



# Development of integrated solutions for the decentralisation of electricity supply to power-hungry regions

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## ABSTRACT

The relevance of the study is conditioned by the need for practical development and implementation of integrated solutions for the decentralisation of power supply to various geographical regions suffering from a shortage of electric energy due to pronounced problems with the energy supply. The purpose of this study is to identify the main aspects of the development of integrated solutions for the decentralisation of energy supply to power-hungry regions, which may be of significant practical importance from the standpoint of improving the quality of energy supply to such regions. The leading methodological approach in this study is a combination of methods of system analysis of existing principles for the development of integrated solutions for the decentralisation of electricity supply to regions suffering from power shortages, with an analytical investigation of various aspects of electricity supply to power-hungry regions, which is of significant practical importance in terms of improving the quality of electricity supply to remote settlements and districts of the Republic of Kazakhstan. The results obtained clearly indicate the existence of significant prospects for the use of alternative sources of electricity in the issues of decentralisation of power supply to power-hungry regions, and also demonstrate the sequence of development and practical implementation of integrated solutions aimed at timely solving this problem, aimed at meeting the demand for electric energy of residential facilities in these regions and industrial production located in them. The results of this study and the conclusions formulated on their basis are of significant practical importance for employees of power supply systems, who solve practical issues of electric energy supplies to remote geographical regions suffering from power shortages.

## 1. Introduction

The main objectives of the energy strategy of any state and the Republic of Kazakhstan, in particular, is to create an extensive energy supply system capable of self-regulation and meeting the electricity needs of all, without exception, even the most geographically remote regions of the country. The implementation of a regional policy in the field of electric energy supplies involves mandatory consideration of the needs of all geographical regions of the state in certain amounts of electricity, to meet the needs of the population and industrial enterprises in it (Altawell et al., 2020).

Electrification of specific consumers has its own characteristic features, while in this context it is necessary to take into account both the geographical remoteness of the regions where these consumers are located and the volume of their average electricity needs. The

decentralisation of electricity supply to power-hungry regions allows timely and high-quality solutions to a wide range of practical issues of electricity supply to end-users and solving a large number of practical problems related to electricity consumption (Kyriakopoulos, 2021). Currently, an effective way to practically resolve issues of the quality of electricity supplies and ensure the reliability of power supply to power-hungry regions is the use in these regions, along with conventional power supply systems, of modern autonomous power supply systems, which act as separate elements of a single electrification system (Zavalna and Starynskyi, 2021).

The last three decades of the 20th century were marked by increased attention of the world community to the problems of the energy sector associated with large-scale socio-economic transformations in society, which have a significant impact on various scientific and technical processes related to the pressing problems of electricity supply of power-

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hungry geographical regions (Azar and Kamal, 2021). This state of affairs was largely facilitated by significant problems of an economic and energy nature, which significantly worsened in the 1970s and the aftermath of which still affect the state of the energy industry of the former USSR states and a number of European and Asian countries (Zhornokui and Slipchenko, 2020). The creation of the necessary conditions for ensuring the energy security of individual geographical regions is facilitated by the timely qualitative forecast of the development of the energy industry for the next few decades, which would take into account the main trends in the development of the energy sector on the scale of both a single state and an entire geographical region, and a number of individual regions falling under the category of energy deficient.

To form a qualitative assessment of the energy potential of a particular geographical region, it is necessary to allocate sites that are most promising from the standpoint of the development of renewable sources of electricity, the operation of which is based on the use of solar, water, and wind energy (Sandu et al., 2020). In addition, it is important to assess geographical regions from the standpoint of the prospects for the introduction of biogas plants on these territories at various scales (Hlushchenko and Sahaidak, 2021). In general, the development of integrated solutions for the decentralisation of electricity supply to power-hungry regions includes the parallel implementation of a number of economic projects aimed at significantly reducing energy costs for the production of basic types of industrial products in these geographical regions. Nowadays, a large number of industrial production enterprises and energy associations are forced to carry out their activities based on the principles of interaction in the conditions of the development of market relations, which generally determines the development of the trend of energy supply decentralisation (Katsoulakos and Kaliampakos, 2016).

The main problems of research devoted to the consideration of a wide range of issues related to the decentralisation of power supply to power-hungry regions are the weak disclosure of the role of state structures in this aspect, and the lack of development of a programme aimed at ensuring the practical implementation of integrated solutions to ensure high-quality decentralisation of power supply to regions suffering from power shortages. In this paper, the task is to carry out the qualitative development of integrated solutions for the decentralisation of power supply to power-hungry regions, taking into account their characteristic features, both geographical and economic.

## 2. Materials and methods

The basis of the methodological approach in this study is a combination of methods of system analysis of existing principles for the development of integrated solutions for the decentralisation of power supply to regions suffering from problems with electricity supplies, with an analytical investigation of various aspects of power supply to power-hungry regions. The methodology of this study has been compiled taking into account the specifics of the subject matter and involves conducting a given amount of research aimed at creating a model for the consistent implementation of integrated solutions for the decentralisation of electricity supply to power-hungry regions, taking into account their specific and characteristic features that are essential from the standpoint of their economic and energy development.

The theoretical basis of this study is the scientific developments of a number of Kazakh and foreign researchers, studying a number of fundamental aspects of the development and subsequent implementation of integrated solutions aimed at solving the fundamental issues of decentralisation of electricity supply to power-hungry regions. To create the most objective and qualitative picture of research and to ensure an appropriate level of understanding of the information provided, all the developments of researchers taken in the order of citation and presented in this paper have been translated into English.

This research assumes compliance with the sequence of its main

stages.

At the first stage, the theoretical basis necessary for the further systematic investigation of a wide range of issues within the framework of the stated topic was prepared. In addition, this stage included a systematic study of existing principles for the development of integrated solutions for the decentralisation of electricity supply to regions suffering from power shortages using the prepared theoretical base.

At the second stage, the analysis of the main aspects of power supply to power-hungry regions was carried out, which is of significant practical importance from the standpoint of improving the quality of electricity supply to remote settlements and regions of any state. In addition, at this stage of the study, an analytical comparison of the preliminary results obtained with the results and conclusions regarding the problems of building integrated solutions for the decentralisation of power supply to power-hungry regions, taking into account the peculiarities of their geographical location and energy supply conditions, was carried out. The implementation of such an analytical comparison contributes to the development of the most objective picture of the conducted research, taking into account the peculiarities of its subject matter and the chosen methods of its disclosure.

At the final stage, based on the practical results obtained, the final conclusions were formulated, acting as their logical reflection and summing up the results of the entire complex of research efforts. In general, the results obtained and the conclusions formulated on their basis can subsequently serve as a qualitative theoretical basis for further research in the framework of studying the development and practical implementation of integrated solutions for the decentralisation of electricity supply to power-hungry regions, which would be of great practical importance for ensuring the proper level of electricity supply to any, even the most geographically remote economic regions.

## 3. Results and discussion

The study of a number of fundamental aspects of the development of integrated solutions for the decentralisation of electricity supply in power-hungry regions has yielded the following results.

Decentralisation in the energy complex of a number of states and in the Republic of Kazakhstan, in particular, is conditioned by a number of reasons, the most significant include:

1. Gradual increase in the volume of electricity consumption in absolute and structural dimensions.
2. Significant increase in the level of consumer requirements for the efficiency of the provision of electricity, the flexibility of supply conditions, and the quality of electricity supplied.

Issues of timely development of integrated solutions for the decentralisation of electricity supply to power-hungry regions presuppose the definition of approaches to the principles of energy sector management. Table 1 presents comparative characteristics of the principles of

**Table 1**

The main characteristics of the principles of technological and market management.

| Market                                                                              | Technological                                                                       |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Decentralised investment                                                            | Centralised investment                                                              |
| Disintegration in the conditions of overcoming the big business syndrome            | Integration without overcoming business-related syndromes                           |
| Decentralised management while maintaining the quality of technological connections | Centralised management with the installation of development modes                   |
| Optimisation of the power supply mode by fuel cost                                  | Optimisation of the power supply mode by fuel consumption                           |
| Coordination of the energy supply mode according to the established tariffs         | Coordination of the power supply mode according to the power flow parameter tariffs |
| There is a competition                                                              | There is no competition                                                             |

technological and market energy management, which are of key importance from the standpoint of decentralisation of power supply to power-hungry regions of the Republic of Kazakhstan.

Comprehensive solutions for the decentralisation of electricity supply to power-hungry regions involve mandatory consideration of the following factors that are of fundamental importance from the standpoint of compliance with the basic principles of energy supply management:

1. Remoteness of power-hungry regions relative to a single power supply centre.
2. Features of the geographical location of specific power-hungry regions.
3. Features of economic development of power-hungry regions.
4. Opportunities for the development of alternative energy sources in power-hungry regions.
5. The possibilities of building a flexible system for regulating the issues of decentralisation of electricity supply to power-hungry regions.

The use of alternative power supply systems along with a centralised power supply system should be considered the most effective method of solving the problems of decentralisation of power supply in power-hungry regions. In this context, it should be considered mandatory to apply new, scientifically sound technological solutions that would allow creating a system of decentralised power supply to end consumers that meet objective requirements for the parameters of reliability and quality of supplied electricity (Sorensen, 2017).

The process of developing integrated solutions for the decentralisation of electricity supply to power-hungry regions includes the following stages:

1. Analysis of prospects for the decentralisation of electricity supply in individual geographical regions.
2. Assessment of prospects for improving the power supply of industrial enterprises and the residential sector of the region through the decentralisation of power supply.
3. Development of a comprehensive strategy for the decentralisation of electricity supply in a particular region, taking into account the peculiarities of its geographical location and economic development.
4. Implementation of concrete solutions in practice to obtain a rational model of decentralisation of electricity supply to power-hungry regions.

In the context of the development and practical implementation of integrated solutions for the decentralisation of electricity supply to power-hungry regions, special attention should be paid to the use of renewable sources of electric energy in these regions. To date, in the Republic of Kazakhstan, the production volumes of such energy resources do not cover the real needs for them, determined by the needs of the residential sector and the needs of existing industrial enterprises in the region. This explains the growing problem of ensuring minimum volumes of electricity supply for the needs of the population and industrial and production facilities located in this region. Such a problem causes an increase in the risks of emergency outages caused by the need to redistribute electricity, which is especially important for remote rural areas (Welsch, 2017). Such a problem determines the difficulties in providing electricity to the population and industrial facilities of most

rural areas located at a considerable distance from the places of electricity production, which causes numerous problems of vital activity in power-hungry regions. This state of affairs can partly be explained by the peculiarities of the energy structure of the state, and problems of an organisational and legal nature. For the qualitative development of the use of autonomous sources of electricity in the Republic of Kazakhstan, it is necessary to develop at the state level a programme of legal support for alternative energy and its subsequent implementation in practice.

Fig. 1 shows an approximate diagram of the process of developing and practical implementation of integrated solutions for the decentralisation of power supply to power-hungry regions.

The issues of decentralisation of electricity supply to power-hungry regions are closely related to various aspects of the life of these regions, such as supply issues and general management issues. In addition, in the conditions of the development of market relations, the close interaction of industrial enterprises and energy associations causes the manifestation of trends towards the decentralisation of power supply to the regions where these enterprises are located, which is expressed in a significant reduction in the energy component of the cost of their industrial products. This state of affairs poses a number of tasks for industrial enterprises, the timely solution of which is designed to ensure:

- cyclical and continuous provision of the technological process of production at these enterprises with all necessary types of energy;
- development and consistent implementation of automated control systems for distributed energy flows into the practical activities of enterprises;
- utilisation of secondary energy resources in the daily activities of industrial enterprises in the region, such as waste from chemical production, and heat from the production processes themselves, in particular, this applies to large-capacity production facilities;
- gradual introduction of advanced production technologies, and technologies for the distribution and practical application of energy to consistently reduce the energy component of the cost of manufactured industrial products;
- consistent development and practical implementation of alternative, renewable energy sources.

Highly efficient and timely solution of such tasks can be carried out by fully decentralised power supply or by combining power supply with heat supply, which acts in this context as an alternative option for the energy supply of power-hungry regions. In this context, it is advisable to use steam-gas and gas turbine installations for the needs of manufacturing enterprises, as power supply facilities, due to their compactness, low noise, high reliability, and high efficiency. Such installations are supplied from manufacturers in a block or modular design, their technical and technological characteristics are such that they ensure high economic efficiency of energy supply to industrial enterprises through the practical use of these installations (Jones, 2017).

The use of a combined power supply system in power-hungry regions for the needs of the population and industrial enterprises located in these regions allow purchasing from the main supplier a part of the energy necessary for the qualitative implementation of the working, production process, and to generate another part of the electric energy through the use of their own autonomous sources, while the amounts of energy of the first and second kind are determined by the current production volumes and the fact of the presence or absence of secondary

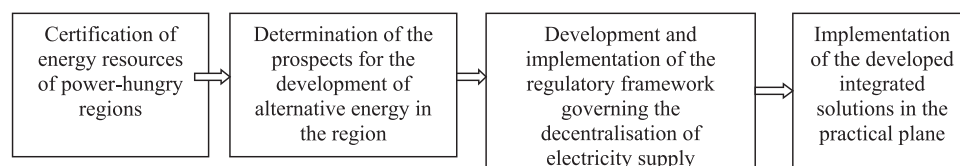


Fig. 1. Diagram of development and practical implementation of integrated solutions for the decentralisation of electricity supply in power-hungry regions.

energy resources, and the volume of such.

Thus, the issues of development and subsequent implementation of integrated solutions for the decentralisation of electricity supply to power-hungry regions require a detailed study of various aspects related to the specifics of the organisation of industrial activities in these regions, and the possibilities of using alternative, renewable energy sources in each case. In this context, the main one should be considered the consistent reduction of the energy component of the cost of manufactured industrial products, as the main aspect of the decentralisation of energy supply in these regions.

#### 4. Discussion

Electrification of consumers located in remote areas has its own characteristic features associated with the supply of electric energy to specific regions of its use and allowing it to be allocated to a relatively new and independent branch of modern science and technology. Such features are influenced by the specifics of the production of products in remote geographical regions, dispersed over a significant area of territory with weak specific electrical loads, which, moreover, differ in seasonal nature. The strong connection of technology with biological objects, dependence on weather conditions, and the real historical process of development of electrification of power-hungry regions with significant geographical remoteness are also of significant importance (Antonov, 2017).

The large-scale crisis that has engulfed the world economy today has affected the state of the energy industry, which indicates the urgent need to find optimal ways out of the current situation, taking into account its specifics and characteristic features. The use of innovative solutions in the development of the fuel and energy complex plays an important role in this context. This applies to various aspects of the management of this system, including the issues of ensuring high-quality power supply to power-hungry areas located at a significant geographical distance from the places of electric energy production (Vypkhanova and Zhavoronkova, 2021).

One of the main tasks of the state policy in the field of energy supply of geographical regions is to create optimal conditions for sustainable regulation of the functioning of the electric energy supply system of the most remote power-hungry regions from the standpoint of geographical location. It is also necessary to take into account the need to maintain a high quality of timely regulation of energy security issues, with the creation of multi-level monitoring systems of the state of power supply systems, to prevent possible violations of their activities related to problems of electricity supply to specific regions suffering from power shortages (Letcher, 2021). Such circumstances determine the number of requirements for the construction of power supply systems for a number of power-hungry geographical regions.

Of great importance from the standpoint of ensuring the proper quality of the development of integrated solutions for the decentralisation of electricity supply to power-hungry regions is the study of the energy potential of these territories, which would allow creating strategies for the energy development of these regions, taking into account their characteristic features, both economic and determining the main trends in the subsequent development of these regions, taking into account the specifics and prospects for the creation of renewable energy sources in these territories and their subsequent improvement (Clausen and Rudolph, 2020). All this together would determine the factors that are of key importance from the standpoint of the specifics of these regions, and which can subsequently have a significant impact on the processes of developing and implementing integrated solutions for the decentralisation of power supply to power-hungry regions.

Nowadays, power plants and modern energy systems have the opportunity to present a significant amount of goods and services to the market for various categories of consumers. This concerns the possibilities of providing electricity generation services, and commissioning and repair work and a number of other services. The choice of the final

volume of services is the task of the consumer, which determines the establishment of a certain system of relations between suppliers and consumers of energy supply services (Poudyal et al., 2019). In this context, it should be noted that the modern electricity market is changing numerous ideas about the prevailing features of the implementation of energy supplies, which is essential from the standpoint of the quality of solving issues related to the development of integrated solutions for the decentralisation of electricity supply in regions where there are problems with the supply of electric energy.

Today, the electric power industry is the largest and practically "omnivorous" consumer of energy sources, which allows achieving a low-carbon future for the whole society faster and more economically. This circumstance explains the fact that the bulk of investments into the development of modern world energy are investments in the development of the electric power industry, at the moment they amount to approximately 45% of the total volume (Martinez et al., 2019). A large amount of funds are annually allocated for the development of renewable energy sources, electric networks, and for the development of fuel and nuclear energy. There are steady trends towards large-scale electrification conditioned by the development and improvement of renewable energy sources.

One of the most effective means of solving the problem of the quality of electric energy supplied to consumers, in combination with the issues of developing integrated solutions for the decentralisation of power supply to power-hungry regions, is the use in various geographical regions, along with a centralised power supply system, of autonomous-type power supply systems that act as subsystems of a common electrical network. New, scientifically sound high-tech solutions allow creating decentralised power supply systems for end consumers that meet modern requirements in terms of reliability and quality of electricity supplied (Kariniotakis, 2017). In this context, the certification of the resources available to a particular geographical region is one of the priorities that should be paid attention to when developing a set of measures aimed at decentralising the power supply of power-hungry regions.

Currently, expert assessments of hydropower, wind and solar energy potentials have already been formed, which allows for more effective promotion of the principles of development and practical implementation of methods for decentralising electricity supply to power-hungry geographical regions. In addition to the use of wind, solar and water energy, research should be conducted on the use of technologies aimed at large-scale processing of household and industrial waste to obtain sufficient electricity (Wu, 2020). Thus, it should be expected that for industrial areas with a lower population density, large energy producers, which, first of all, should be considered coal-fired power plants and large hydroelectric power plants, will be replaced by local, environmentally safer renewable sources of electricity, which, nevertheless, allow providing electricity to various economic sectors.

The effective use of the energy potential of a particular geographical region is possible provided that the volume of harmful emissions of toxic substances into the environment is significantly reduced during the operation of enterprises that form the basis of the energy sector of the region, and also conditioned by the high-quality organisation of the functioning of renewable energy sources. The results will be a reduction in the level of pollution of the surrounding area, and an increase in the energy potential of the region as a whole (Zhang et al., 2018).

In recent decades, the main trend in the development of the complex of electric networks in a number of former Soviet states was a purposeful increase in the reliability of the supply of electric energy to end consumers. In this context, it should be noted that electrification of remote geographical regions, together with the settlements located there, is mandatory. At the same time, the quality of power supply of these geographical regions is largely determined by the level of development of renewable sources of electric energy located in them. Until recently, in many remote regions, they were used as alternative sources of electricity, when the local population could not use a centralised power

supply network (Batinge et al., 2019). The prospects for decentralising power supply to power-hungry regions today are largely related to the expansion of the range of applications of autonomous power sources, as the most promising area for increasing the energy potential of individual regions and the state as a whole.

Energy planning allows identifying specific zones of centralised and decentralised power supply, and this practice is actively used in many countries today. There is no unified system for structuring power supply zones, which is explained by the significant variety of electricity supply systems used. Intelligent management of electricity sources is used to ensure a centralised supply of electricity to various regions of the country, with different modes of energy consumption. At the same time, the decentralisation of electricity supply to power-hungry regions is of significant importance from the standpoint of the quality of providing electricity to end consumers, which has a positive effect on the prospects for increasing the energy potential of the regions where these consumers are located.

Modern ideas about centralised and decentralised energy supply are based on the possibilities of implementing a complex of electricity supplies to end users in combination with the use of renewable electricity resources. Compared with the beginning of the last century, there have been significant changes in the attitude of consumers to the issues of increasing the level of centralisation of electricity supply in individual regions. The task of gradually increasing this level is not particularly relevant, while the objective need for the development of decentralised power supply is recognised, which includes the mandatory implementation of a set of measures for the development of alternative energy sources (AlQattan et al., 2018).

Heat supply, like the electric power industry, implies the simultaneous use of two interrelated and interchangeable concepts – centralised and decentralised heat supply. At the same time, the difference from electricity supply lies in the complete absence of a unified understanding of the relationship between these concepts, which makes possible the existence of an extreme position based on the idea that a decentralised power supply system should be considered a system based on the use of energy from a local source, whose capabilities are limited to servicing a single building or office space, without the use of outdoor, street heating networks. The practical use of such networks is a sign of a centralised heat supply system.

The issues of implementing innovative solutions in the field of modern energy are relevant in the context of the most important role that the energy complex plays in the economic system of any state. Nowadays, the situation is complicated by the presence of many typical problems of legislative regulation of issues and problems of the energy sector, which are of priority importance from the standpoint of the role of the electric power industry in the national economy. In particular, innovative development programmes have been successfully implemented in the Russian Federation and have been operating for a long time, assuming control over various aspects of the sphere of practical use of renewable energy sources. At the same time, a number of regulatory documents have been adopted governing numerous issues of investment support for the construction of electricity generation facilities based on the use of renewable sources. Investment projects for the development of geographically remote areas and small energy facilities should be considered the most popular. Experts in the field of energy note the high efficiency of energy systems built using the capabilities of renewable energy sources. This is conditioned by their ability to operate completely autonomously, in regions with decentralised energy supply. Nevertheless, in addition to the relatively high cost (the cost of one kWh of electricity in these zones is ten times higher than the average selling price of electricity), such systems are unsafe from an environmental standpoint and significantly pollute the surrounding air in their locations (Capellan-Perez et al., 2018).

Numerous issues of practical use of the possibilities of renewable energy sources affect the prospects of decentralisation of electricity supply to power-hungry geographical regions. In these regions, there is a

significant increase in the problems of ensuring the minimisation of energy supply for the needs of the population and the agricultural sector. The risks of emergency shutdowns, and outages in energy distribution networks, are significantly increasing, in particular, this is especially true in relation to rural settlements. In part, this state of affairs can be explained by the peculiarities of the structure of energy distribution in the energy system of a single state, and the presence of certain shortcomings in the organisational and legal aspects. In this context, this refers to the lack of a high-quality regulatory framework necessary to regulate the operation of alternative energy enterprises to allow them to become a full participant in the modern energy distribution market. In modern conditions, the centralisation of power supply systems is both a disadvantage and an achievement of the energy system. In the conditions of a directive economy, there are a number of restrictions on over-centralisation, while in market conditions, restrictions apply mainly to the introduction of innovations. In these conditions, the transition to the use of alternative energy sources is an expensive and forced measure that requires great efforts on the part of the government of a particular country.

## 5. Conclusions

The implementation of a complex of studies on a number of features of the development of integrated solutions for the decentralisation of power supply to regions suffering from power shortages has led to the following conclusions.

In practice, the decentralisation of electricity supply to power-hungry regions involves a series of sequential operations aimed at reducing the energy component of the cost of industrial products, which in real production conditions should be combined with maintaining high-quality standards. At the same time, in the context of ensuring high-quality power supply in these regions, issues of the practical combination of methods of using alternative energy sources with secondary energy resources, which are by-products of the activities of industrial enterprises in this region, are of significant importance. At the same time, the options for using such secondary resources can be different and include both wastes from chemical production and the use of heat directly from the industrial production processes themselves.

Of particular importance in the context of the practical implementation of the developed integrated solutions for the decentralisation of power supply to power-hungry regions is the preparation of a high-quality regulatory framework coordinating various aspects of the implementation of the developed solutions. Such a legal framework would allow for the proper regulation of all possible aspects of the use of renewable energy sources in power-hungry regions, and reliably protect the rights of users. In addition, the use of alternative sources of electric energy to meet the needs of production and industrial enterprises of the region in combination with the use of secondary resources presupposes the availability of a proper level of training of service personnel of these enterprises, which should also be consolidated by creating the necessary regulatory documents governing these aspects.

In general, the issues of developing integrated solutions for the decentralisation of electricity supply to power-hungry regions include many different aspects that are important from the standpoint of creating a high-quality system for the long-term energy supply of these regions. Qualitative consideration of all such aspects would allow creating an effective power supply system for these regions in the future, which in general would have a positive impact on their economic development and will contribute to the planned economic development of the entire state as a whole.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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