
Competitive factor (Co)	$Co = T_i \times d_t \times St + T_i \times d_e \times Se$ • St is the proportion of users who use several types of transport (personal, horse-drawn, etc.); • Se is the proportion of users who simultaneously use different types of energy supply (generators, solar, wind, etc.); • dt is the average cost of transport services; • de is the average cost of electricity services; and • Ti is the total number of households and business units.
General demand (GD)	$GD = Rtr + PCDlp + PCS_B$

Expected amount of annual revenues (EP)	EP = 12 (GD + Kt – Co)

The sequence of calculation for the expected amount of annual revenues from ICT infrastructure co-deployment with road transport or energy infrastructure is given in Table 15.

Table 15: Sequence of calculation for the expected amount of annual revenues from ICT infrastructure co-deployment with road transport or energy infrastructure

Indicator	Formula
Traffic revenue (R_{tr})	$R_{tr} = R_{tr}^{av} \times L_i$ • R_{tr}^{av} is the average revenues per kilometre of road from traffic; and • Li is the length of the road.
Potential constant demand from the local population (PCDlp)	$PCDlp = d_t \times A_i \times d_{lps} \times P_r$ • d_t is the proportion of the population’s expenses for communications services; • A_i is the average incomes of the population (in national or other currency); • d_{lps} is the proportion of the solvent population (age 18-65 years); and • P_r is the region’s population.
Potential probable demand from the local population (PPDlp)	$PPDlp = d_{tc} \times A_i \times d_{lps} \times P_r \times K_{di}$ • Kdi is the possibility of increasing demand, and therefore, the cost of transport and communications services in case of quality improvement.
Coefficient considering the demand for transport and communications services from the older age group (Kold)	$Kold = d_{old} \times P_r \times P_{old} \times d_{tc} \times A_i$ • d_{old} is the proportion of the population over 65 years old; • P_r is the region’s population; • P_{old} is the average proportion of transport and communications services used by this age category (the demand for similar services for people aged 18 to 65 is taken as 100 per cent); • d_{tc} is the proportion of the population’s expenses for transport and communications services; and

	• Ai is the average incomes of the population (in national or other currency).
Coefficient considering the presence of regular demand from various tourists (Kt)	Kt = Qt × Ec • Qt is the number of tourists; and • Ec is the average expenses for transport and communications services for this category of users.
Coefficient considering the presence of regular demand from various tourists (Kch)	$Kch = d_{ch} \times P_r \times (1 - P_b) \times d_t \times A_i$ • d_{ch} is the proportion of children aged 7-18 years; • P_r is the region's population; • P_b is the share of content not received by children due to parental control; • d_t is the share of the population's expenses for communications services; and • A_i is the average incomes of the population (in national or other currency).
The coefficient considering the provision of regional services to social services (medical, financial, educational and other organizations) in terms of their average remoteness from settlements (Tsi)	$Tsi = d_{mcs} \times P_r \times d_t \times A_i$ • d_{mcs} is the proportion of the population who regularly receive medical, financial, educational and other services at a considerable distance from home; • P_r is the region's population; • d_t is the proportion of the population's expenses for transport services; and • A_i is the average incomes of the population (in national or other currency).
The coefficient considering the presence of the population's own transport, which reduces the demand for transport infrastructure services (OwnT)	$OwnT = d_{ot} \times P_r \times d_t \times A_i$ • d_{ot} is the proportion of the population with own transport; • Pr is the region's population; • d_t is the share of the population's expenses for transport services; and • Ai is the average incomes of the population (in national or other currency).
Expected amount of annual revenues (EP)	$EP = 12 (R_{tr} + PPDlp + Kold + Kt + Kch + Tsi - OwnT)$

A special calculator tool (in *.xlsx format) using the above methodology is available at https://owncloud.onat.edu.ua/index.php/s/jL200B8MsjBQryZ.

2.4 Methodology for Identifying Road Transport and Energy Infrastructure that Could Include ICT Infrastructure Co-Deployment

The active and widespread development of road transport and energy infrastructure in developing countries has led to the emergence of multiple opportunities that ICT infrastructure operators could consider for expanding the national fibre-optic network through co-deployment.

However, choosing a specific road transport infrastructure or energy infrastructure project for co-deployment with the ICT infrastructure is not easy. To determine the most worthwhile project, the simplified method of hierarchy analysis is used, which consists of calculating a weighted indicator based on point estimates of several criteria and their weight coefficients, calculated by pairwise comparison.

To obtain a single comprehensive comparative assessment of several compared infrastructure projects, a linear convolution of the form is used, as follows:

$$Q = \sum_{i=1}^{n} (K_i \times B_i)$$

- K_i is the weight coefficient of the i-th criterion;
- B_i is the score of the i-th criterion; and
- n is the number of criteria.

Weighting factors for pre-accepted criteria are calculated by pairwise comparison. For this, a comparative matrix is created with the size of n x n elements, where each element of the matrix is the result of a weighted expert comparison of the i-th and j-th criteria. If the i-th criterion is considered by a field expert (or experts) to be more significant than the j-th one, the element a_{ij} should be equal to 2 (in turn, the mirror element of the matrix – a_{ji} should be equal to 0). Conversely, in the case when the i-th criterion is considered less significant than j-th, the element a_{ij} should be equal to 0 (and a_{ji} should be equal to 2). If the i-th and j-th criteria are considered equivalent, the elements a_{ij} and a_{ji} should be equal to 1. Elements of the main diagonal of the matrix are equal to 1.

Thus, as a result of comparing the criteria, a matrix of pairwise comparisons is obtained, and the values of the elements reflect the subjective conclusion of expert (or experts) on the importance of the i-th criterion compared with the j-th criterion in specific conditions.

To determine the weight coefficients (or quantitative expression of the importance of the criteria) of the i-th criterion, it is necessary to find the sum of the matrix elements of each row:

$$S_i = \sum_{j=1}^{n} (a_{ij}),\ i = 1 .. n$$

Next, it is necessary to calculate the total sum of the elements in the matrix:

$$S = \sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij}) = \sum_{i=1}^{n} (S_i)$$

The normalized value of the weight coefficient of the i-th criterion is calculated using the formula:

$$K_i = S_i / S,\ i = 1 .. n$$

As the selection criteria, the factors given in section 2.1 of this toolkit are used by adding an economic criterion to them.

A single approach for determining the numerical value of indicators is needed for their summation and/or comparison. Since all indicators are heterogeneous within the framework of the criterion, it is possible to use a point system (the appropriate methodological basis for converting dissimilar indicators into points) to compare options. For example, for an economic criterion, the most suitable indicator is NPV, which considers capital costs, revenues, expenses, etc.

The list of proposed criteria for use and the principles for creating a point score are given in Table 16.

Table 16: Proposed criteria and principles for assessment

№	Criterion	Criterion description	Assessment principles
1	Economic	Considers economic indicators such as the amount of capital investment in the construction of road transport or energy infrastructure; current annual maintenance costs; and payback period of investments. As a basis, NPV can be used.	10 points – $C_{min} \leq C_{x_i} \leq C_1$ $C_1 = C_{min} + \frac{(C_{max} - C_{min})}{10}$ C_{x_i} – NPV for the x_i project C_{min} – minimum NPV from all projects C_{max} – maximum NPV from all projects 20 points – $C_1 \leq C_{x_i} \leq C_2$, $C_2 = C_{min} + \frac{2(C_{max} - C_{min})}{10}$ 30 points – $C_2 \leq C_{x_i} \leq C_3$, $C_3 = C_{min} + \frac{3(C_{max} - C_{min})}{10}$ 40 points – $C_3 \leq C_{x_i} \leq C_4$, $C_4 = C_{min} + \frac{4(C_{max} - C_{min})}{10}$ 50 points – $C_4 \leq C_{x_i} \leq C_5$, $C_5 = C_{min} + \frac{5(C_{max} - C_{min})}{10}$ 60 points – $C_5 \leq C_{x_i} \leq C_6$, $C_6 = C_{min} + \frac{6(C_{max} - C_{min})}{10}$ 70 points – $C_6 \leq C_{x_i} \leq C_7$, $C_7 = C_{min} + \frac{7(C_{max} - C_{min})}{10}$ 80 points – $C_7 \leq C_{x_i} \leq C_8$, $C_8 = C_{min} + \frac{8(C_{max} - C_{min})}{10}$ 90 points – $C_8 \leq C_{x_i} \leq C_9$, $C_9 = C_{min} + \frac{9(C_{max} - C_{min})}{10}$ 100 points – $C_9 \leq C_{x_i} \leq C_{max}$
2	Technical	Considers the level of technological complexity of ICT infrastructure co-deployment with road transport or energy infrastructure.	If co-deployment (from a technological point of view) is easier, the number of points is higher.
3	Geographical	Considers the sections along the route of the road transport or energy infrastructure that are	If there are less sections that are difficult to access for ICT infrastructure construction, the number of points is higher.

		difficult to access to construct the ICT infrastructure.	
4	Organizational	Considers the regulatory framework for ICT infrastructure co-deployment with road transport or energy infrastructure.	If the regulatory framework clearly promotes and supports co-deployment, the number of points is higher.
5	Social	Considers the need to provide the population, business structures or international transport corridors with ICT services along the highway; the presence of international agreements governing the need for the development of ICT; and other political or strategic aspects.	If the social importance of the road transport or energy infrastructure is more significant, the number of points is higher.

It should be noted that both the list of criteria and the principles for assessment can be changed while maintaining the general approach for calculating the weighted average ratings presented above.

An example of calculating weighting coefficients using the methodology is given in Table 17, which shows that the most significant criterion is the economic criterion (its weight is 0.36), and the least significant criterion is the organizational criterion (its weight is 0.08).

Table 17: Example of pairwise comparison of criteria for calculating weighting coefficients

Criterion	Economic	Technical	Geographical	Organizational	Social	Weighting coefficient
Economic	1	2	2	2	2	0.36
Technical	0	1	1	2	1	0.2
Geographical	0	1	1	1	0	0.12
Organizational	0	0	1	1	0	0.08
Social	0	1	2	2	1	0.24

An example that compares three different road transport and energy infrastructure projects by the criteria is given in Table 18, which shows that the most promising infrastructure project for co-deployment with the ICT infrastructure is T2.

Table 18: Example comparing three road transport and energy infrastructure projects by criteria

№	Criterion	Weighting coefficient	Assessment of road transport or energy infrastructure (100-points system)		
			T1	T2	E1
1	Economic	0.36	50	80	40
2	Technical	0.2	25	90	20
3	Geographical	0.12	30	10	100
4	Organizational	0.08	80	80	60
5	Social	0.24	70	15	75
Single comprehensive comparative assessment, Q			**49.80**	**58.00**	**53.20**

A special calculator tool (in *.xlsx format) using the above methodology is available at https://owncloud.onat.edu.ua/index.php/s/CKdtBXuIOcPzq08.

3. Technical Aspects of ICT Infrastructure Co-Deployment with Road Transport and Energy Infrastructure

This section describes a typical design process with a set of procedures for participants involved in ICT infrastructure co-deployment with road transport and energy infrastructure. The process involves two interrelated tasks:

- Selection of the route for co-deployment; and
- Technological design of the fibre-optic cable for construction with the road transport or energy infrastructure.

Typical design documentation for the creation of the ICT infrastructure should determine:

- Architecture, structure and composition of the infrastructure;
- Technologies and facilities;
- Key performance indicators of the ICT infrastructure operation;
- Connections between newly-designed fibre-optic cable sections and the existing ICT infrastructure; and
- Compliance with the requirements for regulatory and legal documents in the design of fibre-optic links and the management of co-deployment.

3.1 Initial Data Templates for the Design of ICT Infrastructure Co-Deployment with Road Transport and Energy Infrastructure

The initial data used for designing the co-deployment process is prepared by both the infrastructure owner of the road transport or energy infrastructure and the telecom operator. The initial data plays a crucial role in the development and implementation of the co-deployment project since it details the following:

- Permissions and technical conditions necessary for laying fibre-optic cables;
- Technical and functional requirements for transmission bit-rate and technology;
- Conditions for the implementation of the project; and
- Special requirements from the infrastructure owner.

For example, for the co-deployment of fibre-optic cables along roads, the following initial data is required:

- Longitudinal profile of the road;
- Structure of the subgrade and roadside; and
- Presence of artificial structures and their characteristics (type, length, general layout drawings).

In case of insufficient initial data provided by the infrastructure owner or telecom operator, technical survey of the route along which the fibre-optic cable is planned will need to be carried out to collect initial data such as, cable route, georeferences, presence of curb, its width and distance from the axis of the road, and presence of embankments and their height, etc.

The list of initial data depends on the characteristics of the project's geographical location, the scale of implementation (local, national or international), and the conditions for implementation (including economic, social, technical, organizational and regulatory conditions).

A typical list of initial data for designing the co-deployment process contains the following:

- Project terms of reference;
- Technical conditions for design;
- Location and characteristics of sections of the route;
- Technologies used for co-deployment;
- Data on existing fibre-optic cable sections that will connect with the newly-designed system;
- Requirements for scientific and technical support, inventions, and research results;
- The required availability and bit-rates of the designed channels;
- Routes, schemes and plans for the co-deployment, and definition of the framework of easements (if any);
- Planned material investments associated with the laying of fibre-optic links;

- Specific requirements due to geographical location;
- Disaster risk reduction aspects; and
- Environmental and social aspects.

The above list is typical, but not comprehensive. The initial data for the design of ICT infrastructure co-deployment with road transport or energy infrastructure can be expanded based on approved regulatory and legislative documents. Two sample forms for the provision of initial data is proposed in this toolkit.

Table 19 shows a proposed Form № 1 of initial data for completion by the infrastructure owner and telecom operator for designing the co-deployment project. The "*" sign in the form indicates the fields in which data can be provided by the design organization after performing a technical survey.

Table 19: Form № 1 for filling in initial data for the design of ICT infrastructure co-deployment with road transport or energy infrastructure

Route section number	Coordinates for the beginning of route section*	Coordinates for the end of route section*	Type of infrastructure (road transport, energy)	Stage of implementation of infrastructure (new, existing)	Engineering constructions	Type of technology used for laying fibre-optic cable, according to Table 20*	Estimated month of route section building	Specific characteristics of the transport or energy infrastructure
1	2	3	4	5	6	7	8	9

Details for completing Form № 1 by column are as follows:

1. Reference number allocated for the route section for co-deployment;
2. Coordinates for the start of the route section using the coordinate system adopted in the project (e.g., geographic coordinates, addresses, etc.);
3. Coordinates for the end of the route section using the coordinate system adopted in the project (e.g., geographic coordinates, addresses, etc.);
4. Type of route along which the fibre-optic cable co-deployment is expected (e.g., highway, railway, power transmission line, etc.);
5. Stage of implementation of the road transport or energy infrastructure – new (co-deployment with ICT), reconstruction (co-deployment with ICT), operating (laying of ICT infrastructure along existing route);

6. Presence or absence of engineering facilities along the route section (e.g., bridges, viaducts, tunnels, etc.);
7. Type of technology used for laying the fibre-optic cables (see Table 20);
8. Estimated month for constructing the route section; and
9. Specific characteristics of the designed transport infrastructure or energy infrastructure – voltage class of power transmission lines, and class of roads or railways (e.g., administrative [national or international railways, public or private roads] or operational [freight, passenger, commuter, transit, industrial, temporary]).

Table 20: Modern technologies for ICT infrastructure co-deployment with road transport and energy infrastructure

Type	Laying environment	Fibre-optic cable laying technology	Brief description of application	Advantages	Disadvantages
A1	Soil	Laying of fibre-optic cable in open soil	The trench method lays the cable in the trench, and the trenchless method uses cable layers or horizontal drilling rigs	Surpasses air fibre-optic cable in reliability	Assumes the use of armoured cable
A2	Soil	Laying of fibre-optic cable in a mini trench in the soil	Mini trenches are about 10 cm wide. They are used when laying fibre-optic cable in the ground on cottage plots and lawns	The appearance of the sites does not deteriorate	Cable laying depth is shallow
A3	Road surface	Laying of fibre-optic cable in a mini trench in the road surface	It takes place before laying asphalt. The fibre-optic cable is laid in a trench with a width of 19-32 mm and a depth of up to 305 mm. The cable can be protected either by a special box or by several layers of protective materials that are laid over it.	A narrow and shallow trench allows the passage of fibre over the soil, causing minimal damage to the road infrastructure	Difficult to maintain

Type	Laying environment	Fibre-optic cable laying technology	Brief description of application	Advantages	Disadvantages
			After laying the cable, the trenches are poured with bitumen and asphalt is laid		
A4	Soil	Cable routing in protective polyethylene pipes (PPP)	PPP, made of high-strength polyethylene, of 600-4,000 m are delivered on special bays or drums. They are laid in open trenches or use the trenchless method	The service life of PPP in the earth is 50 years. It allows the use of inexpensive fibre-optic cable without armour	Takes longer to install than laying a fibre-optic cable in open soil, and may cause damage to fibre-optic cable during earthwork
A5	Cable ducts	Fibre-optic cable installation in ducts	Cable drainage consists of separate blocks (it can be concrete, asbestos-cement or plastic pipes of circular cross-section with an inner diameter of 100 mm) at a depth of 0.4-1.5 m, hermetically joined together	Asbestos-cement non-pressure pipes are not subject to corrosion and decay, are not prone to fouling, have low thermal conductivity and high strength, and is much cheaper than products of other materials	Sharp edges and rough inner surface can lead to damage to the cable insulation
A6	Tunnel	Fibre-optic cable installation in manifolds and tunnels	They are installed only when necessary, for example, during the construction of the tunnel		
L1	Air environment	Suspension cable installation using anchor clamps	Suspension of a self-supporting cable or 8-shaped cable on supports	Construction time is reduced, land allotment and coordination is not necessary, cables are less likely to be damaged at construction sites,	Shortened service life due to environmental influences, susceptibility to increased mechanical stresses in adverse weather conditions, and
L2	Air environment	Replacing conventional ground wire	Widely used in the construction of intrazonal and		

Type	Laying environment	Fibre-optic cable laying technology	Brief description of application	Advantages	Disadvantages
		of **high-voltage** power lines with new ones, inside which optical fibres are placed	backbone fibre-optic networks	and independence from soil types. The reliability of the fibre-optic cable laying along the supports is guaranteed when using a cable with tension that does not exceed 60 per cent of its ultimate tensile strength (in any operating conditions)	difficulty of calculating when exposed to loads in various operating conditions
L3	Air environment	Attaching a fibre-optic cable to a ground wire or phase cable of a **low voltage** power line	On interzone and local lines, a self-supporting cable suspension with fastening on the lower traverse is used. This option is used on power lines with a voltage of 110 kV and higher, on overhead lines of lower voltage (10 kV and lower), as well as on low-voltage lines, lighting lines and supports of contact networks of railways		

Source: Технология прокладки ВОЛС. Available at https://skomplekt.com/technology/tehnologii_prokladki_vols.htm/.

Table 21 shows a proposed Form № 2 of initial data for completion by the infrastructure owner and telecom operator for designing the co-deployment project. The “*” sign in the form indicates the fields in which data can be provided by the design organization after performing a technical survey.

Table 21: Form № 2 for filling in initial data for the design of fibre-optic cable co-deployment with road transport or energy infrastructure

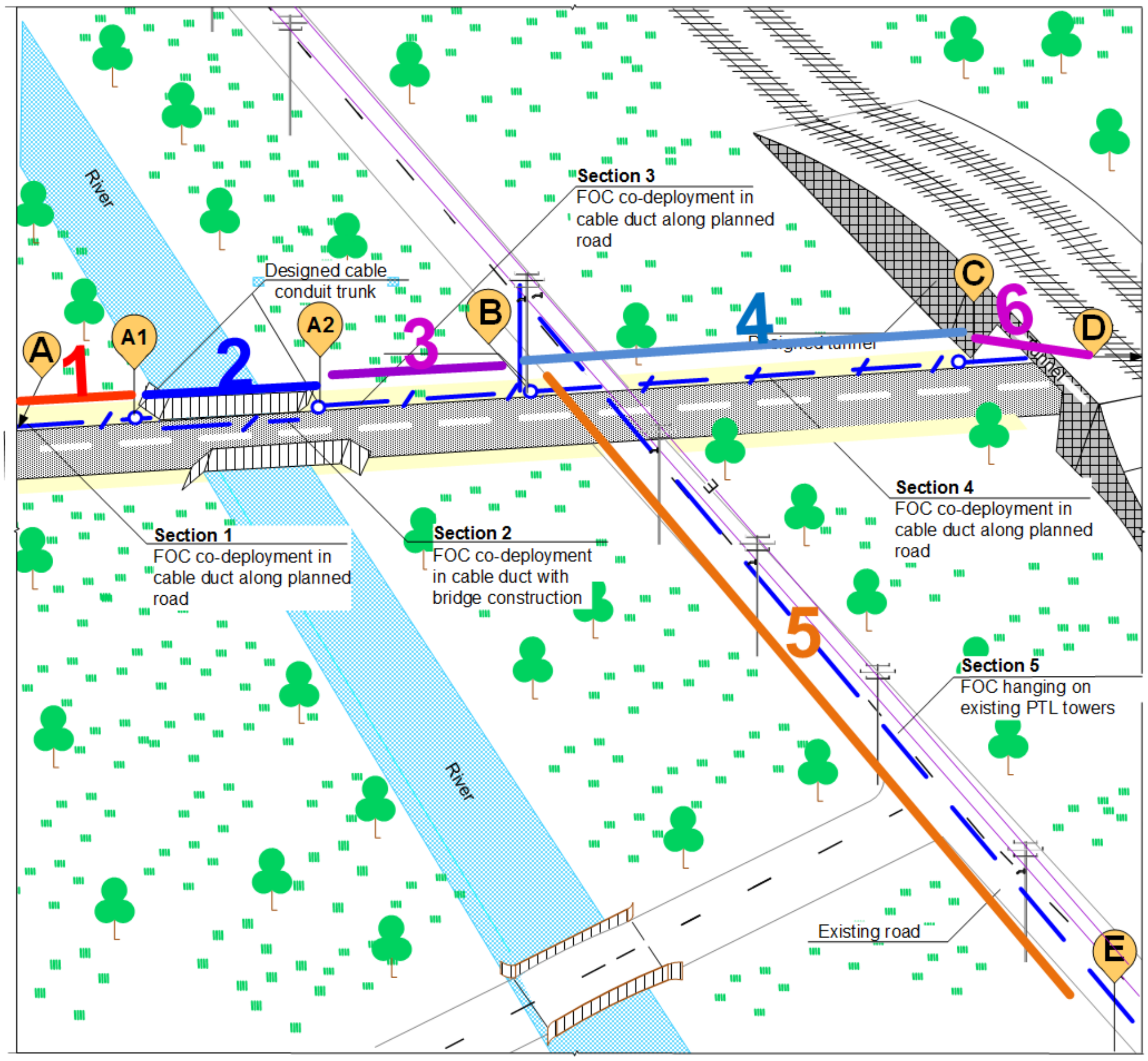
Route section number	Type of transmission system technology	Equipment needed in point		Length of route section, considering the terrain,* km	Type of fibre-optic cable	Required number of optical fibres, pcs	Notes
		Beginning of route section	End of route section				
1	2	3	4	5	6	7	8

Details for completing Form № 2 by column are as follows:

1. Reference number allocated for the route section for co-deployment (according to Form № 1);
2. Type of transmission system technology used in the route section to determine the length of the regeneration section (e.g., dense wavelength division multiplexing, coarse wavelength division multiplexing, passive optical network);
3. Model of the necessary active or passive equipment for connecting with other sections or demarcation points at the beginning of the route section (e.g., optical cable box, optical splitter, patch panel, switch with optical ports, optical coupling Crosver FOSC-M023/24-1-12, Mikrotik Cloud Router Switch CRS106-1C-5S, etc.);
4. Model of the necessary active or passive equipment for connecting with other sections or demarcation points at the end of route section (e.g., optical cable box, optical splitter, patch panel, switch with optical ports, optical coupling Crosver FOSC-M023/24-1-12, Mikrotik Cloud Router Switch CRS106-1C-5S, etc.);
5. Length of the route section, considering the terrain;
6. Type of fibre-optic cable on the route section; and
7. Number of optical fibres that need to be laid on the route section.

Figure 1 shows a scenario of ICT infrastructure co-deployment with road transport and energy infrastructure. Based on this scenario, the two forms with initial data have been completed. Table 22 gives an example of a completed Form № 1 based on the scenario in Figure 1.

Figure 1: Example of ICT infrastructure co-deployment with road transport and energy infrastructure.



Source: Author.

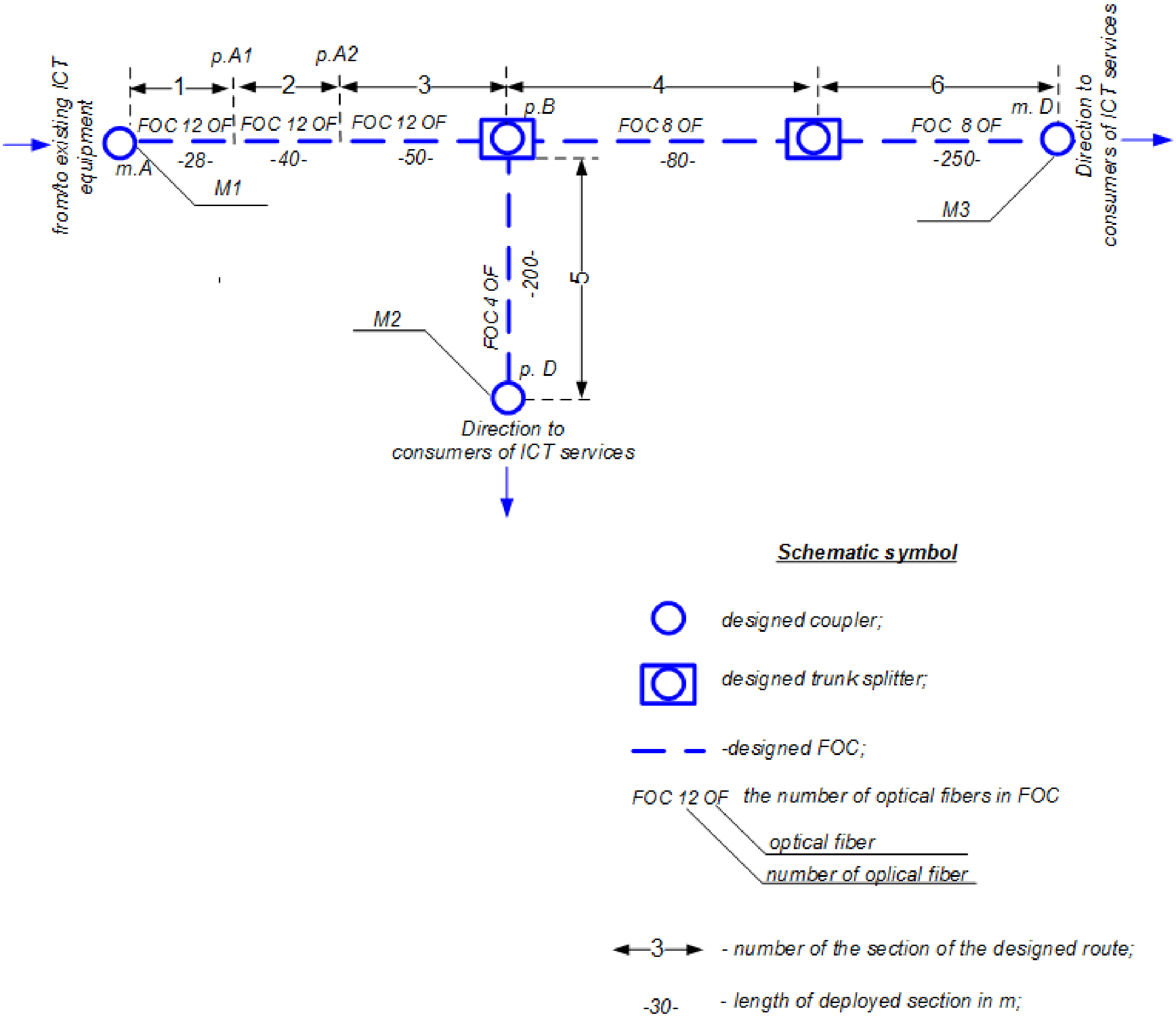
Notes: FOC = fibre-optic cable; and PTL = power transmission line.

Table 22: Example of a completed Form № 1 based on the scenario in Figure 1

Route section number	Coordinates for the beginning of route section*	Coordinates for the end of route section*	Type of infrastructure (road transport, energy)	Stage of implementation of infrastructure (new, existing)	Engineering constructions	Type of technology used for laying fibre-optic cable, according to Table 20*	Estimated month of route section building	Specific characteristics of the transport or energy infrastructure
1	2	3	4	5	6	7	8	9
1	A	A1	Highway	New	No	A1	April	Public road
2	A1	A2	Highway	New	Yes	A3	May	Public road
3	A2	B	Highway	New	No	A1	May	Public road
4	B	C	Highway	New	Yes	A1	June	Public road
5	B	E	Power transmission line	Existing	No	L1	June	Power transmission line of middle voltage class
6	C	D	Highway	New	Yes	A1	June	Public road

Prior to completing Form № 2, the telecom operator usually drafts a scheme for organizing communications of the designed ICT network. An example of a communications organization scheme is given in Figure 2.

Figure 2: Example of a communications organization scheme



Source: Author

Table 23 gives an example of a completed Form № 2 based on the scenario in Figure 1.

Table 23: Example of a completed Form № 2 based on the scenario in Figure 1

Route section number	Type of transmission system technology	Equipment needed in point		Length of route section, considering the terrain,* km	Type of fibre-optic cable	Required number of optical fibres, pcs	Notes
		Beginning of route section	End of route section				
1	2	3	4	5	6	7	8
1	GPON	Optical coupling Crosver FOSC-M023/24-1-12	-	28	ОКТБг-М(2,7)П-12Е1-0,40Ф3,5/0,30Н19-12	12	-
2	GPON	-	-	40	ОКТБг-М(2,7)П-12Е1-0,40Ф3,5/0,30Н19-12	12	-
3	GPON	-	Optical splitter 1x8, SC/UPC, 900 um, G657A FiberField	50	ОКТБг-М(2,7)П-12Е1-0,40Ф3,5/0,30Н19-12	12	-
4	GPON	Optical splitter 1x8, SC/UPC, 900 um, G657A FiberField	Optical splitter 1x8, SC/UPC, 900 um, G657A FiberField	80	ОКТБг-М(2,7)П-8Е1-0,40Ф3,5/0,30Н19-8	8	-
5	GPON	Optical splitter 1x8, SC/UPC, 900 um, G657A FiberField	Optical coupling Crosver FOSC-M023/24-1-12	200	ОКТБг-М(2,7)П-4Е1-0,40Ф3,5/0,30Н19-4	4	-
6	GPON	Optical coupling Crosver FOSC-M023/24-1-12	Optical coupling Crosver FOSC-M023/24-1-12	250	ОКТБг-М(2,7)П-8Е1-0,40Ф3,5/0,30Н19-8	8	-

Note: GPON = Gigabit Passive Optical Network

3.2 Content of a Typical Design Project and Project Documentation

The project documentation for designing ICT infrastructure co-deployment with road transport or energy infrastructure should include the following:

- General explanatory note on the project;
- Composition of the project;
- General construction plan;
- Working drawings for the construction of communications facilities;
- Construction organization plan; and
- Labour protection and fire safety in the construction of linear communications facilities.

The main decisions are recorded in the explanatory note on the project, and are specified by drawings and diagrams. As part of the main design decisions, the following should be included:[6]

- Technical requirements for the designed infrastructure according to technical standards and specifications;
- Technologies, tools and types of transmission systems necessary for the implementation of the services provided;
- Composition of the equipment used;
- Applicable topologies, architectures, standards and protocols of the data transmission networks;
- Formation of the territorial and logical structure;
- Boundary indicators necessary for high-quality traffic transmission;
- Initial data for drawing up contracts for the supply of equipment and fibre-optic cables; and
- Safety measures and labour protection during the construction, installation, maintenance and operation of the designed infrastructure.

[6] These recommendations are based on the author's experience.

3.3 Content of the Project's General Explanatory Note[7]

The project's general explanatory note should include the following sections:

- Introduction;
- Compliance of design solutions with regulatory documents;
- Basic design solutions; and
- Environmental impact assessment.

These sections of the general explanatory note are detailed below in turn.

Introduction

In the introduction to the general explanatory note, the co-deployment project's goals and objectives should be clearly stated, followed by a brief overview of the content of the general explanatory note, which is typically based on the initial data collected, including:

- Completed Form № 1 and Form № 2;
- Results of surveys and technical examinations (provided by specialists of the design organization); and
- Technical characteristics of telecommunications equipment that will be used to build the ICT infrastructure.

Compliance of Design Solutions with Regulatory Documents

This section ensures that the fibre-optic cable design process complies with the following legal and regulatory requirements in a country at the time of design:

- Laws and state standards;
- International standards and basic regulatory documents approved for use in the fields of road and rail transport, energy, and telecommunications;
- Building codes;

[7] This subsection is based on the author's experience in telecommunications network design.

- Standards for the issuance of project documentation;
- Standards for determining the categories of premises for explosion and fire hazard;
- Industry standards for telecommunications technology; and
- Industry building codes and design guidelines for linear cable communications facilities.

To ensure the safety of design decisions made, it is necessary to be guided by the requirements of the following documents:

- Laws on labour protection and environmental protection;
- Fire safety rules and codes of civil protection;
- Fire protection systems;
- Electrical installation rules;
- General requirements for construction and electrical safety;
- Safety rules when working on cable communications lines and wire broadcasting; and
- Basic provisions of labour protection and industrial safety.

Basic Design Solutions

This section indicates the applicable technology for ICT infrastructure co-deployment with road transport or energy infrastructure (see Table 24).

The most common method is the laying of fibre-optic cable in the right of way of roads or railways outside the subgrade. If this is not possible for economic or other reasons, the fibre-optic cable can be laid in the subgrade of a road or railway in compliance with current rules and standards.

As part of the basic design solutions, the prospects for road expansion or construction of additional rail tracks, drains and other structures need to be considered when choosing a route for laying the fibre-optic cable.

When designing in the right of way, the route should ideally run at the same distance from the edge of the road (or the nearest railway track) on the side of the terrain that is less rough, and with smaller areas of forests, snow-protected forest plantations, and marshy and flooded places, with a minimum exit over the right of way.

When choosing a route, priority should be given to directions with minimal intersections, and minimal proximity to the ground and underground structures and natural barriers. The choice of the route for cable laying is made after the completion of the vertical and horizontal plans for the construction of the road or railway lines.

Table 24: Types of fibre-optic cable laying technology along road transport and energy infrastructure

Infrastructure	Type of construction	Fibre-optic cable laying technology
Highway	In the body of the road In the right of way	• Laying fibre-optic cable in the ground • Laying fibre-optic cable in plastic pipes
Railway	Self-supporting fibre-optic cable suspension	• On the supports of contact network of the railway and power lines with voltage above 1,000 V
	In the body of railway In the right of way	• Laying fibre-optic cable in the ground • Laying fibre-optic cable in plastic pipes
Power transmission line	Fibre-optic cable suspension	• Fibre-optic cable placed inside lightning protection cable • Fibre-optic cable wound on phase or lightning protection wiring • Fibre-optic cable suspended between supports

Sources: Укладка волокна в асфальт - новая техника строительства ВОЛС. Available at http://www.fopc.ru/content/view/100/122/; Прокладка ВОЛС по опорам. Available at https://skomplekt.com/technology/prokladka_vols_po_oporam.htm/; and ГОСТ 33799-2016 Железнодорожная электросвязь. Правила подвески самонесущего волоконно-оптического кабеля на опорах контактной сети железной дороги и линий электропередачи напряжением выше 1000 В. Available at http://docs.cntd.ru/document/1200137173.

When designing the laying of fibre-optic cable directly into the ground (regardless of laying in the body of the road or the right of way), the following needs to be considered:

- Geological conditions, as well as chemical and mechanical influences;
- Preparation of the trench, the size of which depends on the number of cables being laid. The bottom of the trench needs to be filled with a 10 cm sand cushion, with all the stones, debris, bricks, and other sharp and dangerous objects removed from the ground;

- Method of rolling the cable, laying it in a trench and straightening, and providing at least 3 per cent of the cable stock in the length;
- Backfilling of cable with a layer of soft earth or seeded sand;
- Laying of warning tape to avoid damages to the fibre-optic cable in case of road reconstruction. The warning tape should be laid in a trench above the cable at 250 mm from its outer cover;
- Laying of coating to protect the fibre-optic cable from mechanical damage; and
- Backfilling of the trench and infrastructure reinstatement.

When the fibre-optic cable is to be laid in soils that are subject to displacement, design solutions include using wire armoured cable or putting in place measures to eliminate the forces acting on the cable (e.g., strengthening the soil with sheet pile or pile rows).

At the junction of the fibre-optic cable, and when designing the technological stock of cables, consider the installation of special cable joints on the soil surface in such a way that the coupling hatch is on the same level with the road surface.

In the executive schemes of the cable laying routes, route bindings are applied to constant landmarks (roads, railways, etc.).

The preferred design technology is the laying of fibre-optic cable in plastic pipe as it enhances the safety of the cable. The plastic pipe can be laid in the trench of the road body, on the side of the road (embankment) or in the right of way. Such a design solution has the following advantages:

- Extension of the construction season for laying fibre-optic cable in conditions of freezing soil at temperatures of up to -10 °C, provided that the pipes are laid earlier;
- Possibility of laying additional cables;
- Convenience of emergency recovery work without the need to excavate a trench or roadway;
- Additional protection of cable against loads resulting from soil deformation, the impact of rock fragments and effects of permafrost processes;
- Increase in the possible length of the segment due to the use of unarmoured cable; and

- Simplification of cable installation and increased safety for staff due to the lack of metal elements.

In making design decisions for laying a fibre-optic cable in soil or in plastic pipes, the distance between the fibre-optic cable and the outer surface of the road needs to be determined on a case-by-case basis. This distance should correspond to the design depth of the fibre-optic cable, and deployment should not deviate from the design by more than ± 0.1 m.

The choice of cable laying method should be justified by design decisions. In the design decisions for fibre-optic cable co-deployment with installation of the power transmission line, one of the three main types of fibre-optic cable laying is suggested:

- Fibre-optic cable is placed inside lightning protection cables;
- Fibre-optic cable is wound on phase or lightning protection wiring; and
- Fibre-optic cable is suspended between supports below power transmission lines.

When designing intrazonal and backbone fibre-optic networks, a fibre-optic cable is usually provided for inside a lightning protection cable, as the most convenient and reliable way to suspend a fibre-optic cable on a power transmission line. However, on interzone and local transmission line, the fibre-optic cable is often suspended below the power transmission line. This option is used on power transmission line with a voltage of 110 kV and higher, and on overhead lines of lower voltage (10 kV and lower), as well as on low-voltage lines, lighting lines and supports of contact networks of railways.

The design decisions determine the advantages and disadvantages of fibre-optic cable laying during the co-deployment of one kind or another. When co-deployed with construction of the power transmission line, the advantages are:

- Reduction of construction time;
- Lower capital and operating costs;
- Lack of need for land allotment and coordination with interested organizations;
- Reduction of possible damage; and
- Soil type independence.

The disadvantages of fibre-optic cable co-deployment with construction of the power transmission line include:

- Shortened service life due to environmental influences;
- Susceptibility to increased mechanical stress in adverse weather conditions;
- Calculation difficulties when exposed to loads in various operating conditions; and
- Additional calculations required to measure the bearing capacity of metal or reinforced concrete supports of the power transmission line for the additional load from the fibre-optic cable.

Environmental Impact Assessment

Equipment, materials and cable products used in the design of the fibre-optic network should be certified and approved for use, and meet the requirements of relevant laws and regulations, including those related to land, water and forest resources management, environmental protection, and environmental impact assessment.

Cable laying and installation of equipment do not affect the climate and microclimate, the geological environment, the aquatic environment, soils, flora and fauna. As a result of the operation of the equipment for cable laying and installation, there are no emissions polluting the atmosphere, and the existing ecological state of the environment is not affected.

Electrical and optical signals arising from the operation of the designed ICT equipment are localized in their ruling systems and are not sources of any radiation affecting the environment.

Fibre-optic cable terminal equipment and materials are environmentally friendly, as under operating conditions they do not produce harmful emissions, industrial wastes and noise, and do not harm the environment. They are also not included in the list of facilities that cause increased environmental risks.

For transportation to the installation site of fibre-optic cables, vehicles are used that pollute the atmospheric air, surface water and soil with toxic components from the exhaust gases of internal combustion engines, and contribute to industrial and operational waste. To reduce the impact of road transport on atmospheric air, the content of carbon monoxide and hydrocarbons in the exhaust gases of gasoline engines, and smoke in the exhaust gases of diesel engines should be monitored. The conformity of engine designs and their systems to the vehicles on which they are installed should be observed as well.

4. The Way Forward

To help state bodies and infrastructure owners successfully co-deploy the ICT infrastructure with road transport and energy infrastructure, methodologies and tools have been developed within the framework of this capacity building toolkit in consultation with policymakers of Kazakhstan and Kyrgyzstan in October 2019 in Almaty, Kazakhstan. The proposed methodologies and tools include the following:

- Methodology for determining the compatibility potential of ICT infrastructure co-deployment with road transport and energy infrastructure. This potential is defined through an evaluation of key parameters using a scoring system of either points or percentages;
- A parametric model of ICT infrastructure co-deployment with road transport and energy infrastructure. This model assesses the cost difference between separate deployment of infrastructure (ICT, road transport or electricity) and their co-deployment;
- Methodology for assessing the economic efficiency of ICT infrastructure co-deployment with road transport and energy infrastructure. This methodology is based on the principle of comparing an indicator of the speed of a specific increment in value for cases of co-deployment and separate deployment of the corresponding infrastructures;
- Methodology for identifying road transport and energy infrastructure projects that could include ICT infrastructure co-deployment. This methodology is based on hierarchy analysis, which consists of calculating a weighted indicator based on point estimates of several criteria and their weight coefficients, calculated by pairwise comparison; and
- Content of a typical design project together with initial data form templates for the design of ICT infrastructure co-deployment with road transport and energy infrastructure.

One of the main aspects that need to be strengthened for successful co-deployment is the coordination and cooperation of organizations, including the infrastructure owner of the road transport or energy infrastructure and the telecom operator, as well as relevant public and private organizations involved in the co-deployment process.

To promote coordination and cooperation, the development of a single information portal is recommended. It is envisaged that the portal includes information about all existing and planned engineering works that could potentially co-deploy fibre-optic cables. From the portal, online representatives of organizations, government agencies, potential investors and telecom operators would be able to find partners for the co-deployment of the ICT infrastructure with road transport or energy infrastructure, as well as post their information on priority areas for current investment.

Using this portal, all interested parties would be able to exchange documents, make changes and receive information on the status of the fulfilment of certain requests, as well as access and use the methodologies and tools proposed in this toolkit.

This single information portal could potentially increase competitiveness and provide access to relevant information based on equality and transparency, which in turn would minimize corruption.

As a way forward, the proposed set of methodologies and tools in this toolkit should be further tested through multidisciplinary and multisectoral efforts by planners in a real case-scenario along a transport or energy corridor, requiring the ICT infrastructure. The results gathered through this test would be instrumental in the decision-making process. These results of feasibility study should be reviewed and recorded by experts and peers for the attention of decision-makers.

Annex: Assessment of the Infrastructures' Compatibility for Co-Deployment

Annex 1: Assessment for Kazakhstan

Analysis of Compatibility Characteristics of Projects R1 and T1

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of the ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	8 (most of the route runs near existing power transmission line)	7 (technology depends on electricity)
		Service life of infrastructure	7 (15 years and above)	7 (20 years and above)
	Mean value		7.5	7
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of regulatory acts)	1 (lack of regulatory acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	3 (lack of clear and direct document approval mechanisms in case of co-deployment)	3 (lack of clear and direct document approval mechanisms in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	1 (no co-deployment experience)	1 (no co-deployment experience)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	3 (lack of clear operational management mechanisms)	3 (lack of clear operational management mechanisms)
	Mean value		1.8	1.8
3	Geographical	Extent to which the various infrastructure routes coincide	9	3 (not all fibre-optic cable length

			(not the entire road coincides with the fibre-optic cable)	coincides with the road)
		Influence by climatic and weather conditions, geodetic, and other features on infrastructure construction and operation	7 (road goes around the Kordai mountain pass)	3 (difficulty laying in the highlands)
	Mean value		8	3
4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	10 (significant rise in costs)	7 (rise in costs due to the complexity of delivering equipment to the mountainous regions)
		Social or military (defence) significance of the infrastructure	10 (international importance)	7 (social value)
		Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	7 (additional opportunities for the implementation of smart technologies)	5 (enhanced reputation)
	Mean value		9	6.3

Assessment of the Compatibility of Projects R1 and T1

Factor (*j*)	**Road transport or energy infrastructure**	**ICT infrastructure**	**Maximum deviation**
Technical	7.5	7	0.5
Organizational	1.8	1.8	0
Geographical	8	3	5
Socioeconomic	9	6.3	2.7
Mean value	6.6	4.5	2.05

Analysis of Compatibility Characteristics of Projects R2 and T2

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of the ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	3 (no existing power transmission line along the highway)	7 (technology depends on electricity)
		Service life of infrastructure	7 (25 years and above)	7 (20 years and above)
	Mean value		5	7
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of regulatory acts)	1 (lack of regulatory acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	3 (lack of clear and direct document approval mechanisms in case of co-deployment)	3 (lack of clear and direct document approval mechanisms in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	3 (probably no co-deployment experience)	3 (probably no co-deployment experience)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	3 (lack of clear operational management mechanisms)	3 (lack of clear operational management mechanisms)
	Mean value		2.2	2.2
3	Geographical	Extent to which the various infrastructure routes coincide	10 (the entire route coincides with the fibre-optic link)	10 (the entire route coincides with the fibre-optic link)
		Influence by climatic and weather conditions, geodetic, and other features on infrastructure construction and operation	5 (difficult to detect)	5 (difficult to detect)

	Mean value		7.5	7.5
4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	3 (terrain without complex geographical features, but with elevations, which can increase the cost of project)	1 (terrain without complex geographical features for fibre-optic lines)
		Social or military (defence) significance of the infrastructure	8 (partial international importance)	7 (social value)
		Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	7 (additional opportunities for the implementation of smart technologies)	5 (enhanced reputation)
	Mean value		6	4.3

Assessment of the Compatibility of Projects R2 and T2

Factor	Road transport or energy infrastructure	ICT infrastructure	Maximum deviation
Technical	5	7	2
Organizational	2.2	2.2	0
Geographical	7.5	7.5	0
Socioeconomic	6	4.3	1.7
Mean value	5.17	5.25	0.9

Annex 2: Assessment for Kyrgyzstan

Analysis of Compatibility Characteristics of Projects R1 and T1

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of the ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	8 (most of the highway route runs near existing power transmission line)	7 (technology tied to the availability of energy)
		Service life of infrastructure	7 (concrete coating – from 15 years and above)	7 (from 20 years and above)
	Mean value		7.5	7
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of legal acts)	1 (lack of legal acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	3 (lack of clear and direct document approval mechanisms in case of co-deployment)	3 (lack of clear and direct document approval mechanisms in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	1 (no co-deployment experience)	1 (no co-deployment experience)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	3 (lack of clear operational management mechanisms)	3 (lack of clear operational management mechanisms)
	Mean value		1.8	1.8
3	Geographical	Extent to which the various infrastructure routes coincide	5 (half of the highway route does not include fibre-optic cable)	10 (the entire length of the fibre-optic cable coincides with the highway route)

		Influence by climatic and weather conditions, geodetic, and other features on infrastructure construction and operation	8 (it is necessary to build two flyover bridges, and difficulty of highway construction through a narrow gorge)	5 (complexity of construction in mountainous areas, however, less costly than highway construction)
	Mean value		6.5	7.5
4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	8 (significant rise in costs)	7 (rise in costs due to the complexity of delivering equipment to the mountainous regions)
		Social or military (defence) significance of the infrastructure	10 (highway construction is of national importance)	8 (high social significance in the framework of the country's digitalization project, Digital CASA-1000)
		Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	7 (promising additional opportunities for the implementation of smart technologies)	7 (enhanced reputation from implementation of the country's digitalization project, Digital CASA-1000)
	Mean value		8.3	7.3

Assessment of the Compatibility of Projects R1 and T1

Factor	Road transport or energy infrastructure	ICT infrastructure	Maximum deviation
Technical	7.5	7	0.5
Organizational	1.8	1.8	0
Geographical	6.5	7.5	1
Socioeconomic	8.3	7.3	1
Mean value	6.02	5.9	0.625

Analysis of Compatibility Characteristics of Projects E3 and T2

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of the ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	10 (full dependency)	10 (full dependency)
		Service life of infrastructure	9 (25 years)	9 (20 years)
	Mean value		9.5	9.5
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of legal acts)	1 (lack of legal acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	3 (lack of clear and direct document approval mechanisms in case of co-deployment)	3 (lack of clear and direct document approval mechanisms in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	8 (experience hanging OPGW cable during construction of the Datka – Kemin power transmission line)	8 (experience hanging OPGW cable during construction of the Datka – Kemin power transmission line)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	2 (lack of clear operational control mechanisms in the presence of high voltages)	2 (lack of clear operational control mechanisms in the presence of high voltages)
	Mean value		3	3
3	Geographical	Extent to which the various infrastructure routes coincide	10 (the entire route coincides with the fibre-optic link)	10 (the entire route coincides with the fibre-optic link)
		Influence by climatic and weather conditions, geodetic, and other features on infrastructure	3 (according to the project)	1 (no additional constructions are needed)

		construction and operation		
	Mean value		6.5	5.5
4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	5 (terrain without complex geographical features, but with elevations, which can increase the cost of project)	2 (terrain without complex geographical features for fibre-optic cable)
		Social or military (defence) significance of the infrastructure	10 (international transit power line)	7 (fibre-optic cable can potentially have social significance due to proximity to large populated areas)
		Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	7 (promising additional opportunities for the implementation of smart technologies)	5 (plans for social use of fibre-optic cable on power line are difficult to evaluate, but the prospect to enhance reputation is quite high)
	Mean value		7.33	4.66

Assessment of the Compatibility of Projects E3 and T2

Factor	Road transport or energy infrastructure	ICT infrastructure	Maximum deviation
Technical	9.5	9.5	0
Organizational	3	3	0
Geographical	6.5	5.5	1
Socioeconomic	7.33	4.66	2.67
Mean value	6.58	5.665	0.9175

Analysis of Compatibility Characteristics of Projects R2 and T2

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of the ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	3 (low dependency)	10 (Need for electrification)
		Service life of infrastructure	5	5
	Mean value		4	7.5
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of legal acts)	1 (lack of legal acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	1 (there is no compatibility mechanism in case of co-deployment)	3 (lack of clear and direct document approval mechanisms in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	1 (no co-deployment experience)	8 (experience hanging OPGW cable during construction of the Datka – Kemin power transmission line)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	1 (lack of clear operational control mechanisms)	2 (lack of clear operational control mechanisms in the presence of high voltages)
	Mean value		1	3
3	Geographical	Extent to which the various infrastructure routes coincide	1 (there is no correlation)	1 (there is no correlation)
		Influence by climatic and weather conditions, geodetic, and other features on	7 (high mountain area)	1

		infrastructure construction and operation		
	Mean value		4	2
4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	7 (significant rise in costs)	5 (rise in costs due to special equipment usage)
		Social or military (defence) significance of the infrastructure	8 (access to minerals)	1 (due to mismatch of routes, social value is minimal)
		Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	2 (benefits of co-deployment are unclear)	2 (benefits of co-deployment are unclear)
	Mean value		5.66	2.66

Assessment of the Compatibility of Projects R2 and T2

Factor	Road transport or energy infrastructure	ICT infrastructure	Maximum deviation
Technical	4	7.5	3.5
Organizational	1	3	2
Geographical	4	2	2
Socioeconomic	5.66	2.66	3
Mean value	3.665	3.79	2.625

Analysis of Compatibility Characteristics of Projects R2 and T1

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of the ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	3 (low dependency)	7 (technology depends on the availability of energy)
		Service life of infrastructure	5	7 (20 years)
	Mean value		4	7
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of legal acts)	1 (lack of legal acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	1 (there is no mechanisms for documents approval in case of co-deployment)	3 (lack of direct mechanisms for documents approval in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	1 (no co-deployment experience)	1 (no co-deployment experience)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	1 (there is no operational control mechanisms)	3 (lack of clear operational control mechanisms)
	Mean value		5	1.8
3	Geographical	Extent to which the various infrastructure routes coincide	2 (pass nearby but do not match completely)	2 (pass nearby but do not match completely)
		Influence by climatic and weather conditions, geodetic, and other features on infrastructure construction and operation	7 (high mountain area)	5 (complexity of construction in mountainous areas, however, less costly than rail construction)
	Mean value		4.5	3.5

4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	8 (significant rise in costs)	7 (rise in costs due to special equipment usage in high mountain area)
		Social or military (defence) significance of the infrastructure	8 (access to minerals)	3
		Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	5 (promising additional opportunities for the implementation of smart technologies, but it is not known whether this is included in the business plan)	2 (benefits of co-deployment are unclear)
	Mean value		7	4

Assessment of the Compatibility of Projects R2 and T1

Factor	Road transport or energy infrastructure	ICT infrastructure	Maximum deviation
Technical	4	7	3
Organizational	5	1.8	3.2
Geographical	4.5	3.5	1
Socioeconomic	7	4	3
Mean value	5.121	4.075	2.55

Analysis of Compatibility Characteristics of Projects E3 and T1

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	10 (full dependency)	6 (technology depends on the availability of energy)
		Service life of infrastructure	9 (25 years)	7 (20 years)
	Mean value		9.5	7
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of legal acts)	1 (lack of legal acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	3 (lack of clear and direct document approval mechanisms in case of co-deployment)	3 (lack of clear and direct document approval mechanisms in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	8 (experience hanging OPGW cable during construction of the Datka – Kemin power transmission line)	1 (no co-deployment experience)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	2 (lack of clear operational control mechanisms in the presence of high voltages)	3 (lack of direct mechanisms for documents approval in case of co-deployment)
	Mean value		3	1.8
3	Geographical	Extent to which the various infrastructure routes coincide	1 (there is no correlation)	1 (there is no correlation)
		Influence by climatic and weather conditions, geodetic, and other features on infrastructure	3 (according to the project)	7 (difficulty of laying fibre-optic cable in the mountain areas)

		construction and operation		
	Mean value		2	4
4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	5 (terrain without complex geographical features, but with elevations, which can increase the cost of project)	7 (rise in cost due to special equipment usage for mountainous areas)
		Social or military (defence) significance of the infrastructure	10 (international transit power line)	5 (social significance in the framework of the country's digitalization project, Digital CASA-1000)
		Amount of additional opportunities gained from infrastructure co-deployment, including quality improvement	7 (promising additional opportunities for the implementation of smart technologies, but it is not known whether this is included in the business plan)	4 (enhanced reputation from implementation of the country's digitalization project, Digital CASA-1000, but the number of potential customers is difficult to assess)
	Mean value		7.33	5.33

Assessment of the Compatibility of Projects E3 and T1

Factor	Road transport or energy infrastructure	ICT infrastructure	Maximum deviation
Technical	9.5	6.5	3
Organizational	3	1.8	1.2
Geographical	2	4	2
Socioeconomic	7.33	5.33	2
Mean value	5.46	4.41	2.05

Analysis of Compatibility Characteristics of Projects R1 and T2

№	Factor (j)	Parameter	Assessment of the road transport or energy infrastructure	Assessment of the ICT infrastructure
1	Technical	Dependency of infrastructure on the availability of electricity	8 (most of the highway route runs near the existing power transmission line)	10 (full dependency)
		Service life of infrastructure	7 (15 years)	9 (20 years)
	Mean value		7.5	9.5
2	Organizational	Regulatory support for infrastructure co-deployment	1 (lack of legal acts)	1 (lack of legal acts)
		Number of approvals required for infrastructure co-deployment compared with separate deployment	3 (lack of direct mechanisms for documents approval in case of co-deployment)	3 (lack of direct mechanisms for documents approval in case of co-deployment)
		Presence of specialists with knowledge and skills in co-deployment in infrastructure project teams	1 (no co-deployment experience)	8 (experience hanging OPGW cable during construction of the Datka – Kemin power transmission line)
		Form of ownership (public or private) of the planned infrastructure project	1 (public)	1 (public)
		Level of complexity in infrastructure management	3 (lack of direct mechanisms for documents approval in case of co-deployment)	2 (lack of clear operational control mechanisms in the presence of high voltages)
	Mean value		1.8	3
3	Geographical	Extent to which the various infrastructure routes coincide	1 (there is no correlation)	1 (there is no correlation)
		Influence by climatic and weather conditions, geodetic, and other features on infrastructure	10 (it is necessary to build two bridges, and difficulty of highway	6 (presence of power lines along route)

		construction and operation	construction through a narrow gorge)	
	Mean value		5.5	3.5
4	Socioeconomic	Level of difficulty in the technological process of addressing terrain challenges	8 (significant rise in costs)	6 (presence of power lines along the route)
		Social or military (defence) significance of the infrastructure	10 (highway of national importance)	6 (fibre-optic cable can potentially have social significance due to proximity to large populations)
		Additional opportunities received by the infrastructure from co-deployment with other, including improving the quality	7 (promising additional opportunities for the implementation of smart technologies)	5 (plans for the social use of fibre-optic cable are difficult to evaluate, but the prospect to enhance reputation is quite high)
	Mean value		8.33	5.66

Assessment of the Compatibility of Projects R1 and T2

Factor	Road transport or energy infrastructure	ICT infrastructure	Maximum deviation
Technical	7.5	9.5	2
Organizational	1.8	3	1.2
Geographical	5.5	3.5	2
Socioeconomic	8.33	5.66	2.67
Mean value	5.78	5.41	2.135