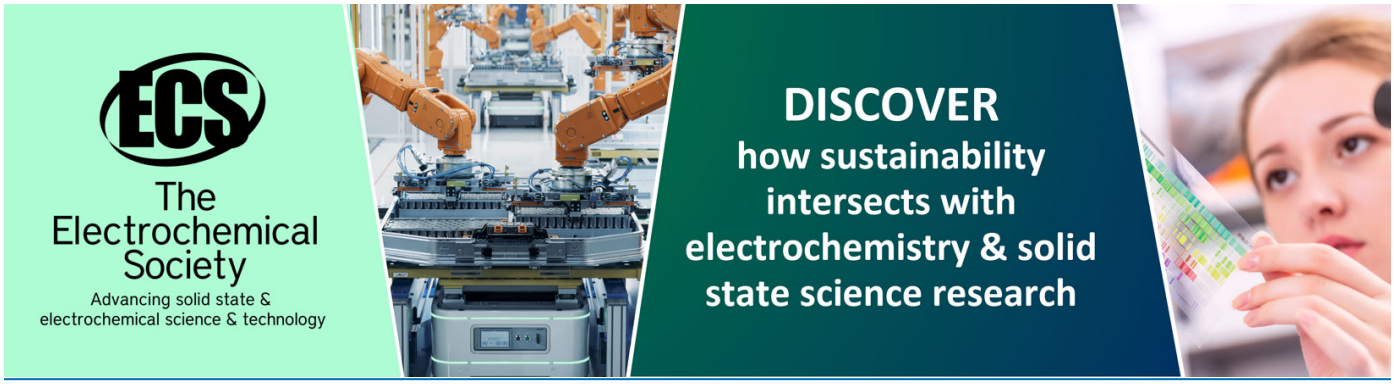
Economic Models and Methods for Assessing and Regulating the Sustainability of Distributed Post-Carbon Energy Development



Economic Models and Methods for Assessing and Regulating the Sustainability of Distributed Post-Carbon Energy Development

A Alabugin[1], V Shashkin[1], Y Sun[2], S Jiao[2], Z Xiong[2]

[1]Department of Industrial Heat Power Engineering, South Ural State University (National Research University),76, Lenina ave., Chelyabinsk, 454080, Russia
[2]Department of Energy Power and Mechanical Engineering, North China Electric Power University (NCEPU), 2, Beinong road, Changpin District, Beijing, 102206, China

E-mail: pte2017pte@mail.ru

Abstract. 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 distributed post-carbon energy. Models and methods for assessing the stability of the spatiotemporal dynamics of the integration of resources and the processes of combining technologies for the production and consumption of energy and energy carriers in the formation of the energy complex are supplemented. The evaluation tool differs in its ability to model the indicator-property by factor factors and the criterion of a minimal imbalance between the interests of producers and consumers of an expanded number of types of energy products under cogeneration conditions, reducing the costs of non-renewable resources and losses. This allows us to regulate the stability of the normative level of sustainability and to justify the overall strategy of energy-saving development of the complex.

1. Introduction

The urgency of research and assessment of the sustainability of energy-efficient development of energy producers and consumers is determined by the need to reduce the imbalance of their goals in the context of centralized energy supply. With the continuous development of the industrial society, traditional energy sources have already dried up. Under such a background, distributed energy has been developed and utilized by humans because of its characteristics of cleanliness, large storage, and convenient use [1, 2, 3, 4]. Trends of the new industrialization have increased the significance of the problems of developing tools for the convergence of theoretical approaches to regulating the stability of complex systems. Distributed energy production realizes the concept of generating energy sources and distribution networks in conditions of cogeneration of energy by different sources for territorially close consumers. At the same time, surplus energy is sent to the general network of centralized energy supply. This means that the consumer becomes a requester, that is, both an object of both generation and consumption of energy in the formed energy complex. The complex, in general, includes gas-piston, gas-turbine and other micro-power plants, heat pumps and other NTRSEs. This combination allows us to introduce the concept of the process of polygeneration, as the simultaneous production of an expanded range of products, their consumption and accumulation. A small installed capacity of the complex (up to 50 MW), a variety of sources, developed networks and communications are technical

and organizational factors for ensuring the sustainability of energy supply for energy, environmental and economic indicators. They are much higher than in a centralized system with a high concentration of power capacities.

2. Theoretical part

The existing theoretical and methodological approaches to assessing the utility of development in a multifactorial and multi-criteria evaluation of the quality of processes and results usually use the apparatus of vector functions of many variables. To implement them, it is common to build goal-oriented utility functions to improve the balance of goals based on subjective data from expert surveys. Therefore, we set ourselves the task of supplementing the tools for estimating and maximizing the utility of energy saving results in terms of the sustainability of the energy complex development with a mathematical justification of the decision to regulate the imbalance of goals using the cost minimization criterion. The law of the diminishing marginal utility of the stability of the development of complex systems is applicable to the determination of the investigated dependences. It is established that the overall utility (OU_{LS}) of the mutual harmonization of the goals of energy producers and consumers increases with the increase in the sustainability of the energy-saving development of the complex. However, each additional increment in the additional or marginal utility of sustainability (MU_{LS}) reduces the recognition of it by decision-makers. Consequently, the MU_{LS} decreases with time as the exponent LS grows in the model in Fig. 1. To eliminate the inconsistency of the performance of indicators of general and marginal utility A.A. Alabugin proposed to evaluate the integral utility of ensuring the sustainability of the development of the IU_{LS}. It takes into account the state of compromise of the goals of general and marginal utility as an allowable imbalance that harmonizes the interests of producers and consumers of energy in a complex [5, 6, 7]. The integral utility of the result "the allowable level of variability of the sustainability index of energy-saving development in the long-term period" was suggested to be estimated by the regulatory range of changes in the current costs of energy production under conditions of polygeneration. They can be reduced in two cases: with minimal and large volumes of sales and consumption of energy products in the ΔVS complex (curve 2 in Figure 1). In the first case, this is expressed in the growth of regulatory costs due to the regime constraints on the schedules with a reduction in the loads of consumers. This reduces the effect of the integral utility of ensuring a stable level of sustainability of long-term energy-saving development (shown by an increase in costs in the section of the AB curve). In the second case (the section of the BC of the ABC curve), the increase in costs can be explained by the inefficient use of power plants based on NTRSE with a lower efficiency, the wear and tear of the fixed assets of traditional energy, and the insufficient focus on energy-saving development of the complex's facilities. Consequently, when adjusting the imbalance of producers and consumers' goals, a minimum of costs is achieved during cycle 1 (C^*_{LS}). It can be considered the maximum utility $IUmax_{LS}$ of the results of increasing the level of sustainability of development in the zone of trade-off in the conditions of polygeneration of energy products in a complex of closely located consumers. The magnitude of the overall utility can be estimated by the level parameter, since it is composed of additive-type indicators. This follows from an understanding of the usefulness of the results of the gradual evolutionary development of distributed energy. These are the processes of increasing energy and environmental efficiency with an increase in the share of production of NTRSE. The flatness of curve 2 in Fig. 1 is confirmed further on the basis of mathematical models. Economically, it is explained by the prevalence of conditional-constant costs in achieving and securing a zone of compromise of the goals of increasing energy and environmental efficiency. Value of costs C_{LS} can be interpreted as an optimal premium to the value of commodity results of polygeneration, which provides a level of stability in this zone [8, 9, 10].

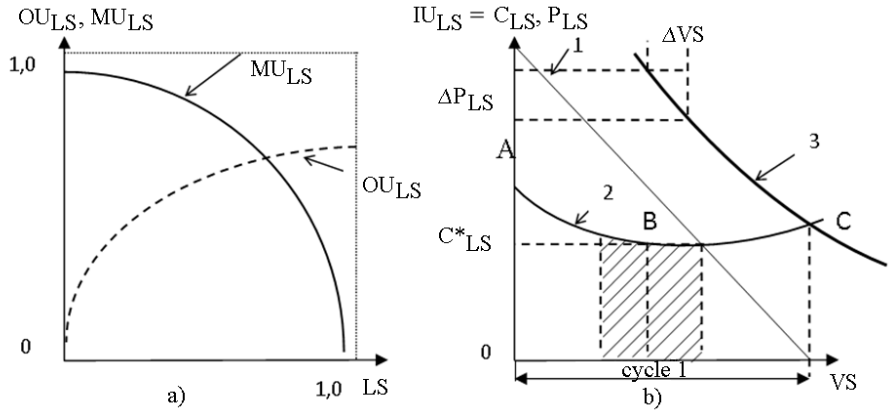


Figure 1. Interrelation between the overall and marginal utility of ensuring the stability of the zone of trade-off of the goals of energy saving development of the distributed energy complex.

The gradual decrease in sales is expressed in the transition from curve 2 to curve 3: a decrease in prices (ΔP_{LS}) more leads to increased sales ΔVS, as consumers in the energy complex pay extra for the possibility of stable relationships with producers of an expanded number of energy carriers with a lower cost. Consequently, energy-saving development in the zone of trade-off of goals is more effective in terms of environmental and economic criteria. The proposed model of the imbalance of the opposite goals of managing energy-saving development Alabugin uses the notion of a vector optimum proposed by V. Pareto and the equilibrium of goals in the theory of L. Nash [1]. This allowed us to formulate the research concept as a set of scientific methods to increase the level of sustainability of energy saving development of a complex of producers and consumers of the post-carbon type, provided that one goal cannot be improved without worsening the other (in this case it links the goals of economic efficiency and sustainability of energy-saving development). The relationship of goals is shown in the model in Fig. 2 dependence of the qualitative form (solid line). The use of the functions of regulation of the imbalance of the goals of the development processes of the complex should lead, within a cycle or several cycles, to the emergence of a zone of sustainable compromise of goals as a region (shaded) of the permissible variability of the property index being studied. It is justified that the deviation of its trajectory from the zone is economically impractical [5].

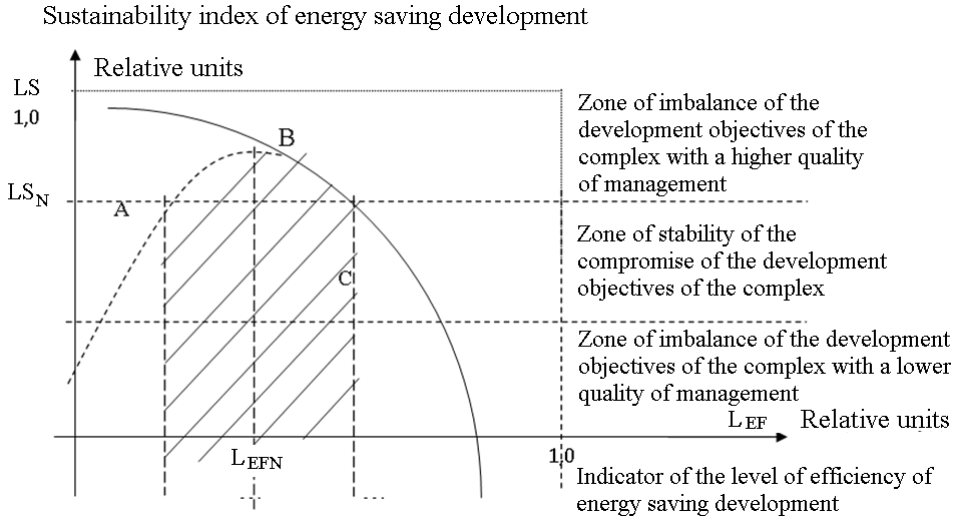


Figure 2. Model for determining the zone of sustainability of the results of distributed energy development.

Decrease in the level of efficiency (LEF) with a decrease in the level of sustainability of energy-saving development in the ratio LS<LSN (below the normative values), as shown by the dashed line, is explained by the increase in losses from the increasing delay time in responding to environmental changes (for example, and their adjustment). This justifies the decline in efficiency, as a condition for

increasing the level of sustainability of energy-saving development. Obviously, the process of reaching a compromise or consensus goals (point B) may be accompanied by a decline in individual development indicators. The magnitude of the decrease increases with the realization of goals of an increasingly high level, which corresponds to a certain assumption about the economic inexpediency of deviating parameters from the state of stable equilibrium of interests in assessing the goals of energy saving development of producers and consumers of the complex.

3. Scientific novelty and a new economic method

The problem arises of finding the region of admissible changes in the trajectory of the stability indicators of the process of energy-saving development of the system. For this purpose, the hypothesis of a cyclic change in the trajectory of the sought-for indicator (curve 1, or ABC in Figure 3) is proposed for the development and implementation of an innovative project for the formation of a distributed-type power complex. Section AB, illustrating its pre-investment phase of the formation of the energy complex in the context of uncertainty of development results, is characterized by an increase in one-time and current costs. Short-term decline in economic efficiency is due to the need for high-risk investments for marketing and research, development and technological work in a high-tech project. The high probability of loss of profit by enterprises-producers and consumers is shown by a fall in the indicator of economic efficiency (curve 2). At point B there should be a minimum of the indicator of economic costs for the life-cycle period 1 of the project along the time axis t in the model in Fig. 3, which shows the possibility of forming a zone of compromise of goals (shaded). Within its limits, it is proposed to regulate the coefficient-factors stability of the normative level of sustainability of energy-saving development LSN. It is taken as an average value in the range of variability of the property under study in the range from 0 to 5 relative units of the cycle time estimate. During the time from 5 to 15 units of cycle 1 on the segment BC of curve 1, the indicator of the stability of development gradually increases, which is explained by the growth in the scale of development of distributed energy in terms of the number of enterprises of the complex being formed. At point C, the state of a dynamic trade-off between the interests of producers and consumers is reached, which is estimated by the value of the normative level of stability LSN. Therefore, it is necessary to evaluate and regulate the preservation of the zone of compromise of opposite goals by the criterion of the permissible variability of the utility index of the normative stability zone of development (indicated by dashed lines in Figure 3). In practice, this means the emergence of the need for a transition to polygeneration processes with the expansion of the number of power plants and types of energy products produced on the basis of NTRSE. Confirmation of the proposed hypothesis and substantiation of the concept of modeling the usefulness of the results of the cyclic dynamics of regulation of the stability of the development of the energy complex is carried out by a new mathematical method proposed by S.V. Alyukov.

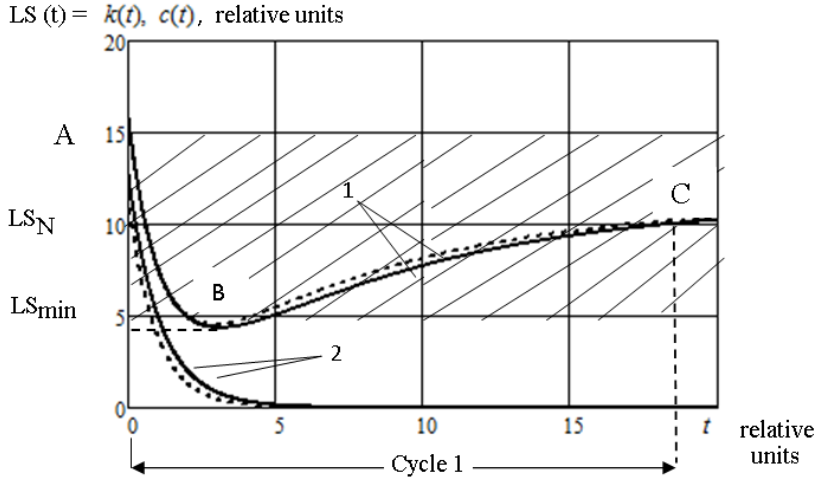


Figure 3. Model for assessing the cyclic dynamics of the levels of sustainability and efficiency of energy-saving development of distributed energy.

The method is based on known models of economic growth. It allows analyzing the imbalance of opposite goals for assessing the sustainability of energy-saving development of a complex of producers and consumers. With some assumptions, the Ramsey model is described by the following system of differential equations (1):

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

where k and c – indicators of the assessment of the sustainability and efficiency of the development of distributed energy, regulated by the following factors-factors of the formation and development of a complex of distributed energy enterprises of the post-carbon type: $\delta\equiv const$ ($\delta\in[0,1]$) – wear of the technical and technological base of distributed power facilities in a complex of producers and consumers; ($\alpha\in[0,1]$) – elasticity of the basic factor of investment in fixed assets of the formed energy complex; $\sigma\equiv const$ ($\sigma\in[0,\infty)$) – elasticity of the regulated substitution of the sustainability of energy-efficient development of distributed energy and the efficiency of enterprises of the complex; $\rho\equiv const$ ($\rho\in[0,\infty)$) – speed of switching targets while regulating the sustainability of energy-saving development based on NTRSE on the efficiency of enterprises of the complex. It was revealed that the first of the equations of the system (1) represents resource constraints in the formation and development of the complex, the second equation corresponds more to the conditions for ensuring its effectiveness and is the Euler equation. In the investigations of S.V. Alyukov it was established that the equilibrium position is of the saddle type and is unstable. In this case, it characterizes the critical point B of the economic stability indicator trajectory in the model. A new equilibrium position is mathematically justified, which is asymptotically stable. This means the possibility of solving the stated task of maximizing the utility of the development of distributed energy in assessing the zone of stability of the normative level of process stability in the zone of compromise of the objectives of the sustainability of processes and the efficiency of enterprises of the complex. The established equilibrium position, when in its zone the level of development efficiency decreases to zero in the short term, means that there is an objective limitation of traditional fuel resources. In the pre-investment phase of the project, significant high-risk investments are needed that, in the long run, the cycles of changes in the sustainability of energy-saving development pays off when trade-offs are achieved. After a series of transformations of the system (1), S.V. Alyukov proposed a modified system of equations of linear type. It is more simply solved when making $\check{k}0=\check{k}(t=0)$ $c0=c(t=0)$ as initial conditions that take into account the initial level of indicators of stability and efficiency of development of the energy complex in the cycle. In order to verify the solutions, they were verified to verify the convergence of the results by a numerical Runge-Kutta method in the MathCAD computer environment. The verification showed an acceptable coincidence of the obtained analytical results with numerical calculations. The results of comparative studies are shown in Fig. 3, where curve 1 corresponds to a variable k, and curve 2 – variable c. The solid line corresponds to numerical solutions, point-to-analytical solutions obtained with the help of the small parameter method. This confirms the hypothesis proposed by us of the existence of a stable utility zone for the results of energy saving development of a complex of energy producers and consumers on the basis of criteria for the minimum variability of the indicator-stability properties in the compromise zone with efficiency objectives.

4. Application

The possibility of using the modernized mathematical model of research and assessment of the stability of the development of a complex of distributed power engineering facilities for testing the hypothesis of providing a compromise zone of the main indicator-property with the efficiency of the enterprises of the complex and choosing strategies based on the coefficient factors of modeling and regulating the formation of the complex in the developed matrix is substantiated [11]. The presented results of the research are distinguished by the fact that the expanded composition of the complex's facilities and the number of types of products under the conditions of polygeneration open up new properties of the generated complex of distributed energy, consisting in the formation of a zone of compromise between

producers and consumers in assessing the regulatory level of sustainability with sufficient efficiency of enterprises of the complex.

5. Conclusion

The objects of the distributed energy of the post-carbon type are specified, the peculiarities of which are the space-time dynamics of integration of resources and processes of combining traditional and green technologies, the organization of the interrelations of producers and consumers in the special composition of energy complex objects with their territorial proximity and limited (in comparison with centralized power systems) installed capacity.

The concept of cogeneration is expanded to the term "polygeneration", which refers to the processes of combining technologies of simultaneous production of an expanded number of types of energy products, their consumption and accumulation in a distributed type energy complex to reduce the costs of nonrenewable resources and losses. The evaluation toolkit is developed on the basis of the author's concept of the integral utility of the results of energy conservation, taking into account the possibilities of regulating the sustainability of development by the criterion of a minimal imbalance between the interests of producers and consumers of energy when combining traditional and renewable resources using the measured factor characteristics of the imbalance of sustainability and efficiency objectives.

References

[1] Van der Vleuten E and Raven R 2006 Lock-In and Change: Distributed Generation in Denmark in a Long-Term Perspective *Energy Policy* **34** 3739-48
[2] Ferreira H, Costescu A and L'Abbate A 2011 Distributed Generation and Distribution Market Diversity in Europe *Energy Policy* **39** 5561-71
[3] Davis G and Owens B 2003 Optimizing the Level of Renewable Electric R&D Expenditures: Using Real Options Analysis *Energy Policy* **31** 1589-1608
[4] Chien T and Hu J 2007 Renewable Energy and Macroeconomic Efficiency of OECD and Non-OECD Economics *Energy Policy* **35** 2007 3606-15
[5] Alabugin A 2005 *Managing the Balanced Development of an Enterprise in a Dynamic Environment* (Publishing House of SUSU) p 362
[6] Alabugin A 2017 Methodology for Managing the Integration of Intellectual, Research and Investment Resources to Improve the Efficiency of Non-Industrial Technological Development of Systems *Intellect, Innovations, Investments* **4** 4-11
[7] Cooney S 2008 *Build a Green Small Business: Profitable Ways to Become an Ecopreneur* (New York: McGraw-Hill) p 128
[8] Zhang H 2007 *Research on Solar Photovoltaic Power Generation System* (Shandong University: master's degree thesis) p 12
[9] 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
[10] Adrianov V 2015 Current State, Problems and Prospects of Development of the Fuel and Energy Complex of Russia *Informational and Analytical Portal Viperson* **21** 17-31
[11] Alyukov S 2011 Approximation of step functions in problems of mathematical modeling *Mathematical Modeling, Journal of the Russian Academy of Sciences* **23** 75-88

Acknowledgments

The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0011.