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Modeling Regulation of Economic Sustainability in Energy Systems with Diversified Resources

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Abstract: The imperfection of theoretical and methodological approaches to regulate the jump process transition when combining differentiated energy resources is a pressing issue. The goal of this paper is to develop a theory and a method to regulate the integration-balancing processes of combining diversified resources. The concept of combining integration and balancing models has been substantiated by methods of transforming multidimensional space and approximating generalized functions that represent jump-like processes. Theoretical and operational-regulatory models of economic sustainability have been developed, substantiating new concepts, patterns, properties, dependencies and indicators of the dynamics of the processes of combination; the optimality conditions for the number of approximations of generalized functions, interpreting the effects of control functions of combining resources, are thus determined. New methods for solving problems have been developed: the organization of the energy technology complex of facilities for enhanced resource diversification and the Sustainable Development Center, improving the quality of managing dynamic processes in terms of combining and diversifying resources. Emphasis is placed on four elements: theoretical and methodological approaches to regulate the jump process transition when combining differentiated energy resources is a pressing issue; the goal of this paper is to develop a theory and a method to regulate the integration-balancing processes of combining diversified resources; the concept of combining integration and balancing models has been substantiated by methods of transforming multidimensional space and approximating generalized functions that represent jump-like processes.

Keywords: economic sustainability; energy technology complexes; regulating combined resources; degree of diversification; approximation of functions of abrupt development

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1. Introduction

The urgency to improve the regulation of differentiated resources of systems and the effectiveness of the results of their evolutionary modernization and spasmodic development processes grows in conditions of instability and uncertainty. It is necessary to develop a special methodology for combining, integrating and replacing diversified resources and methods to allow for the convergence of target trajectories. We formulate the methodology as integration-convergent and organizational–technological, since it determines the growing importance of the results of the unification of the totality of generally accepted scientific achievements in the theory of managing the processes of system formation and development. It determines the direction of actions to ensure sustainability in the long-term development of systems when combining differentiated resources. The processes of the first type correspond to the modernization of technologies, mainly with minor degrees of combination and diversification of resources. Consequently, separate centralized and single-product production prevails on a constant technical–technological and organizational basis. The processes of the second kind are distinguished by the abrupt replacement of existing technologies and methods of organization. In this study, this means a transition to medium and high degrees of combination and diversification of resources by high-tech activities of interconnected facilities in multipurpose complexes of various types. The relevance of the economic justification for renewable energy development projects determines the need for new models and methods for project evaluation. Such energy production consumes renewable energy resources (RERs). For example, the volume of solid household and industrial waste in the world is about 0.5 billion tons, or 500 kg/person per year [1]. In the Russian Federation, an average of 63 million tons is produced, with 4–6% of the total volume being useful, according to various estimates, despite the fact that the climatic and geographical conditions of most of the territory of Russia and significant reserves of nonrenewable resources do not contribute to an increase in the use of natural renewable energy resources such as the energy of the sun, wind, tides, ocean currents, etc. Nevertheless, it is advisable to refer to the experience and forecasts of developed countries: in Germany by 2025, energy facilities consuming nuclear and coal fuels should be closed, and by 2035, the share of renewable energy resources should be 8% [2]. The global scale of the problem of their insufficient use is associated with the expected depletion of nonrenewable energy resources and the increasing importance of environmental protection in the concept of sustainable development. At the same time, the volumes of a new type of material resources with energy potential are increasing иособенно это относится кsolid household waste (SHW), in the amount of about 0.5 billion tons or 500 kg/person per year [3,4]. This is aimed at improving the quality of life of the population and takes into account the rapid increase in the cost of traditional energy resources of a nonrenewable type. The costs include the environmental component, since the norms of environmental activities must be strictly observed.

In this paper, five aspects are briefly disclosed and substantiated with statistical information: needs, purpose, methodology, methods and results. The need of the energy economy to solve the scientific issue of developing new approaches is revealed: to improve the regulation of differentiated resources of systems and the effectiveness of the results of their evolutionary modernization and spasmodic development. The problem is defined as such: development processes grow in conditions of instability and uncertainty. The research goal is to develop a special methodology for combining, integrating and replacing diversified resources and methods to allow for the convergence of target trajectories. To achieve this goal, the author's methodology is defined as integration-convergent and organizational–technological, since it determines the growing importance of the results of the unification of the totality of generally accepted scientific achievements in the theory of managing the processes of system formation and development. The new methods of implementing the methodology are briefly described: the direction of actions to ensure sustainability in the long-term development of systems when combining differentiated resources; the modernization of technologies mainly with minor degrees of combination and diversification of resources; separate centralized and single-product production prevailing on a constant technical–technological and organizational basis; and others. The results of applying the new methods were obtained: the relevance of the economic justification for renewable energy development projects determines the need for new models and methods for project evaluation. Such energy production consumes renewable energy resources (RERs). For example, there is a big volume of solid household and industrial waste in the world. Brief background information is given, and a conclusion is made about the insufficient degree of solution of the problems identified in the introduction. This made it possible to identify the main contradiction of scientific research, which determines the main direction of the present work.

The article has five major focuses: 1. The development of theoretical and methodological approaches to regulate the jump process transition when combining differentiated energy resources is a pressing issue. 2. The statement and implementation of the goal of this paper is the development of a theory and a method to regulate the integration-balancing processes of combining diversified resources. 3. Definitions of the concept of combining integration and balancing models have been substantiated by methods of transforming multidimensional space and approximating generalized functions that represent jump-like processes. 4. Development of theoretical and operational-regulatory models of economic sustainability have been developed, substantiating new concepts, patterns, properties, dependencies and indicators of the dynamics of the processes of combination. 5. New methods for solving problems have been developed, as exemplified by the organization of the energy technology complex.

2. Literature Review/Background

The insufficient degree of scientific elaboration of the ecological and energy component of the research problem conditioned is a factor of the predominance of modernization approaches to the improvement of energy efficiency. This is exacerbated by the global-scale problem of the irrational use of natural resources. With the depletion of primarily nonrenewable energy and other material mineral resources, the importance of energy-saving and environmental protection activities in the concept of the sustainable development of the society of a postindustrial economy increases. At the same time, the volumes of a new type of anthropogenic resources with energy potential are growing in it. Such forecasts are substantiated by Topuzov and his coauthors in a multicriteria model. However, it does not show the methods for regulating the jump-like processes of transition to high-tech methods of energy saving. The advantage is the assessment of the use of hydrogen fuel, which is aimed at improving the quality of life of the population and takes into account the rapid increase in the cost of traditional energy resources of a nonrenewable type. In the work of Razuvaev, the environmental component is considered, but he justifies the technology only with a low degree of diversification of resources [3]. This reduces the potential for the full use of the possible energy and resource conservation at the energy technology complexes (ETC) scale. In official statistical forecasts [4], objects with a current low degree of combination and diversification of resources are taken into account more. It is not possible to predict the formation of multipurpose industries such as ETC in the presence of many optimization criteria.

Models and mechanisms for regulating combined diversified resources and integrating objects of the scientific–educational sphere, industry and traditional and renewable energy to achieve a compromise of their interests in the structures of complexes are not sufficient. The models and mechanisms do not correspond to the needs of the postindustrial economy in innovative methods for effectively solving the environmental problems of the post-carbon energy type. It determines, especially in developed European countries, the tendency of transition in the period up to 2025 to the preferential use of renewable energy sources. The impact of technical–technological and economic factor challenges of the environment and competition of developed countries on the increase of the energy and environmental efficiency of the Russian energy sector by high-tech innovative methods of combining resources is growing.

The type of energy aggregates suitable for different energy sources [5] proposed for scaling by Goldoliner et al. also has low possibilities for resource differentiation and cogeneration. At the same time, a regulated reduction in the imbalance of interests of traditional and renewable energy facilities is most effective if they have multipurpose opportunities for energy-saving development in the formation of ETC.

In the work by Li et al. [6], using the example of the propagation of biological phenomena as an example, a model representing the zones of their stability and bifurcations is studied. It should be noted that the generalizations declared by them of the applicability of the model raise doubts about their application to technical and especially power systems. The nonlinear processes of the periodic development of such systems are more pronounced, more specifically reflecting the specifics of this study of linear differential systems in proposals for estimating the jump-like bifurcations of Euzébio [7]. However, in the three indicated works, the tasks of interactions of objects whose processes have a high degree of diversification of resources are not solved. To ensure positive synergy of the interaction between different objects, it is necessary to combine the processes of the evolutionary modernization of technologies and revolutionary (spasmodic) and bifurcation development as part of a multipurpose ETC. It is necessary to specify organizational methods for achieving practical results in regulating economic sustainability based on calculations of the entropy synergy results of combining resources of a high degree of diversification. This follows from the particular complexity of the processes of combining traditional resources and energy resources.

The policies in the post-carbon industrialization of the economy increase the need for tools to regulate the economic sustainability of multipurpose energy systems with the inclusion of the so-called “smart” energy-saving and generating facilities, hydrogen and other energy-efficient accumulators.

The singularity of technologies, as “breakthrough” innovative challenges of the post-industrial economy, is manifested in their exponential growth since the beginning of the 21st century. Indeed, many forecasts confirm the well-known methodological proposals of Adizes [8] that favor creating biosimilar management structures of “live” organizations. Sen and Lalu note that [9,10] holacratic flexible (agile) methods of creating self-governing teams of different profiles are effective. They correspond to the spiral dynamics model of the so-called “turquoise enterprises” [10]. Despite their practicality, they are more applicable in the design and engineering field. This narrows the applicability of such methods in the formation of ETC. More concrete forecasts for the development of intellectual resources forecasts by Frumin [11] include the increase in the number of digital and network companies such as “Amazon”, the expected growth by 2035 of the capabilities of computer systems and artificial intelligence in assessing their computing power (they will exceed the total analogous potential of the human biological system), and the growth of high-tech and high-tech engineering services in the innovation ecosystem. In the modern conditions of the Russian Federation, universities of types 2.0 and 3.0 prevail, being drivers/challenges for the development of industry. At the same time, the scale of their transformation into educational and scientific 4.0 complexes is growing, with universities that are distinguished by a high degree of globalization of education and the use of new educational methods, such as online study and creative development along individual trajectories of students, and the use of training digital simulators (doubles) in virtual or real cognitive technologies for solving practical problems of the postindustrial economy and energy.

In such a digital economy, it is necessary to use open educational platforms based on large databases. In particular, they are necessary for analyzing the possibilities of advanced combination of resources based on the organization of ETC with the inclusion of objects of distributed energy, other multipurpose productions and participation in projects of such transformation of research and educational complexes of type 4.0. In the study of the impacts of knowledge management practices, the quality and competitiveness of the results of Azizi and coauthors [12] took into account only a part of the necessary organizational tools for the development of complex systems. Hoegl and Schulze [13], exploring the initial stage of creativity of the innovation cycle, and Liu and coauthors [14] in their empirical evaluations of correlations with product updates revealed the significance of process uncertainties. However, they have not solved many problems of modeling at the stages of self-organization of complex adaptive systems. This was complemented by the work of Lafond [15] and McCarthy and coauthors [16]. At the same time, due to the specifics of their scientific research, they could not take into account the peculiarities of the interaction of energy technology objects of various purposes. Special methods are needed to regulate their interdependencies in the event of radical change in the results under the conditions of singularity of technologies.

Similar studies on solving complex problems of an organizational type were carried out by Kirsch [17]. Puschke [18] proposed multimodel approaches to the dynamic optimization of processes under parametric uncertainty. The promising methods of analytical modeling of the processes of management of differentiated innovations by Kim should be noted [19]. Taken together, their proposals justify the need to study the structure of complex systems, which are characterized by significant scales of exponential or abrupt growth of a number of "breakthrough" technologies: digital modeling of new products with optimization of all the necessary quality criteria of their designs and operating conditions, cross-sectoral technology transfer and reverse engineering for low-cost modernization of low- or medium-level innovative technology, and additive technologies with the possibility of simultaneous formation of the material and product design. The number of virtually distributed digital factories of global scale and operating digital counterparts of technologies and products are increasing. Such technologies should be taken into account in mathematical modeling of the sustainability of the processes of combining expanded complexes of material (energy types under consideration, technological ones) and nonmaterial resources (competences of educational, research and design spheres). Such resources are proposed to be characterized by a high degree of diversification (HDD), justifying the integration of objects in the ETC.

The answer to the competitive challenges of the digital economy is to apply the methods of efficient polygeneration based on the combination of the resources of the HDD and the organization of a multipurpose ETC. In order to achieve positive synergy and energy savings, the interaction processes should take into account the principles of bio- and nature similarity. They are based on the anthropic concept of the philosophy of ensuring the similarity of the complex material systems of the universe, organizations and humans in an objectively existing space of all possible and interacting development options [20]. The possibilities of quantum mechanics and quantum computers will expand the scope of design of materials and processes with predetermined properties. Chandra made a significant contribution to the study of such revolutionary processes [21] in terms of modeling processes of a periodic type. Approaching the objectives of this study in the proposals for strategies for managing the merger of radical innovations in nanobiotechnology was work done by Maine [22]. Methods of Cunningham [23], according to the predictions of innovation brought to the practical training tasks, are taken into account in the methodology of this study.

The trends of postindustrial development and the challenges of the singularity of post-carbon energy technologies do not only impact the imbalance of the goals of sustainability and the effectiveness of its development at certain stages of the innovation cycle; it is also necessary to take into account the aggravation of the conflict of interests of producers and consumers of decentralized and centralized types using only traditional renewable resources or when they are insufficiently combined with renewable energy resources. The complexity and diversity of existing market factors, the intensity of material and information flows and the dynamics of their growth in a highly competitive environment necessitate energy saving and diversification of energy supply technologies [2]. However, the proposed methods of theory and practice do not provide for the regulation of the processes [24]. They do not take into account the integration of objects and the combination of the resources of the HDD in the extended range of their effective interaction.

An important factor in the sustainability of energy development processes due to the insufficiency of centralized generating capacity is the intensive development of low efficient energy [4]. This is hampered by insufficient support from the state budget and the inertia of the thinking of supporters of traditional energy [25]. The relatively energy and economic efficiency of the use of renewable energy resources due to significant investments in the creation of power plants using renewable resources, and the relatively low cost and availability of traditional energy resources, should also be noted. The presence of a centralized dispatch control and a large potential for the development of alternative energy do not solve the existing problems of the Russian energy industry (Figure 1). The uneven localization of consumers of fuel resources and their distribution in different regions (deposits in the Eastern regions, consumers in the Western ones) is obvious. The energy intensity of the gross domestic product remains high (2.5 times higher than the global average and 2.5–3 times higher than in developed countries) and the degree of depreciation of fixed assets of the fuel and energy are complex. For example, the degree of depreciation is 58% in the electric power industry and gas industry and 80% in the oil refining industry [26]. The underdeveloped infrastructure of the innovative modernization of the fuel and energy complex maintains the asymmetry in the supply of electricity to individual regions of the country: there is some surplus in the energy balance in the Urals and the Far East, and there is a shortage in the European part. The dependence of the energy industry on the supply of imported components and maintenance supplies remains [2,4].

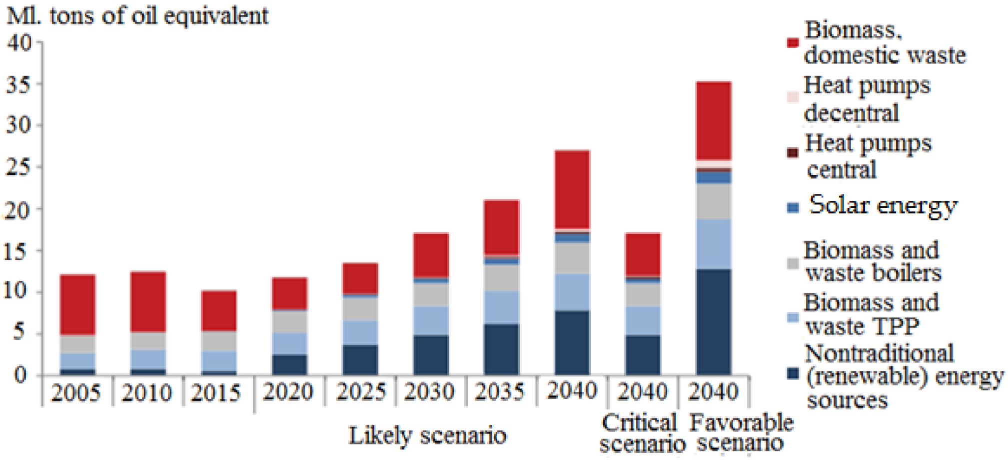

Figure 1. Russia's estimated use of nonconventional renewable energy resources, 2005–2040 [1,2].

Until the mid-1970s, the development of the world fuel and energy complex was reliant upon traditional carbon fuels. The fuel crisis in the end of 1970s led to a significant increase in the cost of oil and new energy policy [1,2]. The following decades were characterized by the growth of electricity consumption from nontraditional sources. For 10 years from 2006 to 2015, wind power use increased by almost 6 times and solar energy increased by 37 times (Figure 2).

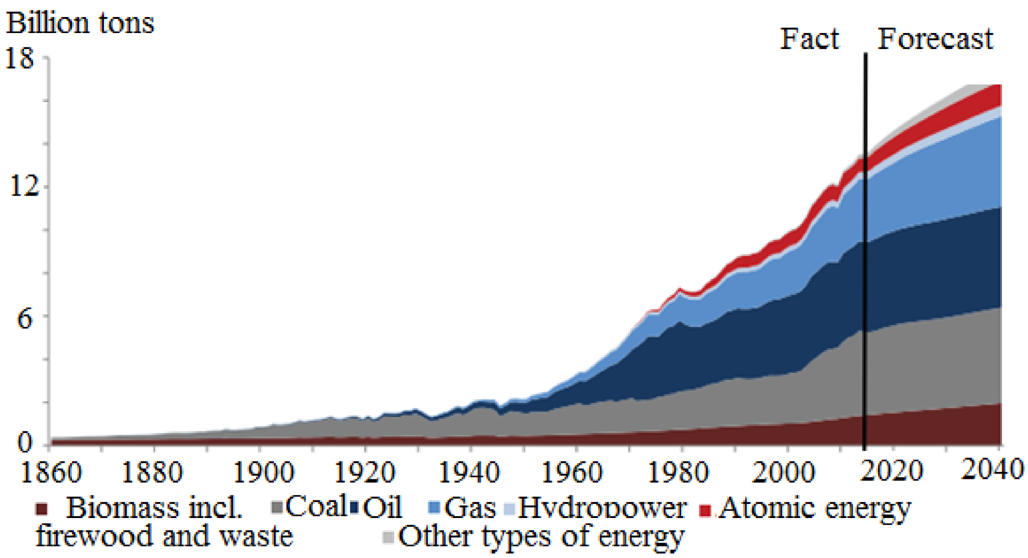

Figure 2. Russian electricity consumption of nonconventional renewable energy resources, 1860–2040 [2].

At the same time, the fuel-substituting potential for the development of alternative energy in the Russian Federation is quite large, amounting to about 270 million tons of mercury equivalent, including solar energy, 12.5; wind power, 10; geothermal energy, 115; biomass energy, 35; energy of small rivers, 65; and energy of low potential heat sources, 31.5 [3,4]. Historically, Russia has lagged behind a number of developed countries in terms of the share of unconventional fuel in the overall structure of energy consumption.

However, according to the forecasts of the Analytical Center under the Russian Government (Figure 1), Russia's total use will increase by 1.6–3.3 times and its share in energy consumption will increase from 1% (in 2015) to 2–3% by 2040. This is due to the lack of reasonable proposals for combining the resources of the HDD. Separate functioning of most of these energy facilities does not enable the regulation of their sustainable development.

The insufficiency of the pace and scale of the transition to energy saving is confirmed by the fact that only 5% to 6% of industrial enterprises in developing countries have developed relevant technological innovations, compared with 60% to 70% of those in developed ones. The lag in the pace of transition to industry 4.0 determines that the exporting of high-tech and high-tech products from Russia does not exceed 3–5% to GDP [2]. Nobel Prize winners Heckman and Schulz (1975) substantiated this discrepancy in their work on human capital, arguing that the main contribution to labor productivity is related to what has been achieved in education, science and production facilities and openness to the new, ensuring in developed countries up to 80% of their growth [24]. The significance of such an attitude can be confirmed by a number of statements from experience and forecasts, such as an exponential increase in the number of participants in scientific conferences from the beginning of the 21st century [16] and the number of freelancers, and assumptions about the disappearance by 2025 of a greater number of jobs (especially intermediaries engaged in routine manual and cognitive labor) than those appearing [9,10]. Consequently, intellectual capital, which is characterized by the predominance of nonroutine, analytical and creative work based on interpersonal communications and holacratic methods of the spiral dynamics model by Lal and Robertson, should be the main focus [10]. Together with Schulz, they argue that investment in such capital should grow at a faster pace. At the same time, the characteristics of professional competencies prevalent in most domestic enterprises do not fully meet the requirements of the theory and methodology developed by the organization of high-tech processes and methods for integrating objects into ETC for combining HDD.

3. Models of Combining Diversified Resources

The diversified resources were understood as the following types of resources: nonrenewable resources of traditional energy facilities (for example, thermal power plants using gas, coal, etc.) and renewable resources of solar and wind energy used by nontraditional energy facilities.

The article analyzes in detail the possibilities of modeling both evolutionary and discontinuous processes in their investigated cycle. It has been established that the transition to an innovative level of high-tech combination of types of resources has corresponding stages of transformation, differing in the speed of the transition processes. They require a radical increase in the competence of service personnel, the use of original combinations of used energy-related technological equipment. It is necessary to organize and implement strategies for energy-efficient energy production, taking into account the stages of the cycle. Energy transitions as a physical phenomenon are not studied here.

The processes related to abrupt transitions require special attention. The incompleteness of the solution to the economic component of the problem is manifested in the absence of special models for ensuring sustainability based on minimizing the imbalance of interests of traditional and renewable energy with varying degrees of centralization of energy supply.

We present a model of the processes of combining diversified resources and technological processes. The model uses a cyclical sequence of processes and methods to organize energy technology production, which forms three interacting blocks: inputs of factor, target and resource components; processes and methods; and outputs of components.

Block 1, the inputs, represents the initial level of combination and diversification of resources (natural, human-made and anthropogenic). Block 2 includes models for expanding cogeneration along the directions of trigeneration and polygeneration in the space of a complex of objects: the mechanism of organizing the interaction of objects in multipurpose energy technology complex (ETC). Block 3 contains outputs and tracks changes in the management practices to combine HDD resources.

This model introduces the authors' concept of extended cogeneration of thermal and electrical energy and other products using all types of traditional and renewable natural, human-made and anthropogenic resources. The composition of natural resources takes into account traditional nonrenewable (coal, gas, etc.) and renewable (solar energy, wind, etc.). Human-made resources include industrial and household waste and the intellectual (objects of educational and scientific project activities) and fixed capital of objects (capabilities of the technical and technological base of production). Such a high degree of diversification of resources creates opportunities for obtaining a variety of products when organizing their joint activities in a multipurpose waste-free complex.

There is a need to take into account the imbalance of interests of traditional energy facilities and new ETC interests that use the processes of combining resources. This is due to the opposition of the goals of increasing the sustainability of such innovation processes and their effectiveness at some stages of the ETC life cycle. The opposition of goals is particularly evident in the high-tech processes of combining HDD resources with methods of organizing extended cogeneration, when the multipurpose production of energy for industrial and other purposes is carried out. The sustainability of development at the beginning of the cycle often decreases, then a gradual or intermittent increase is possible when regulating the factor indicators of energy, environmental and economic efficiency. This is explained by the discrepancy of staff competencies, insufficient consideration of the differences and capabilities of the cogeneration technology by the developers of projects for such a complex of facilities, the novelty and increased complexity of technologies for combining HDD, etc.

The need to study the formation of a multipurpose system of ETC objects using highly differentiated resources to ensure the sustainability of evolutionary and intermittent types of innovative development has determined the development of management theory and the development of a new methodology for managing the integration of resources according to indicators of integration and balance of opposing interests of sustainability and efficiency [20,25]. It provides for the possibility of achieving a minimum imbalance of goals expressing these interests and stabilizing their zone of compromise in the processes of combining the air traffic control resources organized in the structure of multipurpose, resource-saving, low-waste type systems. For example, these may be multipurpose or multiproduct (target) ETCs, in which these objectives must be coordinated at the level of compromise of interests of traditional and renewable energy and other technologies for combining resources. For this purpose, it is necessary to regulate the convergence of the trajectories of the goals of sustainability and development efficiency in ETC of such objects using multipurpose production technologies (polygeneration).

Regulation is effective when applying a control mechanism based on an operational and integration model of the economic sustainability of the processes of combining air traffic control resources. Its special management functions should influence the application of methods of organizing the interaction of objects of different profiles in ETC by the criterion of minimizing the imbalance of their goals. Combining resources in such processes with the methods of organizing trigeneration (ideally polygeneration) of heat, cold, electricity and other products provides a competitive differentiation of energy-saving results in terms of energy, environmental and economic efficiency. Improving the theory in the proposed formulation of the paradigm of systems development is possible in the concept of regulated stability of the processes of combining not only material energy, but also other resources of the HDD with methods of integrating relevant facilities for expanded polygeneration in organizing a multipurpose ETC. This will allow to take into account these factors and scientific achievements in our proposed theoretical model and operational-integration model of methods for organizing the regulation of the relationship of objects in the complex. The provisions of the high-tech innovation management methodology [20] are based on the joint application of systemic and holistic approaches to the study of a complex system as a complex of interacting objects of different profiles. The authors' theoretical and methodological tools form an interdisciplinary approach to assessing their interaction and transformation (for example, metabolism using analogies and digital simulations of models of biological objects) of varying degrees of innovation and reproduction (replication). It corresponds to the well-known proposals of most modern management theorists. The improvements proposed in the article are aimed at their development and specification of the subject and objects of research on the interaction of ETC objects when combining the HDD resources.

The emergence and sustainable development of a postindustrial hybrid economy using resources of the HDD (intellectual, material, natural, man-made and anthropogenic types) is possible when they are combined in a cycle of evolutionary and revolutionary processes of systematic use of natural, labor and capital resources. For the sustainability of processes to ensure effective results with high added value, it is necessary to complement the integration of objects of different profiles and combine or replace resources (intangible and material) with the HDD for the organization of high-tech balanced development of ETC. This justifies the idea of a unified methodology of integration-balancing management (MIBM), combining theoretical models and methodologies for the integration and replacement of resources [20] with models and methodology for balanced development of systems in a dynamic environment [25]. On their basis, new methods have been developed in the concept of improving the quality of regulation of the economic sustainability of the processes of combining HDD resources during the integration of multipurpose ETC facilities. In order to implement the methods, in the second part of the article, a method and a mechanism for the regulated reduction of the imbalance of interests of objects, measured by the goals of sustainability and efficiency of innovative development in the context of the integration of objects in the ETC, are developed.

Joint research proved the possibility of using the mathematical models of Alyukov for the interpretation of organizational and technological processes of integration and combining resources by the methods of approximation of stepwise and generalized functions in the simulation of dynamic processes based on the MIBM. The models allowed to quantify the evolutionary improvement in the quality of regulation of the economic sustainability of the processes of combining and changing the stepped form when organizing ETC structures by methods of enhanced integration of the resources of its facilities. A measurable assessment of the state and the processes of regulation of the imbalance of their interests was achieved, measured by the opposite objectives of the development of objects.

The theoretical and operational-regulatory models of economic sustainability form the basis of a unified methodology that provides the analytical ability to display the multicyclic expansion of the complex space and time of managerial influences. They are carried out by the functions and indicators of the effectiveness of the use of innovative technologies for combining resources and methods of organizing the indicator-property stability of evolutionary and spasmodic development processes. The existence of such possibilities is confirmed by the methods of geometric algebra of a multidimensional space, which studies computational approaches to compression and stretching as types of space transformation [26]. Subsequently, these approaches formed the mathematical foundations of quantum mechanics. For the first time, such algebra was proposed by William Clifford, the author of the terms "divergence" and "vector analysis" (together with Gibbs and Heaviside) [27]. However, in these studies, purely mathematical problems were solved without practical application. Naturally, they were not specified in the subject and object of this study.

In mathematical and organizational research, we have identified opportunities for the development of geometric algebra based on the use of the toolkit of generalized functions, which makes it possible to describe singular variants and scenarios in relation to spasmodic processes of technological and organizational development. Such functions in many cases are of a purely abstract nature. They do not take into account the inertia property that precludes instant changes in the initial state of the object, which requires an infinitely large amount of energy.

For a better understanding of generalized function solutions to such problems, Alyukov proposed a method for their approximation via analytic functions (Figure 3) [28,29]. Figure 3a represents the delta function. Figure 3b shows how to use the delta function, taking into account the types of combination processes and organizational development of the system. The representation of the nature of generalized functions enables using their features to describe the spasmodic processes of organizational behavior in assessing the sustainability of the effective development of the system, $\delta(x) = H(1)$:

$$\delta(x) = \begin{cases} +\infty, \ x = 0, \\ 0, \ \forall x \neq 0, \end{cases} \tag{1}$$

at that $\int\limits_{-\infty}^{+\infty} \delta(x)dx = 1$.

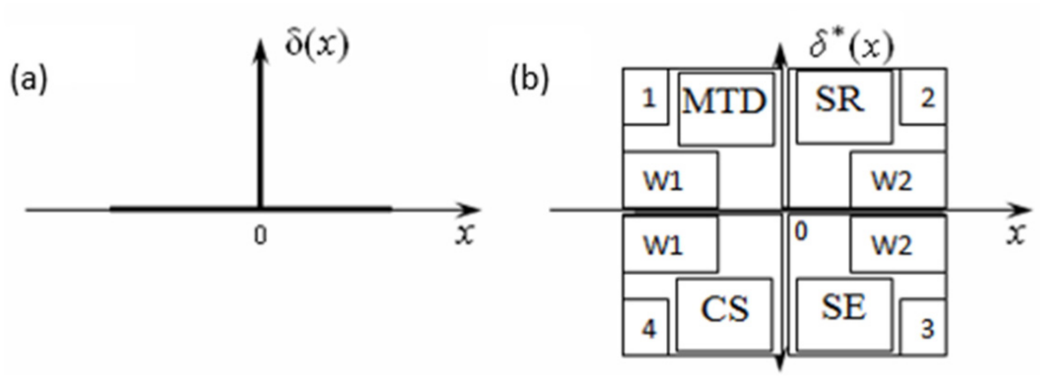

Figure 3. Representation of the delta function (**a**) and its approximation, taking into account the types of combination processes and organizational development of the system (**b**). MTD: medium technological development; SR: structurally revolutionary processes; CS: conservative self-organizing processes; SE: structural-evolutionary processes; W1, Where; W2, When; W3, What; W4, Why.

The value x in this case is an indicator to assess the levels of energy, environmental or economic efficiency (LE) of the factorial effects of technologies combining diversified resources and methods of organizing a multipurpose ETC that has a length in time t. In this study, it is the regulation of combining technologies by changing the degree of diversification of resources and the innovativeness of methods of organizing objects in the ETC that affect the investigated property H efficiency (LE) in assessing the level of economic sustainability (LES) of the application of technologies for combining resources.

The specified ideal mathematical representation in Formula (1) of regulatory actions due to the specified reasons does not enable the revealing of the real, practical content of cause–effect relationships (Figure 3a). To determine zones (surfaces or areas with a three-dimensional approach) of dynamic stability (Figure 3b) in the methodology of balanced development, it was proposed to choose methods that took into account known types of stability: for ETC technical systems, providing a return to their equilibrium state for any environmental disturbances; for the socioeconomic systems of organizing joint activities of objects in ETC, affecting the return of actual indicators in the area of established goals for the integration of objects and the combination of resources in assessing the convergence of their trajectories, taking into account the compromise of interests of objects; unstable and uncertain states of bifurcation in the conditions of resource disintegration and trajectory divergence; spontaneously arising resistance at a certain stage of the cycle of ETC formation; absolute stability of a closed system while reducing stability and efficiency.

To clarify the idea and concept of the scientific work, a theoretical model of "4W" of economic sustainability of a multipurpose ETC-type system is proposed, based on spatial–temporal coordination in the integration-balancing cycle of diversified resources of combination technologies and methods of organizing interaction of objects. This takes into account changes in the imbalance of opposing goals of sustainability and effectiveness in the four stages of the life cycle of the formation and functioning of their complex. The terms Where—W1, When—W2, What—W3 and Why—W4 correspond to the directionality of impacts and the content of cause–effect relationships (in assessments of target indicators of economic sustainability and efficiency of innovative development) of objects in space and time.

Taking into account the objectively positive direction of time changes along the x axis of the theoretical model (Figure 3), we will assume that the planes 2 and 3 interpret the processes of functioning of the ETC (the temporal measurement of the processes, W2). The negative direction of changes in planes 1 and 4 corresponds to the processes of formation and divergence of cooperative relations of ETC objects (spatial dimension of the processes, W1). It is proposed to regulate them with special management functions used in the new organizational structure of the Sustainable Development Center (SDC) ETC. Different directions of influences of processes and methods form the differences between the following types of processes of combining resources and organizational development in the life cycle of the ETC in the following quadrant stages: 1, medium technological development (MTD) by methods of separate functioning of objects (MTD processes) at the functional-evolutionary stage of development of control functions in the SDC in the formation of the ETC, leading to a decrease in LES; 2, combining the resources of the HDD at the structurally revolutionary (SR processes) stage of transition to new management structures (creation of SDCs and ETCs), which determines the abrupt growth of the LES index; 3, structural-evolutionary (SE processes) development with the inclusion of new objects in the ETC and the gradual growth of the LES; 4, low-technology conservative self-organizing (CS processes) development by the methods of separate functioning of facilities or combining with a constant or low degree of diversification of resources (spontaneous processes of preserving the existing ETC structure and the achieved LES).

It can be determined that the plane of a two-dimensional representation of a theoretical model, in which the region of changes of the indicator—the property of economic sustainability of the LES = H—is vertically represented, and horizontally the changes of factor efficiency indicators over time form the life cycle field of the formation and development of ETC functions and structures. The field forms four zones and types of processes of combining resources and methods of organizing a complex of objects, the selection of which is advisable to carry out according to the results of ranking the extent of their impacts in statistical or expert assessments (for example, low, medium and high) indicators of sustainability and efficiency. Such differences in the characteristics of the cycle suggest the main hypothesis of a quantitative representation of the dynamics of economic sustainability levels when regulating the processes of combining resources and organization methods by the criterion of the minimum variability of its imbalance zone with efficiency in cycles of evolutionary and abrupt changes.

At the beginning of cycle 1 (which corresponds to the measurement of processes of the type W1 as in Figure 3), it is possible to observe phenomena in the ETC that are inherent in the opposition of the dynamics of the LES and LE indicators. It follows from the preemptive use of modernization measures at separate facilities (there is no minimal combination of resources, and there is no formation of the ETC). The use of traditional technologies (for example, separate production, high centralization of activities, etc.) ensures high levels of LE and LES processes. However, for the above reasons, energy and environmental performance indicators are starting to decline. Therefore, scientific and project development of decisions on the formation of technologies for combining HDD resources and methods of integrating ETC objects is necessary to regulate the sustainability of processes. The analysis of the experience shows the possibility of stabilizing the LES in the zone of minimum values for the period of cycle 1 and the beginning of its evolutionary growth with the operation of individual energy-saving objects. The spasmodic increase in the level of innovation, determined by the moment of commissioning of polygeneration high-tech facilities in ETC, reduces the indicator of LES for the above reasons for a certain time. Then, when the staff develop the necessary competencies, it begins to gradually increase. Therefore, it can be assumed that by the end of cycle 1, the indicator of the LES will be gradually growing (Figure 3).

In cycle 2, in the case of new high-tech changes in the functioning of ETC, the considered processes should be repeated. At the same time, the indicator property (due to the stabilization of the compromise zone by the proposed methods of the LES and LE indicators) will not fall below the minimum values in cycle 1. Otherwise (the prevalence of modernization), there is a transition to zone 4.

4. Models of Regulation of Economic Sustainability

We use Ramsey′s growth model to confirm the main hypothesis of the dynamics of economic sustainability. The model of economic growth proposed by Ramsey and subsequently modernized by Cass et al. [28,29] is used. It is adapted and specified by us as follows:

$$\begin{cases} \dot{k} = k^{\alpha} - \delta k - c; \\ \frac{\dot{c}}{c} = \sigma\left(\alpha k^{\alpha-1} - \delta - \rho\right), \end{cases} \tag{2}$$

where k and c are indicators to assess the economic sustainability of the ELS and the effectiveness of the LE type, respectively, governed by the following factors:

$\delta \equiv const$ ($\delta \in [0,1]$): the degree of combination of resources provided by the technical and technological capabilities of ETC objects;

$\alpha \in [0,1]$: the degree of substitution of labor resources and fixed capital provided by the technical and technological capabilities of facilities and methods of organizing ETC (it is estimated expertly on the Harrington scale in fractions of a unit: as very low, low, medium, high and very high);

$\sigma \equiv const$ ($\sigma \in [0,\infty)$): the degree of diversification of resources regulated by the composition of ETC objects and their technical and technological capabilities (it is estimated expertly on the Harrington scale in fractions of a unit: as very low, low, medium, high and very high);

$\rho \equiv const$ ($\rho \in [0,\infty)$): regulation by indicating the start time of stages 1 (formation of the ETC), 2 (jump-transition to the combination of resources of the HDD and polygeneration of products) and 3 (speed of increasing the level of stability in the evolutionary processes of combining resources).

The choice of the Ramsey–Kass–Koopmans model was substantiated by the significant experience of one of the authors of the article by Aliukov in its application to complex technical and quantum systems. The Solow model is more often used to analyze large economic systems.

The first equations of System (2) represent the resource constraints in estimating the degree of diversification of resources; the second equation meets the conditions for the effectiveness of ETC organizational development methods and is the Euler equation. Two boundary conditions are also taken into account: the initial volume of investment in the technical and technological base of the objects being formed by the ETC k_0, and the transversality of vector subspaces of regulation functions of innovative technologies and the effectiveness of methods for organizing the interaction of ETC objects generating the vector space of the indicator properties of the economic sustainability of the processes of combining resources.

The use of System (1) provides an equilibrium position having an unstable saddle type. It can characterize the critical point B of the LESmin (the minimum level of economic sustainability) of the hypothetical change trajectory described above. A new equilibrium position [28,29] that is asymptotically stable can be found by writing down the Ramsey Model (2) in a modified Formula (3):

$$\begin{cases} \dot{k} = k^{\alpha} - \delta k - c; \\ \dot{c} = c\sigma\left(\alpha k^{\alpha-1} - \delta - \rho\right). \end{cases} \tag{3}$$

Assuming $\dot{k} = 0$, $\dot{c} = 0$, we find a new equilibrium position in Formula (4):

$$\begin{cases} \bar{k} = \delta^{\frac{1}{\alpha-1}}; \\ \bar{c} = 0. \end{cases} \tag{4}$$

This equilibrium position is asymptotically stable, since it satisfies the well-known transversality condition. It means that the solution of the problem of maximizing the level of process sustainability is achieved in the zone of compromise of subspaces of the vector functions of the innovative and economic goals of the development of the ETC system.

At first glance, the found equilibrium position in Formula (4) may seem strange, since the efficiency of applying the organizational method decreases to zero. On the other hand, given limited resources, as a rule, this equilibrium state is most consistent with the assumptions of hypotheses at the beginning of the periods of cycles 1 and 2.

We use the approximate analytical method of a small parameter. Having designated $\beta = (1-\alpha)\delta$, $\gamma = \sigma((1-\alpha)\delta + \rho)$, it is possible to obtain a linear-type system solved by analytical methods in Formula (5):

$$\begin{cases} \dot{\tilde{k}}^{*} + \beta\tilde{k}^{*} = -c^{*}; \\ \dot{c}^{*} + \gamma c^{*} = 0. \end{cases} \tag{5}$$

Numerical verification of the results obtained using the Runge–Kutta method in the MathCAD computer environment showed consistency of the obtained analytical results. The results are shown in Figure 4, where curve 1 corresponds to the variable k and curve 2 corresponds to the variable c. The solid line is the numerical solution, and the dotted line is the analytical solutions. As seen in Figure 4, the differences in the solutions are minor.

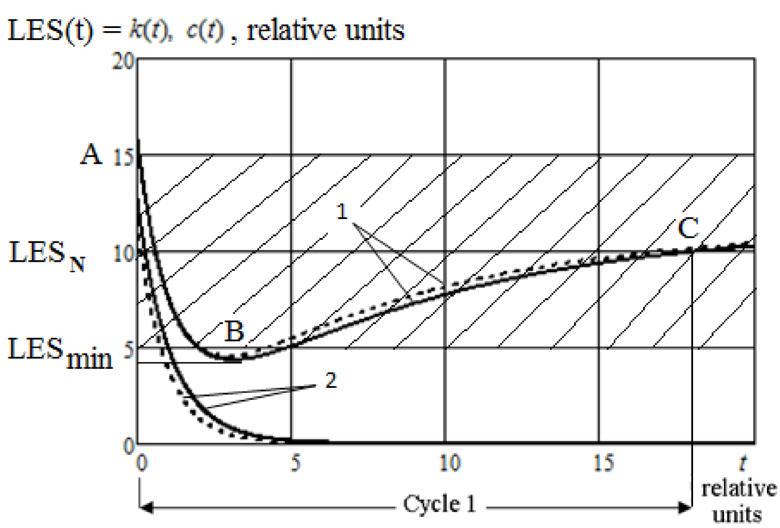

Figure 4. Estimated dynamics of the levels of sustainability and efficiency of the processes of combining resources and organization in the formation cycle of a multipurpose energy technology complex: LES: level of economic sustainability; A is maximum property index; B is minimum property index; C is property indicator standard.

According to the Lyapunov theorem on stability in the first approximation, all eigenvalues have negative real parts. Therefore, the resulting solution is asymptotically stable. This confirms the main hypothesis of the existence of a stable zone of indicators by the criteria of minimum variability of the compromise between the goals of sustainability of processes of innovative combining resources and the efficiency of structures of interaction of objects.

When modeling the dynamics of technologies and organizational methods of a singular type, mathematical tools are needed, shown by Formula (1). The meaning of such generalized functions is revealed in approximations, perceived as the limits of some approximating sequences of ordinary functions (for example, step functions). However, this does not allow the display of the organizational behavior of a complex system of ETC objects in the space and time of the implementation of the jump-like processes of combining resources and the convergence of hopping trajectories by analytical functions. The problem is that step functions have break points at which they are not differentiable in the mathematical sense.

To overcome the problem and implement the research concept, we have specified the main hypothesis of the possibility of a quantitative assessment of the sustainability of the processes of abrupt transitions to the high-tech type of combining HDD resources and the organizational and structural specific set of embedded functions of their analytical approximation. At the same time, the number of functions describing transitions has been proposed to be interpreted by the number of types of integrated or combinable resources of the objects included in the ETC and the regulatory effects of the management functions of the SDC on the convergence of the trajectories of sustainable development goals.

It is proven that the quality of regulation of discontinuous processes is achievable with the elimination of the paradox of space and time compression peculiar to them. It is observed in the theoretically instantaneous period and practically in the short duration of the jump-transition time. For the analysis of the extended process zone, we will distinguish two areas of the theoretical model that determine the dynamics of development: MTD processes at the beginning of cycle 1 of the evolutionary development of additional regulatory functions and the formation of ETC, and the SR processes in cycle 2 of the abrupt transition to new SDC management structures and the processes of combining HDD resources (compare Figures 3 and 5). In the time ranges −0.15–0 and 0–0.15 rad, cycles 1 and 2 of changes in the factors of innovation in the technical and technological base of the objects can be represented by a jump to a high LES based on the technology of combining HDD resources or a new organizational method of regulating the use of special management functions (Figure 4). We have found that such transitions are not sufficiently effective using only the basic standard control functions of separately functioning objects.

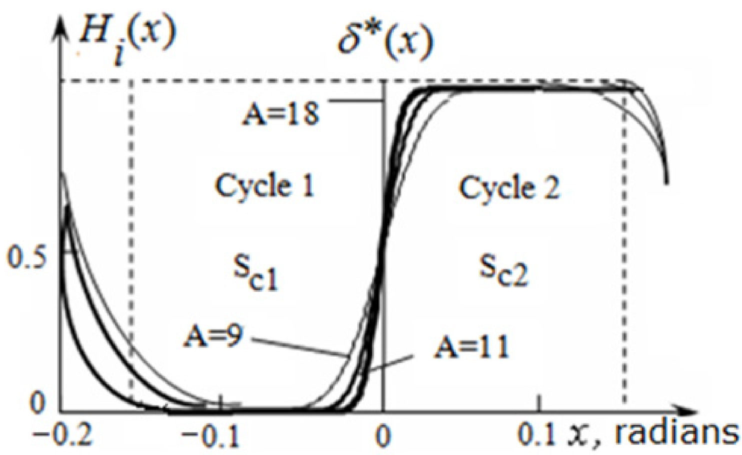

Figure 5. Representation of the effect of expanding the space–time to regulate the stability of processes with an increasing degree of combining resources.

The increase in the integration space of possible resources necessitates the estimator parameters for jump-transition singularity. They assess the possibility of reducing the influence of zero-length paradoxes of transition time and the unpredictability of the behavior of open-loop systems in Laplace. This led to the development of mathematically justified methods of "extending the time interval" for the implementation of short-term technological and organizational solutions of a jump type. A tangible extension value [29] is achieved by approximating a growing number of nested functions in the range A = (9,10,11). Figure 4 shows the graphs of the corresponding successive approximations obtained by Formula (6). The planar representation of the effect of space–time expansion is given in cycle 1 of medium-tech processes of the type MTD during the jump-to-cycle to cycle 2 and high-tech processes of the type SR (6).

$$\begin{gathered} \mathrm{H}_9(x) = 0.5(1+\sin(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(x))))))))) \\ \mathrm{H}_{10}(x) = 0.5(1+\sin(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(x)))))))))) \\ \mathrm{H}_{11}(x) = 0.5(1+\sin(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(x))))))))))) \end{gathered} \quad (6)$$

where $\mathrm{A}(x) = \frac{\pi}{2}\sin x$.

The thickness of the lines in the figure increases as the number of investments of approximating functions increases, interpreting the increase in the integration of objects [30] and the degree of combination of resources to increase the H_i by the factors of innovation x. For A = 18, the approximation corresponds most closely to the approximation of the delta function of Formula (1), shown by the vertical line in Figures 3a and 5.

In Figure 5, cycle 1 represents the zone of disintegration of resources and divergence of trajectories of development. Cycle 2 represents the zone of integration of trajectories of development.

The graph illustrates the jump process in the range of ± 0.1 radians. The number of nested functions that provide the zone with the optimal values of the indicator of the LE should correspond to the number of combined resources or additional SDC control functions displayed on the graph.

The change in the stability of the system under study (H) over time (x) in cycle 2 vs. cycle 1 is also displayed. It can be determined by the ratio of the areas of the interaction zone of complex objects bounded by dashed lines. Moreover, Sc1 corresponds to zone 1 of the implementation of low- and medium-tech processes based on the use of evolutionarily added control functions, and Sc2 corresponds to the zone 2 jumps to the high-tech level and zone 3 of evolutionary changes in the structures of the complex.

5. Results of Verification of Methods and Verification of Their Practical Implementation in a Real Development Project Based on Diversification of Resources

Possibilities of modeling the effect of the expansion of the process space with an increasing degree of combining resources and the time of making managerial decisions based on a theoretical model of the "4W" of economic sustainability of a multipurpose ETC-type system (Figure 3) are mathematically substantiated. We propose to implement in the methodology verification methods and verification of the results of regulation of economic stability according to static, dynamic and probabilistic criteria for ensuring the efficiency and stability of the processes of combining resources. Providing a stability zone in the range of 5–15 relative units in cycle 1 is simulated by the estimated dynamics of the levels of sustainability and efficiency of the processes of combining resources and organization in the formation cycle of a multipurpose energy technology complex model, as presented in Figure 4. This is possible by using additional control functions displayed by the system of Equation (6) and shown in Figure 5 in cycles 1 and 2, implemented using the methods of the theoretical model "4W". The verification methodology should show that the basic theoretical representation of the four stages and methods of the cycle in Figure 3, modeled by functional analysis tools and shown in Figures 4 and 5, is reliably verified using criteria-based indicators according to Formulas (7)–(11) in the mathematical modeling of organizational and technological processes. Verification is an analysis of the results of a real project, corresponding to the experience and directions of development of energy and resource conservation [31–37] for use of products in the formed energy technology complex combining objects and polygeneration (ETC) of solid, household and other waste (SHW-based products; in general, liquid for plasma-fire neutralization or biogas production). The result of the project may be the reduction of losses from the insufficient quality of energy-saving control processes, expressed in the underutilization of the results: replacement of traditional energy resources; more types of energy products in terms of cogeneration, trigeneration and, in general, their polygeneration; diversification of energy production methods, increasing the reliability of energy supply in remote areas; increased processing of SHW to solve environmental problems; sale of waste to other countries.

Verification of the results includes the following steps of the methodology.

1. Static criteria made it possible to determine initial estimates of the level of imbalance of goals to increase the level of economic stability (LES = H) and efficiency over time (x = −0.2) at the beginning of the resource combination cycle in Figure 5 and verify their compliance with the methods of quadrant stage 4. Despite the application of control functions, efficiency decreases in the time range of 0–5 relative units (Figure 4). This can be estimated by the ratio of the area of the zone displaying the cycles. A static representation of the processes is sufficient to study the situation at the moment of the planning period, for example, with a slight combination of nondiversified resources. Modeling is carried out according to the criteria for improving the quality of efficiency regulation in the final increments in Formula (7):

$$|H_i(x)x_{c2}| \geq |H_i(x)kh_{c1}|; \frac{H_i(x)x_{c2t2}}{H_i(x)x_{c2t1}} \geq 1. \quad (7)$$

The ratios of the static areas (in the estimates of the products of efficiency and time) formed by dashed lines in Figure 5 made it possible to evaluate the results of improving the quality of regulation based on the effect of the expansion of space and decision time. Failure to comply with Formula (7) corresponds to the implementation of decisions on plans and projects for the evolutionary modernization of technologies for combining resources of a low level of diversification and innovation using slow transformation methods. This is consistent with the methods of quadrant stage 4, low-technology conservative self-organizing (CS processes) development by the methods of separate functioning of facilities or combining with a constant or low degree of diversification of resources (spontaneous processes of preserving the existing ETC structure and the achieved LES). At the stage of diagnosis before the project situation, an unacceptable state of the orientation of actions in the region to preserve single-purpose facilities, the use of mainly renewable resources was revealed. Noncompliance with the criteria was confirmed by the calculation of cost indicators of insufficient efficiency (profitability, payback period below existing standards or industry average values). This confirmed the need to develop plans and projects for combining diversified resources for energy and resource conservation goals in cycle 1.

2. Dynamic criteria made it possible to identify critical points of the singularity of technologies for combining highly diversified resources at x = 0, which determine the loss of stability of the development of energy system objects (Figure 5). Quadrant 1 reflects the implementation of the first stage of the project based on medium technological development by methods of separate functioning of objects (MTD processes) at the functional-evolutionary stage of development of control functions in the SDC the formation of the ETC, leading to a decrease in the LES. The duration of the short-term effect from this stage (the evolutionary transition to combining slightly diversified resources) at the end of cycle 1 (in the range of −0.1–0.0 rad of the graph in Figure 5) is revealed. The simulation results show the completion dates for the relevant plans and projects at the time of completion of the commissioning of medium-tech equipment with the possibility of combining resources. At stage 1 of the cycle, i.e., evolutionary development, a relatively low-cost version of the unregulated SHW storage project for

personnel and public safety and structural development (forming ETC for the production of complementary or complementary types of energy and by-products) based on RER was developed. It has been established that such domestic waste begins to emit a mixture of gases containing up to 50% methane and hydrogen sulfide, and when burning waste, much more harmful gases occur. It is 20 times more harmful than carbon dioxide in creating the greenhouse effect [5–12]. In this case, it is possible to use functional mathematical models with dependences of a continuous type on time.

In the range of 0.0–0.1 rad, the results of increasing the efficiency were revealed in terms of the intensity of application of high technologies, additional functions and indicators of stability control by changing their speed according to Formulas (8)–(10). At the time of commissioning of high-tech equipment, it was necessary to increase the intensity of the application of additional functions in the ETC control center. This corresponds to the methods of quadrant 2 of the theoretical model: combining the resources of the HDD of high-tech equipment at the structurally revolutionary (SR processes) stage of transition to new management structures (creation of SDCs and ETCs), which determines the abrupt growth of the LES index. The regulation of such processes was simulated by increasing the number and intensity of application from 9 to 11 additional control functions in the previously identified optimality range, according to the criterion of matching the number of embedded approximation functions according to Formula (6). At stage 2 of the cycle, a transition was made from the separate functioning of facilities to the organization of a radical increase in technical and technological capabilities based on combination and polygeneration. The structure-forming variant of energy-saving development is envisaged by the formation of ETC for the production of complementary or complementary types of energy and byproducts using SHW as the main source of RER. This corresponds to the direction of ensuring the sustainable development of a transformable landfill (repository) or region over a cycle or several cycles of change. Ideally and over the decades, it will be possible to create an industrial park of the Suzhou Singapore type in a similar place with full reclamation of the occupied area and ensuring payback of the project.

The decrease in efficiency in cycle 2 determined the beginning of the development and implementation of plans and projects for scaling up innovations within the energy system. This corresponds to the quadrant 3 methods of the theoretical model structural-evolutionary (SE processes) development with the inclusion of new objects in the ETC and the gradual growth of the LES. For their implementation, measures were taken to implement projects at a number of enterprises in the system for training personnel in the elements of experience of foreign countries. The value of the initial investment resources was formed as the sum of one-time costs for the development of the project and the formation of the ETC or the park in terms of applied research. Basic research was not required, as technical solutions and experience for any level of SHW processing were all available (e.g., plants for degassing and flaring waste work in the urban centers or on the outskirts). In Japan, for example, the company “Hitachi Zosen Inova” can be mentioned. According to the project of this company, four such plants are built in the Moscow region using domestic metal-consuming parts of domestic production (pipes, boilers, etc.).

The growth of the innovation can be specified as an increase in the intensity of application of the functions and regulation of the structure of the ETC project management center. This, for example, means an increase in the frequency and volume of requests for data on the characteristics of the processes of combination and polygeneration (by decision makers) and the frequency and number of their communications over a certain period of time. The dominance of the strategy of evolutionary growth of efficiency in the short-term period of stage 1 was carried out mainly by applying the basic concrete and general management functions of separately working objects.

Management consulting was conducted in the areas of increasing economic sustainability and concretizing the factors of combining diversified resources and the formation of the ETC, included in the structure of the system.

Using Formulas (8)–(10), the geography of expanding the space of objects in the sphere of combining diversified resources was modeled. Based on the results of evolutionary processes of applying high-level technologies and ETC formation methods, estimates of the stability of scaling the share of highly innovative ("breakthrough") transformations are obtained. Therefore, the points 0.05 and 0.05 radians, corresponding to the zero efficiency of innovation, determined the beginning of the selection of investment projects and the choice of objects of cooperation formed by the ETC. A quantitative substantiation of the magnitude and possibilities of expanding the space–time zone at the stages of the singularity and scaling of technologies is used. For this, the values of dynamic areas (as the products of the rates of changes in efficiency and time) were estimated. They reflected the magnitude of the increase in efficiency over time from cycle 1 to cycle 2 in Figure 5 and Formula (8), during the transition to the use of methods and processes of quadrants 2 and 3:

$$S = \frac{dHi(x)}{dx} \cdot x. \tag{8}$$

Mathematically, the maximum value of S can be calculated using a certain integral. Estimating the derivative on the graph as the tangent of the angle of inclination on the tangent, one can notice that

$$\tan \alpha_i = \frac{dH_i(x_i)}{dx_i}. \tag{9}$$

Therefore, with the number of embedded functions A = 11–18, we can draw a practical conclusion of the maximum degree of speed and intensity of the effects of control functions at $\alpha = 90^\circ$ (10):

$$\tan \alpha_i = \frac{dH_i(x_i)}{dx_i} \underset{\alpha_i \to 90^\circ}{\to} \infty. \tag{10}$$

3. The acceptability of the achieved speed and intensity of the impacts of the functions were verified by the fact of the equality of the relative growths of the actual indicators of the effectiveness and innovativeness of development at the time of their evaluation by Formula (10). This means achieving a compromise of such goals, expressing the minimum necessary imbalance of interests of the ETC facilities expressing such goals. The control center has increased the time for the use of additional functions and indicators of their quality. The determination of the gradients of the efficiency function in the ranges of preparation of managerial decisions (−0.15–0) and their implementation (0–0.1) provided confirmation of the necessary direction of dynamics. If Criterion (10) is not met, the center made decisions on enhancing the impact of the management functions by increasing the intensity of application of the relevant indicators (frequency of bringing to objects, converting planned indicators to normative, etc.). Modeling of this type and analysis of experience led to the conclusion that gas-piston type cogeneration plants are cost-effective at an installed capacity of approximately 1000 kW for SHW of cities with at least 1 million residents and waste storage period of 25–30 years. Therefore, the construction of a mini combined heat and power plant (HPP) of experimental designation based on the cogeneration of thermal and electrical energy using the abovementioned renewable resources will create additional capacity.

The gas utilization system of this type of renewable sources will allow to regulate the production of thermal energy over a wide range. To do this, it is necessary to vary the gas supply using the storage of the appropriate type. This scheme allows you to provide simultaneously independent electrical and heat schedules of the station load can cover them without significant losses to transfer even heat, so many industrial and residential consumers are located within a radius of 1–5 km from the waste storage facility of a large city. With a greater installed capacity, a transition to gas turbine installations of HPP plants as part of ETC for the complete processing of SHW with the observance of environmental standards is necessary.

In the course of experimentation, the ranges of changes in the heat of combustion of a mixture of gases from an unconventional source, such as a repository of waste of various types, were identified. It is known that the majority of such domestic RER sources are characterized by excessive differences and uncertainties in the fractional composition of the stored components due to the SHW collection practices that are inappropriate to modern requirements. Therefore, it is necessary to introduce additional technical means of automation and temperature stability control over a larger range of changes in fuel consumption.

It should be noted that gas-piston units are able to work for a long time at partial loads (from 50% to 100% of nominal capacity) [5] without detriment to their resource indicators that meet existing environmental standards. This makes them reliable in the conditions under consideration. The optimal operating mode at the maximum power level (100%) is achievable provided the organization of the SHW separate collection system facilitates their storage and processing in specially designed and constructed facilities according to the principles of combination and cogeneration or polygeneration.

It is practically established that in the conditions of trigeneration, maximum results are achieved when the useful use of the RER of the specified type reaches 80–85%. In such a complex, standard conditions for the safety of personnel and the public and environmental standards can be better ensured. This follows from taking into account the location of many objects of the considered types of renewable waste (close to human settlements or even within the boundaries of a large city).

4. Regulation of the dynamic stability of processes and evaluation of development results, taking into account the entropy of the organizational behavior of the system as an additional indicator of efficiency [4–6,10]. The uncertainty of the dynamics results in the conditions of technology singularity determines the need to take probabilistic factors into account in assessing the positiveness of the synergy (SE) entropy as a criterion for achieving the goal of improving the quality of development management. For this, the Shannon formula [14] is used according to two assessment options (without using this technique, when the separate functioning of objects is analyzed without combining resources, with no or minimal integration in the complex) and with the application of Formula (11):

$$SE = -\sum_{i=1}^{n} p_i \cdot \log_2 p_i, \tag{11}$$

where p_i is the probability of the occurrence of the synergy of processes (determined on the basis of expert assessments when analyzing the results of joint projects or plans for high-tech resource combination under the conditions of an ETC) and n is the number of such projects or plans. The positiveness of the indicator (SE $\geq$ 0) and the direction of its changes (SE$\updownarrow$) corresponds to the convergence (with a decrease in entropy) and divergence (with an increase in it) of the trajectories of target development in conditions of integration of objects and combination of resources and disintegration of objects and resources, respectively.

When using the methods of quadrants 2 and 3, we determined the value of SE $\geq$ 0 and the fact of its decrease, which means an increase in the predictability of high-tech development processes. To ensure the positivity of the indicator (SE $\geq$ 0) and its stability during evolutionary bifurcation (SE $\approx$ const), additional functions are used to control the integration of objects and the combination of resources and indicators of their quality. As a result of regulating the number of functions and resources, the intensity of their application, the probability of successful implementation of projects and plans for combining resources in ETC were increased.

6. Conclusions

The conclusions of the article are formulated according to the so-called formula of triple novelty, which presupposes, as it were, a discussion of the results obtained in three directions: listing the results and their names, differences of the results from similar studies existing in theory and practice, and new possibilities of application in theory and practice.

Below are the key findings.

1. An integration-convergent organizational–technological model is formulated to assess and regulate the development of a multipurpose energy technology type system. Mathematical methods to model evolutionary and spasmodic technological and organizational change are presented. Methods include the evaluation of indicators that differ with varying degrees of combining resources and integrating the interaction of objects in the energy technology complex.
2. The theoretical and operational-regulating models of the spatial–temporal combination of resources and integration of complex facilities are specified, justifying methods for quantitative modeling of processes to improve the quality of managing economic sustainability by the criterion of minimizing imbalance with the goals. The concept of the organizational effect of expansion of the space and time of the jump-transition to a new level of technology is proposed. The regularity of the dynamics of the zone of maximum effect of the expansion in space and time of the regulation of spasmodic development is revealed. The hypothesis of representing jump transitions to high-tech types of combined resources and integration methods of organizing the interaction of objects in a complex with a set of nested approximation functions corresponding to the number of types of integrable resources and objects is formulated.
3. Mathematical tools make it possible to model abrupt technological changes in complex systems.
4. Verification of theoretical models and methods was carried out on the basis of original criteria indicators, the use of which allowed the drawing of conclusions about the theory′s compliance with the subject of research and the choice of specific tools to improve the quality of management by combining diversified resources. Verification of criteria based on relevant economic assessments of a real project for the formation of an energy technology complex increases the practical value of the study.

The authors proposed to regulate the integration processes of the energy facilities and industrial technologies in the formed complex (ETC). The understanding of regulation as the organization of indicative and recommendatory influences is given. This is carried out not by the government, but by the Center for Combining Diversified Resources as a structural element of the emerging energy technology complex (ETC). Measurement and technical control processes were not considered. We understand economic sustainability as the dynamic ability of the Center′s regulation functions and their interrelationships with facilities (energy enterprises) in the ETC′s organizational structure to ensure that the objectives of the facilities comply with the declared strategic goals of high-tech development. We do not consider sustainable development in this context as the concept of people, planet and profit, which was not the subject of our research in the article.

In summary, the research results will allow firms to improve the quality of managing economic sustainability of processes that combine resources with a high degree of diversification and multipurpose energy technology complexes with low-waste use. The addition of such mathematical and organizational tools will help improve the accuracy of analytical assessments and the speed of integration and balancing effects that increase the economic sustainability processes by combining the expanded number of technological energy development resources in the postindustrial economy.

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References

1. Adrianov, V.A. Current issues, problems and prospects of development of the fuel and energy complex of Russia. *Inf. Anal. Portal Viperson* **2015**, *7*, 17–31.
2. Topuzov, N.K.; Shchelkonogov, A.E.; Amelin, I.S. Multi-criteria approach to hydrogen fuel technology. In Proceedings of the International Conference of Electrical Engineering and Electronics Engineering, London, UK, 5–7 July 2017; Volume 1, pp. 308–311.
3. Razuvaev, A.V. The expediency of using heat recovery systems for internal combustion engines. *Turbines Diesel Engines* **2010**, *1*, 48–50.
4. Makarov, A.A.; Mitrova, T.A.; Malakhov, V.A. World energy forecast and consequences for Russia. *Stud. Russ. Econ. Dev.* **2013**, *6*, 511–519. [CrossRef]
5. Goldiner, A.Y.; Tsyrkin, M.I.; Bondarenko, V.V. *Gas Piston Electrical Aggregates*; Gallery Print: Saint Peterburg, Russia, 2006.
6. Li, J.H.; Teng, Z.D.; Zhangm, L. Stability and bifurcation of a malaria transmission with a delay. *Math. Comput. Simul.* **2018**, *152*, 15–34. [CrossRef]
7. Euzébio, R.; Pazim, R.; Ponce, E. Jumping bifurcations in some systems of the three zones. *Phys. D Nonlinear Phenom.* **2016**, *325*, 74–85. [CrossRef]
8. Adizes, I.K. *Integration: Survive and Become Stronger in Times of Crisis*; Alpina Publisher: Moscow, Russia, 2009.
9. Sen, A. *Development as Freedom*; New Publishing: Moscow, Russia, 2004.
10. Lalu, F. *Discovering the Future Organizations*; Mann, Ivanov and Ferber: Moscow, Russia, 2016.
11. Frumin, I. Human Capital 2.0. New Tasks of Education [Electronic Resource]. Available online: https://www.youtube.com/watch?v=e6K5sPkee8I (accessed on 26 November 2018).
12. Azizi, R.R.; Azizi, M.; Moradi-Moghadam, M.; Maleki, V. Cruz-Machado. *Manag. Prod. Eng. Rev.* **2016**, *1*, 4–12.
13. Hoegl, M.; Schulze, A. How to support knowledge creation in new product development: An Investigation of knowledge management methods. *Eur. Manag. J.* **2005**, *23*, 263–273. [CrossRef]
14. Liu, P.L.; Chen, W.C.; Tsai, C.H. This is a study of Taiwan's industries. *Technovation* **2005**, *6*, 637–644. [CrossRef]
15. Lafond, F. Self-organization of knowledge economies. *J. Econ. Dyn. Control* **2015**, *52*, 150–165. [CrossRef]
16. McCarthy, I.P.; Tsinopoulos, C.; Allen, P.; Rose-Anderssen, C. Adaptive system of decisions. *J. Prod. Innov. Manag.* **2006**, *5*, 437–456. [CrossRef]
17. Kirsch, L.J. The Management of Complex Tasks in Organizations: Controlling the Systems Development Process. *Organ. Sci.* **1996**, *1*, 1–21. [CrossRef]
18. Puschke, J.; Zubov, A.; Kosek, J.; Mitsos, A. Multi-model approach based on semi-batch processes with parametric uncertainties. *Comput. Chem. Eng.* **2017**, *98*, 161–179. [CrossRef]
19. Kim, Y. The effect of process management on different types of innovations: An analytical modeling approach. *Eur. J. Oper. Res.* **2017**, *262*, 771–779. [CrossRef]
20. Alabugin, A.A. Methodology for managing the integration of intellectual, research and investment resources to improve the efficiency of neo-industrial technological development of systems. *Intellect Innov. Invest.* **2017**, *4*, 4–11.
21. Chandra, Y. A time-based process of international entrepreneurial evaluation. *J. Int. Bus. Stud.* **2017**, *4*, 423–451. [CrossRef]
22. Maine, E.; Thomas, V.J.; Utterback, J. Radical innovation technology for the emerging nanobiotechnology industry. *J. Eng. Technol. Manag.* **2014**, *32*, 1–25. [CrossRef]

23. Cunningham, S.W.; Kwakkel, J. Innovation forecasting: A case study of engineering and technology literature. *Technol. Forecast. Soc. Chance* **2011**, *2*, 346–357. [CrossRef]
24. Shultz, T. Human Capital in the International Encyclopedia of the Social Sciences. *Invest. Hum. Cap.* **1971**, *6*, 26–28.
25. Alabugin, A.A. *Manage Balanced Enterprise Development in a Dynamic Environment. Book 1. Methodology and Theory of the Formation of an Adaptation Mechanism for Managing the Development of an Enterprise: Monograph*; Publishing House of SUSU: Chelyabinsk, Russia, 2005.
26. Klimenko, V.N.; Mazur, A.I.; Sabashuk, P.P. *Cogeneration Systems with Heat Engines: A Reference Guide*; Kiev, CPI ALCON NAS of Ukraine, Institute of Applied Research: Kiev, Ukraine, 2008.
27. Newman, J.R. William Kingdom Clifford. *Sci. Am.* **1953**, *2*, 78–84. [CrossRef]
28. Alyukov, S.V. Approximation of generalized functions and their derivatives. *Questions of atomic science and technology. Ser. Math. Model. Phys. Process.* **2013**, *2*, 57–62.
29. Alyukov, S.V. Approximation of step functions in problems of mathematical modeling. *Math. Models Comput. Simul.* **2011**, *3*, 75–88. [CrossRef]
30. Qureshi, M.I.; Rasiah, R.A.; Al-Ghazali, B.M.; Haider, M.; Jambari, H. Modeling Work Practices under Socio-Technical Systems for Sustainable Manufacturing Performance. *Sustainability* **2019**, *11*, 4294. [CrossRef]
31. Cohen, M.A. Systematic Review of Urban Sustainability Assessment Literature. *Sustainability* **2017**, *9*, 2048. [CrossRef]
32. Shen, L.; Kyllo, J.; Guo, X. An Integrated Model Based on a Hierarchical Indices System for Monitoring and Evaluating Urban Sustainability. *Sustainability* **2013**, *5*, 524–559. [CrossRef]
33. Khasreen, M.M.; Banfill, P.F.G.; Menzies, G.F. Life-cycle assessment and the environmental impact of buildings: A review. *Sustainability* **2009**, *1*, 674–701. [CrossRef]
34. Alfonso Piña, W.; Martínez, C.P. Development and Urban Sustainability: An Analysis of Efficiency Using Data Envelopment Analysis. *Sustainability* **2016**, *8*, 148. [CrossRef]
35. Vidyanandan, K.V.; Balkrishn, K. Grid Integration of Renewables: Challenges and Solutions. In *Emerging Energy Scenario in India—Issues, Challenges and Way Forward*; United Nations Department of Economic and Social Affairs: Neyveli, India, 2018.
36. Renewable Energy Sources (RES): Potential and Development Prospects in Russia//Viperson.ru: Daily. Online Edition [Electronic Resource]. Available online: http://viperson.ru/articles/vozobnovlyaemye-istochniki-energii-vie-potentsial-i-perspektivy-razvitiya-v-rossii (accessed on 28 March 2019).
37. *Forecast of the Development of Energy in the World and Russia 2016*; Analytical Center for the Government of the Russian Federation: Moscow, Russia, 2016.