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Assessment of the level of innovation of a metal industry company using the life cycle assessment and technology readiness level

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ABSTRACT

The article presents a comprehensive assessment of the innovativeness of a manufacturing enterprise from the metal industry company, using an original method of diagnosing the state of innovativeness of enterprises. This method allowed for a comprehensive assessment of the level of innovativeness and eco-innovativeness of the enterprise, identification of sources of environmental impacts - product, production process, determination of the environmental profile of the enterprise, as well as assessment of the technologies used by the enterprise in terms of the TRL classification. The study showed that the enterprise has an average level of innovativeness, focuses primarily on the implementation of implementation works using technologies obtained from external sources. The process of manufacturing metal products is characterized by a significant impact on the environment, mainly due to high energy consumption. Energy used during production is a key source of pollutant emissions in all main categories of environmental impact, such as ecotoxicity (marine and freshwater), eutrophication of freshwater and toxicity to humans. In order to reduce the negative impact of operations on the environment, the enterprise should focus its activities on improving the energy efficiency of production processes.

Keywords: Innovatis, eco-innovatis, TRL, LCA, enterprise.

INTRODUCTION

Innovations and eco-innovations are an important factor in economic development, contributing to both economic growth and increasing the competitiveness of countries, regions and enterprises. Innovations can concern many areas of activity, such as: development of new or improved products, production processes, implementation of modern technologies, improvements in logistics and distribution, management innovations, as well as activities leading to material savings. The concept of innovation is interpreted differently both in scientific literature and in business practice. The concept of innovation was first introduced to the literature by the Austrian economist Schumpeter, already in 1911 in his first book "Theory of Economic Development". He treated it as a factor in economic development [1].

The word "innovation" comes from the Latin word "innovatis", meaning renewal, creation of something new [2]. The definition of the Organisation for Economic Co-operation and Development (OECD) and the Statistical Office of the European Communities (Eurostat) presents innovation as a new or improved product or process (or their combination) that is significantly different from the previous products or processes of an entity and that is made available to potential users (product) or put into use by an entity (process) [3].

The analysis of the literature on the subject allows us to distinguish three main stages in the development of the approach to innovation. The first stage, which took place in the 1960s and 1970s, focused mainly on defining and conceptualizing the concept of innovation itself. The publications were dominated by a descriptive nature, and research focused on analyzing the impact of various environmental factors on the functioning of enterprises. The second period, covering the 1980s and 1990s, brought interest in designing and shaping organizational structures that support innovation. Research began to address issues related to creating models of innovative enterprises [4]. The third, lasting from the 1990s to the present day, is characterized by treating innovation as a key tool that allows enterprises to achieve competitive advantage and better economic results. Greater importance began to be attributed to the economic aspects of innovation, not only technological ones. In this approach, innovation is perceived as a strategic effort of an organization aimed at introducing new products and services and maintaining competitiveness.

Nowadays, innovations are considered the foundation of economic development and attract the attention of researchers from many fields, such as sociology, psychology, engineering, economics and marketing. According to Repetowski the concept of innovation is understood as a certain complex of processes and phenomena covering not only the creation and implementation of innovation, but also its economic and social effectiveness [5, 6].

Measuring the ability to implement new solutions in an enterprise is a very important research task, which encounters difficulties resulting from the ambiguity of the concept of innovation and the multitude of methodological approaches [7]. In the literature on the subject, general studies of innovation and eco-innovation are often found, which allow for a statistical presentation of the level of innovation of countries, regions and enterprises [8]. Based on the results of these studies, rankings are developed to show the level of competitiveness of the surveyed entities on a local, regional and global scale. Detailed studies of the innovativeness of enterprises are published much less often, which makes it difficult to accurately assess their innovative activity, necessary for their development [9, 10].

The aim of this article is to present an assessment of the innovativeness of a manufacturing enterprise from the metal industry using the method of diagnosing the state of innovativeness of enterprises. The method used is a new perspective on the assessment of the innovativeness of enterprises, taking into account, among others, the impact of manufactured products and applied technologies on the natural environment [10]. This method was created in response to the deficiencies in the existing tools for assessing the innovativeness and eco-innovativeness of enterprises. It proposes a new approach to the analysis of innovative activities and indicates possible paths for further, sustainable development of the company.

Taking into account the need to implement innovative and pro-ecological solutions in the activities of enterprises, the analysis of innovativeness carried out in the article can be seen as a significant contribution to the implementation of development goals set by the European Union [11, 12].

METHODOLOGY

The method of assessing the innovativeness of enterprises used in the study belongs to the group of detailed studies, the aim of which is to assess individual enterprises. Within this approach, the assessment of innovativeness refers to two functional groups: technological innovativeness and intellectual innovativeness. Technological innovativeness covers what is directly related to products and the production process – i.e. products, machines and devices, applied manufacturing technologies. Intellectual innovativeness, on the other hand, focuses on creative activities, such as design, creative thinking or research and scientific work, the result of which are intangible effects, primarily knowledge. Innovation is assessed on a six-point scale [9]. The LCA (life cycle assessment) and TRL (technology readiness level) methodology were also used in the assessment of the innovativeness of the enterprise. The LCA measure allows for the quantification of the company's environmental impacts [10, 13]. The TRL measure shows at what TRL levels the company has experience in the product development process [14–17]. The company's environmental profile was determined, which allows for the indication of the source of impacts - whether the company's impact on the environment results from products, processes or other activities related to production [14]. The result of the analysis is a detailed characterization of the innovativeness of the examined entity, which is not limited to indicating the current level of the company's innovativeness, but also allows for the determination of favorable development scenarios that are aimed at improving the company's innovative and environmental efficiency. This approach allows the company to identify future development opportunities, as well as to determine the directions in which they can develop to increase their competitiveness and innovativeness. he research process was carried out according to the stages presented in Figure 1.

CASE STUDY

The case study presented below aims to comprehensively assess the innovativeness of a manufacturing company from the metal industry. Data for the analysis were obtained through face-to-face interviews based on a specially developed research questionnaire. Interviews were conducted in person with management representatives and employees of the research and development (R&D), technology, and production departments of the studied company. The questionnaire contained both closed-ended and open-ended questions, allowing for the collection of both quantitative and qualitative data. In terms of technological and intellectual innovation, the interview focused on identifying activities related to the development and implementation of new products, processes, services, and organizational and marketing solutions. In terms of assessing eco-innovation, the interview focused on identifying products and related production processes, as well as their impact on the environment. The collected data concerned the input and output aspects of the analysed processes, including the consumption of raw materials, materials and energy, emissions of pollutants into the air, soil and water, as well as generated waste. As part of the technological readiness assessment, the interview made it possible to identify the company's potential in terms of developing and implementing new technologies – from the concept stage to their practical application in the form of final products and processes. The interviews were conducted according to a pre-prepared script, ensuring the consistency of the information collected while maintaining flexibility in exploring interesting themes. The data was supplemented by analysis of internal company documents (e.g., environmental reports, technological development plans, technical

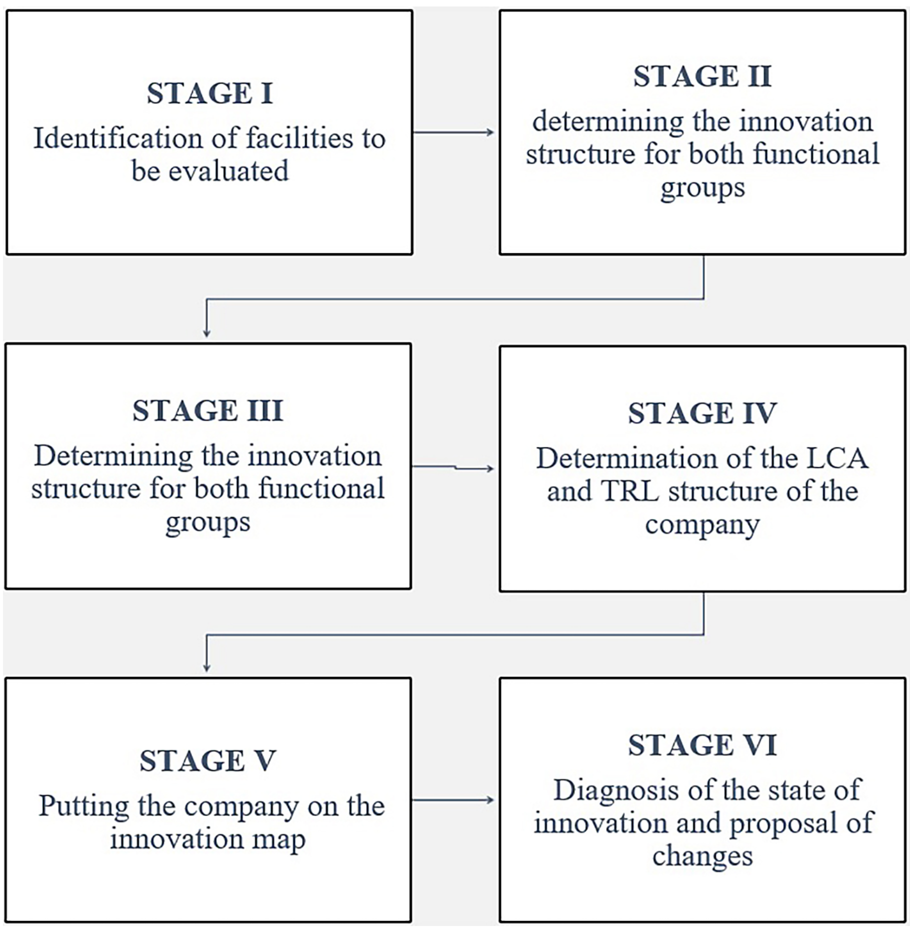

Figure 1. Stages of the methodology for the evaluation of the level of innovation of enterprises [14]

documentation) and direct observation during a site visit. All collected data was subjected to content analysis and source triangulation to ensure the credibility and reliability of the study results.

Stage 1

The first stage of the study, presented in Table 1, consisted in defining the objects subject to assessment, which were divided into two functional groups. The technological innovation group included activities directly related to products and production processes, such as products, machines and devices, applied production methods and employees involved in production [13]. Intellectual innovation is activities related to creative design, creative thinking, research and development work, i.e. activities that result in intangible products [14].

Stage 2

In the enterprise, the innovation structure coefficients αi and βi were determined for both functional groups according to formulas (1) and (2) [13]. The innovation structure of the enterprise is presented in Table 2 and Figure 2.

$$\alpha_i = \frac{u_i}{\sum_{i=1}^{6} u_i} \cdot 100\% \tag{1}$$

$$\beta_i = \frac{v_i}{\sum_{i=1}^{6} v_i} \cdot 100\% \tag{2}$$

where: μ_i – is an indicator of the number of objects assigned to the innovation zone i (i = 1,...,6) in the field of intellectual innovation; υ_i – is an indicator of the number of objects assigned to the innovation zone i (i = 1,...,6) in the field of technological innovation area.

Stage 3

During this stage, the values of the indicators of the structure of intellectual innovation (α_0) (3) and technological innovation (β_0) (4), are determined, based on which the values of intellectual innovation W_{IK} and technological innovation W_{IT} are determined, according to formulas (5) and (6) [13, 14].

Table 1. Assessment of the company's innovativeness

Enterprise			
Functional group	Scope of activity		
	Range	Evaluated factors	Rate
Technological innovation	Manufactured product	New generation paints High quality materials Simple construction of manufactured products	$\beta_{5=0.1}$ $\beta_{4=0.1}$ $\beta_{3=0.1}$
	Manufacturing techniques	Welding machines and robots Ecological requirements met Manual assembly in unit production	$\beta_{4=0.1}$ $\beta_{4=0.1}$ $\beta_{3=0.1}$
Intellectual innovation	Research and development work	Designing unusual systems Own design office Cooperation with research centres	$\alpha_{5=0.1}$ $\alpha_{5=0.1}$ $\alpha_{5=0.1}$
	Organization and management	Regular attendance and participation in exhibitions Quality management system Routine employee education	$\alpha_{3=0.1}$ $\alpha_{3=0.1}$ $\alpha_{4=0.1}$

Table 2. Enterprise innovation structure

Parameter	Innovation zone	Structure coefficients α of intellectual innovation		Structure coefficients β technological innovation	
Conservative (non-innovative)	Definitely	α_1	0.0	β_1	0.0
	Average	α_2	0.0	β_2	0.00
	Moderately	α_3	0.23	β_3	0.32
Innovative	Definitely	α_4	0.69	β_4	0.34
	Average	α_5	0.08	β_5	0.34
	Moderately	α_6	0.0	β_6	0.0

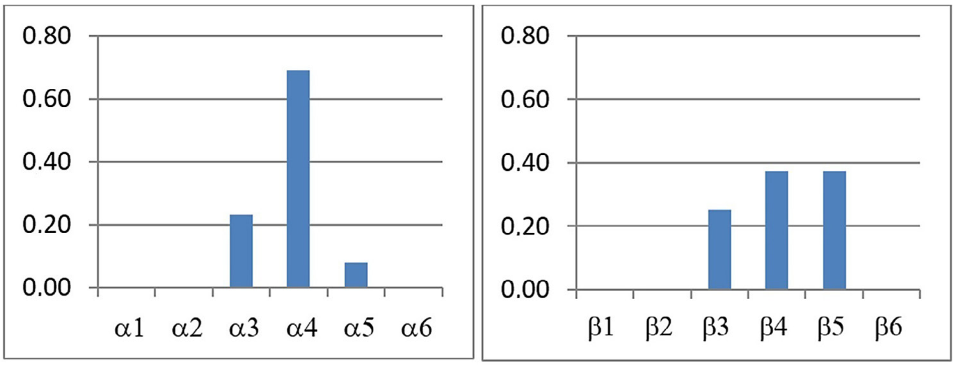

Figure 2. The structure of the company's innovation for both functional groups

$$\alpha_0 = \frac{\sum_{i=1}^{6} i \cdot (i \cdot \alpha_i)}{\sum_{i=1}^{6} (i \cdot \alpha_i)} \quad (3)$$

$$\beta_0 = \frac{\sum_{i=1}^{6} i \cdot (i \cdot \beta_i)}{\sum_{i=1}^{6} (i \cdot \beta_i)} \quad (4)$$

$$W_{IK} = W_{I,\text{ for}}\, \mu_0 = \alpha_0 \quad (5)$$

$$W_{IT} = W_I \text{ for}\, \mu_0 = \beta_0 \quad (6)$$

$$\begin{aligned} W_I &= 0.10 \cdot \mu_0 - 0.10 \text{ dla } 1 \leq \mu_0 < 2 \\ W_I &= 0.15 \cdot \mu_0 - 0.20 \text{ dla } 2 \leq \mu_0 < 3 \\ W_I &= 0{,}50 \cdot \mu_0 - 1.25 \text{ dla } 3 \leq \mu_0 \leq 4 \\ W_I &= 0.15 \cdot \mu_0 + 0.15 \text{ dla } 4 < \mu_0 \leq 5 \\ W_I &= 0.10 \cdot \mu_0 + 0.40 \text{ dla } 5 < \mu_0 \leq 6 \end{aligned}$$

In the enterprise, the indicator values are:
$W_{IT} = 0.71$ $W_{IK} = 0.79$

Stage 4

LCA structure

In accordance with the adopted objective of the study, which is to assess the impact of the company on the environment, the scope of the LCA analysis includes unit processes (products and production processes identified in the company) [19]. The company has 3 production lines: a steel container production line, a steel container and box production line, and a transport pallet production line. The study used a functional unit of 1 ton (1 Mg) of the final product as a reference point for the inventory of input and output data [20]. Then, the system boundaries were determined and all environmental inputs and outputs for the identified unit production processes and products were collected and quantified (Figure 3) [19–23]. As a result, the company's environmental balance was obtained, including, among others, used materials, energy, water, emission of pollutants into the air, soil and water, and final waste. Figure 4 illustrates the scope of the LCA analysis and the individual unit processes in the enterprise.

LCIA in a company using SimaPro 8.1 and ReCiPe Midpoint (H) methods. Individual products are assigned a weight that shows their relative share in the company's total production, which includes a detailed definition of the overall detailed profile. The obtained results were saved in the form of a MAT_{LCA} matrix table, thus obtaining the environmental profile of the company.

The study uses the ReCiPe Midpoint (H) method, whereby the columns correspond to different impact categories, such as climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical smog formation, dust formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land take, urban land take, conversion of natural land, water use, mineral use, fuel use [19]. The LCA structure is presented in Table3 and Figure 5.

The results of the company's LCA analysis show that the most significant negative

MAT_{LCA} matrix table:

$$M_{LCA} = \begin{bmatrix} 0.00034 & 0.00000 & 0.00046 & 0.00728 & 0.00056 & 0.00408 & 0.00013 & 0.00040 & 0.00002 & 0.00922 & 0.00002 & 0.00003 & 0.00005 & 0.00003 & 0.00091 & 0.00000 & 0.00132 & 0.00048 \\ 0.00021 & 0.00000 & 0.00028 & 0.00447 & 0.00033 & 0.00263 & 0.00009 & 0.00026 & 0.00001 & 0.00584 & 0.00687 & 0.00001 & 0.00002 & 0.00003 & 0.00061 & 0.00000 & 0.00102 & 0.00029 \\ 0.00012 & 0.00000 & 0.00017 & 0.00264 & 0.00022 & 0.00132 & 0.00004 & 0.00012 & 0.00001 & 0.00313 & 0.00365 & 0.00001 & 0.00001 & 0.00001 & 0.00027 & 0.00000 & 0.00021 & 0.00017 \end{bmatrix}$$

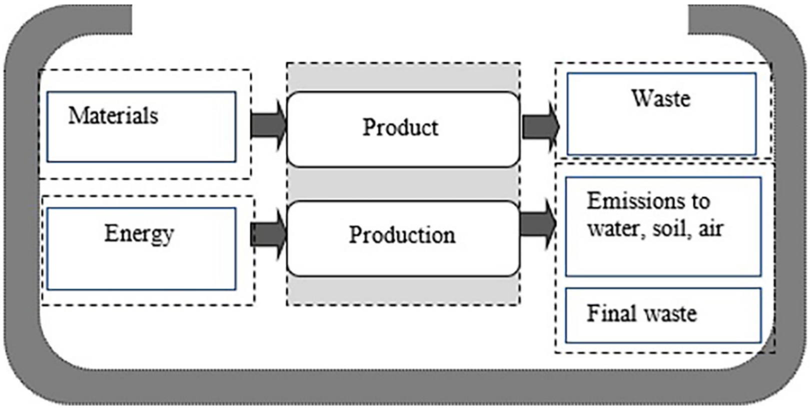

Figure 3. The general scheme of the inventory analysis of product and related to it production process [17]

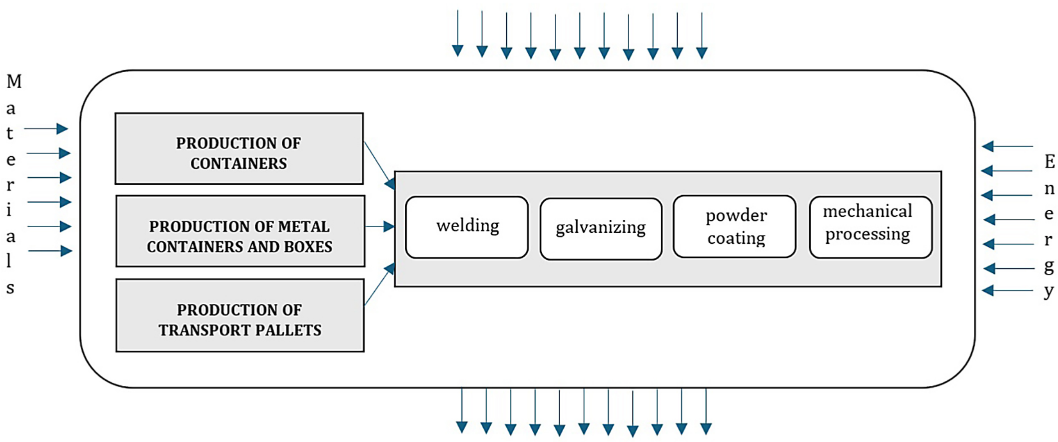

Figure 4. The area of life cycle analysis (LCA) and its basic unit processes

environmental impacts are concentrated in specific categories as marine ecotoxicity, freshwater ecotoxicity, and freshwater eutrophication (Figure 5). These impacts mainly come from the production of containers (Figure 6).

The analysis of the environmental impact profile of the adopted functional unit of 1 Mg of the analyzed product, i.e. production of containers, production of metal containers and boxes, production of transport pallets, shows that the greatest negative environmental repercussions occur in the following impact categories: freshwater ecotoxicity, marine ecotoxicity, freshwater eutrophication (Figure 7). The influences in the listed impact categories come mainly from the production of metal containers and boxes (Figure 8).

The analysis revealed that energy use during production processes constitutes the main source of pollution across all major impact categories. For instance, in the production process of containers, energy consumption is responsible for 69.8% of all impacts generated in the impact category of human toxicity (Figure 9). In the production process of transport pallet, energy is responsible for 94.5% of all impacts generated in the impact category of agricultural land occupation (Figure 10).

The source of pollution is also the materials used to manufacture products. In the analysed enterprise there are also impact categories where the dominant source of environmental impacts are materials, e.g.: in the production of metal containers and boxes, materials constitute 49.8% of all impacts related in the category natural land transformation (Figure 11), in the production of containers, steel constitutes 95.5% of pollution generated in the category of metal depletion (Figure 12).

Table 3. Enterprise structure coefficients in individual impact categories in the ReCiPe Midpoint (H) method

	Container production	Production of metal containers and boxes	Production of transport pallets	Structure factors $\alpha_i = \sum_{i=1}^{j} \alpha_{n1}$
Climate change	0.00034	0.00021	0.00012	0.00067
Ozone depletion	0.00000	0.00000	0.00000	0.00001
Terrestrial acidification	0.00046	0.00028	0.00017	0.00091
Freshwater eutrophication	0.00728	0.00447	0.00264	0.01439
Marine eutrophication	0.00056	0.00033	0.00022	0.00111
Human toxicity	0.00408	0.00263	0.00132	0.00802
Photochemical oxidant formation	0.00013	0.00009	0.00004	0.00026
Particulate matter formation	0.00040	0.00026	0.00012	0.00078
Terrestrial ecotoxicity	0.00002	0.00001	0.00001	0.00004
Freshwater ecotoxicity	0.00922	0.00584	0.00313	0.01819
Marine ecotoxicity	0.01083	0.00687	0.00365	0.02135
Ionising radiation	0.00002	0.00001	0.00001	0.00003
Agricultural land occupation	0.00003	0.00002	0.00001	0.00006
Urban land occupation	0.00005	0.00003	0.00001	0.00009
Natural land transformation	0.00091	0.00061	0.00027	0.00179
Water depletion	0.00000	0.00000	0.00000	0.00000
Metal depletion	0.00132	0.00102	0.00021	0.00254
Fosil depletion	0.00048	0.00029	0.00017	0.00095

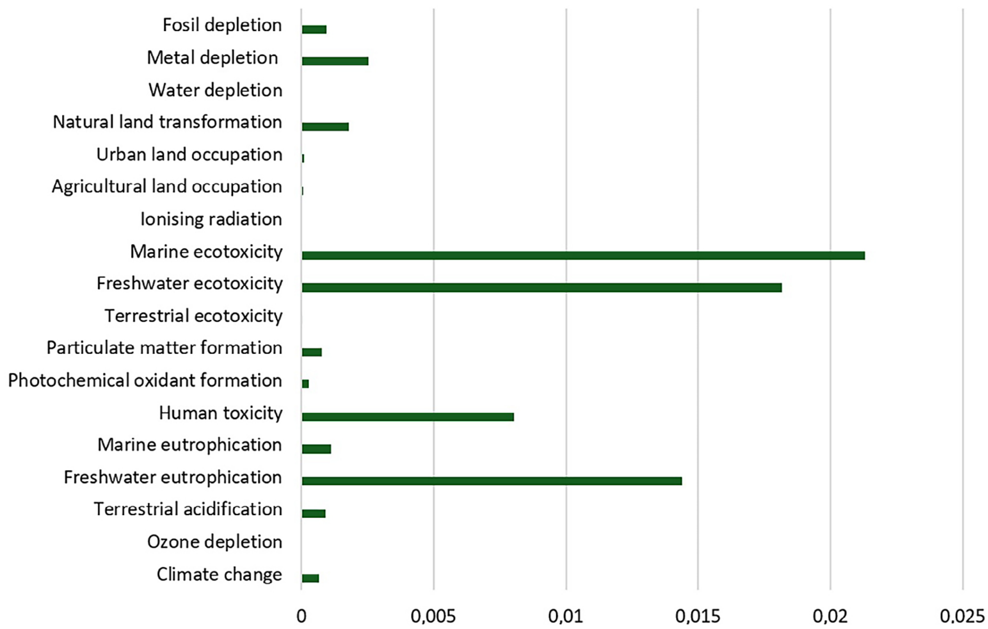

Figure 5. The LCA structure of enterprise

TRL structure

Five technologies were identified in the company that were subjected to TRL assessment. These technologies correspond to the subsequent rows of the $M_{\_TRL}$ matrix and are presented in Table 4.

$$M_{TRL} = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 2 & 2 & 2 & 2 & 1 & 1 & 1 & 1 & 1 \\ 2 & 2 & 2 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 2 & 2 & 2 & 1 & 0 & 0 & 0 \end{bmatrix}$$

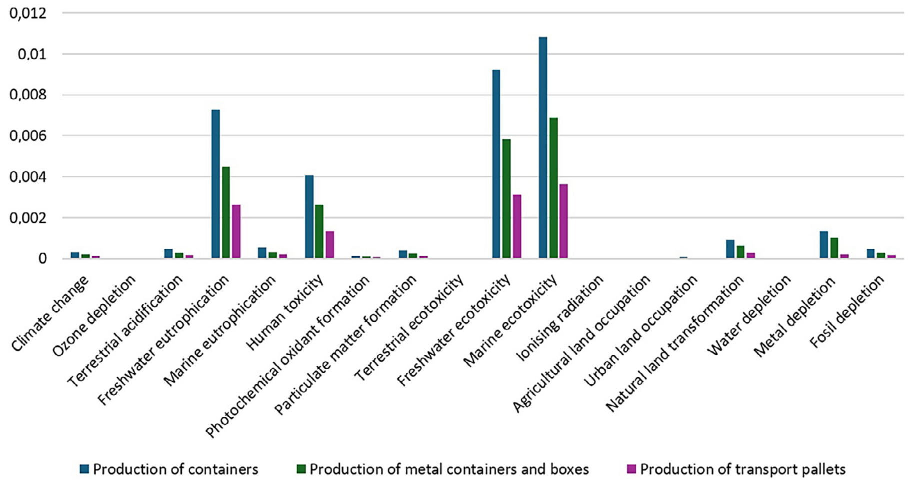

Figure 6. The LCA structure of enterprise: production of containers, production of metal containers and boxes, production of transport pallets

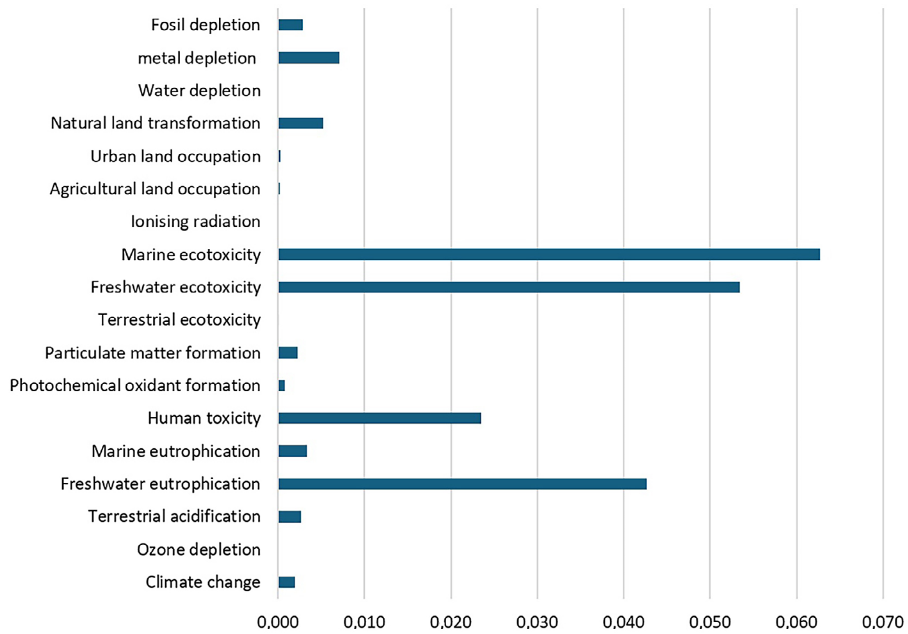

Figure 7. Ecological profile of 1 Mg of manufactured products in the enterprise

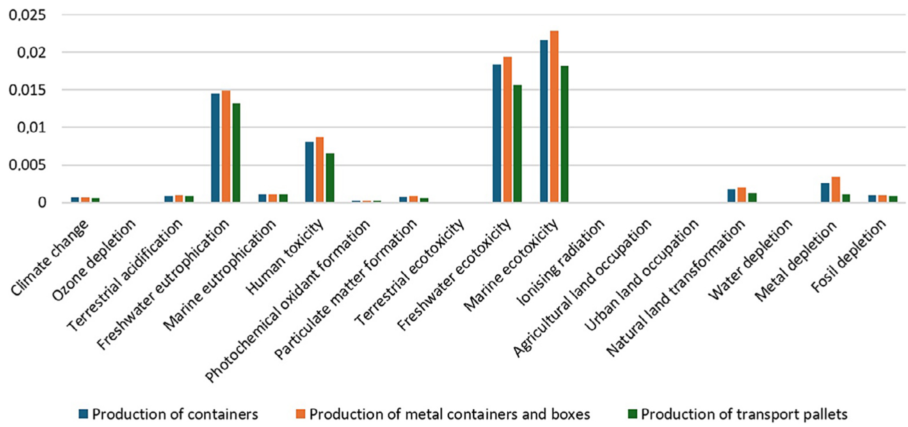

Figure 8. Ecological profile of 1 Mg of production of containers, production of metal containers and boxes, production of transport pallets

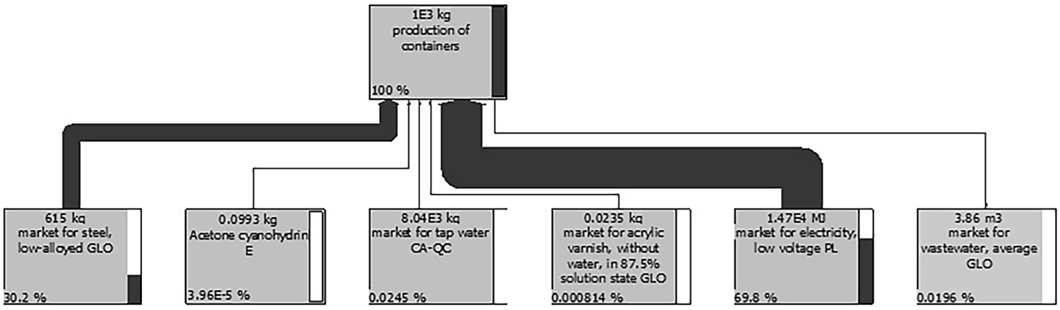

Figure 9. The proces tree of production of containers in the category of human toxicity

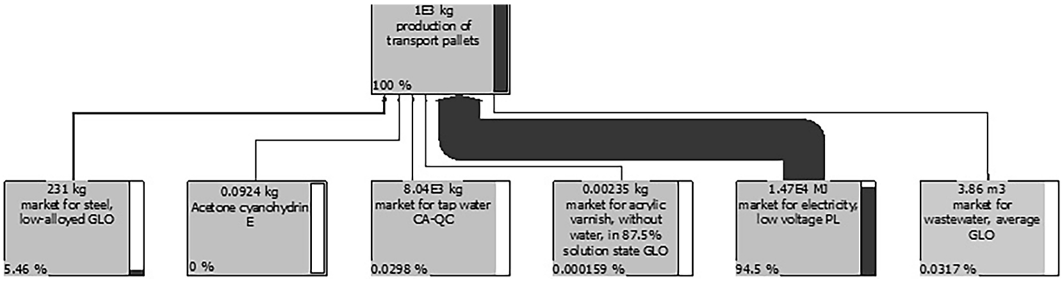

Figure 10. The process tree of production of transport pallets in the category of agricultural land occupation

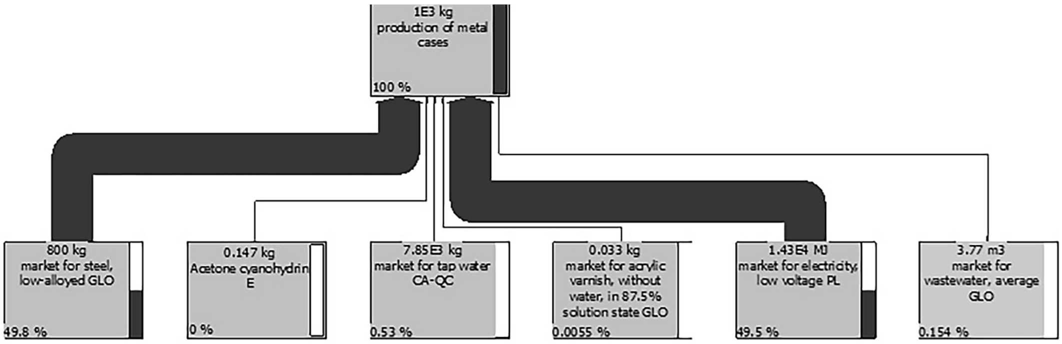

Figure 11. The proces tree of the production of metal containers and boxes in the category of

- *Technology 1* – development and implementation of a new container. Work related to this technology falls within the range of TRL levels 1 ÷ 4 with an average degree of complexity.
- *Technology 2* – development and implementation of a new material into the production process. Work related to this technology falls within the range of 1 ÷ 9, with an intensive and high degree of complexity.
- *Technology 3* – machining of the surface layer of a steel box based on its own patent. Intensive work with a high degree of complexity, located in the range of 1 ÷ 7.
- *Technology 4* – work on obtaining raw materials from waste (raw material recycling). These activities are in the range of 1 ÷ 4 with a medium level of complexity.
- *Technology 5* – technology for modifying the structure of the surface layer. Work related to this technology falls within the range of 2 ÷ 6 with a high degree of complexity.

The TRL structure factor calculated according to the formula (7) [12]:

$$\vartheta_i = \frac{\sum_{k=1}^{n} a_{ik}}{\sum_{i=1}^{9}\sum_{k=1}^{n} a_{ik}} \; for \; i = 1 \ldots 9 \qquad (7)$$

$$\vartheta_i = 0.02$$

The TRL index was calculated according to the formula (8) [12]:

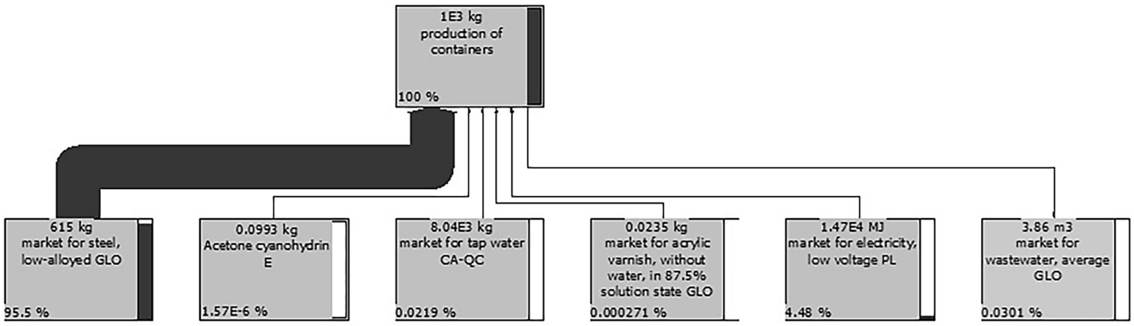

Figure 12. The process tree of the production container in the category of metal depletion

Table 4. The state of technology of the enterprise according to the TRL method

Enterprise	TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Technology 1	1	1	1	1	0	0	0	0	0
Technology 2	2	2	2	2	1	1	1	1	1
Technology 3	2	2	2	1	1	1	1	0	0
Technology 4	1	1	1	1	0	0	0	0	0
Technology 5	0	1	2	2	2	1	0	0	0

$$W_{TRL} = \frac{\sum_{i=1}^{9} i \cdot \vartheta_i}{\sum_{i=1}^{9} \vartheta_i} \quad (8)$$
$$W_{TRL} = 3.62$$

The TRL structure of enterprise is presented in Figure 13.

Stage 5

The innovation map is a graphical presentation of the W_{IK} and W_{IT} indicators determined for both functional groups [11]. These indicators in the analyzed enterprise are $W_{IT} = 0.71$ i $W_{IK} = 0.79$, which is presented in Figure 14.

Stage 6

The location of an enterprise on the innovation map makes it possible to determine the state of the enterprise's innovativeness, determines the recommended directions of change, indicates areas of activity where rational decisions on improvements should be made, and areas that represent the enterprise's strengths [13, 24].

The enterprise has an average level of innovation with a moderate advantage of intellectual innovation. The company is in the area of sustainable development. This result is the effect of most moderately innovative activities in the area of technological innovation and medium and moderately innovative activities in the area of intellectual innovation. A moderate advantage of intellectual innovation is an internal development stimulator. The suggested change scenario includes activities ensuring the maintenance of the current level of innovation with the possibility of developing technological innovation. An example of such activities is the commercialization of own scientific, research and design works, created in the enterprise thanks to the high level of intellectual innovation. An important element is also the further intensive development of employees through training in modern technologies, cooperation with scientific and research centers and investing in own research teams. The assessment of the company using The LCA analysis showed that energy consumption in production processes is the main source of pollutant emissions in all key environmental impact categories. Among the processes identified in the company, the largest burden on the environment is generated by the production of containers. However, taking into account the scale of the company's total production, the largest negative environmental impact is attributed to the production of metal containers and boxes. In order to reduce this impact, the company should focus its activities on increasing the energy efficiency of production processes. The implementation of these activities will allow the company to achieve not only environmental benefits, but also

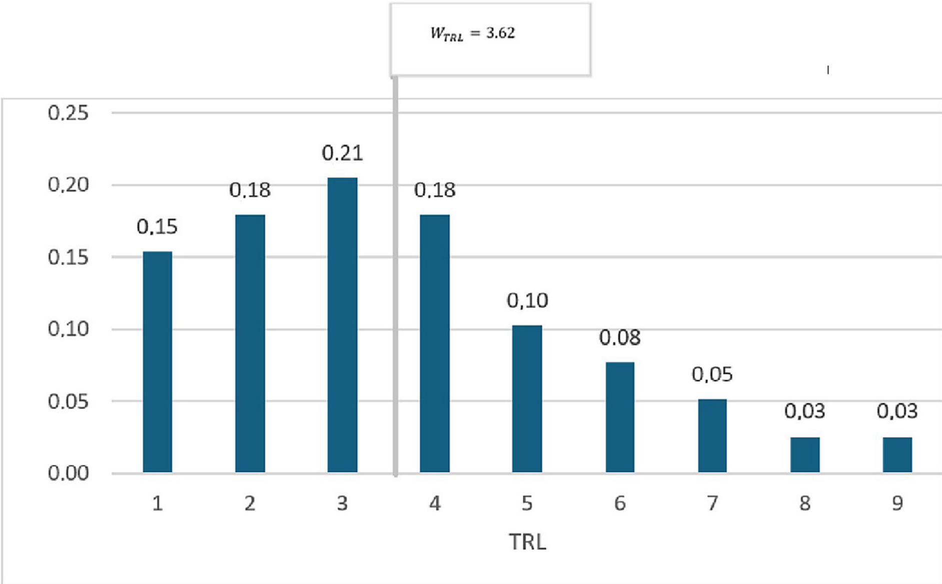

Figure 13. The TRL structure of enterprise

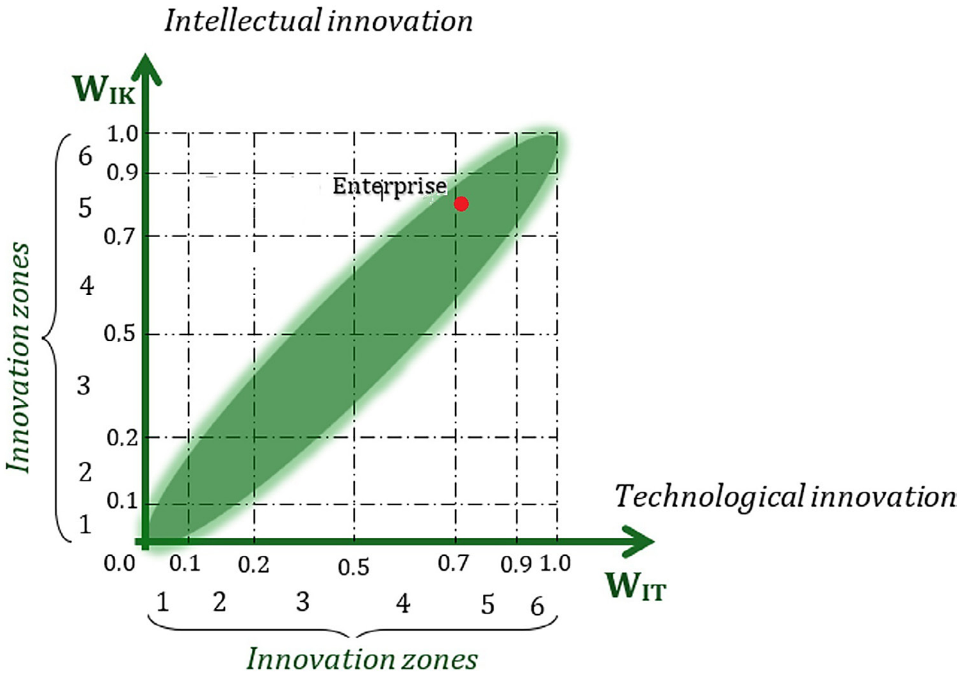

Figure 14. Company shown on the map

economic benefits resulting from lower production costs. The structure of technology readiness levels (TRL) shows relative evenness, which suggests moderately balanced technological development. Works at low TRL levels dominate, which indicates extensive research and development activities and, at the same time, limited implementation activities. The value of the TRL indicator W_{TRL} = 3.62 below the average value (W_{TRL} < 4.5) indicates significantly limited success in implementing the developed solutions. The enterprise should focus its activities on implementing and commercializing its research results.

CONLUSIONS

This paper analyzes the degree of innovativeness demonstrated by a manufacturing company from the metal products industry, using an novel method of diagnosing the state of innovativeness of enterprises. The study made it possible to obtain information on the level of innovativeness and eco-innovativeness of the enterprise. Using the LCA methodology allowed for identifying the environmental consequences of the enterprise's operations, as well as to identify the sources of these impacts - product and/or production process. The TRL method in assessing the level of development of technologies identified in the enterprise made it possible to obtain information on the sources of creation and use of new technologies in the enterprise, as well as information related to the experience of the enterprise in the process of product and technology development. This information presents the potential possibilities of the enterprise in the scope of conducting research and development works, which is helpful in formulating directions of development. The research method employed integrates the assessment of a company's innovation and eco-innovation potential with a technology readiness analysis, combining these three key areas into a coherent and complementary whole. This approach is crucial from a research perspective, as it enables a holistic view of a company's ability to generate and implement innovative technological solutions while simultaneously considering environmental aspects. This method yields a comprehensive picture of the organization's performance, taking into account not only the level of innovation and development potential but also the environmental impact of its operations and the ability to practically utilize new technologies at various stages of their technological maturity. This allows for the identification of synergies and interdependencies between eco-innovations, technological progress, and a strategic approach to development, which constitutes a significant contribution to building competitive advantage in the face of economic and ecological transformation. Considering the need to implement innovative products and technologies in enterprises that limit the negative impact on the environment, it is justified to state that the presented analysis of the enterprise's innovativeness is an answer to the challenges associated with the European Union's development pathways.

The results of the study indicate that the analyzed company is characterized by a moderate level of innovation, with intellectual innovation playing a dominant role. At the same time, a relatively low level of technological innovation is noticeable, as is limited effectiveness in implementing and commercializing developed solutions. The company's main weaknesses include, above all, the prevalence of low TRL, which indicates a concentration of activities on the early stages of research and development, while failing to progress to the implementation and commercialization phases. This problem is closely linked to the lack of a systematic approach to innovation management, particularly the lack of dedicated structures responsible for technology transfer and lifecycle management of innovative projects. Another barrier limiting the company's development is the insufficient utilization of the potential for collaboration with the scientific and industrial communities, which could support implementation processes and strengthen the technological and competence base. In the environmental area, the company faces high energy consumption, particularly in processes related to the production of metal containers and boxes, which translates into a significant negative environmental impact across all impact categories analyzed. These limitations are attributed to a lack of implementation skills, limited financial resources, weak coupling between the research and design phases and production, and the lack of a clearly defined innovation policy. To overcome the identified barriers, the company should undertake a series of strategic and operational actions. First and foremost, it is necessary to establish a specialized technology transfer unit responsible for project development from medium technology readiness levels (TRL 3) to the implementation stages (TRL 7–9). This unit should also be responsible for acquiring industrial partners, financing sources, and conducting implementation profitability analyses. The next step should be a systematic mapping of TRL levels in relation to ongoing research and development projects, along with the development of plans for their further development, tailored to each stage of technological maturity. A parallel program for the commercialization of R&D results should be implemented, including the assessment of market potential, the construction of prototypes, the implementation of pilot implementations, and the development of a market entry strategy. Another important aspect of the development process is strengthening cooperation with scientific and research institutions, including through joint demonstration projects, intensifying knowledge transfer, and organizing internship programs for employees. It is also recommended to conduct an energy audit and implement solutions aimed at improving energy efficiency, especially in the most energy-intensive stages of metal production. The long-term success of the organization will also depend on investments in the development of human capital, including specialized technical training, the building of interdisciplinary implementation teams and the effective transfer of know-how between individual departments of the company.

Compared to other companies with a similar profile (e.g., the production of metal containers and boxes), the analyzed company is at an average level in terms of technological innovation, but possesses above-average intellectual potential. Unlike more advanced entities in the industry, this company demonstrates a low degree of R&D implementation, which may be a barrier to building a competitive advantage. The results of the LCA environmental assessment are consistent with typical impact profiles in the metals industry, where energy consumption is the dominant factor. However, more environmentally advanced companies are already implementing solutions for heat recovery, process automation, and the use of renewable energy – these activities should serve as a benchmark for the analyzed entity. The company has significant growth potential, but its current structure and innovation management practices require reorganization. A key challenge remains the ability to translate concepts and knowledge into concrete technological implementations, which is a prerequisite for increased competitiveness, efficiency, and environmental sustainability.

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