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Economic Methods of Integral-Matrix Analysis of Hydrogen Energy Development Strategies

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Abstract. The paper identifies the problems of combining traditional and existing alternative fuels. It is shown that post-carbon energy determines a multi-criteria approach to the choice of hydrogen fuel production technology based on hybrid technologies. The methods of integral-matrix analysis for the selection of hydrogen production technology according to the criteria taking into account the trends in the development of the market, technology and products are suggested. The content of the article reveals the results of the analysis of trends in the new industrialization of industry in estimates of the development of hydrogen energy. Models and methods for assessing the stability of the hydrogen industry are supplemented.

1. Introduction

The relevance of expanding the scale of hydrogen energy is determined by the low energy efficiency of using traditional energy resources [1, 2, 3]. The presence of available energy carriers on the basis of carbon resources hampers the development of post-carbon energy. The predominance of carbon resources in power systems and transport infrastructure is associated with the advantage of well-established technological processes for their extraction and use. However, there are significant shortcomings, the manifestation of which can be observed in the ecosystem of the planet in the form of an increase in the technogenic load; violations of the hydrogeological regime, pollution of groundwater and soil erosion in the areas of extraction of fossil fuels; pollution of atmospheric air by oxides of carbon, nitrogen and sulfur, soot, heavy elements, hydrocarbons; violations of the thermal balance of the atmosphere and the growth of the greenhouse effect due to the release of man-made heat and other by-products in power plants. Other consequences of these factors are such negative phenomena as melting of ice sheets, an increase in the average temperature of the planet, an increase in financial costs to reduce the negative impact on the ecosystem [4, 5, 6]. The following methods are applied to the evolutionary approach of preventing the growth of emissions from industrial facilities and transport systems: modernization of purification systems for gaseous wastes at industrial facilities and transport [5, 7, 8]; synthesis of fuel additives that reduce harmful emissions from combustion and fuel consumption [9, 10, 11]; creation of alternative fuels with improved technical and economic indicators [12, 13, 14]. The strategy of reducing emissions from fossil fuel combustion by optimizing consumption systems allows only a small reduction in the content of carbon oxides and sulfur, soot in gaseous waste. As a result, intensive consumption of fossil resources occurs, which are becoming increasingly valuable because of the reduction in their reserves. Thus, according to various forecasts, the world's reserves of explored oil fields will last for the next 70 years [10].Consequently, the strategy of a gradual reduction in the consumption of carbon energy resources cannot be selected as the main one for further technological development [1]. It inevitably leads to the formation of substances polluting the planet's ecosystem and the depletion of limited fuel resources, and can be considered as a temporary for the development of alternative fuels [12, 15, 16].

2. Theoretical part

To evaluate and choose the direction of development of the product and socio-economic objects, an integrated matrix analysis [15, 16] is used. This analysis is based on the definition of the mutual relationship between the consumer requirements (CR) and the object characteristics (OC), ensuring compliance with these requirements. This takes into account the internal connection between the individual characteristics. All assessments are conducted in numerical form by a group of experts, consisting of specialists in various fields of activity. The strategic objectives for the selection of hydrogen fuel production technology using the integral-matrix and expert analysis are presented in Table 1.

Table 1. Strategic goals of hydrogen energy development.

	Market (Y_S)	Technology (X_S)	Product (Z_S)
Organizational activities	Increase in economic efficiency of production of hydrogen fuel to the level of alternative analogues	Increasing the efficiency of the hydrogen fuel production process	Development of the infrastructure for the maintenance of hydrogen production plants and vehicles with hydrogen fuel
	Growth of the share of consumers of hydrogen fuel	Transfer of production of hydrogen fuel to renewable raw materials and energy resources	Increasing the productivity of installations for the production of hydrogen fuel from a unit of raw materials used
	Formation of a system of state support for producers of equipment for the production of hydrogen fuel and its components to reduce the cost of fuel	Creation of long-term portable storage of hydrogen with a minimum of diffusion losses	A long interim period of installations for the production and use of hydrogen fuel
	Creation of a network of suppliers and consumers of commodity hydrogen on the basis of petrochemical and energy sites	Development of the infrastructure for storage and delivery of hydrogen fuel to large consumers	Creation of a system for the long-term safe storage of hydrogen fuel in a vehicle and on the territories of generating capacities
	Formation of logistics schemes for interaction between hydrogen suppliers and consumers	Modernization of production facilities and use of hydrogen fuel to improve efficiency and simplify the process	High purity of produced hydrogen

To achieve the set goals within the framework of the development of hydrogen energy, it is necessary to solve a number of current problems, reflected in the form of organizational arrangements. To implement strategic goals, a complex of organizational measures is required (Table 2).

The priority strategic goals and organizational arrangements selected on the basis of the integrated matrix analysis determine the directions of the development of hydrogen energy for energy, environmental and economic criteria in the short and long term. Thus, two three-dimensional graphics are created: the strategic development of the product within the three axes (market-technology-product) and the organizational arrangements for the said development in the same coordinate axes (Figure 1).

The relationships between spatial diagrams are realized by means of an integral-matrix analysis tool [16].

Table 2. Organizational activities for implementation of the hydrogen energy development strategy.

	Market (Y_O)	Technology (X_O)	Product (Z_O)
Strategic objectives	Use of hydrogen as an additive to fossil fuels to increase its demand	Examination of existing nonmaterial for use in hydrogen storage and production systems	Application in the production, storage and use of hydrogen systems for composite materials alloyed with steels; minimizing moving parts, improving the heat balance
	Use of capacities of petrochemical, power and oil refineries for hydrogen production	Development and implementation of catalysts accelerating the process of hydrogen production, reducing energy consumption.	Application of materials, additives, increasing the rate of reaction of hydrogen production, reducing the loss of raw materials and by-products
	Consolidation of efforts of automobile concerns to work on fuel cells and hydrogen production technologies through the formation of joint research centres	Use of reserve capacities of power plants for the production of hydrogen fuel	Application of additives to hydrogen fuel and sensors to prevent the formation of combustible explosive gas
	Creation of a program for the development of the market of commodity hydrogen to attract government support and investors	Replacement of precious metals and other expensive components in hydrogen fuel production systems for cheaper analogues	Modernization of technological processes of hydrogen purification and use of methods of hydrogen production with the greatest degree of purity
	Attraction of cheap electricity (NPP, HPP) for the production of hydrogen fuel	Modernization of fuel systems of vehicles and generating capacities for the use of hydrogen as an additive to the main fuel	Formation of service centres on the basis of producers of hydrogen fuel and power plants

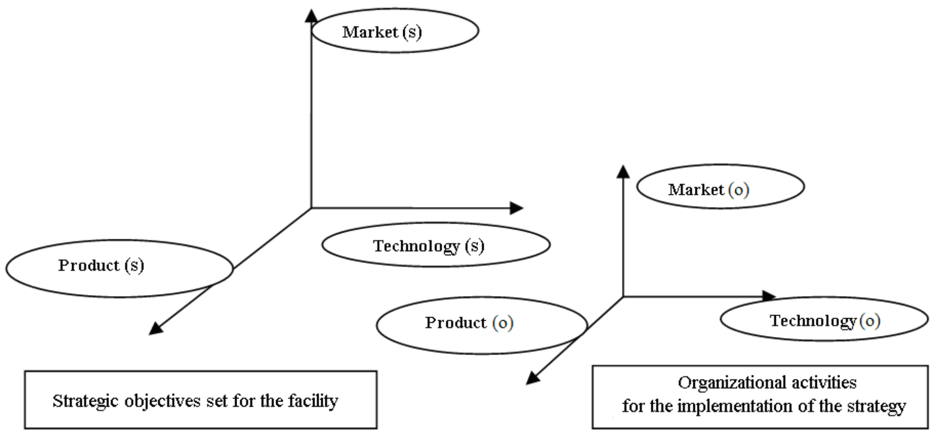

Figure 1. Spatial axes of strategic objectives and organizational arrangements for the implementation of the strategy.

3. Scientific novelty and a new economic method

In each group “market”, “technology”, “product” several strategic objectives are formulated that need to be achieved as a result of the implementation of organizational arrangements. The list of these objectives (5 arbitrarily accepted objectives in each group) is quite universal, but their priority over time, when moving from organizational arrangements to strategic development, is changing. Thus, a list of objectives by groups is drawn up: market (1 ... 5); technology (1 ... 5); product (1 ... 5). The expert ball score establishes the priority of long-term goals, as well as their relationship to goals in neighbouring groups and among themselves in one group. Analysis of the objectives for each axis (group) is carried out with the help of expert assessments and compilation of a vector diagram on their basis. The analysis reveals the main priorities that determine the demand of the product in the market. At the stage of product positioning in strategic development, an assessment of the level of satisfaction of each market requirement (technology, product) is performed with the existing position before the project changes P_{bi}. Next, a list of target values in points for each direction of development of P_{pri}, is formed, which, from an expert point of view, must have a new product in new market conditions and with new technologies. Target values that do not need changes are assumed to be equal to the base:

$$P_{pri}=P_{bi}. \quad (1)$$

Other target values are taken above the baseline

$$P_{pri}\geq P_{bi}. \quad (2)$$

The evaluation of the weightings of the strategic directions of development takes into account both their baseline condition and the necessary degree of improvement in each direction in the project. The degree of improvement is calculated by the formula

$$K_{pi}=P_{pri}/P_{bi}. \quad (3)$$

Further, the rating of each direction for each axis separately in the total score of all project changes

$$R_{nmi}=P_{pri}/\Sigma P_{pri}. \quad (4)$$

Here we set the weight V_{mni} of each project goal for the axes:

$$V_{mni} = K_{pi}\cdot R_{nmi}. \quad (5)$$

Next, the sum of the weights of the project objectives is determined ΣV_{mni} and the proportion of each weight of the target is determined $V_{mni(ru)}$ in the total amount:

$$V_{mni} = V_{mni(ru)} / \Sigma V_{mni}. \quad (6)$$

By weight indicators, priority is determined for the implementation of strategic development goals and the highest priority is given to the priority ones to be implemented in each direction. Let *Ys* be the axis of strategic goals of market development. Then *Ysi* is the *i*-th goal of this development. Similarly, for the technology *Xs* -> *Xsi* and for the product *Zs* -> *Zsi*. Arbitrarily, as an example, we take $i = 1 ... 5$

Each strategic goal, for each axis (market, technology, product) is determined by experts collectively. Priority of strategic goals implementation is calculated using a special methodology, the main one on the ballroom expert assessments and their increments from the base value of the evaluation of each goal to the strategic (project) "*ΔPi*". In this case, both the increment of points and their initial and final values are taken into account.

Axes of states in the short run:

- *Yo* – axis of organizational development activities of the market. Then *Yoi* is the *i*-th goal of this development.
- *Xo* – axis of technological opportunities for organizational activities. Then *Xoi* is the *i*-th indicator of technology.
- *Zo* – axis indicators of the product obtained as a result of the implementation of organizational activities. Then *Zoi* is the *i*-th product index.

Each strategic objective (technological capability or product index) for each axis is nominally reflected in organizational arrangements. That is, *Yo* = *Ys*; *Xo* = *Xs*; *Zo* = *Zs* according to the list of indicators. However, the priority of indicators for each axis in the strategic period and organizational arrangements will be different. This is ensured by coupling coefficients, both between different axes, and between different indices within each axis.

Mutual relations between the organizational and strategic factors of different axes are taken into account by the coupling coefficients:

- *Kyixj* is the numerical coupling coefficient between the *i*-th market indicator (*Y*-axis) and the *j*-th technology indicator (*X*-axis);

- $Kxizj$ – the numerical coupling coefficient between the i-th indicator of technology (X-axis) and the j-th product index (Z-axis);
- $Kziyj$ – the numerical coupling coefficient between the i-th product index (Z-axis) and the j-th market indicator (Y-axis).

Thus, we have the amplitudes, for example, of five interrelated factors of the Yo axis (market):

$$Af1y = [A1y] + Ky1y2 \cdot A2y + Ky1y3 \cdot A3y + Ky1y4 \cdot A4y + Ky1y5 \cdot A5y;$$
$$Af2y = Ky2y1 \cdot A1y + [A2y] + Ky2y3 \cdot A3y + Ky2y4 \cdot A4y + Ky2y5 \cdot A5y;$$
$$Af3y = Ky3y1 \cdot A1y + Ky3y2 \cdot A2y + [A3y] + Ky3y4 \cdot A4y + Ky3y5 \cdot A5y;$$
$$Af4y = Ky4y1 \cdot A1y + Ky4y2 \cdot A2y + Ky4y3 \cdot A3y + [A4y] + Ky4y5 \cdot A5y;$$
$$Af5y = Ky5y1 \cdot A1y + Ky5y2 \cdot A2y + Ky5y3 \cdot A3y + Ky5y4 \cdot A4y + [A5y],$$

where Aiy – amplitude of the uncorrelated i-th factor of the Y axis; $Afiy$ – amplitude of the correlated i-th factor of the Y axis.

Similarly, along the Xo axis (technology)

$$Af1x = [A1x] + Kx1x2 \cdot A2x + Kx1x3 \cdot Ax3 + K1x4x \cdot A4x + Kx1x5 \cdot A5x;$$
$$Af2x = Kx2x1 \cdot A1x + [A2x] + Kx2x3 \cdot A3x + Kx2x4 \cdot A4x + Kx2x5 \cdot A5x;$$
$$Af3x = Kx3x1 \cdot A1x + Kx3x2 \cdot A2x + [A3x] + Kx3x4 \cdot A4x + Kx3x5 \cdot A5x;$$
$$Af4x = Kx4x1 \cdot A1x + Kx4x2 \cdot A2x + Kx4x3 \cdot A3x + [A4x] + Kx4x5 \cdot A5x;$$
$$Af5x = Kx5x1 \cdot A1x + Kx5x2 \cdot \mathrm{A}2x + Kx5x3 \cdot A3x + Kx5x4 \cdot A4x + [A5x].$$

On the Zo axis (product)

$$Af1z = [A1z] + Kz1z2 \cdot A2z + Kz1z3 \cdot Az3 + K1z4z \cdot A4z + Kz1z5 \cdot A5z;$$
$$Af2z = Kz2z1 \cdot A1z + [A2x] + Kz2z3 \cdot A3z + Kz2z4 \cdot A4z + Kz2z5 \cdot A5z;$$
$$Af3z = Kz3z1 \cdot A1z + Kz3z2 \cdot A2z + [A3z] + Kz3z4 \cdot A4z + Kz3z5 \cdot A5z;$$
$$Af4z = Kz4z1 \cdot A1z + Kz4z2 \cdot A2z + Kz4z3 \cdot \mathrm{A}3z + [A4z] + Kz4z5 \cdot A5z;$$
$$Af5z = Kz5z1 \cdot A1z + Kz5z2 \cdot A2z + Kz5z3 \cdot A3z + Kz5z4 \cdot A4z + [A5z].$$

Thus, the development strategy is determined by the relationship between both the factors inside the three-dimensional space and between the axes.

4. Application

Based on the results of the expert analysis, it is evident that the advantage of meeting the strategic goals and organizational measures of a highly efficient hydrogen generation electrolysis system using alkaline zinc hydroxide solution [3] with the use of energy in the period of the decline in power consumption [2]. The use of electrolysis for the production of hydrogen fuel is justified for the following reasons:

- high degree of purity of the hydrogen produced;
- available raw materials;
- possibility of using standby capacity of power plants during periods of decline in electricity consumption for the production of hydrogen fuel;
- production of oxygen as a by-product;
- universality of the use of the energy source (nuclear power plants, hydroelectric power stations, etc.);
- modularity of electrolytic installation.

As an energy efficient method of reducing the high energy intensity of hydrogen production, the approach of using the periods of the decline in the load on the power system can be recommended. The low cost of electricity in periods of a decrease in the daily load of the power system reduces the cost of electrolysis. It is possible to use catalysts and electrode materials that reduce the power consumption and cost of the electrolytic plant: a nickel-based and boron-based catalyst system that replaces platinum components and reduces the specific energy consumption for hydrogen production by 20 % [8].

5. Conclusion

The applied integral-matrix analysis showed that:

– development of post-carbon energy will help solve global environmental problems;

– for the accelerated development of hydrogen energy it is necessary to create a competitive innovative fuel infrastructure based on technologies that meet competitive market criteria;

– for the efficient combined production of electricity and hydrogen fuel, it is recommended to use electrolysis as a hybrid technology for loading the free existing power system capacities.

Thus, the integral-matrix analysis of combining different criteria is proposed and carried out, which is distinguished by the use of three-dimensional modeling in the “market-technology-product” axes, which allows us to systematize expert estimates for determining the directions of development of research objects, both in the current period and at long-term forecast.

References

[1] Alabugin A and Shchelkonogov A 2017 Management of Technological Development of an Industrial Enterprise in Terms of Indicators of Combination of Factors of Production *Economics, Management and Law* **69** 1310–315
[2] Amelin I 2016 *Identification of Reserves of Capacities from Daily Loading of Power Plants for Production of Hydrogen Fuel* (CNS Interactive Plus Publ.) p 62
[3] Horri B, Choolaei M and Chaudhry A 2018 A Highly Efficient Hydrogen Generation Electrolysis System Using Alkaline Zinc Hydroxide Solution *International Journal of Hydrogen Energy* **11** 1-4
[4] Ermolaeva V and Petrova E 2008 Choosing Effective Methods for Treating Gaseous Emissions as a Component of Ecological Safety *Modern High Technologies* **2** 2-24
[5] Laure A 2015 Producing Hydrogen Cheaply Through Simplified Electrolysis *Energy and Environmental Science, Phys. Org* **34** 3-8
[6] Moliner R, Lazaro M and Suelves I 2016 Analysis of the Strategies for Bridging the Gap Towards the Hydrogen Economy *International Journal of Hydrogen Energy* **41(43)** 19500–08
[7] Rahmankulov D, Nikolaeva S and Latypova F 2018 On the Problem of Depletion of the World Oil Reserves *Bash. Chem. m.* **2** 6-12
[8] Senina Y and Vetoshkin A 2011 *Reducing the Negative Impact of Transport on the Ecological State of the Environment* (Moscow: NiKa Publ.) p 36
[9] Khaleev M. and Zaitseva T. 2017 *Instruments for Activating the Development of Carbon Energy* (Cheboksary: CNS Interactive Plus Publ.) p 202
[10] Shidakova E and Starodubtseva Y 2014 Hydrogen and the Prospects of the Development of the Russian Oil and Gas Industry *Electronic Scientific and Practical Journal* **12** 2-4
[11] Stolyarevsky A 2008 Alternative fuel production based on nuclear power sources,” *Russian Chemical Journal of the Mendeleev Society* **52(6)** 73–77
[12] Ferreira H, Costescu A and L’Abbate A 2011 Distributed Generation and Distribution Market Diversity in Europe *Energy Policy* **39** 5561-71
[13] Davis G and Owens B 2003 Optimizing the Level of Renewable Electric R&D Expenditures: Using Real Options Analysis *Energy Policy* **31** 1589-1608
[14] Chien T and Hu J 2007 Renewable Energy and Macroeconomic Efficiency of OECD and Non-OECD Economics *Energy Policy* **35** 2007 3606-15
[15] Rastvorov D, Osintsev K, Toropov E 2017 Influence of Burner Form and Pellet Type on Domestic Pellet Boiler Performance *Earth and Environmental Science* 87 032034
[16] Alyukov S 2011 Approximation of step functions in problems of mathematical modeling *Mathematical Modeling, Journal of the Russian Academy of Sciences* **23** 75-88

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