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Conceptual Management Framework for Oil and Gas Engineering Project Implementation

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Abstract: More than half of the global demand for energy resources is covered today by oil and natural gas, and according to various forecasts, it is expected to grow 1.5–2 times greater over the next 30–50 years. This creates serious prospects for the development of the national oil and gas sectors of various countries, including Russia. Modern industry challenges create significant restrictions for the development of Russian oil and gas resources, and considering their predominant technological nature, the key solution is the increase in internal technological potential, in particular through the implementation of engineering projects aimed at creating the necessary technological solutions. This article presents an approach to the development of a conceptual management framework that will allow for the effective implementation of oil and gas engineering projects. The methodology of the research includes desk studies, systematization, the expert method (including interviews and questionnaires), grouping, generalization, and algorithm design techniques. The results of the study showed that effective implementation of engineering projects should be based on a systematic management approach, one of which is the TRA process. This article analyzes the TRA methods, on the basis of which key project readiness indicators are identified. Based on a literature review and the expert method, the relevant readiness indicators necessary for the assessment of oil and gas engineering projects are substantiated. Given these indicators, the authors proposed a framework for a comprehensive readiness assessment of oil and gas engineering projects and developed an algorithm for management decision-making on project implementation.

Keywords: engineering projects; oil and gas; resources; management challenges; framework; project readiness assessment; Technological Readiness Assessment (TRA); Technology Readiness Level (TRL); Stage-Gate®; Technology Project Readiness Level (TPRL)

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1. Introduction

The development of the global economy is necessarily associated with an increase in the demand for energy resources [1,2]. According to analytical reviews, over the past 10 years, global demand for energy resources has increased by 13%, and in the next 30–50 years, it is expected to grow further by 50–100% [3]. About 80% of the demand for energy resources is covered by three sources: oil (29–32%), natural gas (22–25%), and coal (25–27%) [3,4]. Since more than half of the global demand for energy resources (55%) falls on oil and natural gas, this circumstance creates reasonable prospects for the development of the national oil and gas sectors of various countries, including Russia, whose economic model is based on a resource-oriented policy [5]. The Russian oil and gas complex is one of the main sources of the national economy's growth—according to the Russian Federal State Statistics Service, Ministry of Finance of the Russian Federation, and Russian Federal Customs Service for 2022, the oil and gas sector provides up to 9% of GDP [6], 42% of federal budget revenues [7], and 57% of exports [8].

At the same time, the depletion of traditional hydrocarbon reserves and an increase in the share of hard-to-recover reserves [9–11], the deterioration of the geological and technological conditions for their production [12,13], the lack of Russian technological solutions and the high dependence on foreign technologies [14,15], and increasing efficiency requirements for the industry processes and operations [16] create significant challenges for the modern oil and gas industry, especially in relation to the technological support of the main activities. This fact creates a critical need for the search for technological solutions, within the framework of which two classical options are provided: "to make" or "to buy".

The purchase of technologies from outside (option "to buy") is a generally accepted norm in many industries in various countries and is quite justified since the world economy is based on the global market; some goods are produced and sold by the state, others are acquired through a mutually beneficial exchange of goods. However, in the framework of the case under consideration, this option has two significant drawbacks:

1. The current geopolitical situation does not allow free exchange of goods between Russia and a number of countries, in particular with regard to technologies in the oil and gas industry.
2. The key (supporting) state industries (one of which is the oil and gas sector for Russia) should not be fundamentally dependent on foreign technologies and equipment since inconsistencies with foreign partners or other circumstances leading to technological risks can seriously affect the national economy.

The creation of technologies (option "to make") is often a more expensive and risky option; however, given the importance of the oil and gas industry for Russia and the current geopolitical situation, this option seems to be the most correct and far-sighted.

In this regard, one of the most optimal solutions to the existing problems is the development of intra-industry technological potential through the development of the Russian market for technological engineering in the oil and gas complex [17–19]. The implementation of engineering projects aimed at creating essential technologies will facilitate solutions for the most pressing industry problems, reduce the dependence of the Russian oil and gas complex on foreign technological solutions, and move from the model of extensive economic growth to an intensive one [20–22].

Successful implementation of engineering projects is a result of effective management. Today, global oil and gas companies create a considerable number of technological solutions that significantly increase the efficiency of production business processes, reduce the number of emergencies, and help to implement the strategic initiatives of the companies. However, in the process of engineering project implementation, various problems may arise, making it impractical or impossible to realize the project. For example:

- The confirmation of the possibility of technology creation has not been received (the technological hypothesis has not been confirmed) [23]
- The actual need for funding has exceeded the planned amount [24,25]
- The entire list of necessary works has not been completed within the specified time [24,25]
- The project turned out to be technologically inefficient (the achieved technological effect was significantly inferior to the planned one) [26]. (The non-confirmation of a technological hypothesis reflects the impossibility of creating a specific technological solution under given conditions, while the insufficient technological efficiency of the solution reflects a situation in which a technological solution is created but its actual parameters (effect) are significantly inferior to those planned).

Such situations lead to the suspension of projects, the refusal of their further implementation, and the loss of investments made by the company. Therefore, a detailed analysis of the features and problematic aspects of the engineering project's implementation is of particular relevance.

The process of engineering project implementation inevitably faces three main challenges for any project: productivity, schedule, and budget [26]. A systematic approach to technology development can reduce the uncertainty of all three aspects, while the opposite situation can lead to cost overruns, schedule delays, and lower original performance goals [27]. The solution to these problems lies in the necessity of effective project management, which should be based on a comprehensive and objective assessment of technology readiness and emerging risks at key points in the technology creation life cycle [25].

Technology Readiness Assessment (TRA) is a systematic, formal process whose purpose is to determine the level of maturity of hardware and software technologies and processes, including the required levels of technological, economic, and other characteristics [23,24].

To date, a significant number of methods for technology readiness assessment have been used. Each of them is focused on a specific area of application, is based on the calculation of a number of indicators, and has a range of advantages and limitations. A more detailed analysis of these methods led to the conclusion that most of them are based on one of two classical methods for implementing technology projects: the TRL (Technology Readiness Level) method [25] and the Stage-Gate® method [28]. These methods are based on the linear approach of the innovation cycle, in which the creation of technology is carried out on the basis of passing a certain number of stages from idea generation to the creation of a ready-made technological solution. Despite their widespread use, these methods are subject to certain limitations; in particular, they do not allow for a comprehensive assessment of project readiness and are not fully adapted to the aims of oil and gas projects.

The aim of this study is to develop a conceptual management framework for the implementation of oil and gas engineering projects based on a comprehensive technology readiness assessment, taking into account existing approaches, modern requirements, and industry specifics.

In order to achieve this aim, four research questions (RQs) were posed:

RQ1: What management methods for engineering project implementation are used by companies today?

RQ2: What are the modern requirements for management methods for engineering project implementation?

RQ3: What indicators should be taken into account for a comprehensive readiness assessment of oil and gas engineering projects?

RQ4: Based on what components should a management framework for oil and gas engineering project implementation be created?

RQ5: How should project management decisions be made in accordance with the proposed model?

2. Materials and Methods

The structure of the research is presented in Figure 1.

Key research methods include desk studies, systematization, the expert method (involving interviews and questionnaires), grouping, generalization, and algorithm design techniques.

The desk study was based on the academic literature review and focused on global energy trends and forecasts, the resource potential of Russia, development potential, and actual problems in the Russian oil and gas industry. The purpose of this stage of the study was to conduct a preliminary analysis of global energy processes, the impact of the oil and gas sector on meeting the global demand for energy resources, the potential of the Russian oil and gas sector, the main problems faced by the Russian oil and gas sector, and their solutions based on the management of engineering project realization.

As a theoretical basis for the study, we used:

- Statistical data of analytical agencies, industry companies, core ministries, and departments—S&P Global, Reuters, Shell, IEA, ExxonMobil, BP, Deloitte, the World Bank, the Ministry of Finance of the Russian Federation, the Russian Federal State Statistics Service, the Russian Federal Customs Service, etc.
- Publications in scientific journals—Energies, Resources, Journal of Marine Science and Engineering, Sustainability, Applied Sciences, Oil & Gas Science and Technology, Journal of Mining Institute, International Journal of Engineering Research and Technology, Technological Forecasting and Social Change, Journal of Product Innovation Management, California Management Review, The North and the Market: Forming

the Economic Order, Oil Industry, Oil and Gas Innovations, Oil and Gas Vertical, Mining Journal, The Economics of Science, etc.

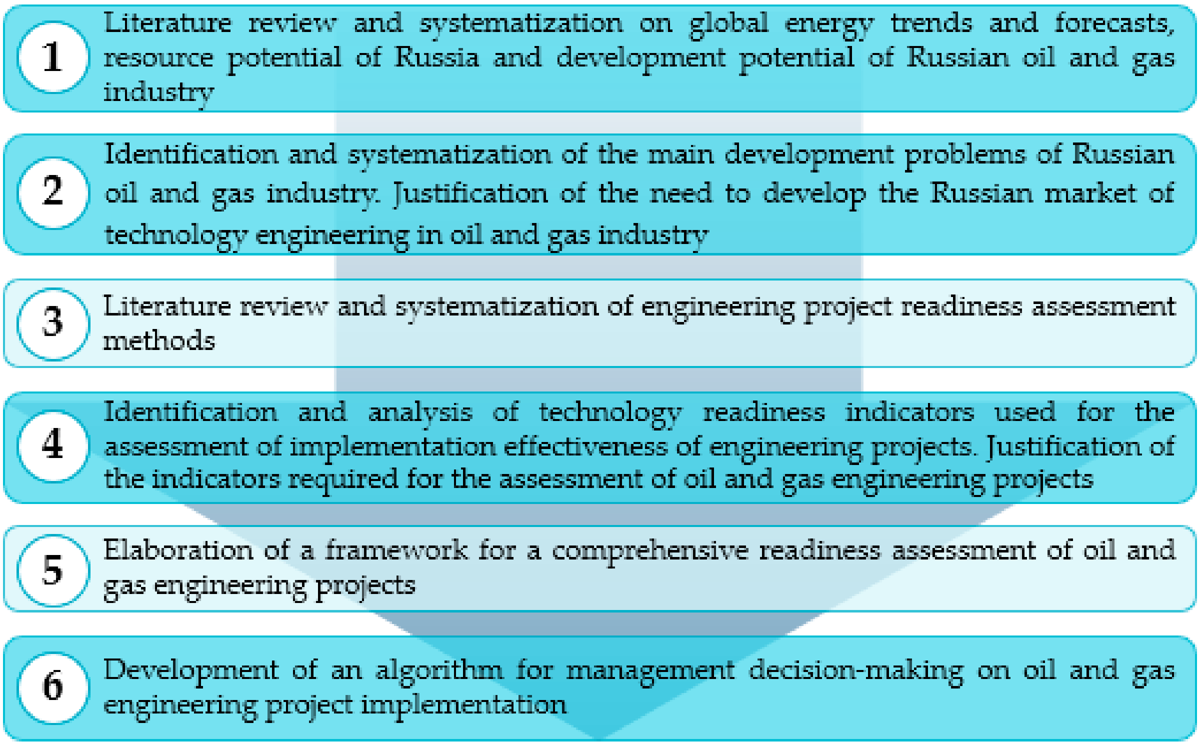

Figure 1. The structure of the research.

As a methodological basis for the study, we used a process approach for the implementation of technological engineering projects—TRA (Technology Readiness Assessment), which is based on the determination of the maturity level of the developed technologies, including the required levels of technological, economic, and other characteristics [23]. Within the framework of this approach, TRA methods such as TRL, MRL, RD^3, SRL, ITAM, TPRL, and others were studied and subsequently used in the elaboration of a conceptual management framework for oil and gas engineering project implementation.

At the first stage of the study, based on a literature review, the authors investigated the technology maturity assessment methods. First, two classical methods were considered—TRL and Stage-Gate®—and their advantages and disadvantages were determined. Furthermore, a more detailed analysis of assessment methods was carried out, on the basis of which all methods were divided into qualitative and quantitative categories, and a conclusion was made about the possibility of their application in various situations.

At the second stage, a conceptual management framework for oil and gas engineering project implementation was developed.

First, the selection of readiness indicators was carried out. In order to justify the set of key indicators required for a comprehensive assessment of the project's implementation effectiveness and the readiness of the oil and gas engineering project as a whole, the expert method was used, which included a series of interviews and questionnaires with relevant specialists. Ten employees of oil and gas companies (Gazpromneft PJSC, Rosneft PJSC, and Lukoil PJSC) who are or were engaged in the implementation of engineering projects were selected as respondents.

In the interviews, the experts highlighted the specifics of oil and gas engineering project implementation, in particular the stages and process approaches for project implementation, the application of the TRA methods in the process of project implementation, and key project problems (Appendix A).

Based on the analysis of the interview results, the respondents were asked to take part in a questionnaire to determine the key readiness indicators recommended for use in the conceptual management framework (Appendix B).

For the selected readiness indicators, based on a literature review and systematization, the functional purpose was determined, and a definition of the maturity levels for each of them was formulated (Appendix C).

Furthermore, a framework for a comprehensive readiness assessment of oil and gas engineering projects was developed. The proposed framework includes a matrix model of achieved project results accounting (based on selected readiness indicators) and an analytical model of the integral readiness index estimation.

As a result, based on the algorithm design technique, the algorithm for management decision-making on oil and gas engineering project implementation was proposed.

3. Oil and Gas Resources: Trends, Forecasts, Problems, and Solutions

3.1. Global Energy Trends and Forecasts

Today, more than half of the global demand for energy resources (almost 55%) falls on oil and gas [3]. According to forecasts until 2030, the share of oil in its structure will vary from 25% to 30.6% (28.5% on average), and the share of gas will vary from 21% to 25.6% (23% on average), which will amount in total to a share of 52% for both energy resources (Figure 2) [3,4,29,30].

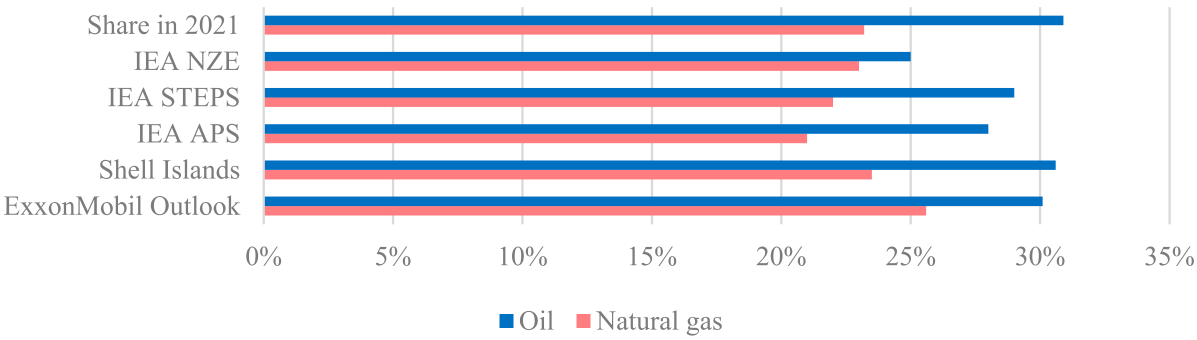

Figure 2. Forecast for the oil and natural gas share in the global energy mix by 2030 [3,4,29,30].

According to longer-term forecasts, by 2050, the spread of values will be more significant—the share of oil is expected to be in the range of 7–27.8% (19.7% on average) and the share of gas is expected to be 9–27.1% (18.3% on average). As a result, the total share of demand for both energy resources will vary from 16% (the most conservative option) to 55% (the most optimistic option) (Figure 3) [3,4,29,30].

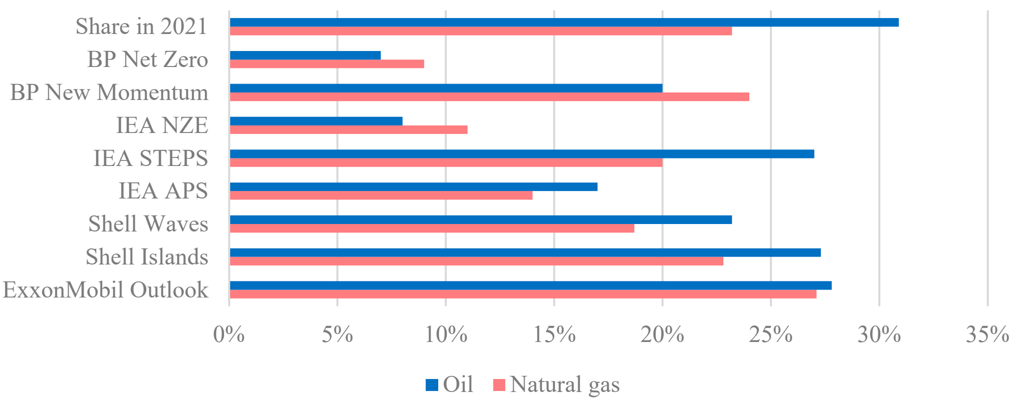

Figure 3. Forecast for the oil and natural gas share in the global energy mix by 2050 [3,4,29,30].

Undoubtedly, although these forecasts are sound analytical studies, they have a number of significant limitations:

1. Analytical agencies apply different methodologies for making forecasts; therefore, their individual comparison is quite difficult and, in some cases, incorrect [31].
2. The current forecasts do not yet fully reflect the change in volume of demand for energy resources and the change in structure of the global energy mix that occurred in 2022.

However, despite these limitations, the presented forecasts, in general, quite clearly reflect the high demand for oil and natural gas in the near future, as well as their certain significance in the longer term. Therefore, given the global growth in energy demand, the flat refusal of oil and natural gas is not seen as a viable option from a global energy perspective. This circumstance creates reasonable prospects for the development of national oil and gas sectors in various countries, including Russia [17,32].

Despite restrictions on the sale of Russian hydrocarbons on the world market, Russia, as before, remains a resource-oriented country whose primary task is to satisfy the internal demand for energy resources. According to the BP Statistical Review of World Energy 2022, annual production in Russia amounted to: oil—536.4 million tons (12.7% of the world production) and natural gas—701.7 billion m^3 (17.4% of the world) [4]. Proven reserves are estimated at: oil—14.8 billion tons (6.2% of the world) and natural gas—37.4 trillion m^3 (20% of the world) [4].

3.2. Problems and Prospects for the Development of Russian Oil and Gas Resources: An Engineering Approach

The significant dependence of the Russian economy on oil and natural gas resources raises a quite reasonable question about the possibility of the Russian oil and gas sector continuing to function effectively in the current environment. Within the framework of the answer to the posed question, an analysis of the problems influencing the development of the Russian oil and gas sector was carried out. Based on the survey of industry documents, analytical reports, and scientific publications, six groups of problems were identified: political-legal, economic, geological, technological, organizational, and personnel.

Political-legal problems. This group includes such problems as the strengthening of the sanctions pressure against Russia [33–35], the complicated international epidemiological situation [36], oil production cuts under the OPEC+ agreement [37], the expansion of specific competition between hydrocarbon resources (development of shale oil and gas production, LNG production) [13,38], the Global Energy Transition Requirements [15,39–42], the reduced demand by EU countries for Russian oil, requirements for "environmental friendliness," the development of electric vehicles, the rejection of heavy Urals oil in favor of lighter Persian oil [13,43,44], etc.

Economic problems. This group includes such problems as the volatility in demand for oil and natural gas [13], price volatility in global oil and natural gas markets [37], increase in inflation rates at the global and national levels [45], low level of state financing of oil and gas companies' innovation and investment activities [46], increase in hydrocarbon production costs [47,48], high level of capital intensity of oil and gas production [49,50], long duration of investment and production cycles [13], etc.

Geological problems. This group includes such problems as the low endowment with conventional hydrocarbon reserves (depletion of reserves, high water cut) [12,13,51], complicated hydrocarbon production conditions (including high-viscosity oil and natural bitumen [52,53], low-permeability and complex reservoirs [10], offshore fields [54], Arctic fields [55–58], gas hydrate fields [59], gas condensate [60,61], etc.), and the low rate of mineral resource base reproduction [12,13].

Technological problems. This group includes such problems as the lack of modern types of equipment and technologies at all stages of the production cycle [13,14,49,62], the high import dependence of oil and gas companies [32,43,63,64], the low level of state technological development as a whole [13,49,65,66], etc.

Organizational problems. This group includes such problems as the underdevelopment of pipeline infrastructure for oil transportation (especially in the regions of Eastern Siberia and the Russian Far East) [67], the geographical remoteness of oil and gas facilities from consumption centers and export corridors [68], the low infrastructural development of hydrocarbon production regions [68,69], difficult natural and climatic conditions in the regions of hydrocarbon production [70], low flexibility of managerial decision-making [47], the large scale and complexity of oil and gas projects [13,27], conflict of interest between shareholders of oil and gas companies (state and private businesses) [71,72], the presence of barriers to industry access, reducing interest in the participation of foreign companies with innovative technologies [5,13,73], etc.

Personnel problems. This group includes such problems as low qualification of employees [74,75], lack of young professionals [76,77], high staff turnover [74,76], etc.

An analysis of the groups of problems considered revealed that the most fundamental and significant group affecting the development of the Russian oil and gas complex, according to leading industry experts, are precisely technological problems [13,14,32,46,49]. The lack of modern domestic technologies in Russian oil and gas companies limits their ability to address current industry challenges and improve the efficiency of production processes [78,79]. Therefore, one of the possible options for increasing the technological potential of national companies is the implementation of engineering projects aimed at creating new technological solutions [32,43,65].

In contrast to the projects of standard technological product creation, the peculiarity of technology engineering projects lies in the high proportion of the risk of implementation failure. The technology developed within the framework of such a project is a potential innovation, while the creation of innovative products is subject to significant uncertainty and the emergence of a number of standard and, more importantly, non-standard problems. In practice, the implementation of engineering projects may be threatened by such significant problems as non-confirmation of the technological hypothesis, low technological efficiency of the developed solution, project budget overruns, implementation schedule delays, and others. These issues create a reasonable necessity for the application of a systematic approach based on effective implementation and management of engineering projects.

One of the most effective approaches to the management of engineering project implementation is the Technology Readiness Assessment (TRA) process, which is based on the determination of the maturity of the developed hardware or software technology [23,24]. TRA process tools allow for the assessment of the required levels of technological, economic, and organizational characteristics of projects, the identification of their key risks, and the development of measures to reduce time, financial, and labor costs. The relevance of the problems considered for oil and gas engineering projects creates the basis for the development of a conceptual framework for their implementation management, the first stage of which begins with a study of modern TRA methods.

4. Technology Readiness Assessment Methods

4.1. TRL and Stage-Gate®

To date, a significant number of Technology Readiness Assessment (TRA) methods have been used, which allow for the assessment of projects that are different in nature as well as the assessment of various aspects (indicators) of the readiness of these projects. However, the results of the study of the principles on which these methods are based allow us to conclude that most of them are based on two classical methods for technology readiness assessment—the unified method for assessing the level of technology readiness, TRL (Technology Readiness Level) [25], and the Stage-Gate® method [28].

The TRL method was proposed in the 1970s by the American space agency NASA as a response to the problem of interaction between different departments and synchronization of their results when developing technologies for space systems. The emerging problem revealed that the development of high-tech systems is strictly dependent on the synchronized development of certain necessary technologies, and if the synchronization is not optimal, this fundamentally affects productivity, planning, and budget [80]. The TRL method is built on a linear innovation cycle approach: the development of a single technology from the research stage to integration with other technologies into a high-tech complex product is carried out on the basis of a 9-level readiness scale (Figure 4).

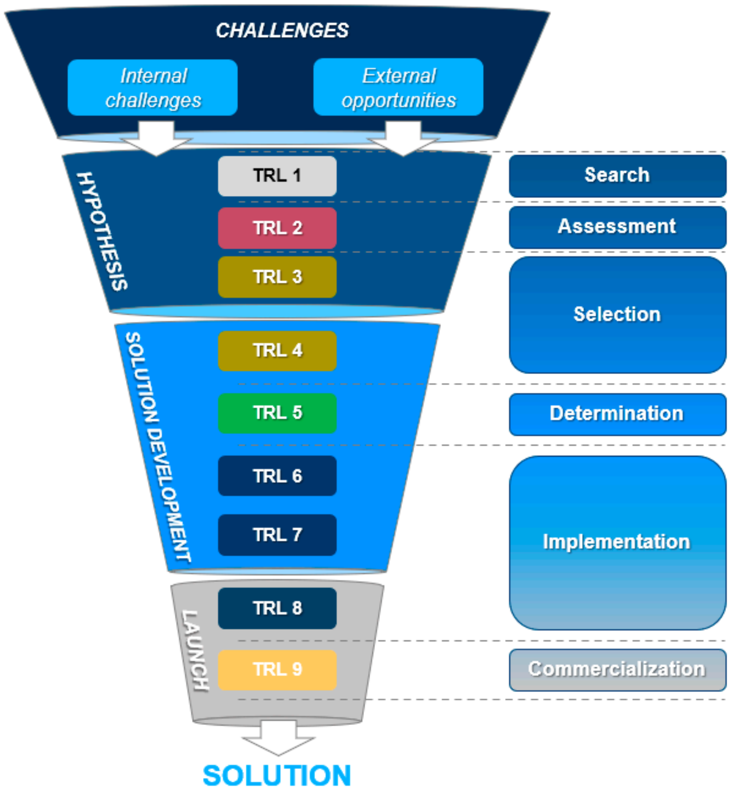

Figure 4. Overview of the TRL scale. Source: developed by authors.

This method is quite sufficient for technology readiness assessment at a basic level; however, despite its obvious advantages, the TRL has a number of fundamental limitations:

- There are no guidelines for using the method—the sources give recommendations on the need to use it but do not offer meaningful guidelines on the specifics of application [26,81].
- Subjectivity of the assessment—there is no formal method for implementing TRL; the TRL value is assigned to the technology by the developer, which may be biased; and the definitions of each TRL level tend to be broadly interpreted [82].
- Insufficiently detailed assessment—one scale does not fully cover the range of issues that arise in the process of technology creation [26,83], etc.

Given the limitations presented, the TRL method is recommended for use in conjunction with other reliable and objective methods for technology maturity assessment to make reasoned decisions [26].

The development of the Stage-Gate® method was also based on the necessity to systematize and improve the efficiency of the process of creating high-tech solutions, implemented as part of large projects in the mechanical engineering and chemical industries in the United States in the middle of the 20th century. Stage-Gate® creator Robert Cooper described it as "a conceptual and operational map for moving new product projects from idea to launch and beyond." The main attention in the method is paid to the management of the process of new product development (NPD), aimed at increasing the efficiency and effectiveness of this process since the results of some studies confirm the random and non-systematic nature of the process of creating new products in many companies [28]. The process of new product creation within the Stage-Gate® method is based on the passage of a certain number of "Stages" (usually 4–6), which are separated by "Gates," where intermediate project results are evaluated (Figure 5).

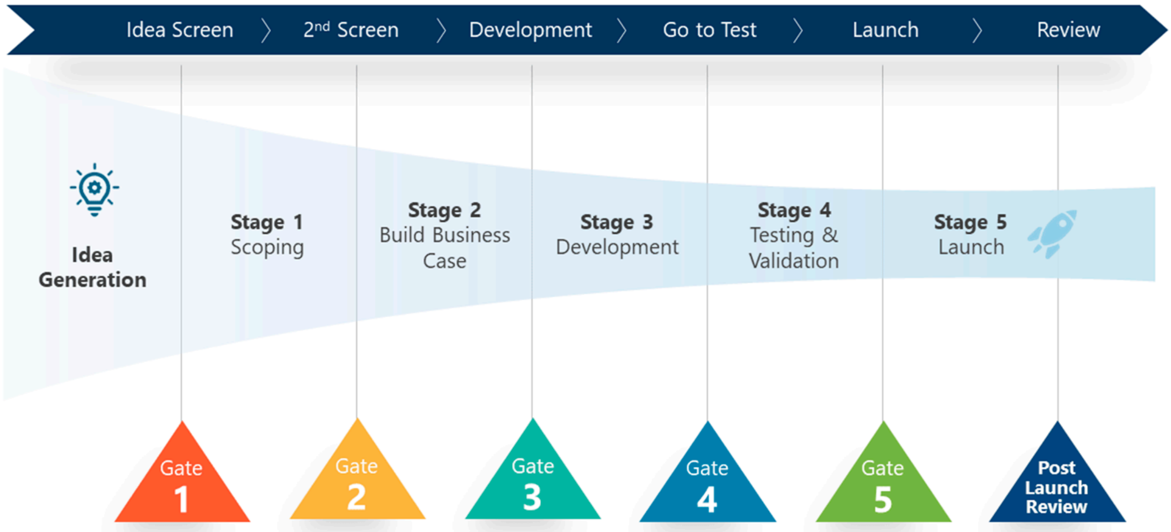

Figure 5. Overview of a Stage-Gate® process [84].

The first stages are aimed at discovering opportunities and generating ideas, and the subsequent ones are aimed at development, testing, and launch [85]. Stages tend to be cross-functional, with each activity running in parallel with others to speed time to market. Gates act as filters and help decide what action to take on a project—Go, Hold, Recycle, or Kill. The decision is made using a criteria-based assessment of the achieved results (for example, target criteria such as strategic compliance, expected financial return, and use of the company's core competencies in the project can be used) [86].

The logic of the Stage-Gate® method is in many respects similar to that of the TRL method; therefore, the limitations of the TRL are also relevant for the Stage-Gate® method.

4.2. Other Methods for Technology Readiness Assessment

Scientific and technological progress and the accompanying complexity of technological processes and innovative products being created systematically led to a change in the requirements for the technology readiness assessment and the need to adapt classical methods of project implementation. A significant amount of research has been conducted by experts to develop tools and methods that can provide insight into technology readiness and track technology maturity throughout the development life cycle to enable continuous risk management and improved decision-making support. For the most part, other existing methods either complement and extend TRL or integrate other indicators with TRL in order to get a more complete picture of the technology and its level of readiness. For the purposes of this study, all methods were divided into qualitative and quantitative categories.

The group of qualitative methods includes the 10 following ones: Manufacturing Readiness Level (MRL), Integration Readiness Level (IRL), Market/Commercialization Readiness Level (MRL/CRL), Scaling Readiness (SR), Regulatory Readiness Level (RRL), Technology Transfer Readiness Level (TTRL), TRL for Software, Moorhouses Risk Versus TRL Metric, Research and Development Degree of Difficulty (RD^3), and Advanced Degree of Difficulty (AD^2). A detailed description of the methods is presented in Table 1.

Qualitative methods for the technology readiness assessment are a convenient tool, as they allow analysis to be carried out in a short time and with a significant number of iterations, but they significantly depend on implicit knowledge, which exposes the assessment results to a high degree of subjectivity. While the idea of definition-based metrics provides flexibility and ease of use, descriptions can be interpreted broadly, leading to inaccurate estimates.

Table 1. Qualitative methods for the technology readiness assessment.

Method	Abbr.	Description	Source
Manufacturing Readiness Level	MRL	Determines the current level of technology production readiness, identifies readiness deficiencies, and identifies associated risks in the transition from technology to production	[87,88]
Integration Readiness Level	IRL	Measures the readiness and compatibility of interfaces between different technologies, consistently compares the maturity of interfaces between multiple integration points, and reduces the uncertainty associated with the development and integration of technology into the system	[89]
Market/Commercialization Readiness Level	MRL/ CRL	Determines the readiness of the technology to enter the market as a commercial offer for a group of customers	[90,91]
Scaling Readiness	SR	Reflects the readiness of technology to achieve a specific effect at scale in a specific context	[92]
Regulatory Readiness Level	RRL	Reflects the reliability of regulatory support for the technology development process and the effectiveness of this support in the development of the necessary regulations	[93,94]
Technology Transfer Readiness Level	TTRL	Describes the process of technology transfer, which consists of identifying a new appropriate application of technology and its subsequent adaptation, and solves the problem of transferring technology from one industry to another	[95]
TRL for Software	TRL (S)	Characterizes the level of maturity of software technology by including other attributes specific to software development	[23]
Moorhouses Risk Versus TRL Metric	MRM	Reflects the regression of risk due to the progression of technological readiness	[96]
Research and Development Degree of Difficulty	RD^3	Reflects the degree of difficulty of the technology transition from one readiness level to another and includes five levels of difficulty	[97]
Advanced Degree of Difficulty	AD^2	Assesses the difficulty of moving a technology from its current readiness level to the desired one on a 9-level scale	[98]

Source: developed by authors.

The group of quantitative methods includes the five following ones: System Readiness Level (SRL), Integrated Technology Analysis Methodology (ITAM), Technology Readiness and Risk Assessment (TRRA), Technology Insertion Metric (TI), and Technology Project Readiness Level (TPRL). A detailed description of these methods is presented in Table 2.

Quantitative methods, in comparison with qualitative ones, are more objective and accurate, but their use can require a significant amount of time and labor costs with repeated use. The development of an erroneous mathematical model can lead to an incorrect assessment of technology maturity, cost overruns, and schedule delays. However, quantitative methods often combine several system indicators, which leads to tangible results in assessing the readiness of technology and in subsequent decision-making.

When choosing a method for the technology readiness assessment, it is necessary to understand that there are no universal methods. Industry-specific features of projects, differences in aims, requirements, resources, financing, schedule, and other characteristic features of projects create the basis for the development of separate methodological bases for assessing the readiness of projects in each individual industry, area, and company.

Table 2. Quantitative methods for the technology readiness assessment.

Method	Abbr.	Description	Source
System Readiness Level	SRL	Determines the technology readiness level, as well as the degree of its readiness for integration into the system, based on a normalized matrix of pairwise comparisons of the TRL and IRL systems	[81,99]
Integrated Technology Analysis Methodology	ITAM	Reflects the cumulative maturity of the system based on the readiness of its constituent technologies and takes into account TRL, Delta TRL, R&D Degree of Difficulty (R&D^3), and Technology Need Values (TNV)	[100]
Technology Readiness and Risk Assessment	TRRA	Assesses the impact of risks on technology creation and takes into account TRL, R&D^3, and TNV	[101]
Technology Insertion Metric	TI	Reflects the degree to which a new subsystem is integrated into an existing host system and the interaction between the system and subsystem for the improvement of overall performance	[99]
Technology Project Readiness Level	TPRL	Reflects the level of comprehensive project readiness based on a balanced approach, taking into account six key criteria—TRL, MRL, IRL, ORL, BRL, and CRL	[83,102]

Source: developed by authors.

5. A Conceptual Management Framework for the Oil and Gas Engineering Project Implementation

The main requirements for modern methods for the Technology Readiness Assessment are:

- Comprehensive readiness assessment of the technological solution
- A high degree of detail in the assessment
- Universal model structure
- Sufficient level of objectivity (due to the formal accounting of project results based on supporting documents)
- The ability to adapt the scale to the requirements of a particular industry or project without violating the general structure
- Availability of tools for monitoring the effectiveness and rating of projects when making management decisions

Taking into account these requirements, the authors propose a conceptual management framework for the implementation of oil and gas engineering projects based on the application of:

1. An expertly-based set of readiness indicators for a comprehensive assessment of project readiness.
2. A framework for a comprehensive readiness assessment of engineering projects, including a matrix model for achieved project results accounting (based on selected readiness indicators) and an analytical model for the integral readiness index estimation.
3. An algorithm for management decision-making on engineering project implementation.

5.1. Readiness Indicators of Engineering Projects

Based on the considered TRA methods, 14 readiness indicators were identified. According to the results of a series of interviews with industry experts as well as an analysis of information and analytical data on the experience of using the selected readiness indicators, a preliminary assessment of their applicability in the model for a comprehensive readiness assessment of engineering projects was made (Table 3). Readiness indicators recommended for use in the model are highlighted in green, "situational" indicators—in orange, and not recommended—in blue.

Table 3. Preliminary assessment of the applicability of individual readiness indicators in the model for a comprehensive assessment of oil and gas engineering projects.

Indicator	Abbr.	Description	Applicability
Technology Readiness Level	TRL	The basic criterion for the readiness assessment of engineering projects, reflecting the current development stage of a particular technology	Recommended for use in the model based on the successful experience of its application by leading companies (Google, John Deere, etc.) and oil and gas companies (BP, Gazpromneft)
Manufacturing Readiness Level	MRL	Reflects the current level of production readiness for the release of a particular technology	Recommended for use in the model as it determines the features of the production process of the technology under development
Integration Readiness Level	IRL	Reflects the possibility of "inclusion" of a new technology into an existing system for its effective functioning	Oil and gas engineering projects are mostly aimed at creating complex technological solutions (fracturing technologies, hard-to-recover reserve production, etc.) that do not require integration with other production systems
Engineering Readiness Level	ERL	Reflects the current level of engineering support for the technology creation process	The indicator partially duplicates other considered indicators (TRL, MRL, and ORL), and therefore its use is not advisable
Organization Readiness Level	ORL	Reflects the current level of process organization for the creation of technology	Recommended for use in the model as it creates the basis for structuring and determining the relationships of all processes for the project's implementation
Benefits and Risks	BRL	Reflects the competitive advantages and key risks associated with the creation of a particular technology	It is not advisable to single out all groups of benefits and risks into one category since it is more convenient to manage and account for each of them within the framework of a separate readiness indicator
Commercialization Readiness Level	CRL	Reflects the readiness of the developed technology to be brought to market	Recommended for use in the model as it allows for the identification of risks to technology commercialization, prepares a plan for their solution, and increases the efficiency of bringing the technology to market and its potential economic effect
Scaling Readiness	–	Reflects the readiness of the developed technology to achieve a specific effect at scale	Oil and gas engineering projects are primarily aimed at solving a specific technological problem, which does not always take on a mass character. It is inappropriate to include the indicator in the model since the low ability of technology to scale can lead to a slowdown in the process of its creation and a delay in the solution of an urgent industry problem.
Regulatory Readiness Level	RRL	Reflects the degree of reliability of regulatory support for the technology development process	Recommended for use in the model as it is a guarantor of copyright compliance and a potential tool for creating a company's strategic competitive advantages
Transfer Technology Readiness Level	TTRL	Determines the possibility of technology transfer from one system to a system with a different functioning mechanism, which is most relevant for cross-field technologies	The creation of new technologies in the oil and gas complex is mainly based on the use of intra-industry technologies; however, at the present stage, there is also a widespread use of non-oil and gas technologies (Internet of things, artificial intelligence, etc.). Therefore, an optional use of the indicator is proposed depending on the specific situation.

Table 3. *Cont.*

Indicator	Abbr.	Description	Applicability
TRL for Software	TRL (S)	Reflects the current stage of development of a certain software technology based on the attributes characteristic of software products	Modern modifications of the classic TRL have become more flexible and versatile, which allowed them to successfully assess the readiness of both hardware and software technologies, so the use of this indicator in the model is not relevant
Moorhouses Risk Versus TRL Metric	MRM	Characterizes the risk regression due to the progression of the technological readiness of the project; it is a derived indicator from TRL	The progress of the engineering project implementation is certainly accompanied by a decrease in the risk of its failure; therefore, the use of this indicator in the model is not necessary
R&D Degree of Difficulty	RD^3	Reflecting the difficulty of the project transition from one level of technological readiness to the next, they are additions to TRL (different in the number of levels—RD^3 includes five levels of difficulty and AD^2 includes nine levels)	They allow for the ranking of engineering projects according to the difficulty of their implementation and subsequently provide targeted support. However, they do not contribute critical information to the decision-making process for the creation of technology; therefore, the use of these indicators is not necessary
Advanced Degree of Difficulty	AD^2		

Source: developed by authors.

For a more reasonable selection of readiness indicators, a series of questionnaires was additionally conducted, in which the selected experts had to unequivocally determine the necessity of using each of the proposed indicators in the model (Appendix B). The results of the questionnaire are shown in Figure 6.

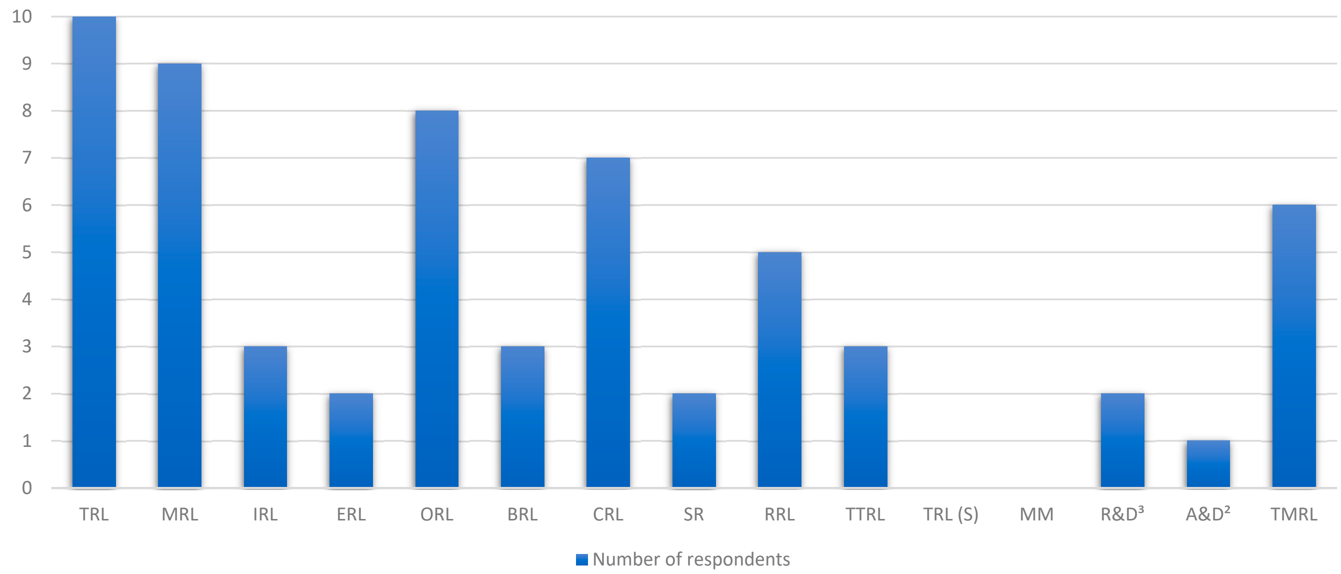

Figure 6. Applicability of individual readiness indicators in the model for a comprehensive assessment of oil and gas engineering projects.

Based on the analysis of the results of the questionnaires, a set of six readiness indicators for engineering projects was formed, which are necessary for a comprehensive assessment of the main directions of the project's development and the readiness of the project as a whole (the authors selected the indicators that were noted by 50% or more of the respondents):

1. Technology Readiness Level (TRL)
2. Manufacturing Readiness Level (MRL)
3. Organization Readiness Level (ORL)
4. Commercialization Readiness Level (CRL)
5. Regulatory Readiness Level (RRL)
6. Team Readiness Level (TMRL)

The Team Readiness Level was not proposed in the original list of indicators but was noted as a necessary criterion by 60% of the respondents due to its significant impact on the decision-making process for project implementation.

For the correct application of the selected indicators, the functional purpose of each of them was detailed (Table 4).

Based on the functional purpose, a definition of the maturity levels for each indicator was developed (Appendix C). Project implementation in the direction of each readiness indicator is carried out on the basis of the classical 9-level scale.

5.2. A Framework for a Comprehensive Readiness Assessment of Oil and Gas Engineering Projects

The TPRL (Technology Project Readiness Level) methodology described in [83,102] was chosen as the basis for the development of the framework for a comprehensive readiness assessment of the oil and gas engineering projects. This methodology allows for an end-to-end comprehensive assessment of project readiness based on the use of a multi-criteria system of indicators, including technological readiness (TRL), production readiness (MRL), engineering readiness (ERL), organizational readiness (ORL), benefits and risks (BRL), and market readiness and commercialization (CRL). TPRL is used: 1. to apply a balanced approach to the readiness assessment of the project as a whole as well as of the individual project indicator; 2. to identify the uncertainties of the project and its key risks; and 3. to simply and objectively present the project maturity level for the next round of investment in unified terms [83].

The framework for comprehensive assessment proposed in this paper includes two components: a model for the achieved project results accounting (based on selected readiness indicators) and an analytical model for the integral readiness index estimation.

A model for the achieved project results accounting is based on a matrix structure (Figure 7). The columns show readiness indicators, and the rows show the maturity levels of the indicators. Each of the levels has a four-level structure.

To achieve a certain readiness level, it is necessary to pass successively all of the TRL's sublevels, within each of which it is necessary to solve a list of key tasks. The fulfillment of each assigned task is confirmed by the relevant document; for example, the execution of a laboratory test is confirmed by the receipt of an act certifying the laboratory test's execution. The result of solving the task is binary: the document was received—1, the document was not received—0. The dynamics of completing sublevels and levels are measured from 0 to 1, depending on the success of solving the tasks within the sublevel and the passed sublevels within the same level.

The numerical result of the project readiness assessment is determined by the analytical model for the integral readiness index estimation. The integral readiness index is calculated based on the index values of all indicators and their weight coefficients. The type of dependence of the weight coefficients and the values of indicator readiness indexes can be set by experts separately for each specific task being solved. For the purpose of simplification, the authors have assumed in the article the same weight for all coefficients.

To carry out the numerical calculation of the integral readiness index of the project, various algorithms can be used, but the choice of a specific one does not affect the general methodology, as the main principle of the assessment is based on the consideration of the values of all individual readiness indicators. For the purposes of this article, the following analytical model was chosen [83]:

$$I = E + \overline{K} \cdot P_L, \quad (1)$$

$$P_L = p_{L_1} \cdot p_{L_2} \cdot p_{L_3} \cdot p_{L_4} \cdot p_{L_5} \cdot p_{L_6}$$

where E is the maximum readiness level achieved by all indicators

Table 4. Functional purpose of the selected readiness indicators.

Indicator	Functional Purpose
TRL	• Determines the levels of technology development and testing from the stage of idea generation to the implementation of a ready-made technological solution • Reflects the status of technology testing from checking single critical functions to a complete performance check, both in laboratory conditions and in real-world conditions of the technological system's functioning • Confirms the current readiness status of elements and technology in general
MRL	• Determines the readiness to create a technology production from the level of a layout to an industrial design • Reflects the degree of integration of the production process into existing production chains (processes, materials, equipment, infrastructure, and employees) • Demonstrates the creation of an effective production (pilot, prototype, and serial), including a quality control system and the supply of materials and components
ORL	• Reflects the progress of approval of the technical characteristics of the developed solution with potential customers • Reflects the status of approval of the concept of technology application with all involved persons (departments of the contractor and external organizations, including suppliers, subcontractors, and customers) • Reflects the completion of the changes and adjustments made to the project based on the results of tests and negotiations with customers • Confirms the adoption of basic decisions, the development of operational plans, and the demonstration of the technology service support system • Shows the result of partner staff training for technology transfer to the customer
TMRL	• Determines the composition of the team at all stages of project implementation • Confirms the availability of the necessary competencies of the project team members at each project level • Reflects the communication process of the project team members at its various stages
CRL	• Reflects the result of the market assessment, taking into account the price and consumer qualities of competitors' technologies introduced to the market • Reflects the development stage of the technology commercialization business model • Fixes the organization of a two-way exchange of information with potential customers in order to obtain feedback on interest and clarify the required technology characteristics • Reflects the gradual adaptation of the pricing model in accordance with the development of the business model
RRL	• Identifies patentable inventions or other RIAs • Confirms the novelty of the considered RIA • Reflects the stage of state registration of a patent for intellectual property • Determines the implementation stage of the strategy for the protection of intellectual property rights (IPRs)

Source: developed by authors with the use of [83,94,102,103].

$\overline{K}$—the mean value of fractional parts of indicators at level $E + 1$
P_L—the probability of completing all tasks at level $E + 1$ (denoted as L)
p_{L_m}—the probability of completing all tasks at level L in terms of readiness indicator m.

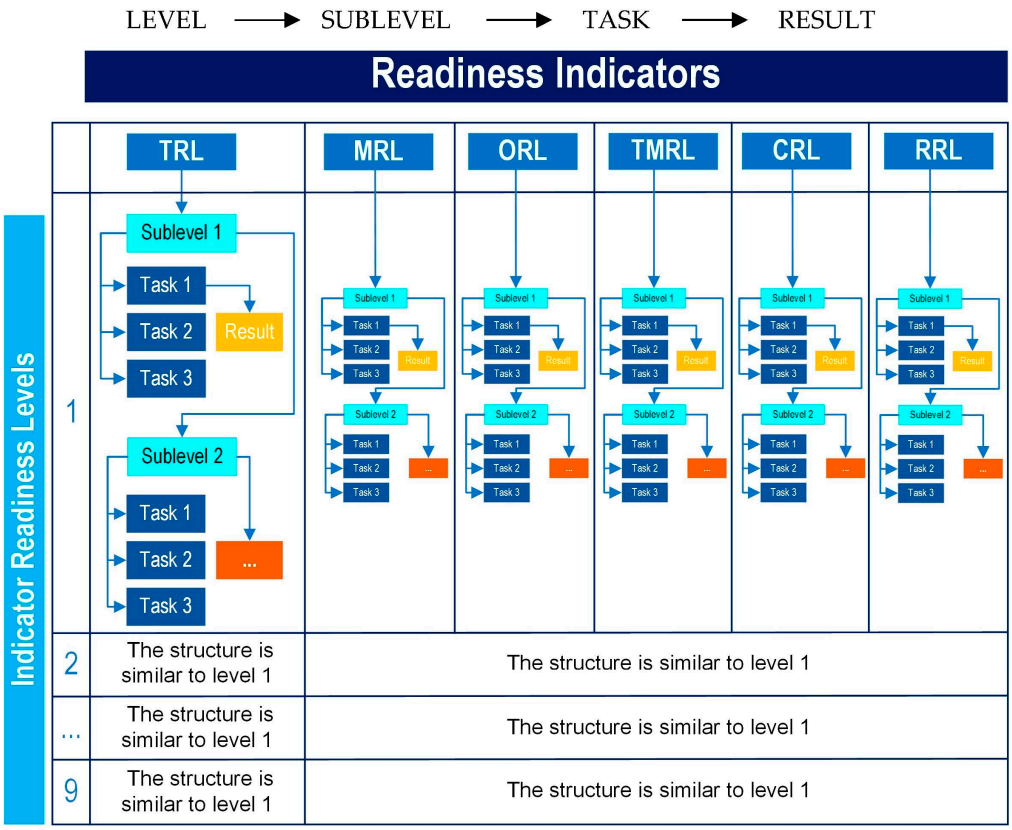

Figure 7. Structure of the framework for a comprehensive assessment.

The choice of the model is justified by the consideration of the factor of probability of achieving the target values of readiness indicators. Due to the fact that engineering projects have a high degree of uncertainty in obtaining technological and economic benefits, the consideration of the probability factor allows for a more accurate assessment of the current status of the project, which is the basis for making informed management decisions for its further implementation.

The first step is the determination of the integer index E corresponding to the lowest achieved readiness level among all indicators. At the second step, the fractional part of the index is determined by calculating the average value of the fractional parts of the indexes of indicators for level $E + 1$. At the third step, the probability of achieving all requirements for the project at level $E + 1$ (P_L) is determined by calculating the product of probabilities (p_{L_m}) when changing m from 1 to 6, taking into account the assumption of independence of indicators. The form of dependence between P_L and p_{L_m} is the subject of a separate discussion that does not affect the content of the proposed model; therefore, it is not considered in detail in this paper.

To visually reflect the results of the assessment, it is recommended to use a radar chart (Figure 8).

The balanced development of the project is achieved with the simultaneous development of all readiness indicators, which graphically correspond to the correct hexagon. In the example considered, project administrators need to pay attention to two problem areas: CRL and RRL. MRL and ORL also lag behind TRL and TMRL.

5.3. An Algorithm for Management Decision-Making on Engineering Project Implementation

One of the key management aspects of the engineering project implementation is the specifics of the decision-making process on the further "movement" of the project, or rather the principle of the project transition from one readiness level to the next. A successful project transition to a new readiness level is a marker of the completion of all tasks set at the current level, while project recycling, suspension, or "killing" indicates significant shortcomings and problems in the implementation process.

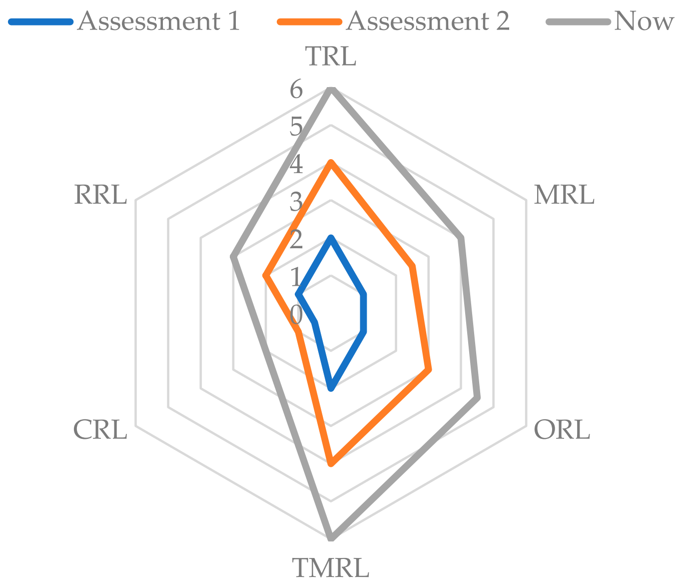

Figure 8. An example of presenting the results of a project readiness assessment.

Based on the selected readiness indicators and the proposed framework for comprehensive readiness assessment, the authors developed an algorithm for management decision-making on engineering project implementation (Figure 9).

The decision-making process based on this algorithm can be divided into five stages:

Stage 1—assessment of the completion of the current readiness level requirements

Stage 2—problem identification

Stage 3—problem solvability analysis

Stage 4—project importance determination

Stage 5—informed decision-making

Stage 1: At this stage, the input project parameters are evaluated based on the completion of all requirements at the current readiness level. If the levels of all readiness indicators correspond to the planned ones, the current economic environment of the project is assessed; if it has not changed, the project proceeds to the next level; if it has changed, the expediency of the project continuation is assessed.

Stage 2: For the projects that have not reached the target readiness levels of the indicators, an analysis of the problems is carried out.

Stage 3: At this stage, an analysis of the problem's solvability is carried out—when taking into account the proposed problem solution, is it possible to adapt the project to the relevant conditions, is it lucrative to continue the project, and will additional research help to achieve the desired result? If the technological hypothesis has not been confirmed or the required technological efficiency has not been achieved and additional research will not lead to the required result, the project must be "killed," otherwise it continues.

Stage 4: For the projects with problems that cannot be effectively solved in the current conditions and do not lie in the technological plane, the project's importance is assessed as a control characteristic for "killing" the project or holding it until favorable conditions occur.

Stage 5: At this stage, depending on the current project status, the decision is made on whether to further the project's movement—"kill," recycle, hold, or go.

Application of the proposed algorithm will potentially allow oil and gas companies to more accurately navigate when making decisions on the project at its control points, to develop internal mechanisms for the various problems responding, to reduce risks, and to increase the implementation efficiency of the engineering projects.

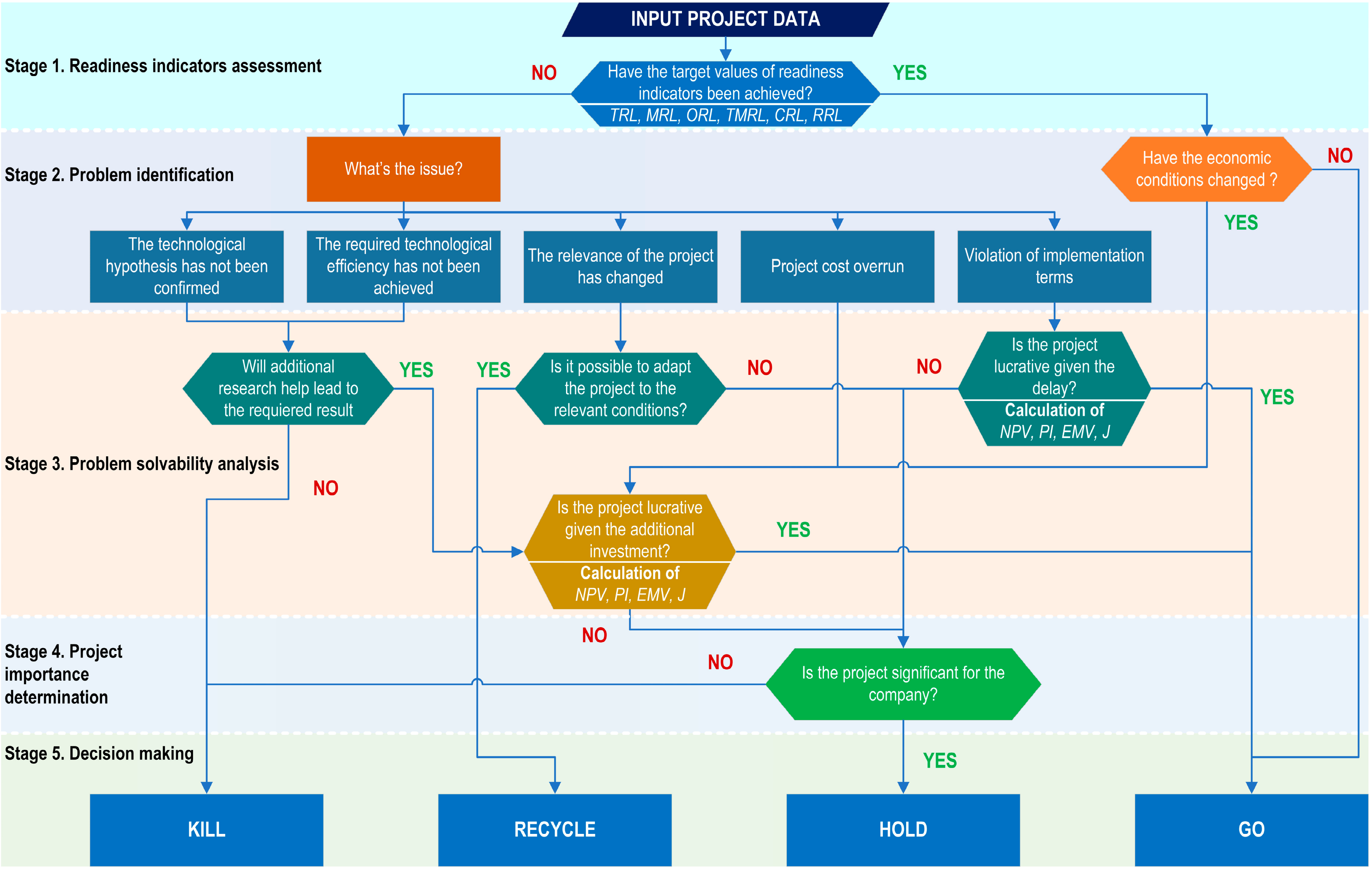

Figure 9. An algorithm for management decision-making on engineering project implementation.

6. Discussion

The demand for efficient development of energy resources entails the necessity of creating complex technological solutions that can respond to modern industry challenges and promote the strategic opportunities of oil and gas companies. In the practice of oil and gas companies, the creation of the necessary technologies is carried out through the implementation of engineering projects, whose effectiveness largely depends on the applied management approach.

An analysis of approaches to the implementation management of engineering projects has led to the conclusion that the most commonly used is the TRA process aimed at assessing the readiness of the developed technology, including the required levels of technological, economic, and other characteristics. As part of this process, a significant number of methods for technology readiness assessment have been developed, the most common of which are TRL and Stage-Gate®. The experience of their use testifies to their significant success in the readiness assessment of engineering projects at a very basic level; however, the complication of modern technological processes and emerging innovative technologies reveals a number of substantial limitations—the lack of a comprehensive view of the readiness assessment process, an insufficient level of assessment accuracy, the lack of guidance on application, etc.

Based on a more detailed literature review, the authors investigated a large number of readiness assessment methods, as a result of which a conceptual management framework for the implementation of oil and gas engineering projects was developed.

This framework is designed to solve the urgent problem of the effective implementation of oil and gas engineering projects, taking into account its existing advantages over other methods, but in practice, its use can be marked by a number of disadvantages and limitations. A list of the main advantages, disadvantages, and limitations of this method is presented in Table 5.

Table 5. Advantages and disadvantages of the proposed conceptual management framework.

Advantages	Disadvantages and Limitations
• Accurate and objective assessment of the project's maturity level • The ability to assess the dynamics of the project implementation in more detail (integral readiness index) • Successful experience in the application of comprehensive TRA methods (on the example of TPRL methodology) in the implementation of diversified engineering projects	• Complex and time-consuming assessment process • Lack of experience in the application of comprehensive TRA methods (in particular, the proposed one) in the implementation of oil and gas engineering projects • The selection of the readiness indicators for the model was made according to the experience of only Russian oil and gas companies

Unlike most of the considered methods, this framework allows for a comprehensive assessment of an engineering project based on various readiness indicators as well as a more detailed dynamic monitoring of the project's implementation; however, the assessment process may turn out to be more complex and costly in terms of time and involved human resources than the same TRL. The comprehensive TRA methods have been tested and are successfully used to assess the readiness of various engineering projects (an example of TPRL methodology), but at the moment there is no information about the use of such methods (and specifically proposed) in the oil and gas industry. A certain limitation for the application of the proposed framework is that it can create a specific set of readiness indicators, which was justified by the expert method with the involvement of specialists only from Russian oil and gas companies. However, it is worth noting that the set of indicators is not static and can be selected in accordance with the task; therefore, it does not affect the generality of the proposed framework.

As for future research directions, the authors will focus on:

- Detailing the structure of assessment indicators and the project results accounting
- Substantiation of analytical dependencies in the integral readiness index calculation
- Application of the proposed framework for the project economic efficiency assessment and project portfolio ranking in terms of the company's goals

Based on the results of the formalized methodology, it is necessary to test it on specific oil and gas engineering projects.

7. Conclusions

This study considers the necessity for high-quality implementation management of oil and gas engineering projects aimed at creating modern technological solutions that will allow for a more efficient development of deposits of oil and natural gas energy resources and will become the basis for creating sustainable competitive advantages for oil and gas companies. Based on the analysis of global energy trends and forecasts, the necessity of the development of national oil and gas complexes as sources of ensuring global demand for energy resources is substantiated, which actualizes the importance of the oil and gas industry for the Russian economy and creates the basis for solving its urgent internal challenges. The prevailing number of technological problems confirms the need to develop modern industry technologies, the effective creation of which is based on the implementation of oil and gas engineering projects and their effective management.

The results of the study provide the following conclusions:

1. Effective management of the engineering project's implementation should be based on a comprehensive and objective assessment of the technology's readiness and emerging risks at all life cycle stages of the technology's creation.
2. Most modern TRA methods are based on the principles of two classical methods—TRL and Stage-Gate®—which can be successfully applied to assess technology readiness at a basic level; however, the complexity of modern technological processes and emerging innovative technologies confirms the limited possibility of their application and the necessity for adaptation.
3. Modern methods for engineering project readiness assessment must meet certain requirements, in particular: 1. allow for a comprehensive and detailed assessment of the current maturity level of the technology; 2. have a universal structure; 3. exercise formalized control over the project results and have a sufficient level of objectivity; 4. have the ability to adapt the scale in accordance with the requirements of a specific industry or project (without violating the general structure); and 5. have tools for project effectiveness monitoring and rating when making management decisions.
4. The most relevant indicators for the readiness assessment of oil and gas engineering projects are:
    - Technology Readiness Level (TRL)
    - Manufacturing Readiness Level (MRL)
    - Organization Readiness Level (ORL)
    - Team Readiness Level (TMRL)
    - Commercialization Readiness Level (CRL)
    - Regulatory Readiness Level (RRL)

    According to the experts at Russian oil and gas companies, these indicators fully cover the process of engineering project implementation and allow for the most comprehensive assessment of the current readiness level of the technology.
5. For the effective implementation of an engineering project, management decisions on the project should be carried out on the basis of a 5-stage algorithm, including: 1. assessment of the completion of the current readiness level requirements; 2. problem identification; 3. problem solvability analysis; 4. project importance determination; and 5. informed decision-making.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Interview on the aspects of oil and engineering projects implementation

1. Please introduce yourself and tell us about your experience in the implementation of engineering projects, in particular, projects in the oil and gas industry.
2. What are the main goals of the implementation of oil and gas engineering projects?
3. What stages of the engineering projects implementation stand out in practice?
4. What problems do companies face today when implementing engineering projects?
5. What methods for the implementation of engineering projects are used today in oil and gas companies? Are you familiar with such methods as Technology Readiness Level (TRL) and Stage-Gate®? Are they used in your company?
6. In your opinion, is it possible to solve a number of topical technological problems of oil and gas companies if, when implementing projects, it is used an approach for a comprehensive maturity assessment of the technology, which includes other readiness indicators in addition to TRL (for example, MRL (Manufacturing Readiness level, CRL (Commercialization Readiness level), others)? If so, what indicators do you think should be used?

Thank you for participating!

Appendix B

Questionnaire on the aspects of oil and engineering projects implementation

Full name	
Age	
Job title	
Place of work	

Dear colleagues!

We ask you to take part in the questionnaire aimed at determining the indicators required to be taken into account in the framework for a comprehensive readiness assessment of oil and gas engineering projects. Select the required indicators from the proposed list, or offer your own, briefly describing their functional role (Table A1).

Thank you for participating!

(During the questionnaire conducting, respondents were provided with a more detailed description of readiness indicators, which is not provided separately in this appendix to avoid duplication).

Table A1. Readiness indicators of engineering projects.

Indicator	Abbr.	Brief Description	Need for Accounting (+/−)
Technology Readiness Level	TRL	Readiness (maturity) of technology	
Manufacturing Readiness Level	MRL	Readiness of the technology production process	
Integration Readiness Level	IRL	Readiness of technology for integration within the system	
Engineering Readiness Level	ERL	Degree of engineering support for the technology development process	
Organization Readiness Level	ORL	Organizational readiness of the technology creation process	
Benefits and Risks	BRL	Availability of benefits and risks of technology creating	
Commercialization Readiness Level	CRL	Readiness of technology to enter the market in the form of a product	
Scaling Readiness	–	Readiness of the technology to obtain economies of scale in production	
Regulatory Readiness Level	RRL	Readiness of regulatory support for the technology development process	
Transfer Technology Readiness Level	TTRL	Readiness of technology for transfer from one system to a system with a different functioning mechanism (cross-field technologies)	
TRL for Software	TRL (S)	Readiness (maturity) of software technology	
Moorhouses Risk Versus TRL Metric	MRM	Regression of the risk of failure depending on the progression of technology readiness	
R&D Degree of Difficulty	RD^3	Difficulty in transitioning technology from the current readiness level to the next. RD^3—5 stages of difficulty, AD^2—9 stages	
Advanced Degree of Difficulty	AD^2		
Other (specify)			

Appendix C

Table A2. A definition of the maturity levels of the readiness indicators.

Readiness Level	Readiness Index	TRL	MRL	ORL	TMRL	CRL	RRL
1	(0;1]	Basic technology principles observed and reported	Basic requirements for technology components production defined	Business process scheme developed	Team basic skills in the target area confirmed	Potential business opportunities identified	Patent analysis on existing related technologies carried out
2	(1;2]	Technology concept and/or application formulated	Basic technology production concepts defined	Availability of materials and manufacturing processes assessed	Project documentation and feasibility studies experience of the team confirmed	Competitive environment assessed	Specific patentable inventions or other patentable RIAs identified

Table A2. *Cont.*

Readiness Level	Readiness Index	TRL	MRL	ORL	TMRL	CRL	RRL
3	(2;3]	Confirmation of the possibility of technology development received	Production concept confirmation received	Technical characteristics of the technology discussed with the consumer	Team skills to research the technology creation possibility confirmed	Value proposition drafted	A detailed description of possible patentable inventions compiled
4	(3;4]	Technology component and/or breadboard validation in laboratory environment	Ability of prototype components manufacturing in a laboratory environment confirmed	Concept of technology application approved	Laboratory testing team skills confirmed	Suppliers, partners, pricing policy determined	Invention novelty and patentability confirmed
5	(4;5]	Technology component and/or breadboard validation in bench tests	Ability of prototype components manufacturing in a relevant environment confirmed	Requirements for technology service support clarified	Bench test team skills confirmed	Exact technology characteristics determined	First full patent application filed. Draft of IPRs protection strategy developed
6	(5;6]	Technology prototype demonstration in a relevant environment	Ability of prototype manufacturing in an operating environment confirmed	Project changes and adjustments stages completed	Skills of prototype creation and testing in relevant environment confirmed	Pricing model improved	A positive response to a patent application received
7	(6;7]	Technology prototype demonstration in a target/operating environment	Pilot production line capabilities confirmed	Partner staff trained	Skills of prototype testing in target/operating environment confirmed	Preliminary market launch of technology completed	Patent registered. Other formal IPRs registered
8	(7;8]	Successful functioning of a full-scale technological system	Initial small-scale production demonstrated	Agreements with interested parties concluded	Skills of full-scale technology creation and functionality testing confirmed	Customer comments worked out	First patent granted. IPRs protection strategy fully implemented.
9	(8;9]	Readiness of the technological system for full-scale implementation	Full-scale production demonstrated	Production and service support implemented	Skills of full-scale technology implementation confirmed	Full-scale market launch implemented	Patent granted in target countries. High level of IPRs support for business.

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