

# ENERGY-INTENSITY'S ANALYSIS OF ROAD INFRASTRUCTURE - METHODOLOGY KEY ASSUMPTIONS

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**Abstract**— The aim of the article is to present the concept of analyzing the energy-intensity of road infrastructure. The concept involves the use of life cycle analysis of the road, therefore considerations are divided according to the stages of the cycle. It indicates how you can measure the energy-intensity of the road during construction, operation and liquidation of the road. Due to the fact that at the stage of designing of the road the energy consumption is marginal, it was omitted in the presented concept. Considerations are theoretical and are a unique concept of measuring resources-intensity of roads. Because of the conceptual nature of the issue, the article does not include a review of the literature.

**Keywords**—transport infrastructure, motorway, energy-intensity, sustainable development

## I. INTRODUCTION

CONDITION of the functioning of any economy is the transport infrastructure. Determines its development and growth. In terms of transport's modes, the most important in the implementation of business processes is a road infrastructure, especially motorways and expressways.

The importance of road infrastructure induces continuous investment needs, involving the construction of new sections or expands existing ones. The increase in roads can be seen in the vast majority of European Union countries, and in the countries of Central and Eastern Europe the highest growth of highways in the last five years occurred in Poland and Romania.

The increase in road infrastructure from the economic point of view is a positive phenomenon. However, you cannot only see the positive aspect of the roads growth. It should also be noted the negative impact on the environment, which is exerted by the roads. It can be seen in the context of resources-intensity, as well as in the context of negative external effects. The problem becomes greater - the greater is the increase in road infrastructure. From the point of view of sustainable development there is a certain conflict – on the one hand there is an obvious need for growth and development of road infrastructure. On the other hand the growth and

development of road infrastructure have a negative effect on the environment.

Resources-intensity of road infrastructure means the use of its various natural resources, such as energy, materials, water, land. The subject of discussion is the analysis of the use of energy for road infrastructure. Looking for a certain conception of the energy-intensity analysis of roads, posed the question: how to measure the energy-intensity of roads?

The justification for urgency such a defined problem is the fact that the world is consuming more and more energy, and this trend is permanent. There is no possibility of balancing energy demand both across the globe and continents, as well as individual countries, without actions aiming for rational use of energy. It is often more economical to the rational use of energy, than the construction of new generating capacity, based on the still imperfect technologies. This fact determines that in terms of energy modern economy puts a strong emphasis on energy efficiency while maximizing the effect of the global economic. This means that it is expected also a rational approach to the consumption of energy for road infrastructure.

## II. GENERAL ASSUMPTIONS

The level of energy consumption of a logistics facility is characterized by energy-intensity. Therefore, energy-intensity can be considered as a measure of the energy saving's level of a logistics facility.

Generally, the energy can be characterized in terms of sources and forms. One can distinguish the following sources of energy: fossil fuels, solar energy, wind energy, water energy, geothermal energy, tidal energy, oceans warm energy.

Because these sources come from nature, they are a group of primary energy sources. In addition to primary energy, you can also specify the secondary (derivative) energy, which is extracted from the derived energy that arises in the process of energy's transformation. Among secondary energy carriers may be mentioned electricity, heat and gas from technological processes. In listing

these examples can be seen that the energy takes different forms but each form may be converted into another one. The most important forms of energy include electrical energy, thermal energy, chemical energy, nuclear energy, radiant energy. The first three of the mentioned forms of energy are most important for the road infrastructure.

Use of energy for road infrastructure can be considered based on the life cycle of the road's object, specifying the following stages: construction stage, stage of use (exploitation), demolition's (dismantling) stage. Full lifecycle also includes the design stage. However, due to the relatively negligible energy consumption at this stage, it can be assumed that design stage, in the analysis of the energy consumption of road infrastructure, may be omitted.

## II. ROAD INFRASTRUCTURE ENERGY-INTENSITY BY STAGES OF THE LIFE CYCLE

### A. Stage of construction

At the stage of road construction, the energy is used in the process of obtaining raw materials, production of building materials and components as well as during construction. It is consumed so-called cumulative initial energy. The road is built with the energy not only in the direct final construction process, but in all known to complex and numerous previous processes. This total energy consumption conditioning the construction of the road referred to cumulative energy-intensity.

The energy consumption used to build the road, the so-called inserted energy; it can be stated in three streams:

- stream of energy carriers as the process of obtaining energy carriers, processing them into secondary carriers and send them to the process of road construction,
- material stream, ie. the process of obtaining natural raw materials, processing them into materials and the process of their transportation to construction site,
- stream of fixed assets as a construction process of machinery, equipment, buildings, etc., making up the objects of technological building's process.

Most often are assumed consumed energy in two streams, ie. in a stream of energy carriers and in the stream of materials. It is defined as cumulative operating energy consumption, and energy consumed in a stream of fixed assets - investment energy-intensity. It may be noted that energy consumption in the third stream, spread over the amount of product produced, which is spread over the length of the constructed road, is an insignificant part of the total cumulative energy-intensity. The biggest part is the material stream. In addition, in the case of imported carriers, as a rule, it takes into account only the accumulated energy that is essential to their processing and energy of logistics service which is carried out in the each country. It is also important that the analysis of energy intensity may include recyclable materials used

for the construction or the repair of roads, eg. road mass. Then it takes into account the consumed energy in the recycling process and the energy consumed during the implementation of logistics processes up to the place of road construction. Research of cumulative energy-intensity is usually conducted in the context of a specific technological process. The starting point is thus to determine which processes make up the process of construction of the road including the order of the adopted technology and work organization. It should be remembered that the construction process is a collection of technologically interrelated processes (works) carried out on the construction site and the hinterland and that can be divided into basic and auxiliary. Basic processes are carried out directly inbuilt object, and auxiliary processes are carried out directly on the object or outside.

Procedure for the energy's analysis of road's investment one should start from dividing the entire construction project for the partial processes which can be considered separately and defines this way the so-called technological grid of road. Here are two important aspects. First, you should determine the limits of the entire construction process determine when start is, and when the end - for example, is if the process starts with site preparation or may include more previous operations, consisting in adapting this area. Secondly, you need to pay attention to the extent of aggregation each process (operations), which results from the assumptions of the process approach. The number of separate sub-processes will depend on the constructional and technological complexity of road and from its size (length and width). Of course, the extent of process aggregation is important as well. Having defined partial processes and mapped sequences (chains) of subsequent technological operations leading to the construction of roads, you can go to determine firstly the energy-intensity resulting from the direct expenditures incurred on the road, and then explore the energy-intensity of individual streams, ie. the stream energy carriers, materials and fixed assets at earlier levels, this means - at the level of processing and sourcing. The condition of the energy intensity's analysis of the processes is to know the quantity of consumed streams and the corresponding indicators of the cumulative energy consumption. You cannot forget about the logistics processes that exist between levels. Energy consumed as a result of their implementation should also be taken into account. Therefore, the cumulative energy consumption in the construction phase of the road grasped cumulatively includes energy consumption, which exists throughout the supply chain, ie. in a sequence of processes to obtaining the raw materials, fabrication materials and equipment, including taking into account the logistics service of individual processes, which can be expressed by the formula:

$$E_{\Sigma b} = E_{bt} + E_{bm} + E_{bl} + E_b \quad (1)$$

where:

$E_{\Sigma b}$  – cumulative energy of road’s construction process,  
 $E_{bl}$  – energy used for site preparation,  
 $E_{bm}$  – energy used for the production of materials, machines and devices necessary in the process of road construction,  
 $E_{bl}$  – energy used in the processes of logistics service,  
 $E_b$  – energy consumed in the proper process of road construction.

Considering the elements of the formula (1), the cumulative energy consumption required to produce basic materials, equipment and construction machinery is expressed as ratio:

$$E_{bm} = x_{bm}^T G_{bm} \quad (2)$$

where:

$x_{bm}^T$  - indicators of cumulative energy consumption necessary for the production of materials, equipment and construction machinery,

$G_{bm}$  - the amount of materials, equipment and construction machinery used in the cumulative process of building,

T – making the operation of transposed matrix.

In order to determine the cumulative consumption of energy in logistic service, especially during transport, eventually even during storage, if these processes exist, you can use the following formula:

$$E_{bl} = E_{btl} + E_{blm} \quad (3)$$

where:

$E_{btl}$  – energy consumed as a result of transport processes,

$E_{blm}$  – the energy consumed by the processes of storage.

If the processes of storage do not exist, it can be assumed that:

$$E_{bl} = E_{btl} \quad (4)$$

The cumulative consumption of energy in the transport of materials, equipment and construction machinery can be determined using the formula:

$$E_{btl} = L_{btl}^T (G_{btl}^D x_{btl}) \quad (5)$$

where:

$L_{btl}^T$  – the distance of transport of materials, equipment and construction machinery,

$G_{btl}^D$  - A number of materials, equipment and construction machinery transported to the construction site,

$x_{btl}$  – indicators of cumulative energy needed to transport materials, equipment and construction machinery,

T – making operation of transposed matrix,

D – operation of creating a diagonal matrix of the column vector.

Formula (5) can be used in the case where the indicators of cumulative energy consumption in the transport processes are known and are expressed in MJ/(Mg·km). However, not always be the case, since the transport indicator MJ/km can characterize processes.

Then, to determine the energy  $E_{blt}$  should be applied pattern:

$$E_{blt} = L_{blt}^T (N_{blt}^D x_{blt}) \quad (6)$$

where:

$N_{blt}^D$  - the number of cycles of materials, equipment and construction machinery transportation.

Considering the cumulative energy consumption in the process of storage of materials, equipment and construction machinery, it can be determined using the formula:

$$E_{blm} = P_{blm}^T (G_{blm}^D x_{blm}) \quad (7)$$

where:

$P_{blm}^T$  – area for storage of materials, equipment and construction machinery,

$G_{blm}^D$  - A number of materials, equipment and construction machinery subjected to storage,

$x_{blm}$  – indicators of cumulative energy needed to processes of the storage of materials, equipment and construction machinery,

T – making operation of transposed matrix,

D – operation of creating a diagonal matrix of the column vector.

Cumulative energy consumption in the process of building a logistics facility is the sum of two components:

a) energy used in the form of auxiliary materials and products used directly in the construction process as well as during the preparatory work,

b) energy used during single works.

They can be expressed by the formula:

$$E_b = x_b^T G_b + z_b^T Z_b \quad (8)$$

where:

$x_b^T$  - indicators of cumulative energy needed to produce the auxiliary materials used in the construction of the logistic facility,

$G_b$  - consumption of auxiliary materials during construction,

$z_b^T$  - indicators of cumulative energy required to perform the works (tasks) during construction,

$Z_b$  - A number of works carried out during construction.

The level of energy consumption during construction of logistics infrastructure is conditioned by many factors. The most important may include:

- 1) the type of the logistics facility,
- 2) the size of the logistics object, eg. the length of the road,
- 3) construction of the logistics facility,
- 4) the structure of the supply chain,
- 5) the type of used materials and used equipment and machinery at different levels of the supply chain,
- 6) energy management in production processes of

materials, equipment, machines,

- 7) the amount and diversity of modal balance of transport processes, resulting from the structure of the supply chain,
- 8) the organization of transport processes,
- 9) the existence and organization of warehouse process.

#### B. Stage of use

In the case of road energy is used primarily for lighting its sections, lighting and power for equipment. Energy is also consumed by the control and traffic management's device, eg. the device for collecting data on traffic, traffic lights, as well as by equipment located on the crown of the road, especially for road signs and traffic signals and road safety equipment, wind and fog sounders, etc., device for measuring the movement, columns of emergency communications. If the road is international, must be considered the energy demand arising from the operation of the border crossings.

Levels of energy consumed during operation of roads are not officially registered. As it is known, there are data on the energy intensity of transport, but this is an approach of showing the energy consumption of individual transport modes without transport infrastructure. There are generally not recorded data in a cyclic manner and mandatory way, showing the size of the energy consumption of specific road. This information can be eventually taken from reports, studies or statements, However, it should be noted that they are usually very general and do not show the e.g. size of the energy consumed by each device on the road. To use an example, it can be mentioned that the level of energy consumption per year on the stretch of the A2 motorway in Poland, ie. between Konin - Nowy Tomyśl, with an indication of its kind is published by the Highway Exploitation Company SA. The report for 2010 shows that the total energy consumption amounted to 5 424 900 kWh and - as marks the company - its main sources of consumption are: motorway lighting, lighting and power supply for devices in the maintaining circuit, squares of Toll and in Service Areas and mechanical workshops. Booths at Toll are also heated by energy. It is difficult to determine whether this value is large or small. Its evaluation is not possible. Interesting would be a statement of comparison with other sections of the motorway A2 or from sections of other highways, both Polish and foreign.

TABLE I  
 ENERGY CONSUMPTION IN THE SECTION OF THE A2 MOTORWAY  
 KONIN - NOWY TOMYŚL (POLAND) IN 2009-2010

Types of energy	Unit	Consumption in years	
		2009	2010
Purchased electricity	kWh	5 607 138	5 424 900,00
Diesel fuel	T	432,6	511,02
Petrol	T	10	9,70
Methane natural gas	m <sup>3</sup>	34 600	381,00
Propane-butane gas	T	61,93	59,10

Source: own study based on data contained in: [1], [2], [3], [4].

How can you think during the operating of the road the energy is consumed to the greatest extent for lighting needs. The level of energy consumption is therefore dependent on the number of technical devices which are energized. The organization of highways maintenance circuits, Toll squares, service seas is also affected.

#### C. Stage of liquidation

In the last stage of the life cycle of the road, in the phase of liquidation, the cumulative energy consumption is the sum of:

$$E_l = E_{lr} + E_{ll} + E_{lu} \quad (9)$$

where:

$E_{lr}$  - cumulative energy consumption of the road's demolition,

$E_{ll}$  - cumulative energy consumption during logistics processes of road's demolition,

$E_{lu}$  - cumulative energy consumption during the waste disposal process after road's demolition or the energy recovery during waste disposal or both together.

Without going into a thorough analysis conducted in relation to this phase, one can add, that energy consumption depends mainly on the way of road's demolition and the choice of technologies for recycling and energy recovery while in the case of logistics processes - on the presence of waste storage processes, next to transport. On this basis it can also be noted that the amount of used energy is determined by the number and complexity of work carried out in liquidation phase of the logistics facility. The distance of landfill sites and the distance from the place where processes of recycling and recovery are realized is also important.

### III.CONCLUSION

The study of energy-intensity of logistics facilities may concern: a single building object, such as road, a group of objects in a given area, ie. the motorway network, and building objects in the entire country.

They can concern the whole life cycle of the logistics facility and can also refer to a selected stage. They serve analytical purposes and may also be the basis of comparative analysis. More precisely, they can be taken to: analyzing the energy demand, analyzing the structure of energy consumption, assessing the need for energy in different conditions of construction and use of the road, comparing the amount of energy needed for the process of road building using a variety of technologies.

#### REFERENCES

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