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Digital Management of Resource Efficiency of Fuel and Energy Companies in a Circular Economy

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Abstract: High-quality managerial decision-making is crucial for improving the resource efficiency of production companies in the context of digitalization. Currently, the use of modern methods and tools to manage the consumption and supply of resources of companies should consider the principles of a circular economy. This study focused on the development of a mechanism to manage resource efficiency in the fuel and energy sector. It used the methodological tools developed by the authors, including a comprehensive integral assessment of resource efficiency and a practice-oriented research methodology adapted for fuel and energy enterprises. Having analyzed the existing state of resource consumption, the authors discovered a disparity of indicators, methods and means in the applied assessment of the accounting, control and expenditure of energy resources. Using the analytic hierarchy process as a foundation, the authors applied a technique for identifying inefficient production processes at the fuel and energy enterprises level as a case study. With the proposed technique, the main areas of the inefficient use of resources were identified. They include the organization of accounting, control and rationing of resource consumption, supplying the resources to production, and measures to improve resource conservation. These areas were ranked by importance and priority. The calculations determined the most resource-intensive process—"Operation of equipment and technologies". On this basis, the authors developed a methodology for resource efficiency management, including a number of digital technologies and tools. As a result of testing the developed mechanism in an oil and gas company based on the principles of a circular economy, the authors found reserves of the inefficient use of energy resources and searched for the best option for the development of an oil and gas company. Moreover, the proposed approach enabled the authors to determine the balanced growth of the company's resource efficiency, develop managerial decisions for the its long-term development, and conduct its environmental and economic assessment.

Keywords: resource efficiency management mechanism; digital resource saving technologies; managerial decisions; circular economy sustainable development

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1. Introduction

A resource-efficient evolution of any production company directly depends on the development of digital technologies for managerial decision-making and the creation of a center on their basis, controlling the resource consumption and resource conservation. Under the conditions of economic transformation, with the transition to a circular model of development, a steady global demand for hydrocarbon products turns fuel and energy companies into the main centers that regulate hydrocarbon production and control the efficiency of consumption and supply of resources.

In today's rapidly changing environment, digitalization of the economy contributes favorably to the implementation of resource efficiency and resource conservation in fuel and energy production companies. In turn, this leads to the development and implementation of new methodical and theoretical–methodological documentation on resource consumption and supply at the federal, industry and company levels. Determining a balanced supply of resources and their efficient consumption for production enterprises is of paramount importance. That is why the company level is a starting point for sound resource efficiency management, using digital technology and the principles of a circular economy. In terms of effective resource consumption and supply, industry and corporate relations should be managed by creating a mechanism for the efficient resource management of fuel and energy companies.

A review of existing approaches for the efficient use of resources that apply digital technologies and the principles of a circular economy in production systems [1–3] showed that many problems remain understudied and underdeveloped [4–8]. Most contemporary authors [9–13], using digital technologies in resource consumption and supply, covered individual industries and regions in their research [14–17]. The statistical methods and models of resource efficiency management proposed by a number of authors [18–22] are undoubtedly based on the use of digital technology, but ignore the principles of a circular economy. Many authors studied savings in production systems that resulted from the efficient consumption and supply of production resources, labor and finance [14,15,17,23,24]. The studies [25–30] considered the resource saving and efficient use of resources at the level of fuel and energy enterprises. In [22,31], the authors argued that the introduction of innovative digital methods and tools in the efficient use of resources into production requires clarification and expansion of the conceptual apparatus of resource efficiency [30,32–34].

In our opinion, the most significant studies are from European authors [8,16], which included legislative, regulatory and methodological documents on improving energy efficiency.

Most authors [27,35–38] considered the principles of a circular economy and application of digital technologies when identifying sources of the efficient use of energy resources in production enterprises. In [39], a method for designing the life cycle of a product in a circular economy was proposed, which can be used in the production operations of enterprises.

Thus, the problems of effective management of resource supply and consumption in fuel and energy companies can be solved using digital methods of multicriteria optimization, and their resource-efficient evolution can be determined. Such studies were conducted, for example, in [27,35,36]. The research used comprehensive approaches to resource conservation in production processes.

Modern scientific, practical and theoretical-methodological developments using digital technologies and the principles of a circular economy are necessary to solve the problems of effectual resource efficiency management and conservation in companies of the fuel and energy complex. In [40], the authors considered the use of circular economy models in industrial enterprises as an effective approach to sustainable development, resource and waste management, as well as energy efficiency. A number of authors [10,11,13,21,22,29] developed single-factor models for solving the issues of saving certain types of resources. Some scientists [3,9,12,14,15,23,41] devoted their research to solving multicriteria problems of optimizing the energy resource consumption.

In [24,29,37,42,43] the authors emphasized the importance of making high-quality decisions in resource efficiency management. This area can be referred to as research that has been sufficiently tested in project management of resource efficiency [24,37,44]. In most of the research [37,44–47] in which predictive models were proposed to evaluate the use of energy resources, the studies were conducted at the level of production systems. In [28,34,38], the authors implemented energy models for individual territories and regions. Noteworthy are models for the efficient use of fuel and energy resources at the level of countries and regions [47,48], considering the balanced supply of resources by all sectors of the economy in the conditions of digitalization. For example, in [47], the authors considered various energy models of efficient resource consumption and supply for countries and regions.

The study considered a nonlinear model [49] that helped the authors analyze the impact of technological development and population growth on the level of climatic load in China. The results of the study showed that the growth of carbon dioxide emissions does not depend on the production and consumption of renewable energy sources and the reduction in hydrocarbon reserves, but directly depends on the development of industrialization in the country and population growth.

In [50], the relationship between commodity markets and foreign currency was studied using the example of modeling Asian economies. The authors believe that in a crisis such as COVID-19, the results of the study will help governments make the right political decisions in the field of energy consumption. Study [51] considered a stable quantile regression model that allowed for determination of the impact of direct foreign investment, economic development and energy consumption at the level of environmental pollution, using the example of G-7 countries.

Improvements in existing energy models [17,23,28,41] and the creation of new methods for resource efficiency management using digital technologies were proposed in [22,28,37,44,52–55]. Some authors suggested using equilibrium models [14,15,23,41], which meet the principles of a circular economy and sustainable development of production systems, in order to develop and make managerial decisions in the field of energy and resource conservation [1–4,19,20,47]. According to [32,38,43], from a practical point of view, predictive models that assess the efficiency of resource-saving decisions are the most in demand in the market of digital technologies.

The authors of [6,35,44,46,56] in their studies proposed predictive models of resource consumption and supply management that reflect the specifics of fuel and energy enterprises in a circular economy, but require the creation of massive information and analytical systems. The results of the study conducted by the authors in [57] showed that the goals of sustainable development in any economy of the world are achieved faster when taking into account environmental, social and economic factors, as well as when there is an innovative culture.

The authors studied a large number of methodological approaches to resource efficiency management using digital technologies, and considered the specifics of the fuel and energy complex, including energy forecasting systems, balance-balance methods, interindustry and multifactor models, and methods of multicriteria optimization. Analytical studies have shown that energy models of production systems [14,15,17,23,47] are the most elaborate, allowing the forecasting of consumption and supply of fuel and energy resources in a circular economy and taking into account the particular nature of an industry. Researchers implemented such practices using modern digital technologies globally to forecast the supply and consumption of energy resources in countries and regions [1,9,11,12,25,32,35].

We should note an in-depth study by [58], in which the authors analyzed more than 200 scientific developments presented in the peer-reviewed Scopus literature for the period from 2015 to 2022. The authors identified a number of models and methods from a practical point of view, as well as the principles of sustainable development that can be used as a model toolkit in production systems.

Study [48] proposed a new software product—Circularity and Maturity Firm-Level Assessment tool (CM-FLAT)—which can be applied in the production activities of companies. The CM-FLAT allows for processing of a wide array of information, and calculates a number of key indicators based on the principles of circularity and sustainable development.

However, an analysis of the key literature sources in the field of the efficiency of using fuel and energy resources has shown that the available forecasting models do not fully meet the current demands under the conditions of increasing digitalization and compliance with the principles of a circular economy [16,17,23,41]. These methods and models mostly lack a sufficient software tool environment to make balanced forecasts, and do not allow management for the efficient use of resources. Furthermore, the existing methodological approaches do not offer mechanisms for managing fuel and energy resources at the corporate, industry and state levels.

In the course of analyzing existing methods and approaches to resource efficiency management by fuel and energy companies in the context of the digitalization of the economy, their insufficient elaboration was revealed both from theoretical and practical points of view. In the theoretical field, there are no basic concepts and principles, a clear conceptual apparatus, and classifications that determine the content of resource saving processes and resource efficiency of industry production processes.

On the practical side, there are no specific tools and means that could be used. The existing approaches are represented either by theoretical abstract models for individual countries and regions that provide approximations, or by statistical methods that deeply consider a separate production process, which, as a rule, are not related to fuel and energy specifics. Industry enterprises are in a constant shortage of energy resources for technological and production purposes. For this reason, companies are trying to identify internal reserves and determine the areas for the efficient use of resources through the principles and approaches of a circular economy and sustainable development. From the standpoint of practical applicability, enterprises in the fuel and energy sector need to find methodological tools and methods to manage resource efficiency, consumption and provision.

Summarizing the analysis of the literature, it should be noted that in the context of the global growth in energy demand for fuel and energy companies, the main goal is the development and adoption of such solutions for energy and resource conservation that will ensure the maximum technological, economic, social and environmental effects. In this context, without modern digital tools and a clear mechanism for resource efficiency management, evaluation of the existing state of resource consumption is impossible.

The authors in [47] proposed a methodological approach for an in-depth evaluation of the efficient use of resources in gas industry companies, which included the development of a software tool environment, allowed for the calculation of performance indicators in all areas of activity, and the integral evaluation of resource efficiency in the reporting and forecast periods for oil and gas enterprises.

The goal of this study was to develop a mechanism for efficient resource management, and test it under real conditions of companies in the fuel and energy complex.

In accordance with the set goal of the study, the following objectives were formulated:

1. Conduct a literature review of existing research in the field of modeling and forecasting managerial decisions aimed at the efficient use of resources by companies in the energy and fuel sector of economies in countries and regions.
2. Build a model of an electronic digital environment for managing the efficiency and optimizing the use of resources in the production processes of fuel and energy companies.
3. Test the developed mechanism for managing the efficiency of resource use in a fuel and energy enterprise.

This study consists of four sections. The introduction presents a rationale for the relevance of the chosen topic, a literature review of the predictive models and tools applied in practice in fuel and energy enterprises to manage the supply and consumption of energy resources, and formulation of the aim of the study. The Section 2 considers the algorithm of forming a mechanism for efficient resource management in a production company. The Section 3 deals with the results of the research and discusses the proposed mechanism for efficient resource management, and the Section 4 presents the main conclusions. Figure 1 presents the research logic.

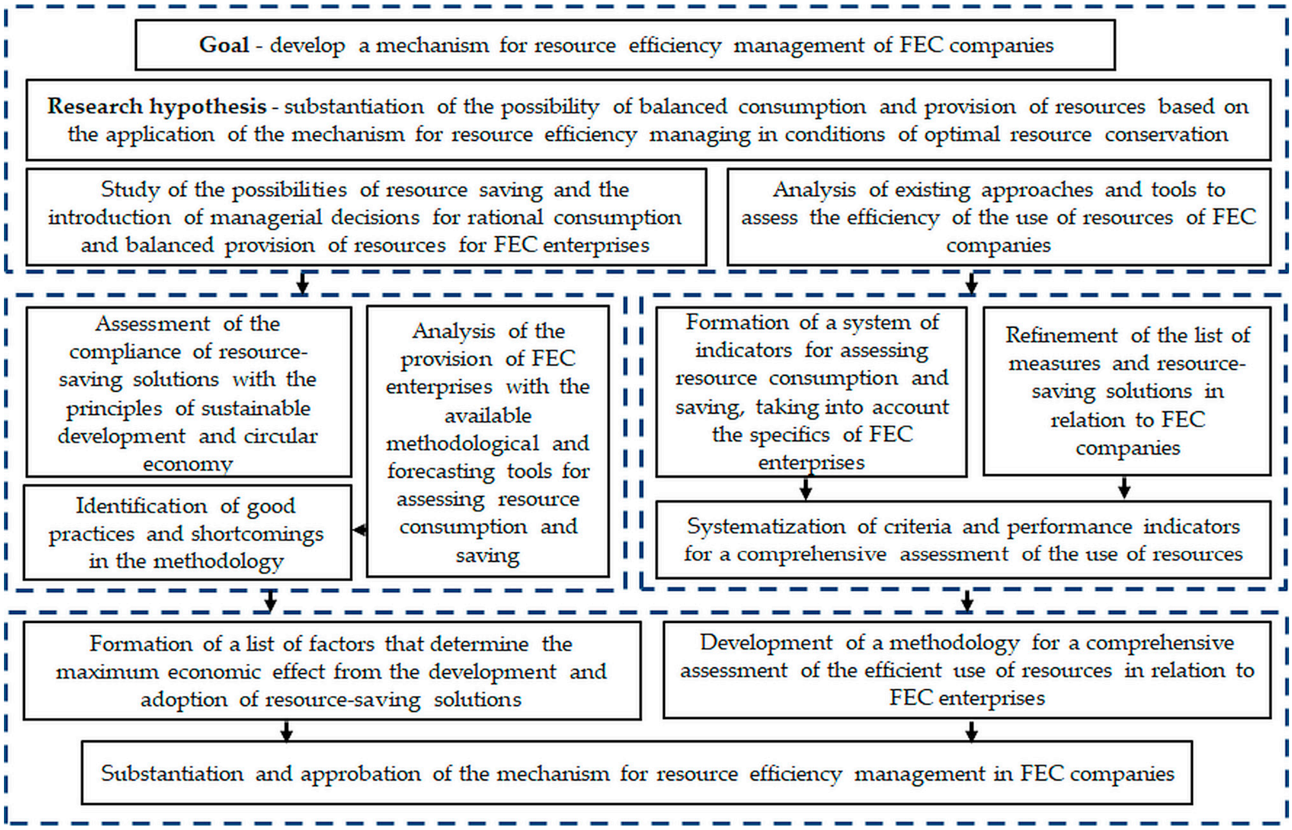

Figure 1. Research logic. Abbreviations used: FEC—fuel and energy complex.

2. Materials and Methods

Production functions underlie the creation of a mechanism for managing the efficient use of company resources. The first function is managing the consumption of resources that form a market supply. The second function is managing a balanced saving of resources that forms a demand for intermediate materials (including fuel and energy resources). In the context of transitioning to a circular economy, there is an urgent need to elaborate criteria for internal management, which could launch the integrated management of consumption and supply of resources and the implementation of corporate programs for resource efficiency and conservation.

The mechanism for efficient resource management should provide a causal relationship between the indicators of the internal management of both production functions, forming a unified simulation model of the production enterprise. This methodology, developed in [47], includes the calculation of a set of indicators for resource efficiency in all company activities, and allows achievement of the highest value of resource efficiency by varying the resource-saving projects. Accordingly, a significant economic effect for the company should be ensured. This important theoretical and practical conclusion substantiates the mechanism for efficient resource management. A comprehensive evaluation of resource efficiency results in a holistic assessment of resource consumption and supply, determination of the existing and future levels of resource saving, and selection of the most resource-efficient managerial decisions for the development of fuel and energy complex companies. Let us consider the mechanism of resource efficiency management for enterprises of energy and fuel companies presented in Figure 2. The indicative criteria of a resource-efficient policy in fuel and energy companies should primarily be used as control parameters. They are target benchmarks in the implementation of state energy strategies involving the calculation of resource consumption and saving indicators, and reflect improvement in resource efficiency.

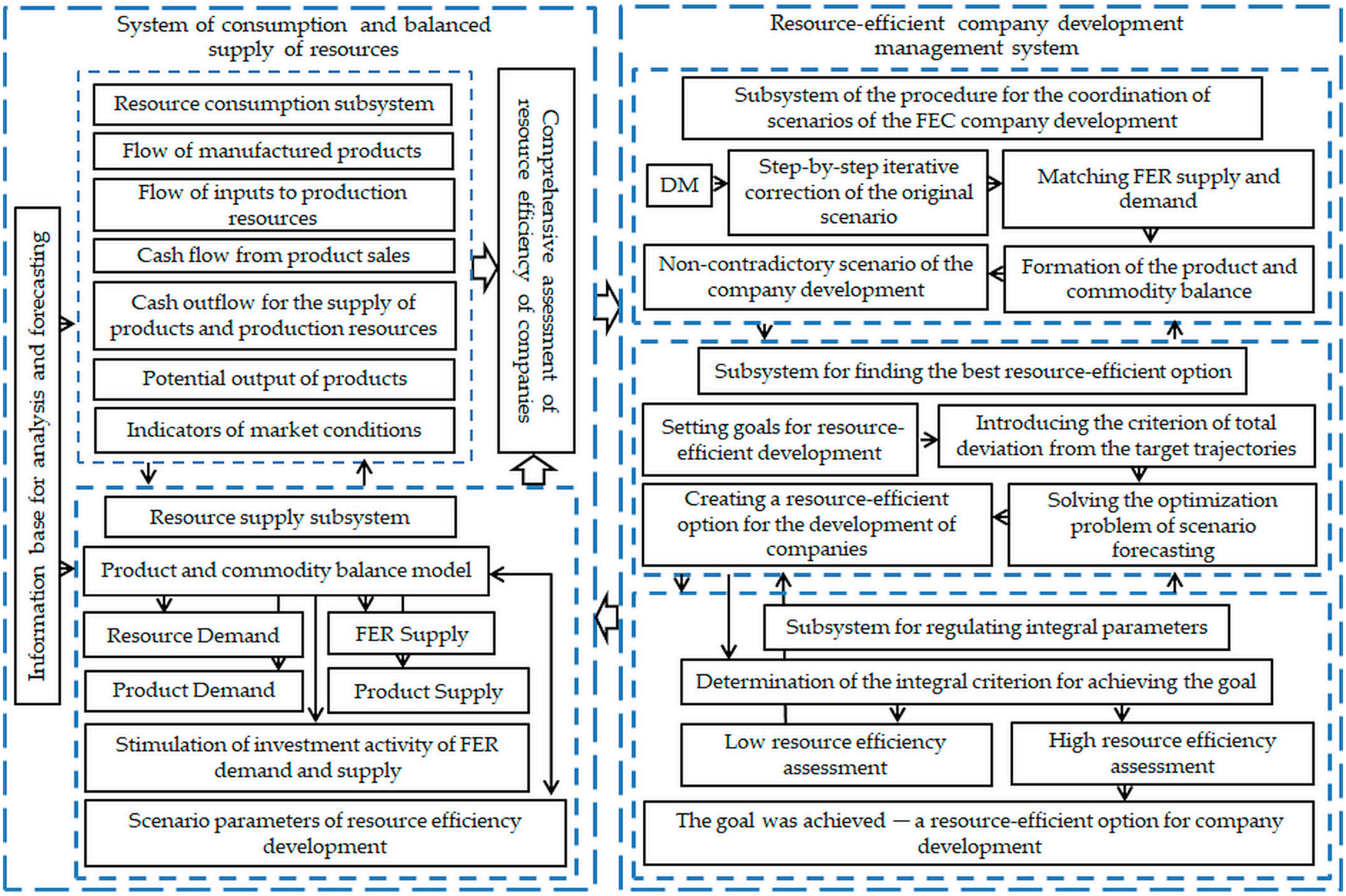

Figure 2. The mechanism for efficient resource management in fuel and power companies. Abbreviations used: FER—fuel and energy resources; DM—decision maker.

The system of resource efficiency management at the level of the fuel and energy complex proposes the following evaluation criteria: volumes of investment and other resources allocated for the implementation of resource-saving measures; main parameters of budget and industry policies for company development; changes in the proportions of tax and credit systems; changes in prices for natural gas, gas processing products, electricity tariffs; amount of savings due to the resource-saving and resource-efficient policies of production companies; incentives for the implementation of resource-saving measures, etc.

The resource efficiency management mechanism proposed by the authors in this study consists of two systems: a system of consumption and balanced supply of resources, and a resource-efficient company development management system. The first system includes two subsystems, resource consumption and resource supply, and is based on monitoring the interaction of companies of the fuel and energy complex and industries.

The subsystem of resource consumption includes production, economic, investment, financial, energy and environmental areas of activity, forming an aggregate production function of the company; this was considered in detail by the authors of [47], where the exogenous parameters of the simulation model used were described.

The resource supply subsystem includes several balance models that were also considered by the authors in [47]. The forecasting procedure is organized in the form of two interconnected contours: an industry or fuel and energy complex forecasting contour, and an individual company forecasting contour. At the first stage, a decision maker (DM) forms a scenario for the development of FEC companies, which contains assumptions about the behavior of economic subjects (except FEC) on the forecasting horizon: demographic scenario; expected production indices and price and tariff deflator indices; parameters of tax, investment and budgetary policies.

Based on the scenario of the development of FEC companies, the volume of production, capital and liquidity are forecasted, and the primary forecast of resource consumption on the left side of the balances is calculated [47]. As a result of these calculations, general requirements for the components of resources in kind are formed. These resource requirements are detailed as requirements for the development of the production base of the relevant companies and segments of the gas industry. Then, taking into account the forecast of tariffs for fuel and energy resources, the effective demand for products in the sectors of the economy in monetary terms is estimated, and the left side of the cost balances of products is formed [47].

In the second contour, according to the scenario of the development of the production company, the development of production capacity for each company is forecasted, taking into account the expected forecast of investment in capital and growth of tariffs. On this basis, the potential production of products in kind is forecasted. Next, the potential supply of products on the hydrocarbon market is formed, taking into account the producers' obligations for their export and shipment to the country's regions.

Taking into account the forecast of prices and tariffs for consumed resources, the supply of products in monetary terms is calculated. The calculated prospective demand for the types of resources is linked, element by element, with the possibilities of their supply. If, on the forecasting horizon, $t \in [t_1, t_T]$, the potential of FEC companies meets the needs for the *i*-th type of resource, and prices and tariffs form the supply of the resource at the level of demand that ensures development, Equation (1):

$$\begin{cases} z_i^q(t) \le z_i^s(t) \\ d_i^q(t) \le d_i^s(t)' \end{cases} \tag{1}$$

Surplus supply can be eliminated by increasing the export of the *i*-th type of resource, reducing the output of the resource, reducing the import of the resource, or replacing the *i*-th product of scarce resources (Equation (2)):

$$\Delta z_i(t) = z_i^s(t) - z_i^q(t) \tag{2}$$

where $Z_i^g(t)$ is the column vector of consumed resources (in natural measurement units); $d_i^s(t)$ is the agent's revenue from product sales (in cost measurement units); $d_i^g(t)$ is the agent's cost for acquiring resources (in cost measurement units).

Decisions on the adjustment of excess supply are formed at the level of adjusting the scenario conditions of development of the fuel and energy sector $Q_{ener}(t)$. If, for some moments of time, $t \in [t_1, t_T]$, then it means that the potential of the fuel and energy sector does not meet the needs for the *i*-th type of resource, as in Equation (3):

$$\begin{cases} z_i^q(t) > z_i^s(t) \\ d_i^q(t) \le d_i^s(t)' \end{cases} \tag{3}$$

It is necessary either to increase the supply potential of the *i*-th resource, or adjust the economic growth, or to do both. It is possible to increase the supply potential by increasing the output of the resource, reducing the export of the *i*-th type of resource, increasing the import of the resource, or replacing the *i*-th product with other resources.

Increasing the FEC potential requires quite certain development resources, which are limited and can be easily evaluated. Import/export operations are evaluated in a comprehensive assessment of resource efficiency by the external environment [47].

Reducing the consumption of resources by industries can be achieved by adjusting economic growth in a circular economy, as well as by carrying out measures to conserve resources, reduce the specific resource intensity of production, and resource efficiency management using digital technology and methodological tools.

Managerial decisions to eliminate the imbalance between product supply and demand are formed at the level of adjusting the scenario conditions of the development of companies and industries or the development strategy of the fuel and energy complex $Y_{FEC}(t)$ within the framework of the balance equations [47]. If, for some $t \in [t_1, t_T]$, Equation (4) is correct, it means that the prices and tariffs for the i-th type of product form the supply of the resource at a level that does not correspond to the effective demand for the i-th type of product.

$$\begin{cases} z_i^q(t) \le z_i^s(t) \\ d_i^q(t) > d_i^s(t) \end{cases}, \tag{4}$$

It is necessary to reduce the price or tariff for this type of product within the balance equation [47].

The management system of resource-efficient development includes three subsystems: the procedure for coordinating the scenarios of development of the FEC company; the search for the best resource-efficient option; and the regulation of integral parameters.

In the first subsystem of the procedure for coordinating scenarios for the development of companies, industries $Q_{com}(t)$ and the FEC $Q_{FEC}(t)$ as a whole are carried out by a step-by-step iterative correction of the initial scenario set by the decision maker, Equation (5):

$$Q^0(t) = [Q^0_{com}(t), Q^0_{ener}(t)]^T, \tag{5}$$

The correction tools are scenario parameters, changes which are aimed at coordinating supply and demand for all types of used resources as part of the formation of a total product and commodity balance (PCB), in kind and in value terms. During iterative coordination, a consistent scenario of improving the resource efficiency of the company, industries and the FEC as a whole is formed, Equation (6):

$$Q^*(t) = [Q^*_{com}(t), Q^*_{ener}(t)]^T. \tag{6}$$

The second subsystem for finding the best option is implemented as follows:

1. Let us assume that the goals are set for improving the resource efficiency of companies in the fuel and energy complex in the form of target settings [47] for economic development indicators and the selected system of resource efficiency indicators.
2. Let us introduce criterion L, characterizing the total relative deviation of the vector of indicators $E(t) = [E_{com}(t), E_{ener}(t)]^T = [e_1(t), e_2(t), \ldots, e_N(t)]^T$ from resource-saving solutions $E^0(t) = [E^0_{com}(t), E^0_{ener}(t)]^T = [e^0_1(t), e^0_2(t), \ldots, e^0_N(t)]^T$ at the checkpoints $t \in [t_1, t_2, \ldots, t_T]$, Equation (7):

$$L(Q,t) = \left\{ \sum_{i=1}^{J} \left\{ d_i \sum_{k=1}^{S} \left| \frac{e_i(Q,t_k)}{e_i^0(t_k)} - 1 \right| \right\} \right\} \tag{7}$$

where J is the composition of resource efficiency indicators; d is the weighting of the i-th indicator; S is the composition of indicators at the forecasting stage.

In this case, the search for a resource-efficient option (Equations (10)–(14)) [47] is represented as an optimization problem: to determine a possible option of resource efficiency of the company, industry and FEC $Q(t)$, minimizing the overall "inefficiency" that results from the failure to meet the goals set for the resource indicators at points $t = t_1, t_2, \ldots, t_T$ in the process of forming the target benchmarks $[0, t_T]$, Equation (8):

$$\min_{Q(t) \subset D_Q} L(Q(t)) = \min_{Q(t) \subset D_Q} \left\{ \sum_{i=1}^{N} \left\{ g_i \sum_{k=1}^{T} \left| \frac{e_i(Q(t_k))}{e_i^0(t_k)} - 1 \right| \right\} \right\}. \tag{8}$$

Here, indicators $e_1(Q(t)$, $e_2(Q(t)$, … , $e_N(Q(t)$ are calculated on the model when solving the direct problem of scenario forecasting [47] for the option of improving the resource efficiency of the company and FEC $Q(t)$, characterizing the set of managerial resource-saving decisions D_Q, set in the form of the adopted intervals of management scenario parameters.

3. Let us reflect the final resource-efficient option $Q(t)$ in the form of a control matrix Q of $L \times S$ dimensions, where $L = m + n$ is the dimension of the combined vector of scenario parameters of FEC $Q_{FEC} = [q_{FEC,1}, q_{FEC,2}, \ldots, q_{FEC,m}]^T$ development and scenario parameters of the resource efficiency of companies included in the FEC $Q_{IC} = [q_{IC,1}, q_{IC,2}, \ldots, q_{IC,n}]^T$, and S is the composition of indicators at the forecasting stage, Equation (9):

$$Q = \begin{bmatrix} q_{1,1}, & q_{1,2}, & \ldots, q_{1,T} \\ q_{2,1}, & q_{2,2}, & \ldots, q_{2,T} \\ \ldots & \ldots & \ldots \\ q_{L,1}, & q_{L,2}, & \ldots, q_{L,T} \end{bmatrix}. \quad (9)$$

4. Let us denote $Q^{(0)}$ as the basic version of the control matrix Q, and present it in the following form, Equation (10):

$$Q = Q^{(0)} \otimes K. \quad (10)$$

Here, $K = \|k_{i,j}\|_{L \times S}$ is the correction matrix of $L \times S$ dimensions; $\otimes$ is the symbol of element-by-element matrix multiplication.

Recording (10) allows us to reduce problem (8) to the search for the optimal correction matrix K^{opt}.

5. Using the matrix method, we develop a mechanism that allows us to automatically identify options for development, Equation (11):

$$Q^{\text{opt}} = Q^{(0)} \otimes K^{opt} \rightarrow \begin{bmatrix} Q^{opt}_{com}(t) \\ Q^{opt}_{ener}(t) \end{bmatrix}, \quad (11)$$

where the values of resource indicators E are as close as possible to the set goals E^0, taking into account the significance of these indicators (weights d) and possible restrictions on the control actions.

The third subsystem of the resource-efficient development management includes regulation of integral indicators. The integral criterion is calculated using the statistical method as follows, Equation (12):

$$\bar{l}_i = \frac{\left(\sum_{j=1}^{n} l_{ij} + \sum_{j=1}^{n} l'_{ij}\right)}{m};\ l_{ij} = \left(\frac{V_{ij}}{\overline{V}_j}\right);\ l'_{ij} = \left(\frac{\overline{V}_j}{V_{ij}}\right), \quad (12)$$

where $\bar{l}_i$ is the integral criterion of the i-th enterprise, which is a part of the fuel and energy complex; l_{ij}, l'_{ij} are the values of the particular indicators for the j-th key indicator, the change in which reflects the level of use of the resources of the i-th enterprise; V_{ij} is the estimate of the parameter by the j-th key indicator of the *i-th* enterprise; $\overline{V}_j$ is the average value of the key indicator for the enterprise in the total aggregate; i is the number of the enterprise in the aggregate under consideration; j is the number of the key indicator; r is the number of calculated indicators.

The evaluation of the efficient use of resources of a fuel and energy company is carried out using the total integral index. According to the calculations, if the integral index $\bar{l}_i$ is greater than one, then the company applies resource-saving solutions in the fuel and energy sector under consideration; if it is less than one, then the company uses the available resources inefficiently.

In the context of implementing the selected resource-efficient strategy and programs of FEC companies, prospective indicators are included in the mechanism of efficient resource management of the company, where the dynamics is a change in the ratio of consumption and supply of resources. Achieving the prospective indicators is possible with the formation of the budget of programs and strategies aimed at resource conservation and improving the resource efficiency of fuel and energy companies.

A systematic approach to financing the efficient consumption of resources and resource-saving policy of FEC companies involves the allocation of funds from the federal budget as part of state programs and energy strategy, industry-specific investment and the company's own funds. According to the authors, the above-described model of resource efficiency management for FEC companies can successfully operate over the long term.

Implementing the proposed mechanism for resource efficiency management of companies in difficult market conditions allows us to solve the following tasks:

1. Analyze and regulate the relationships between resource consumption and resource supply through prospective parameters;
2. Monitor the performance of the production company by tracking the implementation of the target function of improving resource efficiency, as well as analyzing the sensitivity of resource consumption and balanced resource supply on the evaluation of feedback;
3. Provide information on changes in the structural factors of resource efficiency policy in the resource consumption and supply subsystems;
4. Timely adjustments of data in the subsystems of resource consumption and supply, in order to manage the resource-efficient development of fuel and energy companies;
5. Analyze the current state and prospects of development of natural gas supply and demand markets, in order to determine the strategic parameters of resource-efficient policy and develop specific methods and means of achieving them at the state, industry and corporate levels;
6. Consider the specific nature of resource efficiency policy regulation as a system of the highest level, taking into account the coordination of the regional, industrial and corporate levels when implementing resource-efficient programs and strategies of companies;
7. Obtain a significant economic effect of resource-saving procedures, and compare the results and costs of the selected resource-saving management solutions in different prospective scenarios of fuel and energy companies. Such a comparative assessment will make it possible to see the consequences of the economic situation at the regional, industrial and corporate levels, without the implementation of business solutions, and with the implementation of the resource efficiency management mechanism of fuel and energy companies.

3. Results and Discussion

Within the framework of the methodology developed by the authors for assessing and managing resource efficiency in fuel and energy companies [47], along with econometric and formalized methods, expert methods are proposed with the involvement of production personnel, which allows for a better assessment of the current state and prospects for the development of resource-saving processes at the enterprise level. The mechanism of resource efficiency management of FEC companies was tested in the course of research commissioned by a gas pipeline transport enterprise, in order to develop and make managerial decisions in production activities while consuming and saving energy resources. Using the analytic hierarchy process (AHP) developed by T. Saaty, production processes that use resources inefficiently were identified, and promising measures were determined to optimize the company's operations and obtain a significant economic effect.

The expert group included 20 people from energy and fuel enterprises directly involved in production processes who made resource-saving decisions in the face of rational economy, uncertainty and risk. During the survey, the experts were asked to assess the feasibility of using resource-saving measures in the field of improving the organization of production processes, balanced consumption and resource provision, and optimizing control over the implementation of resource-efficient solutions.

According the AHP procedure, at the first "Focus" level, the main goal of the study, "Assessment of the effective use of company resources", was set. At the second "Factors" level, three main blocks were included (Table 1):

1. Assessing the implementation of accounting and monitoring of resource consumption and supply;
2. Assessing resource saving and consumption in the production process;
3. Improving measures to enhance resource efficiency and saving.

Table 1. Composition of the main and auxiliary processes at the "Actors" level.

Actors		
1. Assessing the implementation of accounting and monitoring of resource consumption and supply	2. Assessing resource saving and consumption in the production process	3. Improving measures to enhance resource efficiency and saving
1.1. Commercial accounting of resource consumption	2.1. Operation of equipment and technologies	3.1. Monitoring the results of work and implementing resource-saving measures
1.2. Departmentalized accounting of resource consumption	2.2. Developing production infrastructure	3.2. Introducing a system of material incentives for resource saving
1.3. Monitoring resource consumption and supply	2.3. Performing technological operations and equipment operation conditions	3.3. Applying new technologies and resource-efficient production

The third "Actors" level consisted of the main and auxiliary production processes included in the blocks of the "Factors" level, which are directly responsible for enhancing resource efficiency in the company. The fourth level of the considered hierarchy, "Actors' Targets", reflected the results of production processes of the "Actors" level (Table 2).

Table 2. Main results obtained at the "Actors' Targets" level.

Actors' Targets		
1.1. Full control over the use of resources	2.1. Ensuring reliable operation of equipment and complexes	3.1. Achieving savings and resource efficiency
1.2. Balanced use of resources	2.2. Reducing the duration of the production cycle and compliance with technological conditions	3.2. Engaging personnel in the resource-saving issues
1.3. Balancing resource and cost savings	2.3. Maintaining the operability of equipment through repair and modernization	3.3. Resource saving effect

The "Contrasting Priority Scenarios" level reflected the main results obtained from the implementation of activities at the level of "Actors' Targets" (Table 3). "General Priority Scenario" was the sixth and final level in the hierarchy we considered. It includes the main elements of resource-saving economic effect: 1. Resource savings: natural gas, power and thermal energy; 2. Reducing process losses; 3. Ensuring comfortable conditions for the company's employees.

Table 3. Main results obtained at the "Contrasting Priority Scenarios" level.

Contrasting Priority Scenarios		
Balanced supply of resources of the main production process	Ensuring the normal course of auxiliary and service production processes	Power supply and meeting the resource requirements
Ensuring the specified quality of consumed resources and manufactured products	Creating the necessary competitive production	Increased resource saving and efficiency of production processes

The main task of applying the AHP procedure was to identify the share of each criterion in the total volume, and evaluate the contribution of a separate event at each level to the overall goal of increasing the resource saving of an enterprise. For this, the significance coefficients were calculated to construct the corresponding matrix. The relative importance of the components of the hierarchy were determined using the nine-point scale of relationships developed by the authors. In accordance with the goal, the scale allows the decision maker to set numerical values for the preferred options from a range of 1 to 9, compared to others located at a higher level of the hierarchy. The scale includes two criteria: 1—"objects are equivalent", value one is assigned; 2—"object is more preferable", value two is assigned. Figure 3 shows the degree of influence of each "factor" in relation to the "Focus" level in the overall assessment of the efficient use of company resources.

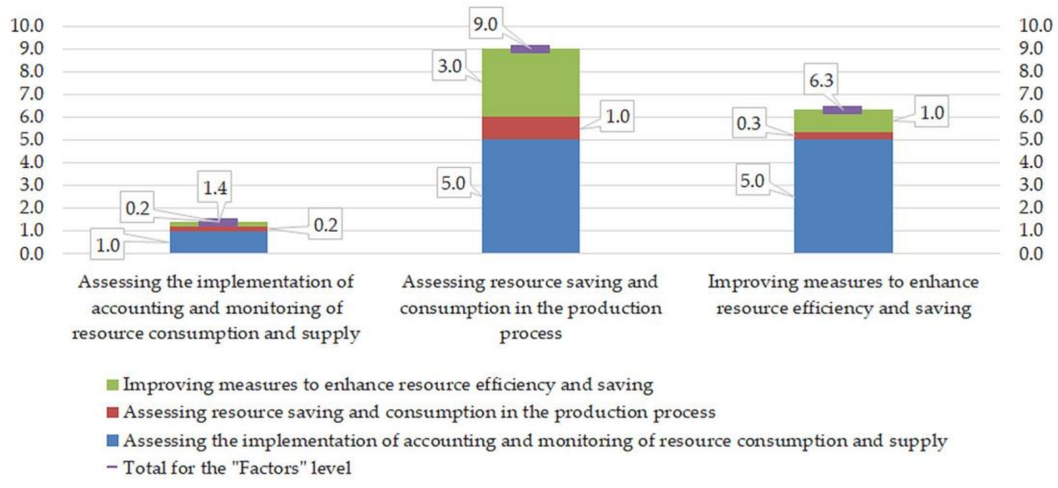

Figure 3. Degree of influence on consumption and saving of company resources at the "Factors" level.

From the calculations, we can see that the second block "Assessing resource saving and consumption in the production process" has the largest value (9). The third block, "Improving measures to enhance resource efficiency and saving", has a value of 6.3. The first block, "Assessing the implementation of accounting and monitoring of resource consumption and supply", with a value of 1.4, has the least influence on the consumption of company resources.

After the hierarchy was built, the pairwise comparison method was used. Matrices of pairwise comparisons were constructed to obtain an answer to the following question: "Which of the two compared components is more important or has a greater impact on the result?". Values were expressed as integers on a stanine scale. To do this, two elements were distinguished in the hierarchy: "resource-saving solutions" and "results".

Pairwise comparison matrices were calculated as follows. If component V_1 dominates over component V_2, then an integer is placed in the cell of the table relating to row V_1 and column V_2, and the reverse value of the number is placed in the cell of row V_2 and column V_1. If component V_2 is preferable to V_1, then an integer is placed in the cell of row V_2 and column V_1. Then, a fraction is placed in the cell of row V_1 and column V_2. If components V_1 and V_2 are equivalent, then the values of the matrix are equal to 1.

As a result of the analysis of the square matrix $[V]$, the components of the investigated hierarchy were ranked using importance eigenvectors (L). The maximum eigenvalue (λ_{max}) of the positive matrix $[V]$ was calculated according to the following formula:

$$\lambda max = e^m \times [V] \times L \tag{13}$$

In order to increase the consistency of any values of rij, that were accepted for comparative analysis of the i-th component with the j-th component, rij was assigned inverse values ($rij = 1/rij$). Thus, if one component was r times more important than the other, then the subsequent ones were $1/r$ more preferable than the initial one. To increase the degree of homogeneity of the expert assessment, deviations of the values of λ_{max} from the order of matrix m were used.

Figures 4–6 show the degree of influence of a separate block of the "Factors" level on the consumption and saving of company resources.

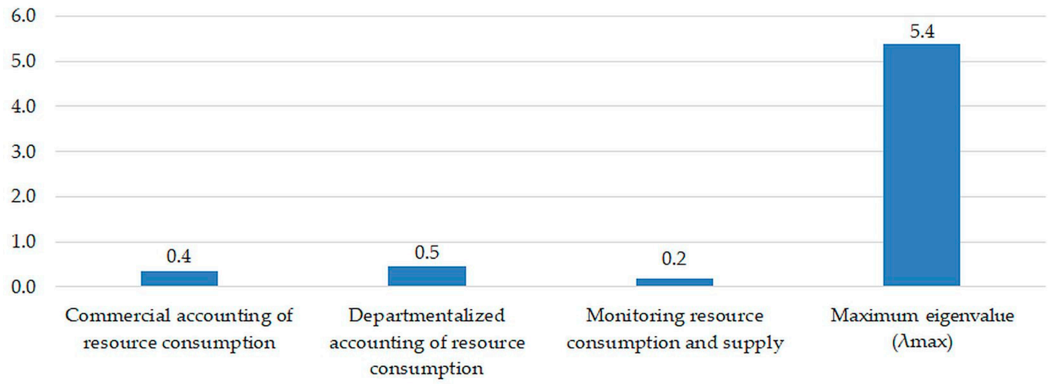

Figure 4. The degree of influence of the "Assessing the implementation of accounting and monitoring of resource consumption and supply" block at the "Factors" level.

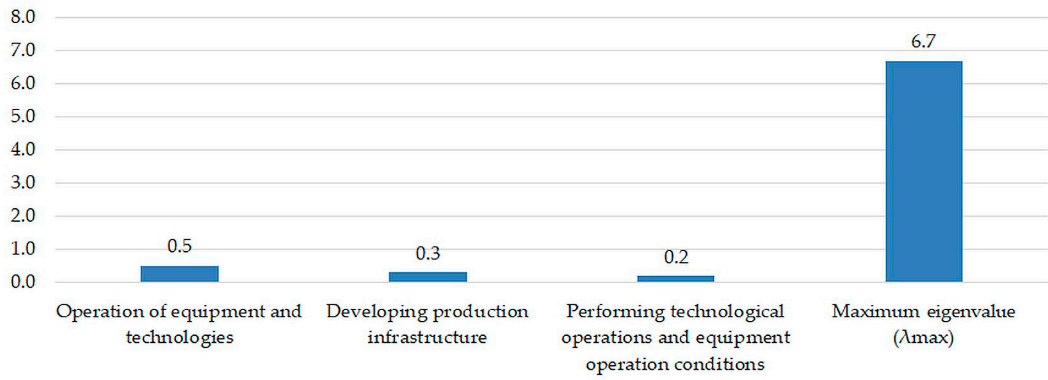

Figure 5. The degree of influence of the "Assessing resource saving and consumption in the production process" block at the "Factors" level.

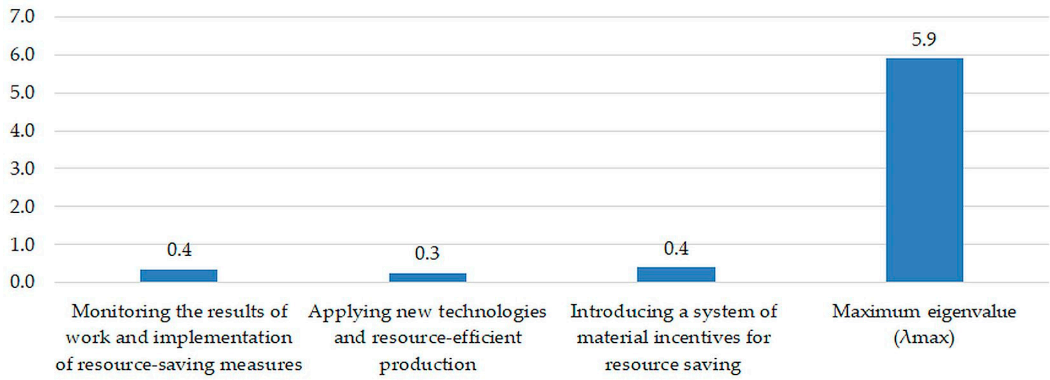

Figure 6. Degree of influence of the "Improving the organization of work to improve resource efficiency and resource conservation" block at the "Factors" level.

The degree of influence at the "Actors' Targets" level was determined using a matrix of pairwise comparisons and calculation of vectors of priorities for each of the nine elements of the "Actors" level. Furthermore, the authors determined the degree of importance of the components of the "Actors" level in the perspective of resource efficiency growth in relation to the "Factors" level (Table 4).

Table 4. Calculation of the matrix of resource-saving solutions.

A	B	C	Amount
0.4	-	-	0.03
0.5	-	-	0.04
0.2	-	-	0.02
-	0.5	-	0.3
-	0.3	-	0.2
-	0.2	-	0.1
-	-	0.4	0.1
-	-	0.3	0.1
-	-	0.4	0.2

The total assessment of the degree of influence on the elements of the "Factors" level and on the growth of resource efficiency was determined by the product of the obtained values in the matrix of Table 4 and the vectors of priorities (Figure 3).

The calculation results show that at the "Actors" level, more than 50 percent accounted for "operation of equipment and technology" and "introducing a system of material incentives for resource saving". Therefore, these significant elements of the "Actors" level were used to determine the weights of the priority scenario and identify the main elements of the "Actors' Targets" level by the product of the eigenvector of each "Actors' targets" element and the weight of each "Actors" element.

Then, according to the AHP procedure, the total vector of weights was calculated based on the normalization of the weights of the maximum values of the "Actors' Targets" elements and the normalization indicator. The latter was defined as the ratio of one to the sum of the key elements of the "Actors' Targets" Equation (14):

$$In = 1/Sum\ of\ key\ ``Actors'\ Targets" \\ In = 1/0.43 = 2.3 \quad (14)$$

The total vector of weights was obtained as the product of the vector of the key elements of the "Actors' Targets" and the normalization indicator, which was used by the authors to calculate the weights of the scenarios, and in total equaled one. Next, the degree of influence of the elements of the "Contrasting Priority Scenarios" level on the components of the "Actors' Targets" level was calculated (Figure 7).

To determine the degree of influence on the "Focus" level, it was necessary to multiply the vector of weights of all the elements of the "Contrasting Priority Scenarios" level by the vector of weights of the "Actors' Targets" level. Thus, the product of the multiplication of vectors of the "Contrasting Priority Scenarios" level and the common vector of weights allowed us to determine the degree of influence on the elements of the resource-saving effect at the level of "General Priority Scenario".

For the first "Resource savings" element, the degree of influence was 0.3 for natural gas, 0.2 for power and 0.1 for thermal energy. For the second "Reducing process losses" element, the degree of influence was 0.4. For the third "Ensuring comfortable conditions for the company's employees" element, the degree of influence was 0.2. An analysis of the "General Priority Scenario" elements showed that the highest value of 0.4 corresponded to "Reducing process losses", which accounted for almost half of the unused resource-saving potential. At the final stage of the study, the authors evaluated the elements of "General Priority Scenario", predicted the possible resource-saving options, and built a general scenario of the company's development (Figure 8).

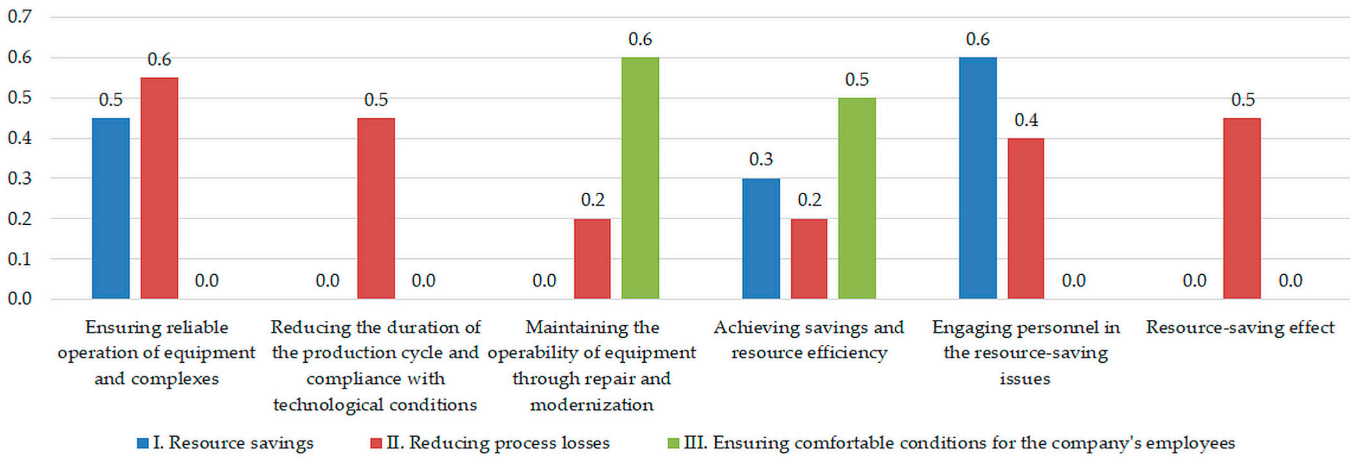

Figure 7. Assessment of the degree of influence of the "Contrasting Priority Scenarios" level on the elements of the "Actors' Targets" level.

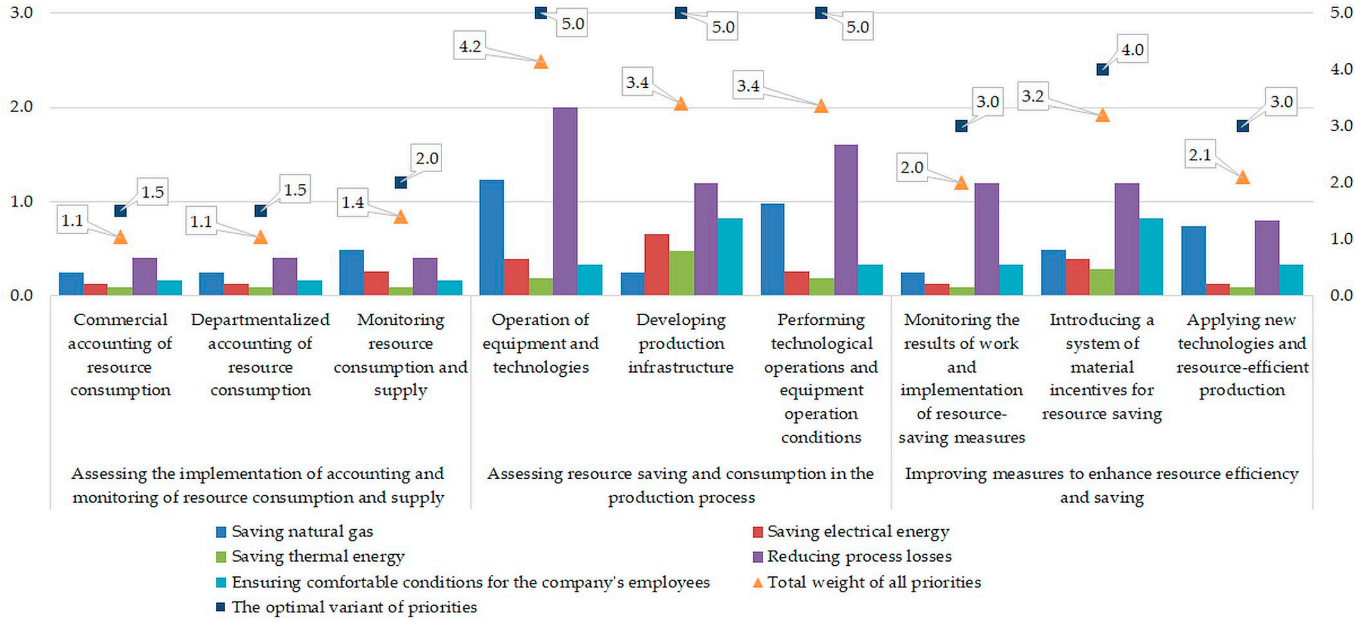

Figure 8. Evaluation of prospective resource-saving scenarios.

The authors interpreted the calculated values using such qualitative characteristics as the "best" and "worst" occurrence of events. According to the forecast calculations, in all elements of the "Actors" level, the consumption of resources will increase long-term, which corresponds to the general trend of growth in demand for hydrocarbons.

The cumulative value of the "General Priority Scenario" was obtained as the sum of the relative values of all elements at each level in the hierarchy we considered, which was 21.4. This assessment of the values obtained characterizes the overall measure or mark of the prospective level of resource consumption, and the possible potential to increase the resource efficiency of the company.

Next, we considered the operating principle of the mechanism of resource efficiency management of the company. Assume that under difficult conditions of uncertainty and risk, production companies of natural gas pipeline transportation have no opportunity to implement international projects to build new gas pipelines, and thus increase exports of natural gas. There is an oversupply of natural gas on the domestic market, and an imbalance between production and sales volumes. This situation hinders the economic development and resource efficiency of pipeline transportation companies. In response to this, in a circular economy the company forms prospective indicators in accordance with the following resource-efficient strategies:

1. The growth rate of natural gas exports by pipeline should decrease in favor of alternative modes of gas transportation, such as liquefied natural gas (LNG) transportation by road, rail and water. The result will be a diversification of natural gas export.
2. The diversification of transportation flows and the development of the LNG industry will lead to an increase in capital investment, i.e., an adjustment of the resource efficiency of the LNG industry. An increase in LNG export will substantially cover the losses incurred by increasing the foreign exchange earnings of the pipeline segment and attracting additional investments to the fuel and energy sector.
3. In the context of digitalization of the economy and changes in the world markets of supply and demand for hydrocarbons, increasing the resource efficiency of fuel and energy companies is possible through the optimization of their raw material base and production structure, the introduction of new digital technologies, and using resource-efficient methods and means of reconstruction and modernization of existing production facilities.

4. Changes in the structure of resource supply of fuel and energy companies through efficient consumption of resources, and the use of digital technologies and resource-saving industries, allow us to achieve higher growth rates compared with resource-intensive enterprises and industries.

In a circular economy, with the use of modern digital technologies, the mechanism of resource efficiency management for fuel and energy companies should perform the following main functions: (1) ongoing monitoring of the state of the resource base of fuel and energy industries and regions; (2) analysis and comprehensive assessment of resource consumption and balanced supply of fuel and energy industries and regions; (3) evaluation of the possibility of optimizing the alternative use of resources; (4) scenario forecasting of the future state and development of resource potential of fuel and energy industries and regions; (5) digital support of regional and industry-related projects in terms of resource saving; (6) providing access to information for independent economic entities while respecting sustainable development and energy security.

At the moment, regional and industry authorities in the system of development and adoption of resource-saving decisions lack digital technologies and methodological tools for a comprehensive assessment of resource consumption and supply [17,20,21]. There are practically no such analytical and consulting organizations in the regions that can provide an assessment of the available and required resources for the development of companies in their territory [22,56]. In this regard, at this stage, it is advisable to talk about the creation of resource-efficient development management systems at the industry and regional levels [24,28,29,44,52,59].

The mechanism of resource efficiency management of FEC companies proposed by the authors from the organizational and structural point of view is part of the regional or industrial system of implementation of resource-saving projects, acting within the framework of public authorities. Such management systems of authorities should include a subsystem of the resource supply project and a subsystem of the implementation of resource-saving projects [44–47]. The resource efficiency management mechanism is implemented as an electronic software and tool environment for fuel and energy companies using MS Access, MathCAD, Mathematica, Mathlab, MS Office, MS Excel and other software products, and meets the requirements of modern digital technologies. The software product is created to develop and adopt promising resource-saving solutions in matters of efficient use of resources and their balanced supply to the technological processes of energy and fuel companies.

As part of such resource management systems, it is possible to apply the mechanism of resource efficiency management of companies and industries of the fuel and energy complex proposed by the authors.

According to the authors, in the subsequent development of the resource and energy infrastructure of industries and regions, increasing the competitiveness of digital technology and economic security, such a task should be undertaken by commercial entities with the participation and control of public authorities [30,38,53,55]. In general, the determination of the effectiveness of industry or regional regulations of resource supply of FEC companies should be considered and controlled on the basis of two principles:

1. Correspondence of the obtained resource-saving result to the set socio-economic goal.
2. Minimization of costs in the process of achieving the goals of resource efficiency management.

The scientific value of the resource efficiency management mechanism developed by the authors and proposed for implementation lies in the fact that the process of implementing the company's resource-saving strategy will involve all management functions: organization of production processes, resource consumption planning, control over resource consumption, and motivation of personnel to engage in resource conservation. The same mechanism is suitable for managing the investment projects in the FEC. The mechanism proposed by the authors has the universal property of being adaptable to the production processes of industry companies, since it uses the same statistical information and the production set of indicators formed in the IFRS and the accounting policy of fuel and energy enterprises.

4. Conclusions

The mechanism of resource efficiency management of FEC companies, developed by the authors, will provide management systems with information and analytical materials that characterize the resource base in terms of consumption and sufficiency. In each specific case, using the proposed mechanism forms integrated assessments. They reflect the level of resource availability of a separate project and company, and provide recommendations for mobilization of the required resources. The overall report provides a comprehensive assessment of resource efficiency and the nature of the prospects for the development of companies, industries of the fuel and energy complex, and regions as a whole.

The mechanism of resource efficiency management of FEC companies by its functional affiliation is a system of control over resource consumption in the process of implementation of resource-saving projects. Its role consists of qualitative and quantitative evaluations of resource consumption, efficient use of resources, resource supply and development of recommendations on the expediency of using certain most-demanded resources at a particular stage. With the development of digitalization and the principles of a circular economy of countries and regions, the use of a resource efficiency management mechanism in the system of development and adoption of managerial decisions is an integral part of regional and industrial authorities.

The functioning of the resource efficiency management mechanism proposed by the authors in the short and medium terms allows optimizing the process of implementation of resource-saving projects for the development of the fuel and energy complex in terms of their resource supply; in the long term, this prevents negative shifts in the regional economy, with generally improved socio-economic development.

The limitation of the proposed method lies in the fact that in order to carry out detailed calculations in the production processes of a company, it is necessary to have reported production data, which is confidential information and, for the most part, not available. The use of only public statistical data from the official websites of companies will not provide complete information about resource saving and resource consumption; moreover, this will not allow determination of the current state of the enterprise's production activities. If calculations are performed according to the methodology proposed by the authors, specifically on request of companies, with all of the necessary information, then the best results can be obtained.

In future research, the authors plan to expand the approbation of the mechanism for managing the efficiency of resources at production and processing enterprises in the oil and gas industry, using the developed predictive and analytical tools.

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