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SYSTEM OF A COMPLEX ASSESSMENT OF TECHNOLOGICAL INNOVATIVE SOLUTIONS

Key words

Technological innovative solutions, complex technology assessment system, implementation maturity level assessment, commercial potential assessment, innovativeness level assessment.

Abstract

The article presents a system for the complex assessment of technological innovative solutions at different stages of their development, whose application facilitates the generation and the development of commercially viable products. The complex assessment comprises three individual technology assessment modules, including the implementation maturity level assessment, the commercial potential assessment, and the innovativeness level assessment.

The system has been developed, according to the conception of the authors of the paper, at the Institute for Sustainable Technologies – National Research Institute (ITeE – PIB) in Radom, Poland. It is mainly used for the assessment of solutions developed at the Institute, and it is also utilised by the Polish business support institutions and enterprises.

Introduction

The undertaking, execution, and implementation of competitive innovative technological solutions and the need for constant improvement of commercialisation procedures are the basic challenges for the sustainable

economic growth of any country. The development of an innovative solution is inherently problematic, because there are many substantial, technical and organisational issues that must be addressed, *e.g.*, the necessity to solve problems of novelty, tight timetables and schedules, and involving and coordinating R&D and industrial centres in the process. These issues constitute major obstacles to the very transfer of a developed solution to the economy.

The Institute for Sustainable Technologies – National Research Institute in Radom, Poland (ITeE – PIB) has broad experience in the development of innovative product, process and system solutions. Many years of the Institute's R&D activity, concentrated both on scientific research and practical implementation of developed technologies in industry, have shown that the very development of an innovative solution is not equivalent with its successful commercialisation. An effective execution of R&D tasks and the practical application of their results require a system approach bringing together the following issues supporting knowledge transformation and technology transfer processes:

- The organisation of operational processes determining the effective execution of tasks at different stages of the development of innovative product and process solutions,
- The search for effective technology transfer mechanisms and structures,
- The evaluation of R&D activity,
- The creation of organisational and IT platforms facilitating cooperation in the area of innovation dissemination, and
- The training of staff involved in the development and use of advanced technologies.

Among these issues, the one that is of crucial importance is the development and practical application of systems enabling the assessment of technical and organisational solutions that are either at the stage of planning, early development, verification, or transfer. The use of such systems facilitates decision-making processes concerning the undertaking of R&D tasks directed at the development of a novel technology or product, and it supports the monitoring of the development process and control over the marketing campaign.

This article presents an original approach towards a complex technology assessment that has been designed and applied by the authors of the paper, at the Institute for Sustainable Technologies – National Research Institute (ITeE – PIB).

1. State of the art

The methods for the assessment of innovative technologies were first used, and their importance appreciated, in the USA during the 1960s [1]. Generally, several trends concerning the understanding of the term "technology assessment" can be indicated, and different areas of this assessment can be identified, depending on the approach towards a technology development

process. One of approaches treats the technological innovation development process as determined by legal requirements, national or regional regulations, or the market forces; whereas, another – as a relatively unconstrained process, whose aim is to fulfil the social and political priorities, which can be executed with the support of either the government or interest groups. In their work, the authors of the paper assume that the basic usefulness of technology assessment methods and models stems from the fact that all technologies should comply with market needs, contribute to the improvement of the level of national economy's innovativeness and competitiveness, and simultaneously be coherent with national, regional, or EU priority R&D directions.

The assessment of technologies can be conducted with reference to numerous factors, i.e. technological, financial, or ecological. The first simple technology assessment models that considered only single factors were proposed in the 1970s by the National Science Foundation. With time, models and methods directed at a complex technology assessment incorporating key aspects of assessment, like implementation maturity or commercial potential, started to be developed and used. Technology assessment models and methods can be divided into different groups that vary with reference to the scope and the objective of the assessment [2]. As far as the scope of assessment is concerned, technology assessment methods focused on the following listed assessment aspects can be identified:

- The implementation maturity assessment (i.e. *Technology Readiness Levels* (TRL) [3] or more advanced – *Engineering Manufacturing Readiness Levels* (EMRL) by NASA, which initially were used by the US, Canadian and British Departments of Defence [4]; the implementation maturity level assessment (SDW) method developed and used at the Institute for Sustainable Technologies – National Research Institute in Radom [5, 6].
- The commercial potential assessment (i.e. *Commercial Potential Index* by NASA [7]; the *QFD* technique developed by Korean researchers representing the Han Nam University and the Electronics and Telecommunications Research Institute (ETRI) that can be used for technology analysis and assessment conducted by the organisation interested in the commercialisation or implementation of the technology to the highest level corresponding to the customers' needs [8]; the commercial potential assessment method by ITeE – PIB [9]).
- The industrialisation potential assessment of new or emerging technologies. It enables the selection of promising, infant technologies, whose implementation can form the basis for the development of local industry and which, at the same time, comply with current infrastructure, personnel and financial resources (practically executed in China[1] [10]).

[1] Used when organising Beijing Olympic Games in 2008 to select suitable construction technologies, i.e. technologies used for the construction of the stadium or the extension of the transportation network.

- The ethical technology assessment, i.e. "eTA" model [11]).
- Assessment of ecological aspects of a technology (i.e. set of simple criteria enabling comparison of green (environmentally friendly) technologies [12]).

As for the objective of the assessment, technology assessment methods facilitating the fulfilment of macroeconomic priorities can be distinguished. Among them are the methods directed at the achievement of the following significant objectives:

- The selection of priority technologies (i.e. the consideration of selection criteria connected with the possibility to obtain public support [13]; identification of critical technologies with significant economic or military importance [13]; the assessment model developed for the Industrial Technology Research Institute (ITRI) in Taiwan, which enables the selection of most promising technological solutions to be financed by governmental institutions [14]).
- The execution of the evaluation of an organisation with a technology portfolio (i.e. the *Technology Assessment Template* [15] by Chartered Financial Analyst Institute (CFA).

Apart from technology assessment methods directed at homogenous groups of assessment factors, the following complex assessment models have been developed that take into account various aspects of technology development:

- The complex technology assessment model used by the French Sophia-Antipolis science park for the analysis of preferred assessment criteria in 50 European and Chinese companies [16] (the model focuses on two basic issues including: company's technological competitiveness (internal factors controlled by the company and dependent on its activity and decisions), and the technology attractiveness determinants (external factors connected with the behaviour of consumers, government institutions and stakeholders));
- The model by Yung-Chi Shen, Grace T.R. Lin and Gwo-Hsing Tzeng from Taiwan's National Chiao Tung University [17] (the model refers to the DEMATEL technique (*Decision Making Trial and Evaluation Laboratory*) and patent analysis aimed at the assignment of proper weights to the agreed evaluation criteria, which include the following: the technological advantage (the advancement and the technology innovativeness level as well), the business effect (also possible return on investment, and the market size), the technology development potential (including availability of technical resources and technical success opportunities), the risk (commercial and technological)).

The experience gained by the researchers at the Institute for Sustainable Technologies – National Research Institute (ITeE – PIB) in Radom, Poland, shows that it is necessary to conduct a complex technology assessment in which a number of factors are taken into account. The development of innovative

technologies and the expected increase in the scale of the commercialisation of research results sets new targets for technology assessment systems. Tasks concentrated on the development of a complex technology assessment system were first undertaken at ITeE – PIB several years ago. The system under development considers the aspects of the implementation maturity level assessment (this module has so far been used for the assessment of several hundred technological solutions for research organisations, business support institutions, and enterprises), the commercial potential assessment, and the innovativeness level assessment (both models still under development and verification). The system is intended for the assessment of technological solutions at consecutive stages of their development, from the concept stage, through the development stage, to the final technology stage. The use of an integrated system of the complex assessment of technological innovative solutions will facilitate the generation and development of those solutions that have the greatest marketability opportunities. It will also support monitoring and control over innovation development, commercialisation, and implementation processes.

2. Complex technology assessment system as a tool facilitating the development and implementation of novel technological solutions

The following are the chosen assumptions of the system for the complex assessment of technological innovative solutions:

- The system is intended for the assessment of innovations in the area of technical support for sustainable development.
- The system is composed of the three following modules: the implementation maturity level assessment, the commercial potential assessment, and the innovativeness level assessment.
- The modules, depending on the objective of the assessment, can be used together as complementary operational packages or separately.
- The evaluated solutions can undergo assessment procedures at different stages of their development (i.e., planning and strategic decision making, innovation development, and its practical implementation) and the assessment results can be of help when generating future research directions.

The application opportunity of a complex technology assessment system or its individual modules at different stages of the assessment cycle is presented in Fig. 1.

The focal point of the article is the application of the system in question for the assessment of technological solutions at a stage of their development or at a stage of the finalisation of R&D works and the procurement of a final product (stages I and II of the assessment cycle). At these stages, the level of a solution's

implementation maturity, commercial potential, and the level of its innovativeness are crucial for further R&D works and the implementation process.

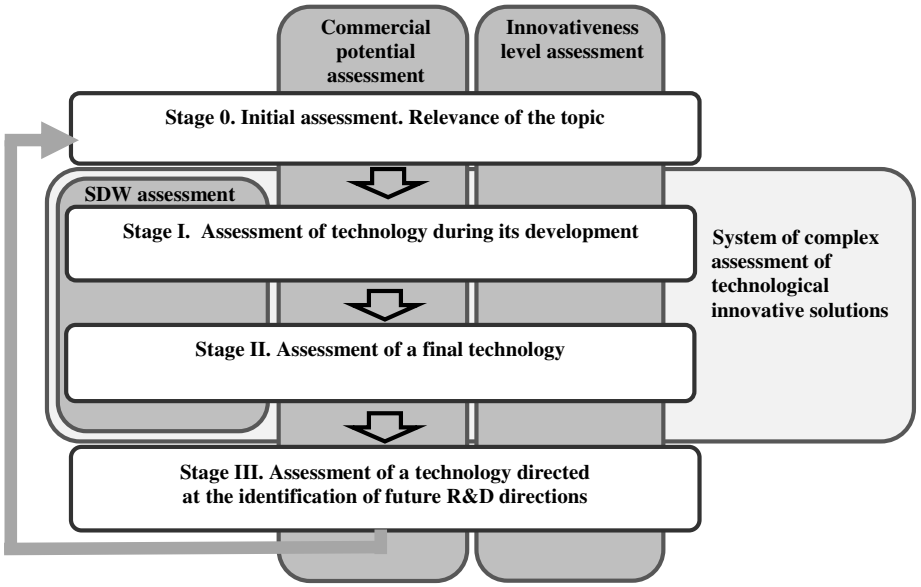


Fig. 1. Application opportunity of a complex technology assessment system or its individual modules at different stages of the assessment cycle
Source: Authors.

The implementation maturity level assessment method (SDW) by ITeE-PIB aims at the identification of the level of the advancement of R&D activities and a precise assessment of the implementation readiness of an innovative technical solution (Fig. 2). The assessment concentrates on technical aspects and pays no attention to issues connected with the implementation process itself (i.e. the way the product is going to be brought to the market, its potential effectiveness ("the business model"), or the level of the user's readiness to use a new technology [5, 6]).

In order to facilitate a successful application of the SDW method and standardise the results of its application, a set of general criteria corresponding with the 10 classified levels of technological solution development was proposed. The SDW classification levels determine the stage of the development of a given solution, including the advancement of R&D works.

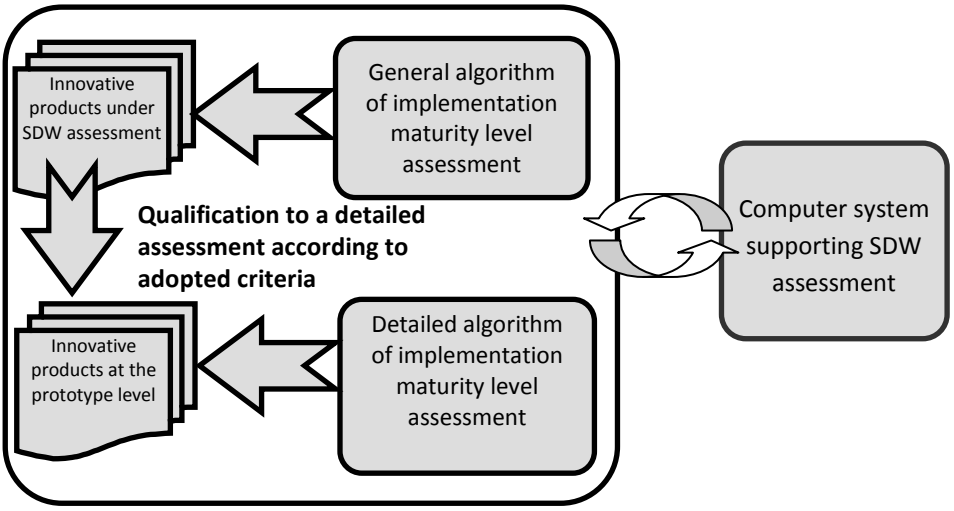


Fig. 2. Module of the implementation maturity level assessment
Source: Authors.

The effectiveness of the method was practically verified during the assessment of more than 280 innovative solutions resulting from the execution of the PW-004 Multi-Year Programme *Development of Innovative Systems of Manufacturing and Maintenance 2004–2008*, which confirmed the accuracy of adopted assumptions, assessment criteria, and as a result the effectiveness of the method [18, 19]. The method is also used for the assessment of innovative undertakings executed for technological parks and enterprises. The SDW method has lately been improved, and currently it constitutes a basic tool for the monitoring and the assessment of the advancement of R&D works within the *Innovative Systems of Technical Support for Sustainable Development of Economy Strategic Programme* realised in the 2010–2014 period within the framework of the Innovative Economy Operational Programme. It is also widely used by individual enterprises and research organisations.

The commercial potential assessment method (PK) is used to evaluate the market need for a particular technological solution. The assessment is conducted at the consecutive stages of a solution development, from the concept stage up to its practical implementation, and allows for the estimation of the marketability of the product. The PK method also enables comparative analyses between the change in the commercial potential and the assessment results obtained at earlier stages of a solution development process. These kinds of analyses are crucial for the commercial potential assessment, because the time factor significantly influences changes in the commercial potential of a given solution.

The PK method focuses on four areas – technological, market, financial, and regulatory (legal and organisational) – with individual assessment criteria. The method can also be extended with a detailed technology competitiveness assessment and a detailed financial assessment (Fig. 3).

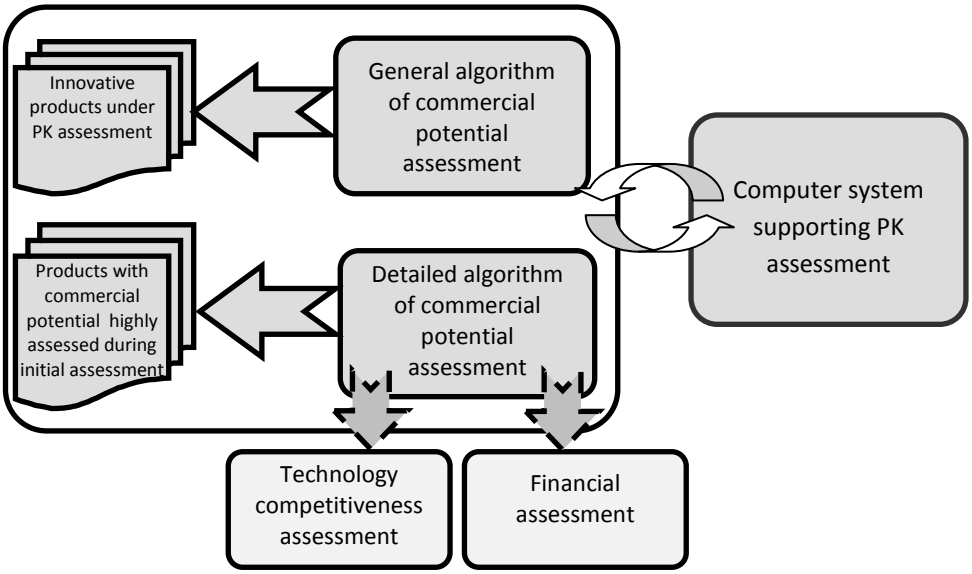


Fig. 3. Module of the commercial potential assessment
Source: Authors.

The application of the method enables the determination of the level of the commercial potential. The higher the assessment result, the lower the risk of commercialisation or implementation failure, and the higher is the probability of obtaining significant economic, technological, and social effects of practical innovation application.

The PK method enables the identification of opportunities and threats in the area of the commercialisation of innovative solutions. It constitutes a tool supporting the decision-making process concerning the continuation or, in the case of a very low commercial potential or the lack of it, the termination of R&D tasks. The effectiveness of the method was practically verified during the assessment of approximately 150 innovative technical solutions developed within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme [9].

The innovativeness level assessment method (PI) enables the identification of the level of the innovativeness of a technological solution expressed by the solution's added value for potential buyers. The initial module of innovativeness level assessment developed at ITeE – PIB takes into consideration the following criteria, which enable the determination of a solution's innovativeness level:

- innovativeness, competitiveness, the role of a technology in an organisation (technology provider),
- the scope of technology application,
- marketing criteria, and
- technological criteria.

The module of innovativeness level assessment is presented in Fig. 4.

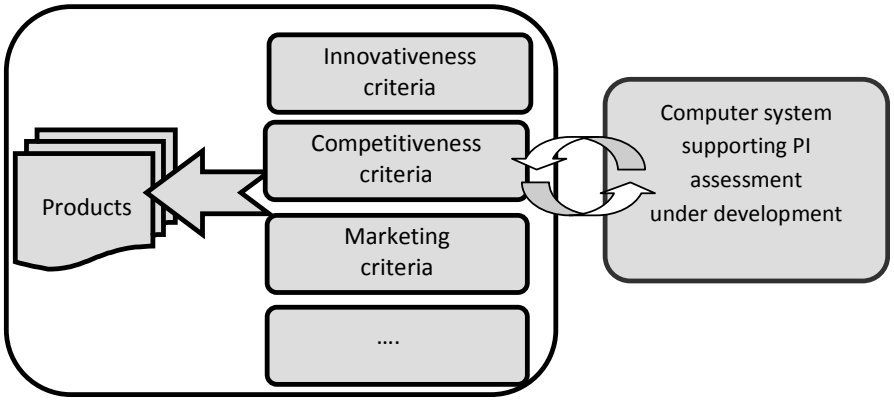


Fig. 4. Module of innovativeness level assessment
Source: Authors.

The module was verified during the assessment of 76 solutions resulting from the R&D tasks undertaken within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme, and it is currently being developed [20].

In order to make the assessment of innovative solutions easier, a computer system supporting the SDW and the PK assessments was designed (Fig. 5). The user interface has a form of a web application accessible through an Internet browser.

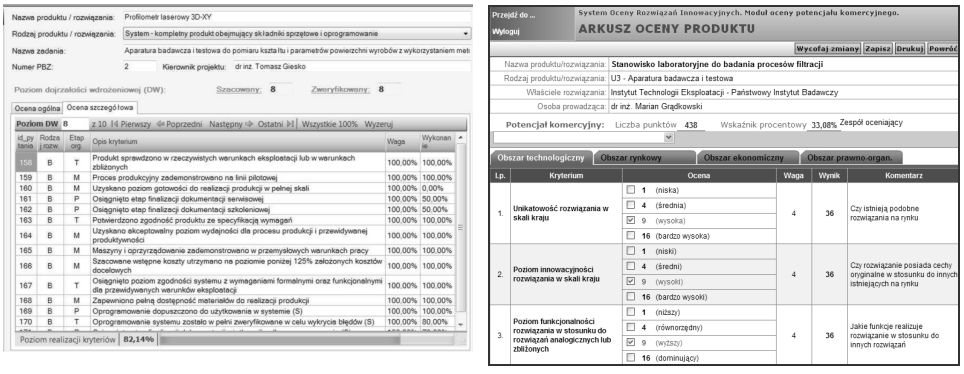
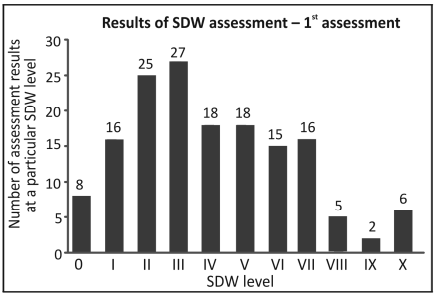
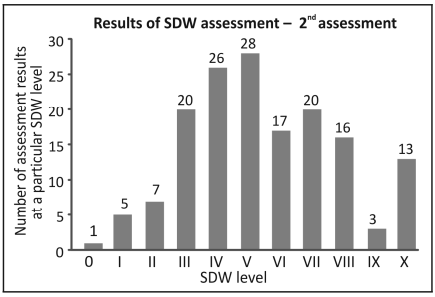
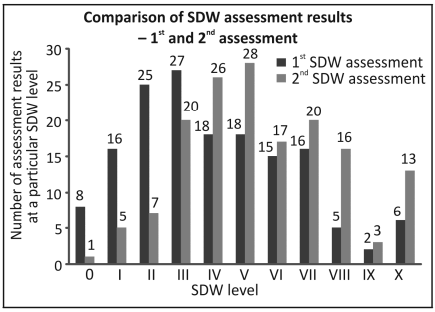


Fig. 5. Example of the application of the computer system for the detailed implementation maturity level assessment and the commercial potential assessment
Source: [5, 9].

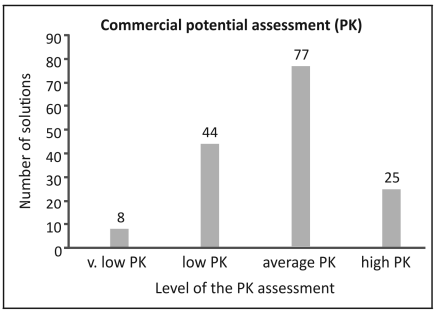
Implementation maturity level assessment (SDW)



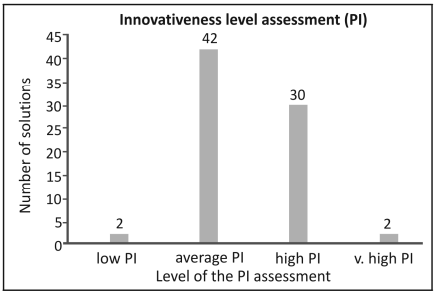




- 156 innovative technological solutions developed within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme were subject to the SDW assessment
- The implementation maturity assessment has been conducted twice so far within the Strategic Programme.



- 154 solutions developed within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme were subject to the PK assessment.
- The commercial potential of 102 of them was assessed as high or average, which shows that there are real chances for the practical implementation of these solutions, which is a very good result.



- 76 solutions developed within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme were subject to the PI assessment.
- The majority of the assessed solutions are characterised by a low or average level of innovativeness, and only 32 by high or very high; the results suggest that most of these solutions are of an incremental nature.

Fig. 6. Selected results of assessments conducted with the use of individual assessment modules and with reference to technological solutions developed within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme (SDW assessment conducted a year and two years after the launch of the Programme (in 2011 and 2012), PK and PI assessments – two years after the launch of the Programme (in 2012)).

Source: Authors.

The modules of this computer system are autonomous and can be used independently of one another. The examples of results of assessments conducted with the use of individual assessment modules and concerning innovative technological solutions developed within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme are presented in Fig. 6.

Nevertheless, the best results are achieved when conducting a complex technology assessment, which includes the implementation maturity level assessment, the commercial potential assessment, and the innovativeness level assessment. The individual modules of such a system for technology assessment are in fact correlated, which is depicted in Fig. 7.

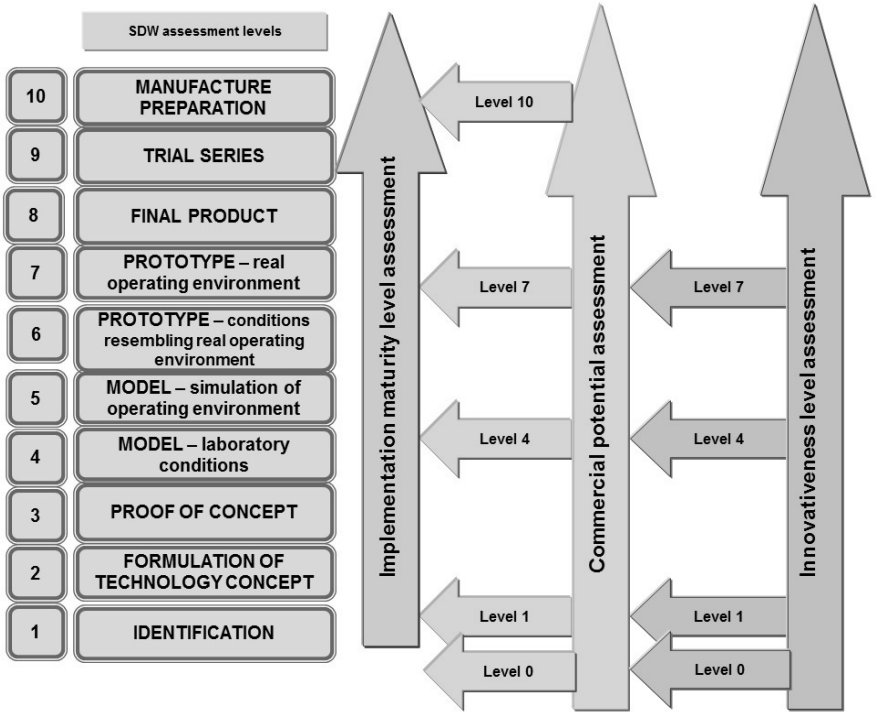


Fig. 7. Correlations between individual modules of the complex technology assessment system
Source: Authors.

The SDW assessment, and similarly the PK assessment, is conducted with reference to all new technological solutions. Commercial potential is assessed at least at four stages of the SDW assessment – identification, model, prototype, and manufacture preparation. The innovativeness level assessment is conducted in a parallel manner. It was assumed that the PI assessment should be conducted at the following stages of the SDW assessment: identification, model, and prototype.

The assessment of solutions at different stages of their development is essential, due to the changing nature of assessment results at different stages of the innovation development process (Fig. 8).

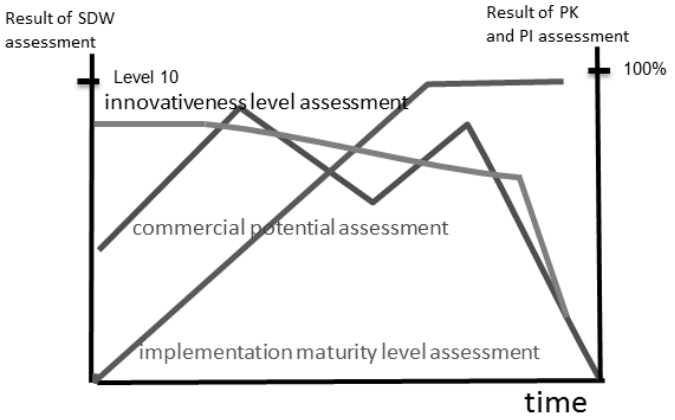


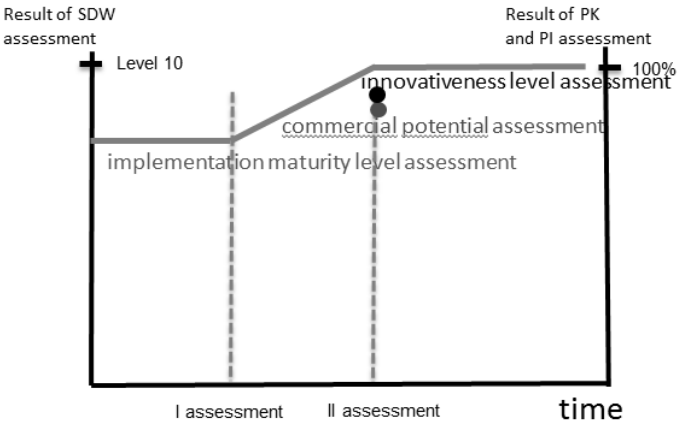
Fig. 8. Selected changes in assessment results during the innovation development process
Source: Authors.

Examples of the results of the complex assessment of selected technological solutions developed within the *Innovative Systems of Technical Support for Sustainable Development of Economy* Strategic Programme are presented in Fig. 9. So far, two SDW assessments have been conducted, whereas the PK and the PI assessment were conducted only once. All the solutions developed within the previously mentioned programme underwent the evaluation. The assessments were cyclical, and they were conducted after each of the product development stages.

Results of a complex technology assessment can be used when the solution is still being developed, which supports decisions concerning the future of the solution (whether the development process should be continued or terminated) and decisions concerning the selection of appropriate mechanisms and structures enabling innovation commercialisation. A complex technology assessment system is a tool supporting the assessment of marketability opportunities of an innovative technological solution. The assessment results show potential possibilities for the commercialisation of an innovation. In case of solutions developed within the mentioned Strategic Programme, the mechanisms for their practical industrial implementation were proposed after their cyclically conducted assessments have reached the SDW level 6 or more (the level of prototype at least), and whose commercial potential and innovativeness level have also been evaluated. When selecting innovation

commercialisation mechanisms additional elements, e.g. the type of the end user (mass or single end user), the type of a technical innovation (mass or single product), and the character of innovation (incremental or emerging), are taken into consideration. The importance and the need for conducting a complex assessment of an innovative technological solution with the use of individual assessment modules varies and depends on the planned scale of practical implementation (single unit, short series, mass production) (Tab. 1).

a) Hybrid layer increasing the durability of forging dies and forms for pressure casting of colour metals developed within the research task *"Hybrid layers with increased resistance to thermo-mechanical fatigue"*



b) Prototype of a modular device for erosive wear tests developed within the research task *"Multifunctional hybrid layers on elements made of low carbon steel and light alloys"*

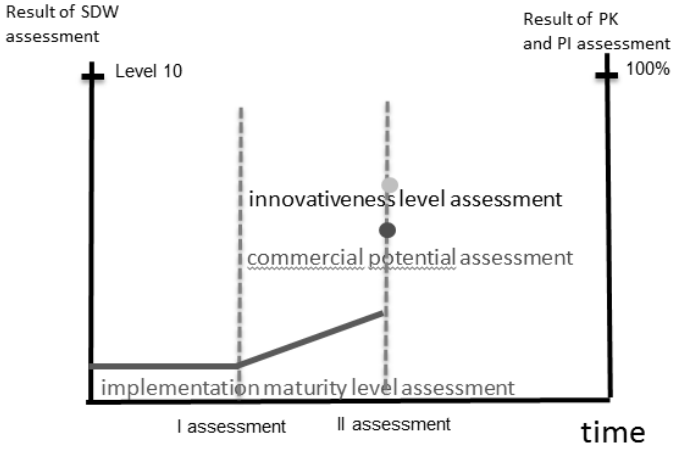


Fig. 9. Results of a complex assessment of selected technological solutions developed at ITeE – PIB

Source: Authors.

Table 1. Dependency between the need for innovation assessment and the character of the product

	Single end user	Short series	Mass production
SDW assessment	+	+	+
PK assessment	-	+ / -	+
PI assessment	- / +	+	+ / -

Source: Authors.

For instance, in the case of an individualised technological solution developed to meet the needs of a single end user, when the characteristics of the solution are already decided upon, the greatest importance is the solution's implementation maturity. Additionally, the PI assessment can be conducted. In practice, a complex technology assessment including the commercial potential assessment, apart from the two above listed assessments, should be conducted with reference to those solutions for which additional users are sought and those which are planned to be implemented on a mass scale.

The innovation implementation process at ITeE – PIB is supported by an original and a specialist system for technology transfer monitoring. The data fed into the system concern the results of the SDW, PK and PI assessments and the character of a solution, including the potential areas of application (market sectors, industry branches, actual end users (enterprises), IP protection, transfer mechanisms considered, and marketing actions undertaken. That information is the starting point for actions aimed at innovation dissemination, which are undertaken within the research task "Platforms for industrial dissemination of innovative solutions developed by research organisations in the area of sustainable development." The monitoring system is useful when selecting promotion and marketing strategies and looking for a particular end user. The data gathered in the system enables the verification of the effectiveness of marketing decisions made at the consecutive stages of innovation development and implementation processes.

Conclusions

Methods and models of the assessment of advanced product and process technologies are useful tools that support the development of innovative technological solutions that comply with the needs and the requirements of the market and enable their effective industrial implementation.

The complex technology assessment system developed by the authors at the Institute for Sustainable Technologies – National Research Institute, Radom, Poland, presented in this article enables the evaluation of the most essential aspects of a new solution, including its implementation maturity level, its commercial potential, and the level of its innovativeness. The main objective of the system is to evaluate innovations and compare the results of their

assessments at different stages of the technology development process, i.e. the concept stage, the development stage, and the final product stage. The system can also help to decide whether a particular solution should be developed. Additionally, it can be used after the finalisation of R&D tasks in order to generate possible directions for further development of a solution.

Individual modules of the system are interrelated. The application of the complex technology assessment system facilitates the monitoring of the innovation development process and an effective control and support for the decision-making process. Thanks to the IT applications, the system also stimulates effective transfer of research results into practice, and, as a result, facilitates the growth of the economy's innovativeness and competitiveness.

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Reviewer:
Andrzej KARBOWNIK

System kompleksowej oceny innowacyjnych rozwiązań technologicznych

Słowa kluczowe

Innowacyjne rozwiązania technologiczne, kompleksowy system oceny technologii, ocena stopnia dojrzałości wdrożeniowej, ocena potencjału komercyjnego, ocena poziomu innowacyjności.

Streszczenie

W artykule zaprezentowano kompleksowy system oceny innowacyjnych rozwiązań technologicznych na kolejnych etapach ich rozwoju, którego stosowanie ma umożliwić generowanie i opracowywanie rozwiązań o największych potencjalnie szansach wdrożeniowych. Kompleksowa ocena uwzględnia stopień dojrzałości wdrożeniowej, potencjał komercyjny oraz poziom innowacyjności.

System opracowany został wg koncepcji autorów w Instytucie Technologii Eksploatacji – Państwowym Instytucie Badawczym w Radomiu i stosowany jest na potrzeby oceny rozwiązań opracowywanych w Instytucie oraz ocen przeprowadzonych na zlecenie instytucji otoczenia biznesu i przedsiębiorstw.