Conclusion

The energy sector development unfolds under the growing complexity of its external and internal interrelationships, drastic changes in the nature and sectoral make-up of the economy, globalization, and the accelerating rate of scientific and technological advances. These and other factors contribute to the uncertainty of the future and urge to be on the lookout for new approaches that would lower the uncertainty and increase the validity of long-term projections.

Our analysis of projections of energy systems development published in Russia and abroad prove the non-linear nature of the escalation of the uncertainty range as the projection time frame extends further into the future. At the same time, this makes the accuracy requirements, that are to be met by projections, much less stringent. Our calculations suggest that the dependency of the value of investment projects for power plants of various types on changes in the demand for electric energy, fuel prices, and the discount rate is significant only within the first 15 years of their expected lifespan.

Accordingly, as the time frame increases projections should prioritize all the more not numeric estimates of energy carriers production and consumption volumes and even less so the guesstimates of their prospective values, but the identification of new trends and threats, the justification of the limits put on possible and feasible energy sector development options, the assessment of the significance of strategic-level threats and challenges, and the identification of their patterns as a function of changing external and internal conditions.

The methodology behind the modeling of the long-term energy sector development and the application practices adopted by those who employ a diverse range of mathematical models and the so named "model and information systems" should incorporate the principle of correspondence between the complexity and the level of granulation of research tools, on the one hand, and the intrinsic uncertainty of input data and accuracy requirements specific to the problem they deal with, on the other hand.

The principle of correspondence is fulfilled in our incremental approach to narrowing down the uncertainty range of conditions and results. This is achieved by iterative calculations performed on models of different hierarchical levels. A subset

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of models catering to a specific time frame of the projection is employed, which is followed by the harmonization of final values of performance indicators in time. To this end, at the initial stage one assumes the most extensive time frame (over 25–30 years) and the least number of hierarchical levels and models.

A major takeaway from the analysis at this stage is a projection of the dynamics of demand and prices in the energy sector with due consideration of a possible effect of anticipated new trends in scientific and technological advances as they manifest themselves in the energy carriers production and consumption, the national economy, and the quality of life. Doing away with such long-term projections of these performance indicators makes it difficult to arrive at evidence-based understanding of the efficiency and the riskiness of the energy sector and large-scale projects development options that are identified at the stages that focus on the development of short-term and medium-term projections.

The incremental approach to projects that we advocate is based on the retrograde movement from the more remote future to the near future. However, it does not preclude a subsequent reverse iteration of the projection: i.e. a revision of long-term projections so that they could accommodate the results obtained by a more granular analysis of a shorter time frame. Iterative calculations carried out at each stage that target a specific segment of the overall time frame (as performed both in top-down and bottom-up fashions) make it possible to account for the features unique to the development of systems (their opportunities and demands) of varying hierarchical levels that constitute the national energy system. To this end, it is practical for projections that cover 15–20 years ahead to account for possible responses to projected price and demand changes by potential investors.

Contingency calculations carried out at each stage assume scenarios of the economic and global energy markets development that are of varying levels of detail. Such calculations define the range of all possible values envisaged by a given projection of the energy sector development and help identify invariant solutions and contingent areas within it (under various criteria and conditions). The proposed approach to the exploration of this zone is based on the risk assessment of the facilities that make it up. Here, the risk value is derived from the inverse of the frequency with which the above facilities make it to the set of balanced out optimal solutions. The less frequently a given facility appears in such solutions the higher its investment risks are. The large number of tests under various combinations of input data, which is a desideratum of an analysis of this kind, can be obtained by blending optimization with Monte Carlo simulation within a single model.

An important role in the study of projections is played by singling out the problems that are of the utmost significance within each segment of the overall time frame and then solving them with appropriate methods. In this book, we focus on the approaches to tackle the following two of them: the problem of long-term projections of the possible state of regional markets (as defined by prices and demand), and the problem of the quantitative assessment of possible barriers that hinder the development of the energy sector on a par with strategic-level energy security threats under assumed scenarios of the economic development.

To solve the first of the two, we simulate the competition of energy carriers and their suppliers in a given region under incomplete information. To assess a possible response of consumers and investors to a change in the energy carriers cost we use original models that blend optimization with methods of statistical testing. To this end, we account for price elasticity of the fuel and energy demand. Our calculations provide evidence for a significant variation over regions and the dependency on the nature of the input data uncertainty.

The values of the price elasticity of demand for individual regions may serve as an energy security indicator: the less the elasticity is the less the possibility for mutual substitution of energy carriers becomes and the more urgent the energy undersupply threat proves in the case of, for example, a gas supply shortage.

Among the barriers that threaten the required energy sector development a prominent role is played by inertia. The identified non-linear dependency of its indicators on the growth rate and the make-up of the energy sector can be rationalized on the basis of high capital and material intensity of the constituent industries and a large share of capital expenditures for linked industries and manufacturing facilities. The importance of these indirect costs increases with higher growth rates of the fuel and energy production but can be lowered by means of higher import levels for equipment and materials. Available methods of quantitative assessment of such inertia indicators as the time and the scale of required look-ahead development of the industries linked to the energy sector and of corresponding capital expenditures can contribute to the improvement of approaches to comparative ranking of the energy sector development options based on the feasibility criterion. Evaluation of risk in individual capital investment projects should serve as a vital part in the process of arriving at such a comprehensive criterion.

The set of all strategic-level energy security threats can be divided into two major groups: the threat of new capacity additions lagging behind the most likely demand scenario and the threat of an excessive increase in the cost of energy carriers. The approaches we champion in this book and elsewhere to handle an approximate assessment of these interrelated threats provide for the identification of the timing and the probability of their occurrence on a par with their severity: the magnitude of possible losses due to the threat event materializing and the costs to mitigate them.

We propose a two-level (that is, encompassing both the national and the regional levels) approach to the assessment of the probability and the severity of the capacity shortage threats. To this end, the problem is treated as an analysis of possible risks of the energy and fuel supply of a given territorial entity under uncertainty.

To obtain an approximate estimate of likely macroeconomic consequences induced by changes (relative to the reference case) in the fuel and electric energy prices one can employ the system of economic and mathematical models (INTEK) developed by the author.

The assessment of strategic threats has to be reflected in the values of energy security indicators. Ideas as to how to extend their composition as well as the methods to calculate them are presented in this book as well.

Obviously, the proposed methods of increasing the validity of long-term projections of the energy sector developments are subject to discussion and call for further research efforts. It is also clear that the list of the problems that are to be treated as part of the projections development goes beyond the scope covered in the book. It depends on a given time frame and the required lead time of decisions to be made.

Of top concerns that, as of today, still lack satisfying solutions one can highlight the following ones:

- Assessment of the possibility and conditions to adjust to a new scenario of the economic development and the state of world energy markets, as well as to the shift from one pathway of the energy sector development to another (in terms of required resources and the time it would take).
- Approaches to assessment and harmonization of the results of projections that are obtained by solving optimization problems at different hierarchical levels based on different criteria of economic efficiency (each appropriate at the levels of individual businesses, industries, and the national economy respectively) as well as the criteria of flexibility (the ability to accommodate changes), reliability, and security.
- Numeric estimates of threshold values of energy security, and national security indicators with due consideration of their functional dependency on the scenarios of social and economic national developments, on projections of scientific and technological advances in production and consumption of energy carriers, and, finally, on a given time frame and other contributing factors.
- The correspondence between employed methods and models of the input data uncertainty, on the one side, and required performance of projections, on the other side, as applied to various time frames. Identification of the minimum required level of detail appropriate for solving a given problem of the adequate representation of elements and links within a given system.

It appears that the above 'to do' list can also be extended to cover the identification of the pitfalls and the root causes of energy and economic systems getting trapped in a zone of instability and bifurcations where even the most negligible of changes in conditions is able to invoke a crisis or an emergency. Arriving at a solution of the latter problem can be facilitated by a dialogue with the cross-disciplinary field of synergetics that studies the laws of evolutionary processes, sustainability, and self-organizing of open non-linear dynamic systems.