Chapter

Dissemination of Distributed Energy Technologies

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Abstract

At present, the electric power industry is undergoing a cardinal transformation all over the world, the main driver of which is technological innovations, which determine the possibilities for the transition of this sphere to a fundamentally new stage of development. The purpose of this chapter is to analyze the amplification of distributed power generation technologies among industrial companies, as well as the factors for the adoption of new technologies by industrial companies in Russia. The following steps were taken for the analysis of the most significant factors of the adoption of distributed power generation technology by industrial companies: in-depth semi-structured interviews with large industrial company representatives (8 companies) and survey of industrial companies (69 companies). The results obtained allow us to conclude that for analyzed companies, technical feasibility, the cost of electricity, and perceived benefits are critical factors in deciding on the use of distributed power generation technologies. Obtaining cheap electric and thermal energy, a gradual increase in energy capacities and evenness of investment with fast energy generation for industrial and household needs are possible today due to the use of energy-efficient solutions based on distributed power generation technologies.

Keywords: electric power industry, distributed power generation, new technologies, factors of innovation adoption, energy efficiency

1. Introduction

At the moment, the sphere of electric power industry is undergoing a cardinal transformation all over the world, the main driver of which is technological innovations, which determine the possibilities for transition of this sphere to a fundamentally new stage of development. Avoiding a centralized energy supply is a global trend, for example, the global market for distributed energy technologies (small distributed power generation, demand management, storage, energy efficiency, etc.) is growing at a rate of about 6–9% per year. It is expected that by year 2025, the input volume of distributed power generation capacity will exceed the input volume of centralized power generation three times. According to the International Energy Agency, distributed energy will provide up to 75% of new connections during global electrification until 2030.

In Russia, the spread of distributed generation technologies is proceeding at a much lower rate; therefore, the factors of its expansion require a deeper analysis.

The purpose of this chapter is to analyze the spread of distributed energy technologies among industrial companies, as well as the factors for the adoption of new technologies by industrial companies in Russia. For the analysis of the most significant factors of distributed power generation technology adoption, industrial companies conducted in-depth semi-structured interviews with representatives of large industrial companies (8 companies) and a survey of industrial companies (69 companies). A regression model was used for the analysis, which allows determining the strength and significance of the influence of selected factors on the companies' decision-making on their own power generation.

The results obtained allow us to conclude that for analyzed companies, technical feasibility, the cost of electricity, and perceived benefits are critical factors in deciding on the use of distributed power generation technologies. The risk factor turned out to be insignificant, which the companies explained in the in-depth interviews by the fact that distributed power generation systems reduce the occurrence of the listed adverse effects to a minimum. Obtaining cheap electric and thermal energy, a gradual increase in energy capacities and evenness of investment with fast energy generation for industrial and household needs are possible today due to the use of energy-efficient solutions based on distributed power generation technologies.

2. Technologies of distributed energy and their structure

Distributed energy technologies (distributed energy resources, DER) in the world practice [1] include a wide range of technologies:

- Distributed generation
- Demand management (demand response)
- Energy efficiency management
- Microgrids
- Distributed power storage systems
- Electric cars

The basic characteristic of all these technologies is proximity to the energy consumer. Distributed generation is a set of power plants located close to the place of energy consumption and is connected either directly to the consumer or to the distribution electrical network (in the case when there are several consumers). The type of primary energy source used by the station (e.g., fossil fuel or renewable energy), as well as the station's relevance to consumer, generating or grid-supplying company, or a third party, does not matter. In foreign practice there is a tendency to limit the power of distributed generation power plants by the top bar, depending on the technology used. For example, Navigant Research uses a 500 kW boundary for wind, 1 MW for solar, 250 kW for gas turbines, and 6 MW for gas piston and diesel power plants. The European Distributed Energy Partnership Project (EU-DEEP) used similar boundaries: thermal power plants (steam, gas turbines, piston engines) up to 10 MW, microturbines up to 500 kW, wind power stations up to 6 MW, and solar up to 5 MW.

In Russia, there is no consensus on this issue, and there are no restrictions in regulatory documents. On the other hand, the 25 MW total for all technologies is sometimes used (which "separates" the power plants from the retail and wholesale electricity and capacity markets). Some experts insist that distributed generation cannot have power limitations—in this logic, distributed power generation should include all power plants owned by consumers, including large industrial combined heat and power plants (CHP) with a capacity of more than 200 MW (located near large factories and plants). There is no consensus about the distributed generation of heating CHP plants with a capacity of more than 25 MW located in cities and towns (the capacity of some of them exceeds 1000 MW).

Among the criteria for the classification of distributed generation types, they also distinguish the type of fuel (from gas to secondary energy resources, for example, blast furnace gas, associated petroleum, and coke oven gas), generation technology (from steam power plants to wind generators), location, the amount of energy consumption by the main ("anchor") consumer (stations), mode factor, voltage level of network connection, and many others.

In this study, we see distributed generation including power plants located close to the consumer, connected to a distribution grid (110 kV and below) or directly supplying electricity to the consumer. The limitation on power and technology is not taken into account (if this is not specified separately). Autonomous power supply zones and isolated power systems are not the focus of this study.

Demand management is the change in energy consumption and power consumption by final users relative to their normal load profile due to changes in electricity prices needed to reduce system-wide costs in exchange for incentive payments from the energy market. For this study, it is important that demand management reduces the magnitude of peak loads in the power system and, accordingly, the system's need for installed capacity of power plants in the short term (day, week), medium term (1 year), and long term (e.g., during long-term power take 4 years ahead).

Energy efficiency and energy saving in this study are considered as a set of actions on the side of electricity consumer and lead to a long-term decrease in its energy demand. The focus of the study is on energy-saving measures that reduce the need for energy at times of power system peak loads and, accordingly, reduce the system's requirements for the given capacity of power plants.

Microgrid is an integrated power system consisting of distributed energy resources and several electrical loads (consumers), operating as a sole managed object in parallel with an existing electrical network or in island mode.

Distributed power storage systems (accumulators) are a set of storage systems installed at ultimate customer's side and at distribution network facilities and providing, among other things, backup and demand management capabilities.

Electric cars are considered as one of the types of distributed energy resources, since they play a role not only to energy consumers but also to distributed accumulators (vehicle-to-grid technology).

The power systems of Russia and foreign countries starting from the second half of the twentieth century historically developed in a similar logic. Large power plants were usually built near fuel extraction sites (in Russia, peat and coal, later—gas and fuel oil) or close to transport corridors along which this fuel was transported, as well as near large bodies of water or rivers. The more powerful was a power plant (scale effect), the cheaper was its construction (per 1 kW of power)—therefore, the average unit capacity of the stations grew steadily, increasing 500 times and more from the 1920s to the 1980s. The stations were often located at a considerable distance from large cities, for environmental reasons. In Russia, combined heat and power plants (CHP), built in close proximity to the consumer of thermal energy (city, plant, etc.) and electrical energy (industrial CHP), became an exception to this practice.

The transmission of electrical energy from the stations to consumers was carried out through the construction of trunk lines (voltage 220–500 kV and above to reduce transmission losses) and through the distribution electrical networks with a total length of hundreds of thousands of kilometers. At the same time, at the level of medium- and low-voltage distribution networks (35 kV and below), the consumer, as a rule, was at the end of the chain and, unlike larger consumers of supergrids, did not always have a backup power source from the power grid.

For several decades, this power system architecture has remained generally unchanged. Centralized power systems successfully, reliably, and at a reasonable price provided consumers with electricity. But by the end of the twentieth century, the scale effect stopped working; it had been working back in the 1950s, and the oil crisis of the 1970s sharply increased the interest of energy-importing countries in new energy-efficient power generation technologies.

The catalyst for change was distributed generation, namely, the emergence of new electricity production technologies in the 1970s and 1980s in the USA and Europe—gas turbine, gas piston, and combined cycle—that allowed creating low-cost and efficient power plants of small capacity from tens of kW to tens of MW (**Figure 1**).

This immediately led to an increase in distributed generation usage (**Figure 2**).

In addition to distributed generation, new opportunities for energy-saving technologies and demand management have opened up in the electric power industry. A classic example is the “Energy Demand Management” program, launched in the 1970s in the USA, aimed at saving electricity by encouraging consumers to reduce energy consumption during peak periods of demand or to shift energy consumption to off-peak demand periods.

In the first decade of the twenty-first century, the rapid development of renewable energy sources began. Governments in Europe, the USA, and other countries, striving for carbon-free energy and reducing dependence on energy exports, adopted large-scale and long-term programs to support renewable energy, after which the cost of solar and wind energy systems dropped several times with a significant increase in their technological efficiency. Thus, the present value of electricity from solar and wind power plants in 2009–2017 decreased by 67–86% (**Figure 3**).

As a result, in just 20–30 years, a consumer from a situation of deterministic centralized energy power supply came to choose from a wide range of alternative solutions that allow using them in an optimal proportion, based on individual priorities of cost, reliability, and quality of power supply.

The experience of the Northern European countries shows that it is better to develop distributed generation in conjunction with distributed heat supply, using cogeneration—the technology of co-production of heat and electricity in a single

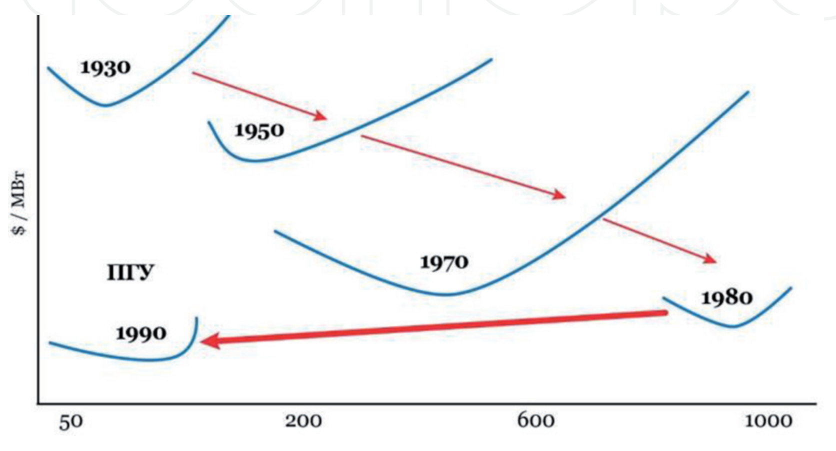

Figure 1.
Illustration of the scale effect (and its exhaustion) in the cost of the gas power plant construction in 1930–1990 depending on their power (MW). Source: Hunt et al. [2].

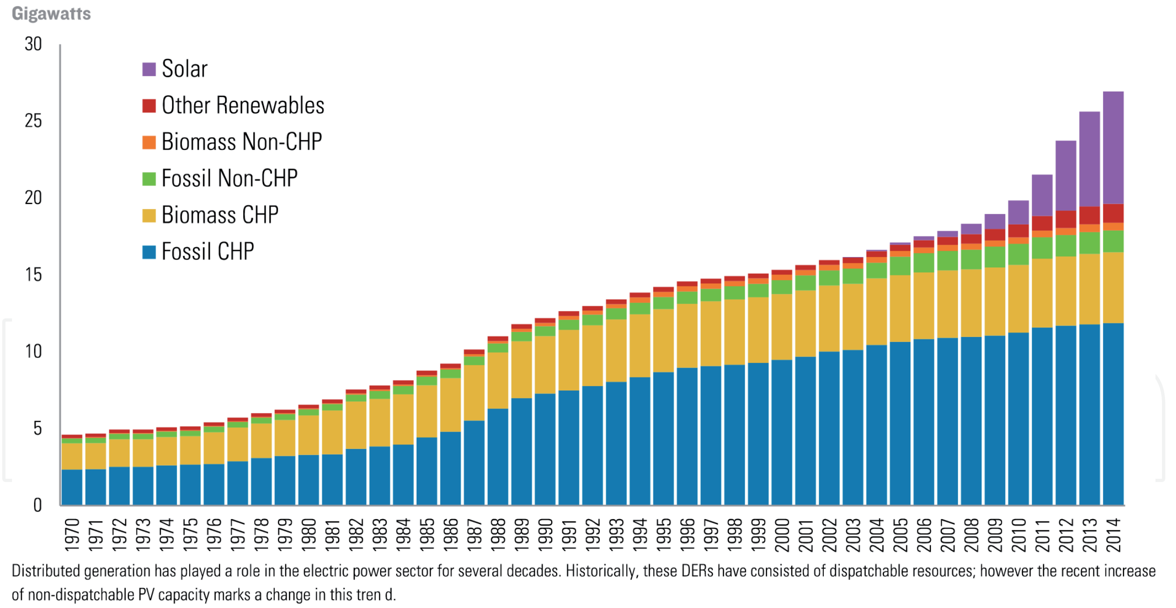

Figure 2.
Dynamics of distributed generation development in the USA (GW). Source: Rhodium Group [3].

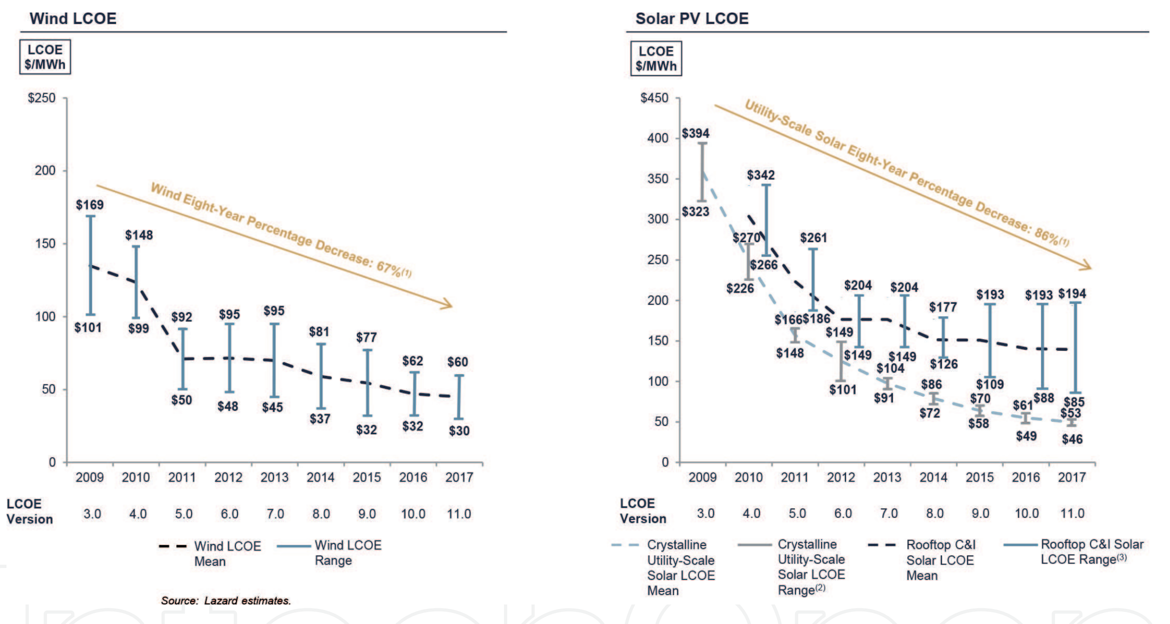

Figure 3.
Dynamics of levelized cost of electricity (LCOE) from solar and wind power plants in 2009–2017, USD/MWh. Source: Lazard's Levelized Cost of Energy Analysis, version 11.0 [4].

cycle. Distributed cogeneration in these countries has become the first step toward effective decentralization of power systems and, among other things, has reduced the cost of maintaining the supergrids and eliminating irrational energy losses. For example, in Denmark, the system of supporting measures for mini-CHP led to the emergence of hundreds of small natural gas and biomass energy centers in only 10–20 years. In addition, the number of wind power plants has increased.

According to the Danish Energy Agency, the development of distributed cogeneration reduced the annual consumption of primary energy in Denmark by 11% and reduced CO_2 emissions by 4.5 million tons per year.

The appearance of many new small generators has complicated the processes of their integration into the unified power grid and management and regulation processes. That situation demanded new technologies of flexible network construction and intelligent control of them, which later became known as the smart grid. The consumer of electricity begins to play an increasing role in the energy system, mastering new roles—generator and accumulator of electricity. Freedom of consumer choice is increasing. At the same time, there are many opportunities for demand management and energy efficiency both at the level of a specific household and at the level of the economy as a whole.

In order to carry into effect these possibilities, the states are changing the models of electricity and capacity markets toward their liberalization. It can be said without exaggeration that a necessary basis is being formed for building a competitive environment at the retail level with the development of distributed energy.

The entry of distributed energy into the Russian energy system became noticeable in the 2000s, but over the past 17 years, in fact, it was limited to only distributed generation. The development of this process in Russia takes place at a much lower rate, which requires a deep study of the spreading factors of distributed energy technologies.

3. Development of research model and hypotheses

Companies will switch to sources of their own generation when they are able to perceive them and are ready for their use. Therefore, the basis for studying the possibilities of using distributed generation technologies is their acceptability or perception on the part of industrial companies.

The use of factor analysis involves the study of factors that have the greatest influence on the industrial companies' decision to adopt new technology.

In the literature, there are a fairly limited number of studies on the adoption of new technologies by industrial companies. The most famous models are:

- Perceived organizational e-readiness (POER) model is used to measure the intraorganizational factors for the adoption of new technologies. This model was proposed by Molla and Licker in 2002 [5] for analyzing the intraorganizational environment factors, including personal characteristics of company's employees, system of internal assistance in the company, and attitude of employees to innovation.

- Perceived external e-readiness (PEER) model is used to analyze external factors. The PEER model [5] analyzes the factors of competitive pressure in the industry, influence of regulators, and technological changes in the industry.

Table 1 presents the intraorganizational and external factors affecting the adoption of new-generation technologies by companies.

Thus, we can formulate the first hypothesis of our study.

Hypothesis 1. Industrial companies' adoption of distributed energy technologies is influenced by intraorganizational factors: (a) technical feasibility, (b) availability of human resources, (c) perceived risks, (d) perceived advantage, (e) connection costs, (f) electricity costs and external costs, (g) market pressure, (h) pressure of the regulator (government), and (i) technological changes in the industry.

To identify the specific characteristics of distributed energy technologies that influence their adoption by companies, we used research results [15–21] and identified the most significant specific factors (**Table 2**).

The conducted analysis allowed us to formulate the second hypothesis of the study.

Hypothesis 2. The decision on the use of distributed energy technologies is influenced by specific factors: (a) the presence of by-products that can be used as

Adoption factors	Studies confirming the importance of the relevant factor
Perceived organizational e-readiness (POER) model	
Technical feasibility (integration, scalability, remote access, infrastructure, complexity, etc.)	Wu [6] Trachuk [7]
Availability of human resources	Vorozikhin [8] Bhowmik et al. [9]
Perceived risks (safety, investment)	Wu [6] Trachuk et al. [10] Bhowmik et al. [9]
Perceived benefits and need for alternative energy sources	Seo et al. [11] Brandon et al. [12]
Cost (transaction fee)	Brandon et al. [12]
Costs	Seo et al. [11]
Perceived external e-readiness (PEER) model	
Market changes affecting the company's decision to use new technologies	Subhes [13] Seo et al. [11] Trachuk et al. [7] Trachuk et al. [10]
Decisions of regulators (authorities), affecting the company's decisions to use new technologies	Subhes [13] Michael et al. [14] Brandon et al. [12] Trachuk et al. [7]
Technological changes in the industry affecting the company's decisions	Subhes et al. [13] Michael et al. [14]

Table 1.
Factors affecting the adoption of new technologies by companies.

fuel, (b) high efficiency, (c) lack of energy transmission costs, (d) lack payments for technological connection to electric networks, (e) the existing ratio of prices for electric energy and natural gas, (f) possibility of changing the volume of generated electricity and heat when economic situation changes, (g) reduced need for energy transmission over long distances, and (h) increased share of local energy resources.

At the next stage, the index was calculated for the main factors influencing the decision on self-generation for intraorganizational factors (technical feasibility; availability of human resources; perceived risks; perceived benefits and the need for alternative energy sources; cost of electricity; costs for construction and installation of distributed sources generation) and external factors (changes in the market that affect the company's decision to use innovation; decisions of regulators (authorities), affecting the decisions of companies on the use of new technologies; technological changes in the industry, affecting decisions of company) by summing up the references to individual items from the questionnaire (**Table 3**).

The frequency of mentioning specific factors is calculated in the same way (**Table 4**).

Then, nonparametric Spearman correlation coefficients (ρs) were calculated for the ranked data. To recognize the relationship between the components of the model as significant, the correlation coefficient had to exceed a threshold value of 0.50.

3.1 Description of variables

For the quantitative phase of the study, questions were formulated, measuring the most significant factors. The questions were formulated as follows: "How much do you agree with the statements below?". The 7-point Likert scale was used for answers (1 "I completely disagree," 4 "I do not know if I agree or disagree," 7 "I completely agree").

The "technical feasibility" factor was measured using a scale consisting of two questions that determine the company's ability to install distributed generation facilities taking into account the existing infrastructure. To assess the "perceived advantage" factor, questions were to evaluate higher rates of distributed generation efficiency than UNEG services. The factor "construction costs and installation of distributed

Adoption factors	Studies confirming the importance of the relevant factor
Specific factors	
Availability of by-products that can be used as fuel	Juan et al. [16]
High efficiency (provided that the generating facility is designed to meet the needs of a specific industrial production in both electrical and thermal energy)	Zhang [21]
No cost for power transmission	Berg et al. [15] Yingyuan et al. [19]
No payment for technological connection to electric networks (if the object of generation is isolated from the power system)	Berg et al. [15]
The existing ratio of prices for electric energy and natural gas indicates a high gas potential	Juan et al. [16]
Ability to change the volume of generated electrical and thermal energy when economic situation changes	Li et al. [18]
Energy production takes place in the immediate vicinity of the consumption points, which leads to less need for energy transmission over considerable distances	Kazemi et al. [17]
Increasing the share of local energy resources	You et al. [20]

Table 2.
The most significant specific factors for companies to adopt new technologies for distributed energy.

	Intraorganizational factors	Percentage of mentioning
1	Technical feasibility (integration, scalability, remote access, infrastructure, complexity, etc.)	61.6
2	Availability of human resources	19.3
3	Perceived risks (safety, investment)	45.9
4	Perceived benefits and need for alternative energy sources	76.3
5	Electricity cost	74.1
7	Costs of building and installing distributed generation sources	81.5
	External factors	
9	Market changes affecting company's decision to use innovation	62.7
10	Decisions of regulators (authorities), affecting company's decisions to use new technologies	96.3
11	Technological changes in the industry affecting company's decisions	73.5

Table 3.
Frequency of mentioning internal and external factors of distributed energy technology acceptance by companies.

		Percentage of mentioning
1	Availability of by-products that can be used as fuel	41.5
2	High efficiency (provided that the generating facility is designed to meet the needs of a specific industrial production in both electrical and thermal energy)	48.4
3	No cost of power transmission	58.9
4	No payment for technological connection to electric networks (if the object of generation is isolated from the power system)	79.4
5	Existing ratio of prices for electric energy and natural gas indicates a high gas potential	42.6
6	Ability to change the volume of generated electrical and thermal energy when economic situation changes	41.2
7	Energy production takes place in the immediate vicinity of the consumption points, which leads to a reduction of needed energy transmission over considerable distances	34.6
8	Increasing proportion of local energy resources	55.6

Table 4.
Frequency of mentioning specific factors of distributed energy technology adoption by industrial companies.

generation sources" was measured using two questions that characterize the need to pay back the construction of our own generation in the medium term or the absence of a significant impact of construction costs on the cost structure of the company.

Measuring the external factors of adopting distributed generation technologies was based on three groups of questions. First, market pressure was measured in accordance with the answers to questions about competitive pressure, comparing the technologies used. Second, technological changes in the industry were evaluated. They were measured by assessing the possibility of equipment repair and equipment operation during peak hours of load. Third, decisions of regulators were measured in the absence of administrative obstacles and support for distributed generation.

Similarly, a questionnaire was formed to analyze the specific factors of the distributed energy technology adoption.

3.2 Description of the data analysis procedure

In conducted analysis, the reliability factors (Cronbach's alpha) were first evaluated for all variables, measured on a scale of several questions. The calculated coefficients corresponded to the recommended minimum level of reliability −0.75. At the next stage, the factor analysis was carried out using the method of principal components for nine questions describing four aspects of intraorganizational factors and six questions describing three aspects of external factors.

The analysis of specific factors affecting the distributed generation technology adoption by distribution network companies was conducted for 15 questions.

In total, four specific factors explained 73.8% of the variation in the answers to questions from companies, which corresponds to the recommendations for explaining 70% of the variation in structural models.

A factor analysis based on the method of principal components with orthogonal rotation revealed the presence of four intraorganizational factors and two environmental factors that described a total of 72.8% of the variation in questions. The values of the factors obtained were used to form a final set of factors influencing the distributed generation technology adoption by companies, which were then included in the regression analysis.

Using the maximum likelihood method, standardized and non-standardized regression coefficients were determined. Non-standardized coefficients were used to test hypotheses, and standardized factors were used to determine factors that influenced the distributed generation adoption by companies more.

4. Results of the study

Tables 5 and **6** demonstrate the regression analysis results showing the influence of various factors on the distributed energy technology adoption by industrial companies (the company's internal characteristics and environmental factors), as well as the influence of specific factors. We evaluated the impact of these independent variables on the adoption of distributed energy technologies using the maximum likelihood method.

Independent factors	Hypotheses	Non-standardized coefficients	Standardized coefficients
Invariable (β_0)		0.191 (0.0134)	
Intraorganizational characteristics			
Technical feasibility (integration, scalability, infrastructure, complexity, etc.) (Ti)	Hypothesis 1(a)[†]	0.264^{***} (0.098)	0.281^{***}
Perceived risks (safety, investment) (RKi)	Hypothesis 1(c)	0.166^{***} (0.015)	0.185
Perceived advantages and need for alternative sources of generation (URi)	Hypothesis 1(d)	0.451^{**} (0.104)	0.454^{**}
Electricity cost (COSTi)	Hypothesis 1(e)	0.598^{***} (0.062)	0.599^{***}
Costs of building and installing distributed generation sources (Ci)	Hypothesis 1(f)	-0.387^{***} (0.209)	-0.385^{***}
Environmental factors			
Market Pressure (EASEi)	Hypothesis 1(g)	-0.196^{**} (0.118)	-0.394^{**}
Technological changes in the industry (TRi)	Hypothesis 1(h)	0.153^{***} (0.201)	0.254^{***}
Decisions of regulators (authorities) affecting decisions of companies on the use of new technologies (GRi)	Hypothesis 1(i)	-0.393^{***} (0.023)	-0.194^{***}
Adjusted R-square		0.709	
Number of observations		69	

[†] *Hereinafter, the designation of the hypothesis corresponds to its formulation in the text.*
[*] *Significance of the coefficient $p < 0.10$.*
[**] *Significance of the coefficient $p < 0.05$.*
[***] *Significance of the coefficient $p < 0.01$.*
Standard errors are given in brackets.

Table 5.
Acceptance of distributed energy technology by industrial companies: the impact of internal organizational characteristics and environmental factors.

Independent factors	Hypotheses	Non-standardized coefficients	Standardized coefficients
Invariable (β_0)		0.216 (0.031)	
Specific factors			
Availability of by-products that can be used as fuel	Hypothesis 2(b)†	0.421^{***} (0.023)	0.419^{***}
High efficiency (provided that the generating facility is designed to meet the needs of a specific industrial production in both electrical and thermal energy)	Hypothesis 2(c)	0.324^{***} (0.127)	0.327^{*}
No cost for power transmission	Hypothesis 2(e)	0.378^{**} (0.212)	0.381^{***}
No payment for technological connection to electric networks (if the object of generation is isolated from the power system)	Hypothesis 2(h)	0.321^{**} (0.041)	0.323
Existing ratio of prices for electric energy and natural gas indicates a high gas potential	Hypothesis 2(g)	0.016^{***} (0.091)	0.009^{***}
Ability to change the volume of generated electrical and thermal energy when economic situation changes	Hypothesis 2(i)	0.163^{*} (0.037)	0.168^{*}
Energy production takes place in the immediate vicinity of consumption points, which leads to a reduction of needed energy transmission over considerable distances	Hypothesis 2(j)	0.211^{***} (0.009)	0.209^{***}
Adjusted R-square		0.628	
Number of observations		69	

†Hereinafter, the designation of the hypothesis corresponds to its formulation in the text.
**Significance of the coefficient $p < 0.10$.*
***Significance of the coefficient $p < 0.05$.*
****Significance of the coefficient $p < 0.01$.*
Standard errors are given in brackets.

Table 6.
Adoption of distributed generation technologies: the impact of specific factors.

In general, the results of the regression analysis confirmed the hypotheses of the study. The models based on the regression equations were able to explain 63% of the variation of internal organizational and external factors in the distributed energy technology adoption by companies and 57% of specific factors.

When modeling the distributed energy technology adoption by companies (**Table 5**), it turned out that technical feasibility ($\beta = 0.264$; $p < 0.05$), comparative advantage of using distributed generation ($\beta = 0.451$; $p < 0.10$), and cost of electricity ($\beta = 0.598$; $p < 0.10$) positively affect the adoption of distributed energy technologies. The factor "perceived risks" ($\beta = 0.166$; $p = 0.01$) does not have a significant impact on the growth in the number of distributed energy users. And, the factor "costs for construction and installation of distributed generation sources" ($\beta = -0.387$; $p < 0.10$) has a negative influence on the decision to use distributed energy technologies.

Among the external factors, regulators' decisions have a significant impact on the distributed energy technology adoption by companies ($\beta = 0.393$; $p < 0.05$).

Market pressure and technological changes in the industry do not have a significant negative impact on the rate of distributed energy technology adoption by companies.

Thus, the technical feasibility, comparative advantage, and cost of electricity are the main factors for the growth in the number of distributed energy technology users in the studied sample.

Table 6 shows the regression analysis results of the specific factors that have influence on the distributed energy technology adoption.

All specific factors had a positive effect on the distributed generation technology adoption by companies with a probability of error p of no more than 0.05. The coefficient β with the variable "efficiency" was 0.324 ($p < 0.01$); for the factor "no energy transfer costs" was β = 0.378 ($p < 0.05$); and for the factor "absence of payment for technological connection to electric networks" was β = 0.321 ($p < 0.05$). At the same time, the factors "the existing price ratio for electric energy" (β = 0.016; $p > 0.10$) and "the possibility of changing the volumes of generated electric and thermal energy when economic situation changes" (β = 0.163; $p > 0.10$) did not have a significant impact.

The results of testing hypotheses are the following. According to Hypothesis 1, which described the factors influencing the distributed energy technology perception by companies, it was partially confirmed for intraorganizational factors, (a) technical feasibility (β = 0.264; $p < 0.05$); (d) perceived benefits (β = 0.451; $p < 0.01$), and (e) electricity cost (β = 0.598; $p < 0.05$), and environmental factor, (i) the regulator's decision (β = 0.396; $p < 0.05$). The factors (f) costs of building and installing distributed generation sources (β = −0.387; $p < 0.01$) and (g) market pressure (β = −0.196; p < 0.01) have a negative impact on the distributed energy technology adoption. For factors (c) perceived risks (β = 0.166; $p < 0.01$) and (h) possibility of changing the volumes of generated electrical and thermal energy (β = 0.153; $p < 0.01$), the hypothesis was not confirmed.

According to Hypothesis 2, companies' perception of distributed energy technologies is influenced by specific factors. This hypothesis is partially confirmed for common factors: (b) the presence of by-products that can be used as fuel (β = 0.421; $p < 0.01$); (d) high efficiency (β = 0.324; $p < 0.10$); (e) no costs for energy transfer (β = 0.316; $p < 0.01$); and (h) lack of payment for technological connection to electric networks (β = 0.363; $p < 0.01$). The influence of factors (g) existing ratio of prices for electric energy and natural gas (β = 0.016; $p < 0.01$); (i) possibility of changing the volume of generated electrical and thermal energy (β = 0.163; $p = 0.45$); and (j) a reduction in need for energy transmission over considerable distances (β = 0.211; $p < 0.01$) has not been confirmed.

Thus, the proposed model of analysis is successful, describing various factors of adoption of technologies of distributed energy by industrial companies. Standardized coefficients not only allow testing hypotheses but can also be used to compare the influence of various characteristics of distributed energy facilities on the likelihood of their acceptance by industrial companies.

5. Conclusions

Thus, according to the obtained results, when deciding on the company's own generation, the main factors are technical feasibility (β = 0.421), perceived advantages (β = 0.363), electricity cost (β = 0.324), and the decision of regulators (β = − 0.309). It can be concluded that for analyzed companies, technical feasibility, cost of electricity, and perceived benefits are critical factors in deciding on the use of distributed generation technologies. The risk factor turned out to be insignificant (β = 0.209), which, when conducting in-depth interviews, the companies explained by the fact that distributed generation systems reduce the occurrence of the listed adverse effects to a minimum. Obtaining cheap electric and thermal energy, a gradual increase in energy capacities and evenness of investment with fast energy for industrial and household needs are possible today due to the use of energy-efficient solutions based on distributed generation technologies.

5.1 Limitations of the study

It is necessary to note some of the limitations of this study. It was not possible for us to interview the entire totality of Russian companies due to limited data collection opportunities. However, our sample of companies covers a representative part by sector, sales revenue, and company size. In the future, researchers would be able to analyze the factors of distributed generation technology adoption in a larger sample of companies.

The results of a sample of 69 companies confirm the practicability of a comprehensive assessment of the distributed generation technology adoption factors. Within the framework of this study, the selected internal, external, and specific factors were measured empirically and used to analyze the distributed generation technology adoption by companies.

The qualitative stage of research allowed us to draw initial conclusions about the significance of certain aspects of distributed generation technology adoption. Thus, in accordance with the results of the theoretical base analysis, it was empirically confirmed that when companies adopted distributed generation, the cost of electricity and technical compatibility were of greatest importance. At the qualitative stage, the majority of respondents named these aspects of adoption as the most important.

Conflict of interest

There is no conflict of interest.

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References

[1] Navigant Research. Global DER deployment forecast Database. 4Q 2017

[2] Hunt S, Shuttleworth G. Competition and Choice in Electricity. England: John Wiley & Sons; 1996

[3] Rhodium Group. The State of the Art in Valuing Distributed Energy Resources. New York, NY: Columbus Circle. 2017. Resources: https://rhg.com/wp-content/uploads/2017/01/RHG_WhatsItWorth_Jan2017.pdf

[4] Lazard's Levelized Cost of Energy Analysis, version 11.0. 2017

[5] Molla A, Licker PS. Perceived e-readiness factors in e-commerce adoption: An empirical investigation in a developing country. International Journal of Electronic Commerce. 2005;**10**(1):83-110

[6] Wu J. Control technologies in distributed generation system based on renewable energy. In: 2009 3rd International Conference on Power Electronics Systems and Applications, PESA 2009; 2009

[7] Трачук АВ. Реформирование электроэнергетики и развитие конкуренции (монография). Москва: 2010

[8] Ворожихин В. Организационно-экономические механизмы развития энергетики. LAP LAMBERT Academic Publishing изд. Saarbrücken: LAP LAMBERT Academic Publishing; 2013. с.245

[9] Bhowmik A, Schatz J, Maitra A, Halpin S. Determination of allowable penetration levels of distributed generation resources based on harmonic limit considerations. IEEE Transactions on Power Delivery. 2003;**18**(2):619-624

[10] Trachuk A, Linder N. Technologies of the distributed generation: Empirical evaluations of the innovations acceptance. Strategic Decisions and Risk Management. 2018;(1):32-48. DOI: 10.17747/2078-8886-2018-1-32-48. (In Russ.) Resources: https://www.jsdrm.ru/jour/article/view/750?locale=en_US#tab1

[11] Seo H, Park M, Kim G, Yu I, Ali M. A study on the performance analysis of the grid-connected pv-af system. In: Proceeding of International Conference on Electrical Machines and Systems ICEMS; 2007

[12] Brandon D, Humayun T, Robert U. The Smart Grid and the Promise of Demand-side Management. McKinsey & Company; 2010. Available from: http://www.calmac.com/documents/MoSG_DSM_VF.pdf

[13] Subhes C. Bhattacharyya Energy Economics Concepts, Issues, Markets and Governance. UK: University of Dundee, Springer; 2011. 645 p

[14] Grubb M, Jamasb T, Pollitt MG. Delivering a Low Carbon Electricity System. Technologies, Economics and Policy. University of Cambridge, UK: Cambridge University Press; 2008. 536 p

[15] Berg A, Krahl S, Paulun T. Cost-efficient integration of distributed generation into medium voltage networks by optimized network planning. In: IET Seminar Digest; 2008. pp. 12380

[16] Lujano-Rojas JM, Monteiro C, Dufo-Lopez R, Bernal-Agustın JL. Optimum residential load management strategy for real time pricing demand response programs. Energy Policy. 2012;**45**:671-679

[17] Kazemi A, Sadeghi M. Distributed generation allocation for loss reduction and voltage improvement. In: 2009 Asia-Pacific Power and Energy

Engineering Conference, APPEEC 2009 Proceedings; 2009

[18] Li H, Leite H. Increasing distributed generation using automatic voltage reference setting technique. In: IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century; PES. 2008

[19] Yingyuan Z. Liuchen C, Meiqin M, Ming D. Study of energy management system for distributed generation systems. In: 3rd International Conference on Deregulation and Restructuring and Power Technologies DRPT; 2008

[20] You S, Jin L, Hu J, Zong Y, Bindner HW. The danish perspective of energy internet: From service-oriented flexibility trading to integrated design, planning and operation of multiple cross-sectoral energy systems. Zhongguo Dianji Gongcheng Xuebao. 2015;**35**(14):3470-3481. DOI: 10.13334/j.0258-8013.pcsee. 2015.14.001

[21] Zhang X. A framework for operation and control of smart grids with distributed generation. In: IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century; PES. 2008