



Demand-side Management in Territorial Entities based on their Volatility Trends

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ABSTRACT

This article explores the issues of assessing electricity consumption by individual countries and territorial entities based on their demand volatility. The current demand-side management (DSM) programs deployed in different countries of the world do not take into account individual characteristics of energy demand, which affects their effectiveness. This article describes the methodology developed by the authors to analyze demand volatility in individual countries and territorial entities using a demand volatility map. The authors introduce new indicators for assessing the electricity demand volatility such as: “*Annual Load Volatility Factor*,” “*Daily Load Factor*” and “*Demand Volatility Coefficient*,” which underlie a demand volatility map. The map is used to identify similar demand volatility trends among individual countries and territorial entities and offer recommendations and management decisions for decreasing volatility in the grid on the level of individual countries and territorial entities. This article presents the results of testing the methodology in the form of two demand volatility maps – one built for the EU, the other for Russia. The EEC volatility map emphasized the need for a differentiated approach to DSM in different countries. It also allowed clustering the countries and revealed states with similar trends where similar DSM models could be deployed. The Russia-wide volatility map showed the regions that are best positioned for DSM and allowed the authors to produce recommendations on DSM for similar regional groups. The results of the study have high theoretical and practical importance which manifests in their potential application for the decision-making in the field of DSM in individual countries and territorial entities, aimed at reducing energy consumption and improving energy efficiency.

Keywords: Demand-side Management, Electricity Consumption, Energy Efficiency, Energy Costs, Energy Cost Management

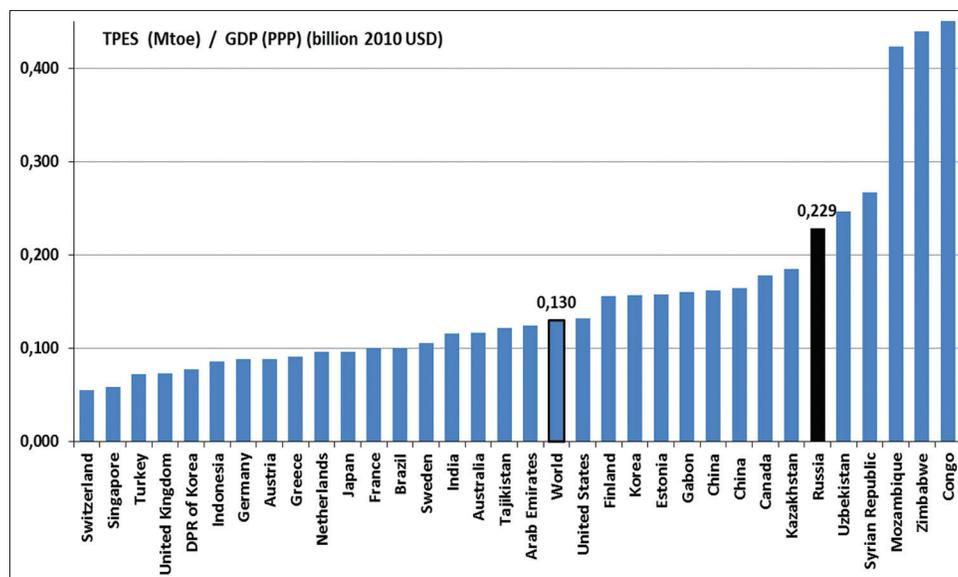
JEL Classifications: Q43, P18, L94

1. INTRODUCTION

The accelerating globalization increases competition between global economies, forcing them to look for new growth areas and improve their efficiency. One possible way of improvement is energy efficiency (Vaninsky, 2018). Faced with the increasing shortage of energy resources, their price growing in global commodity markets, a continuously increasing demand by mature and developing economies, depletion of resources, and adverse environmental conditions in some parts of the world, human mankind has come to realize the need to shift its consumption patterns toward finding ways to decrease energy consumption (Feng and Wang, 2017).

For different countries of the world, indicators of energy consumption efficiency would be different and would depend on a number of different factors. Figure 1 shows the indicators of the total energy intensity of GDP (PPP) in various countries of the world in 2018 (International Energy Agency, 2017). As seen from the chart, Russia’s energy intensity of GDP is 4.2 times higher than Switzerland, 3.1 times higher than the UK and 2 times higher than Australia.

Electric energy is the most common kind of energy massively used by mankind. Most of the extracted fossil fuels – coal and natural gas – go for the production of electricity (International Energy Agency, 2017). Therefore, the authors believe that electricity

Figure 1: Total energy intensity of GDP (PPP) in various countries of the world in 2018

generation has the greatest potential when it comes to improving energy efficiency.

According to Kondratiev's theory of economic cycles (1922), which was later developed by one of the founders of the theory of innovation Schumpeter (2008), the period of the next, sixth cycle, between 2018 and 2060, will be characterized by a new technological structure in the field of nano-, bio-, information and cognitive technologies (NBIC-convergence) (Korotayev and Tsirel, 2009).

Today, Russian and foreign researchers alike have been studying the deployment of smart technologies in the electric power sector (smart grids) (Kobets and Volkova, 2010; Carmoab et al., 2014; Meiling et al., 2015; Ayan and Emre, 2017; Loginov and Loginov, 2012). The roll-out of the smart grid technology will transform the existing control system in the electric power industry with the new technological capabilities (Volkova, 2016; Voropay, 2014; ENTSO-E, 2014; US State Department of Energy, 2003; European Commission, 2016; International Energy Agency, 2015).

Demand-side management (DSM) is one of the core elements of the smart grid's mechanism for managing demand for electricity. This phenomenon has an accepted term that is used between energy providers and customers worldwide – DSM, or DSM (Lampropoulos et al., 2013). It may also be referred to as energy demand management (Government of United Kingdom, 2016) or demand-side response (DSR) (Torriti, 2015). The term DSM was introduced after the world oil crises that took place in 1973 and 1979 (Smith, 2006). These energy crises primarily affected the US economy and revealed a real threat to energy security at the national level (U.S. Department of State, Office of the Historian, 2012). "DSM" was officially introduced by the US Electric Power Research Institute in the 1980s (Balijepalli et al., 2011). In 1993, the International Energy Agency, which was formed by OECD member states after the "first oil shock" in 1974, laid the foundation for the global programs focusing on DSM technologies (IEADSM).

DSM is an initiative form of economic interaction between electric power entities and end users, which provides mutually beneficial, cost-effective regulation of volumes and modes of energy consumption (Gitelman et al., 2013).

DSM smooths out the peaks and falls of electric loads in the grid, thereby reducing the costs of generators as well as the costs for maintaining excessive capacity and preventing incidents in the grid (Solovyova and Dzyuba, 2017).

Many countries nowadays implement different DSM mechanisms in the power sector. DSM technology is being widely deployed in more than 30 countries around the world including the USA (Shariatzad et al., 2015), Canada (López et al., 2009), UK (Jason et al., 2017), the European Union, Germany, France (Jacquot et al., 2017), Australia (Marwan et al., 2011), Denmark (Pavani et al., 2017), Japan (Shiraki et al., 2016), Brazil (Maria et al., 2011), Turkey (Ayan and Emry, 2017), China (Chia-Chin, 2005), Thailand, Vietnam, India (Kumar et al., 2017), and Iran (Zeinaddini-meymand et al., 2017).

A study of existing DSM programs around the world has revealed a commonality of approaches and tools used to manage energy demand, such as: Use of energy-saving equipment, transition to renewable electricity, differentiation of electricity tariffs, etc. The difference is only in the scale of such programs, which is associated with the volume of funding and government support for DSM initiatives.

2. RELEVANCE

The study of global DSM initiatives has generally revealed some common traits:

- Common DSM tools employed by countries implementing DSM;
- Even distribution of all DSM tools between territorial entities rolling out DSM initiatives;

- Uniformity of DSM elements instantly applied to all existing categories of electricity consumers;
- Failure to account for demand volatility during the design and roll-out of DSM initiatives across different territorial entities.

In our opinion, accounting for individual parameters of demand in individual countries that deploy DSM initiatives and territorial entities which constitute a single country is one of the areas for improving DSM.

Figure 2 shows a graph of hourly demand in various countries of the world during a week in Electricity demand differs greatly in different countries, both in terms of general volume indicators as well as volatility in different periods. Figure 3 shows a graph of hourly electricity demand in various countries in 2016 (Eurostat, 2016). As can be seen from the graph, annual demand in different countries differs both in terms of the total demand and the demand curve during a year.

December 2016. As seen from the figure, hourly demand in different countries demonstrates volatility trends which are specific for each country. Figure 2 also shows significant differences between the demand levels during business days and week ends in different countries.

The difference in the demand volatility of different territorial entities depends on a number of individual characteristics associated with several factors such as:

- Economic structure of a given territorial entity;
- Sectoral composition of electricity consumers;
- Total electricity demand;
- Climatic and geographic characteristics of a given territorial entity;
- Individual factors affecting the demand.

In our opinion, DSM of electricity is most efficient when used with a differentiated approach that accounts for specific demand volatility and other factors affecting the demand in individual

Figure 2: Hourly demand for electricity in various countries of the world in 2016 (the scale is preserved)

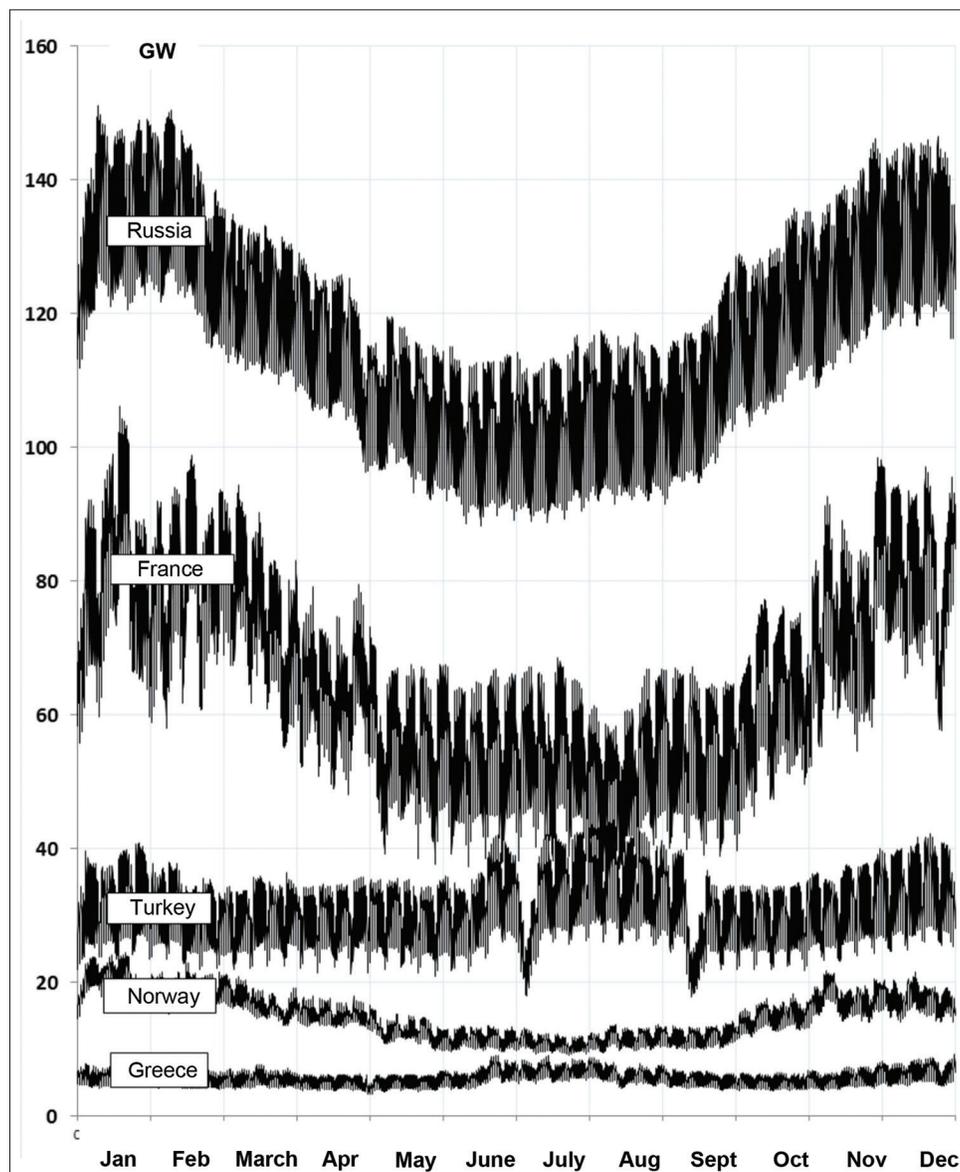
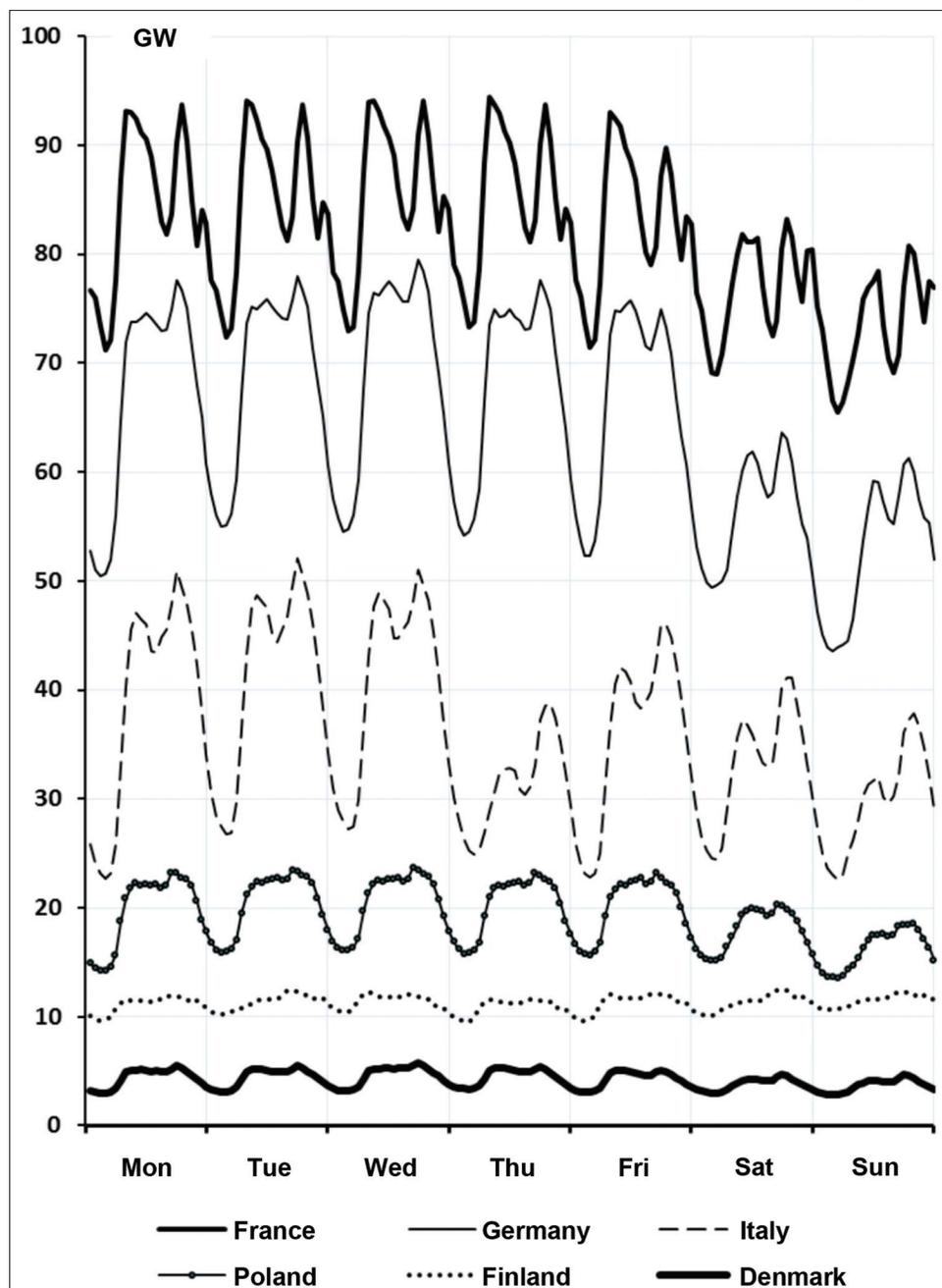


Figure 3: Hourly demand during a week in various countries, December 2016 (the scale is preserved)

countries and territorial entities. This will reduce the time to achieve the desired effect of decreasing the demand and the costs of government's DSM initiatives.

This methodology developed by the authors and accounting for multiple demand volatility parameters when building demand volatility maps of individual territorial entities is recommended for the analysis and differentiation of territorial entities by their demand volatility.

Demand volatility maps of individual territorial entities reveal entities of the national grid which share similar demand trends. This can be used as input for further differentiated DSM programs.

3. METHODOLOGY FOR BUILDING DEMAND VOLATILITY MAPS

Consider the method of building a map of demand volatility of territorial entities. The map is built in several steps:

- 1) Input – demand parameters of a given territorial entity – is collected and prepared.
To build a demand volatility map of a territorial entity, data on the hourly demand is collected for each analyzed entities for at least 12 months. Input period of all analyzed territorial entities must be identical.
- 2) Annual Volatility Factor is calculated for each analyzed territorial entity.

Table 1: Classification of regional groups identified in the cluster analysis of the demand volatility map of the EEC and Russia

Group	Regions	$R_{year} (GW)$	Q_{vol}
Group 1	Netherlands, Finland, Austria, Belgium, Czech Republic, Greece, Switzerland, Serbia, Romania, Portugal, Bulgaria, Denmark, Hungary, Ireland, Slovakia, Croatia, Bosnia and Herzegovina, Slovenia, Lithuania, Estonia, Macedonia, Latvia, Cyprus, Luxembourg, Iceland, Montenegro	26–49.1	0.360–0.617
Group 2	Turkey, Spain, Sweden, Norway, Poland	9.4–16.3	0.418–0.517
Group 3	Russia, France, Great Britain, Germany, Italy	0.3–6.6	0.282–0.650

Table 2: Classification of regional groups identified in the cluster analysis of the demand volatility map of the regions of Russia

Group	Regions	$R_{year} (MW)$	Q_{vol}
Group 1	Republic of Buryatia, Ulyanovsk region, Chuvash Republic (Chuvashia), Kurgan region, Penza region, Ivanovo region, Bryansk Region, Tambov region, Kostroma region, Pskov region, Mari El Republic, Chechen Republic, Republic of Mordovia, Oryol region, Republic of North Ossetia-Alania, Kabardino-Balkarian Republic, Republic of Tuva, Karachay-Cherkess Republic, Republic of Altai, Republic of Kalmykia	41-495	0.274-0.535
Group 2	Republic of Dagestan, Saratov region, Altai Territory, Astrakhan region, Republic of Ingushetia, Omsk Region, Voronezh region, Orenburg region, Volgograd region, Murmansk region, Stavropol Territory, Yaroslavl region, Udmurtia Republic, Kursk region, Vologda Region, Vladimir region, Smolensk region, Kirov region, Tula region, Belgorod region, Tver region, Tomsk region, Zabaykalsky Krai, Lipetsk region, Kaluga region, Ryazan region, Republic of Karelia, Republic of Khakassia, Novgorod region	229-832	0.063-0.843
Group 3	Moscow region, Irkutsk region, Leningrad region, Tyumen region, Krasnoyarsk Territory, Sverdlovsk region, Krasnodar Territory, Republic of Tatarstan, Republic of Bashkortostan, Nizhny Novgorod region, Samara region, Novosibirsk region, Chelyabinsk region, Rostov region, Perm Territory, Kemerovo region	886-7,995	0.475-0.775

Table 3: Characteristics of groups identified using the demand volatility map of Russian regions

S. No.	Metric	Group 1	Group 2	Group 3
1	Number of regions	20	29	16
2	Average daily load factor in a group	0.84	0.9	0.93
3	Average annual load volatility factor	0.46	0.55	0.61
4	Average demand volatility coefficient	0.39	0.49	0.56
5	Total annual range of variation in MW	4,964	16,612	32,871
6	Share in the total annual range of variation in %	9%	31%	60%
7	Share of total power consumption of the group from the studied sample	12%	38%	50%
8	Group’s average power consumption by industry	30%	50%	59%

The annual volatility factor is a metric that measures the comparative degree of demand volatility of a given entity during a year based on its hourly demand.

The annual volatility factor is calculated using formula (1) below:

$$F_{Vol_annual} = \frac{\bar{P}_{min\ 10\%}}{\bar{P}_{max\ 10\%}} \quad (1)$$

where: F_{Vol_annual} is the annual volatility factor;

$\bar{P}_{min\ 10\%}$ is the average capacity in the range of 10% of the hours of the minimum annual load;

$\bar{P}_{max\ 10\%}$ is the average capacity in the range of 10% of hours of maximum annual load.

To calculate the annual volatility factor, it is necessary to identify 10% of hours with a min annual load and 10% of hours with max annual load from the entire set of parameters of the annual hourly consumption by the analyzed territorial entity. And calculate the average value for each sample and substitute in the formula above.

The annual volatility factor varies from 0 to 1. The closer to 0, the higher is the annual demand volatility and, vice versa, the closer to 1, the lower is the annual demand volatility.

- Daily Load Factor is calculated for each analyzed territorial entity. The daily load factor is a metric reflecting the comparative degree of demand volatility in a given territorial entity during a day.

This coefficient is calculated on the basis of the hourly demand curve for a typical business day, using formula (2) [6]. A typical day used in the calculations must be identical for all analyzed territorial entities.

$$F_{daily\ load} = \frac{\bar{P}_{day}}{P_{max\ day}} \quad (2)$$

where:

$F_{daily\ load}$ is the daily factor;

\bar{P}_{day} is the hourly average capacity on the analyzed day; and P_{max_day} is the maximum hourly capacity on the analyzed day.

To calculate the Daily Load Factor, the average daily consumption and max hourly consumption are taken from the hourly load curve of the analyzed day. The load coefficient varies from 0 to 1. The closer to 1, the lower is the daily volatility of the demand and, vice versa, the closer to 0, the higher is the daily demand volatility.

- 4) Demand volatility coefficient is calculated. The demand volatility coefficient is a metric that reflects the integral characteristic of the demand volatility of a given territorial entity and is calculated using formula (3) below.

$$Q_{Vol} = F_{daily\ load} \times F_{Vol_annual} \tag{3}$$

The demand volatility coefficient is calculated as the product of the annual volatility factor and the daily load factor. This indicator varies from 0 to 1. The closer to 1, the lower is the volatility of the integrated demand and, vice versa, the closer to 0, the higher is the daily volatility.

- 5) The range of the annual demand volatility is calculated for the analyzed territorial entity. The annual demand volatility range of a territorial entity is a metric that shows the absolute change in demand for electricity in a given territorial entity during a year (formula 4).

$$R_{year} = \bar{P}_{max\ 10\%} - \bar{P}_{min\ 10\%} \tag{4}$$

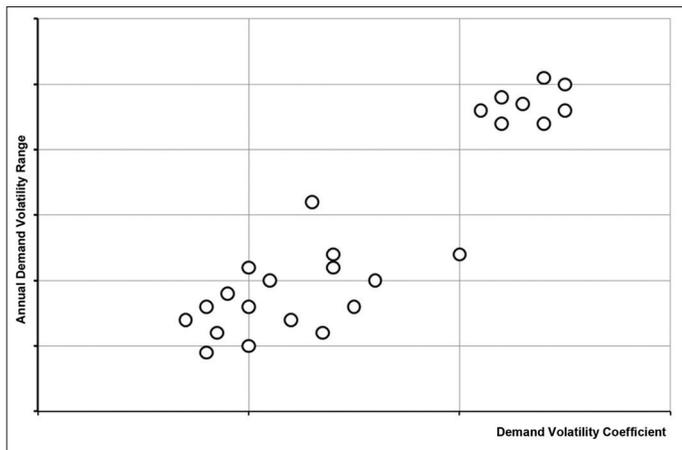
where:

R_{year} is the range of variation of the annual demand in the region.

The annual demand volatility range is calculated in absolute terms, identical for all analyzed territorial entities.

- 6) Demand volatility map of the analyzed territorial entities is built. The demand volatility map is built for all territorial entities under the study. The x-axis shows the values of the demand volatility coefficient of territorial entities. The y-axis shows the values of the annual demand volatility range. Sample demand volatility map is shown in Figure 4.
- 7) The demand volatility map is further analyzed.

Figure 4: Sample demand volatility map



The map’s analysis includes searching for similar groups of territorial entities using the graphical method of the cluster analysis. Groups of territorial entities are clusters with similar indicators of demand volatility and the share of electricity consumption by industry.

- 8) The demand is further analyzed within the identified clusters. At this step, demand parameters of territorial entities within each identified cluster are analyzed, including: typical characteristics of a cluster and cluster elements – territorial entities that differ from the general set of elements in the group. Taking into account the identified specifics of territorial entities during the design and roll-out of energy efficiency programs will accelerate the desired effect, i.e. decreasing electricity demand in a given territorial entity and in the country in general.
- 9) Demand is further analyzed by territorial entity within a particular country.

The sequence of building a demand volatility map of territorial entities is similar to the sequence of building a country-wide volatility map. However, the first step in building a demand volatility map of a territorial entity is to determine the list of territorial entities that fall within the scope of the analysis. The list of territorial entities is determined taking into account a number of conditions:

- All analyzed territorial entities must belong to one state and be part of the same grid;
- All analyzed territorial entities must have the same level of administration; and
- All analyzed territories must allow common energy-saving mechanisms.

Examples of such territorial entities include: Individual states, counties, regions, districts, and administrative centers. Also, given that the territorial entities belong to one country, it is most expedient to introduce an indicator that allows for additional classification of the studied groups of regions according to general parameters. In addition to the above coefficients, the most pertinent indicator is the average annual share of electricity consumption by industry.

The average annual share of electricity consumption by industry is calculated for a given territorial entity. This indicator reflects the share of electricity consumption by the industrial sector in the total volume of electricity consumption of the analyzed territorial entity (5).

$$D_{TE_year}^{ind} = \frac{V_{TE_year}^{ind}}{V_{TE_year}} \tag{5}$$

where:

$D_{TE_year}^{ind}$ is the average annual share of electricity consumption by industry in the analyzed territorial entity (%). is annual electricity consumption by industry in the analyzed territorial entity;

V_{TE_year} is the total annual electricity consumption in the analyzed territorial entity.

Figure 5: Annual volatility factors and demand volatility coefficients of the EU countries and Russia

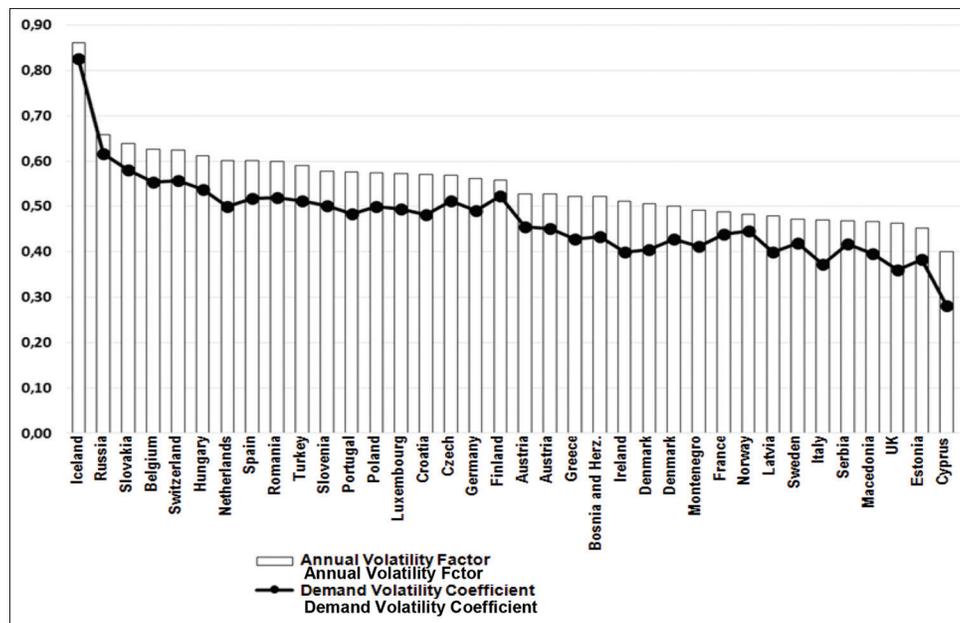
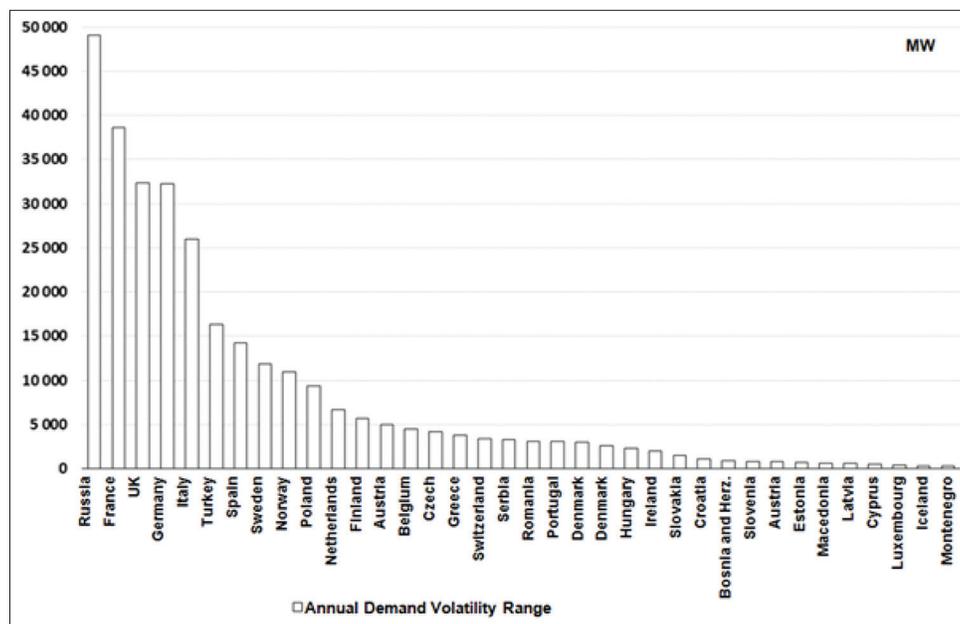


Figure 6: The range of variations in the annual demand volatility in the EU countries and Russia



3.1. Practical Application Different Countries

The proposed approach to assessing and analyzing demand volatility in territorial entities was tested on the example of hourly demand in the countries of the European Union and Russia.

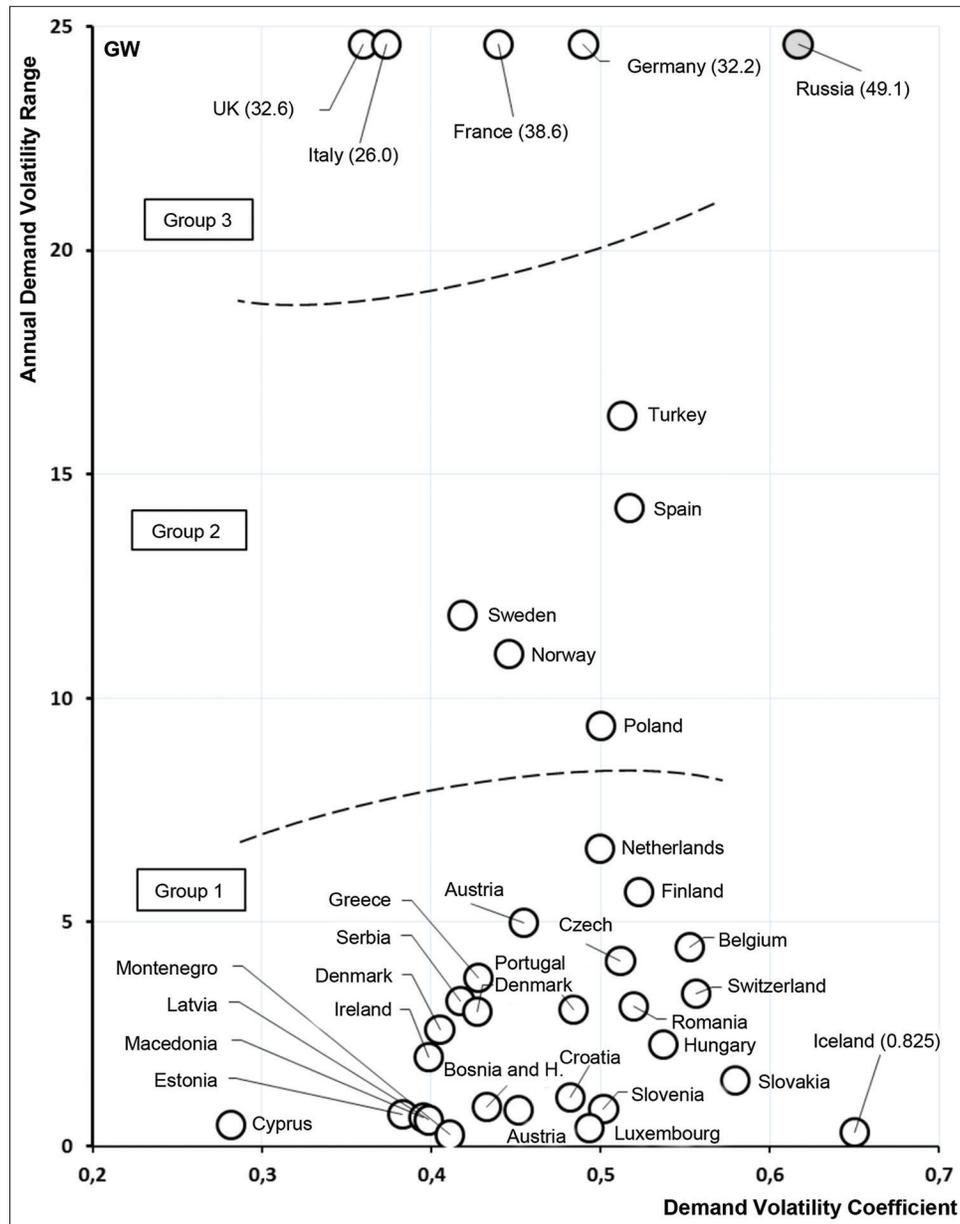
The study used hourly consumption data from 35 countries of the EU and Russia. For each country, we collected and prepared hourly demand data for 1 year. Next, we calculated annual demand volatility factor, daily load factor and demand volatility coefficient for each country.

Figure 5 shows a diagram of the annual volatility factors and the demand volatility coefficients of the EU countries and Russia.

As seen from the diagram, the calculated annual volatility factors and demand volatility coefficients differ significantly between the countries. Annual volatility factors vary from 0.4 to 0.86, daily load factors from 7 to 0.96, and volatility coefficients from 0.28 to 0.825. The revealed differences emphasize the individual specifics of demand fluctuations in different countries on the annual and the daily basis alike, and therefore require different approaches to DSM.

Figure 6 shows a diagram of the annual demand volatility range of EU countries and Russia. As seen from the diagram, parameters of the annual demand fluctuations vary between the countries. For example, the range of volatility variation in Russia is 49 GW

Figure 7: Demand volatility map of the EEC and Russia



versus 2.5 GW in Denmark, i.e., 20 times less than in Russia. The difference in the annual volatility range also indicates the need to implement a differentiated approach to DSM in each country.

Figure 7 shows a demand volatility map built by the authors for the countries of the EEC and Russia. As seen from the map, countries concentrate in several clusters with similar demand volatility and variation range. This allows grouping the countries according to said parameters.

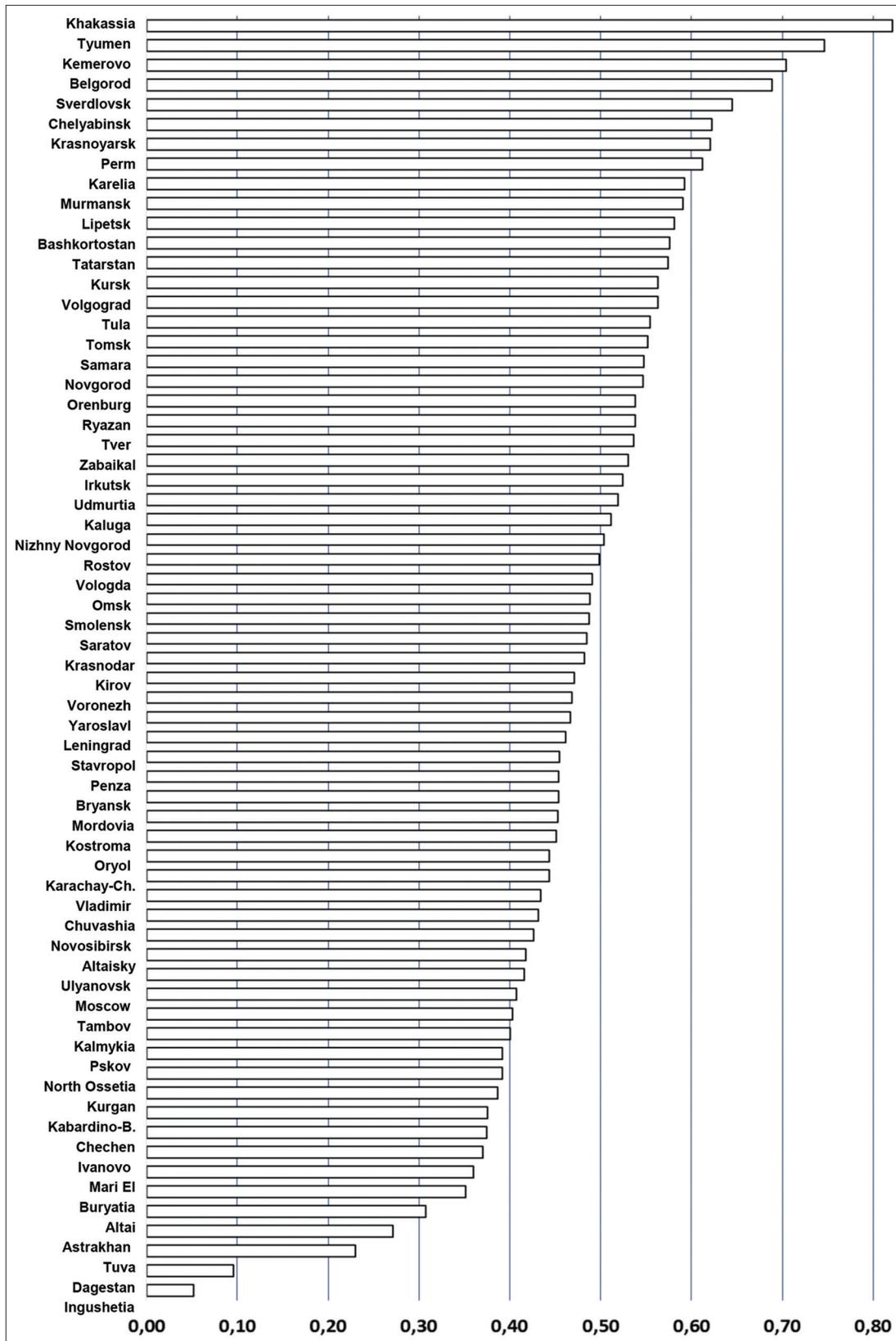
The United Kingdom, Italy, France, Germany, and Russia significantly differ from the rest of the world in terms of the volatility variation range, which allows us to distinguish them into a separate group. Turkey, Spain, Sweden, Norway, and Poland have total parameters that differ from other regions under study, which also allows clustering them as a separate group. Regions that were not included in the selected groups also have similar parameters

of volatility indicators, which allows them to be combined into another cluster.

Table 1 below contains the list of regions and general volatility parameters of each group. For the sake of convenience, Table 1 includes demand volatility parameters of each of the selected groups.

Based on the results of Table 1, it can be concluded that national DSM programs should take into account the specifics of demand fluctuations within the country. For Group 1 countries, it is advisable to deploy DSM programs which would align the annual and daily demand across all categories of electricity consumers. For Group 2 countries, it is advisable to deploy DSM programs which would align the annual load across all categories of electricity consumers. For Group 3 countries, it is advisable to align the annual demand across the largest consumers in the grid.

Figure 8: Demand volatility coefficients in different regions of the Russian Federation

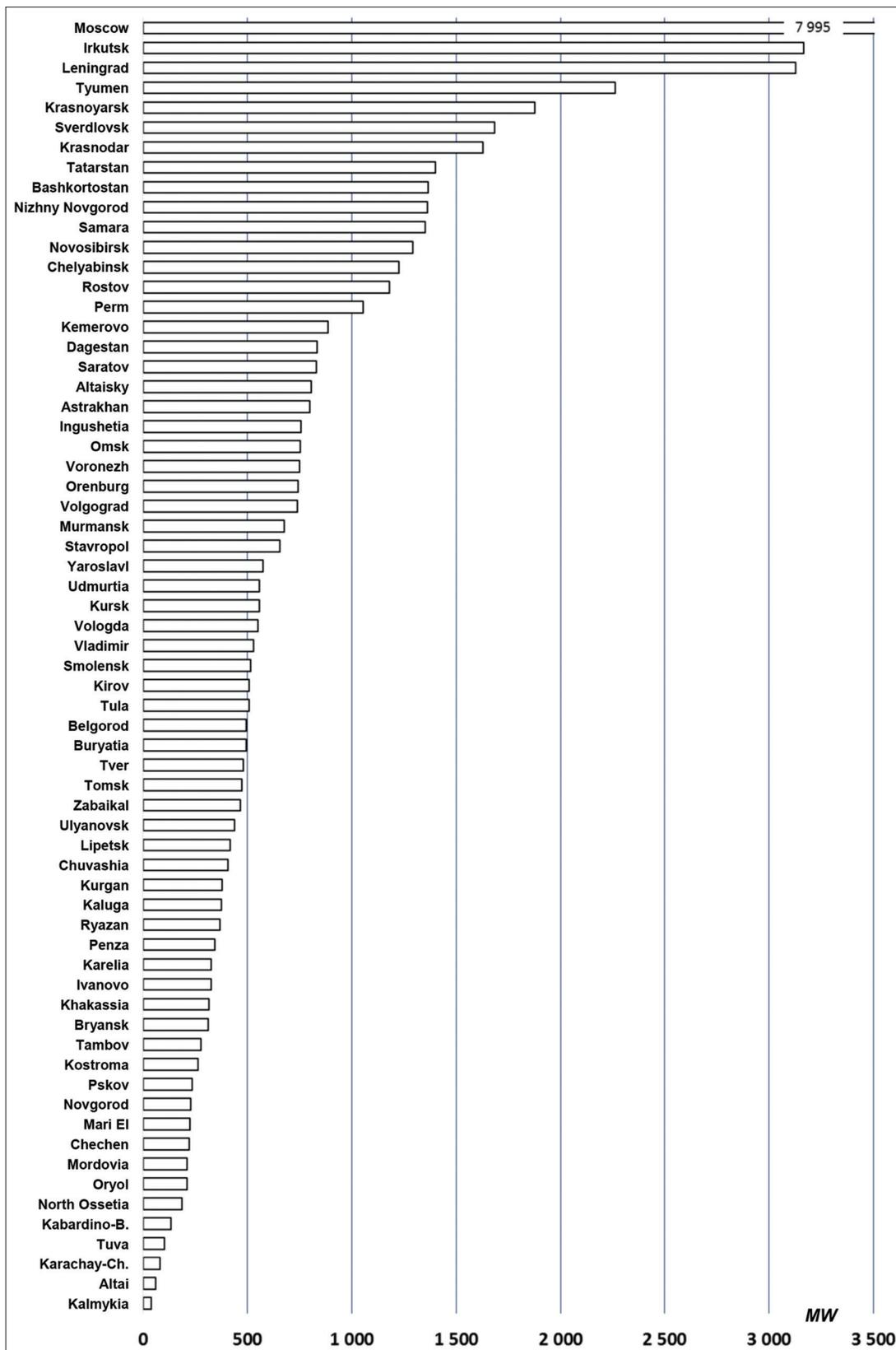


3.2. Practical Application Russia’s Regions

We have further analyzed the demand in different territorial entities within a single country. The analysis was carried out on the example of the Russian Federation. As seen from the

demand volatility map of the countries of the EEC and Russia, Russia differs from other countries in terms of its annual demand volatility range, which is estimated as 49.1 GW. Also, DSM roll-out is especially important in Russia as the country’s GDP is

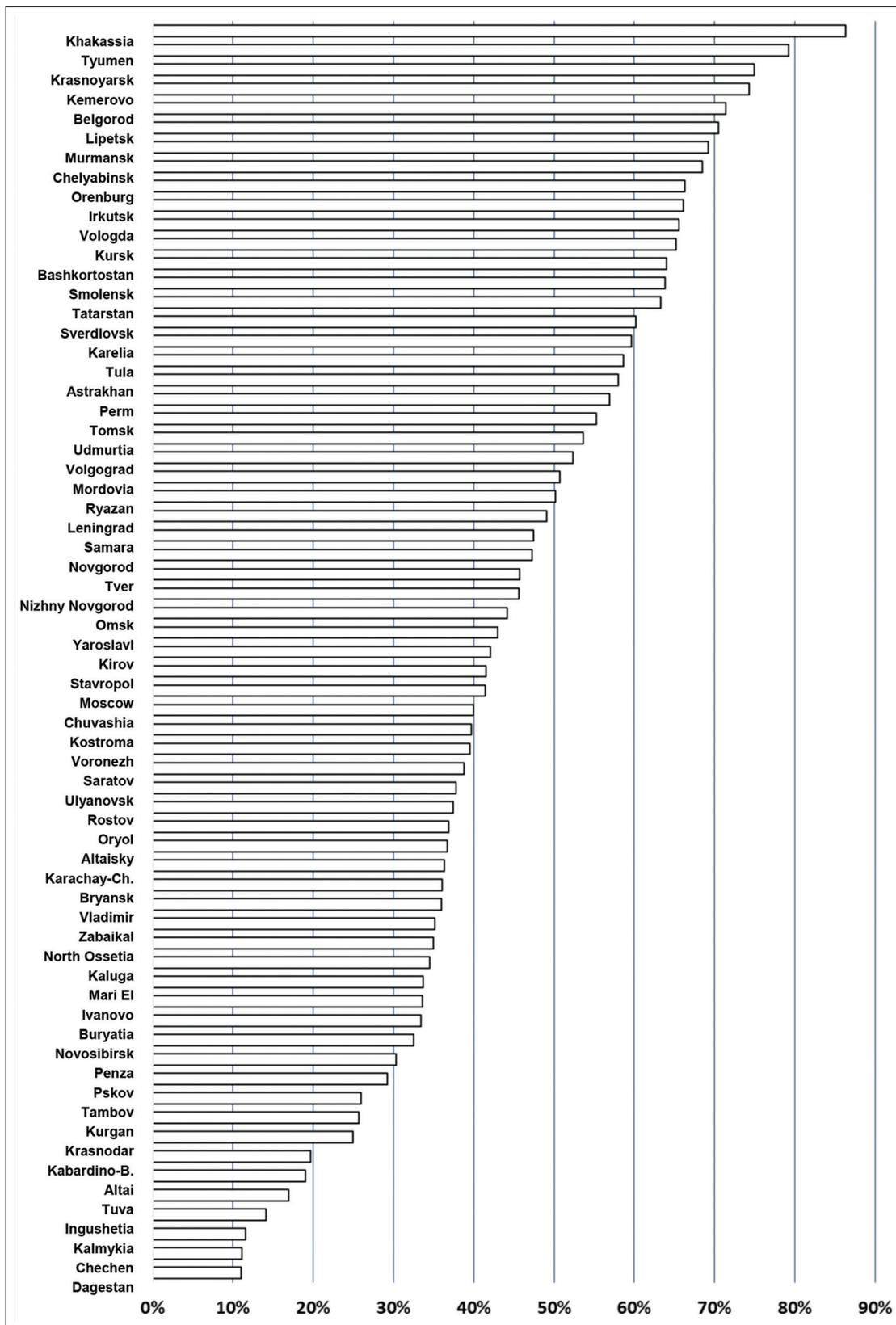
Figure 9: Annual demand volatility range of different regions of Russia



much more energy-intensive than elsewhere in the world. Russia's economy significantly differs from the EEC in that it has higher total electricity consumption and an extensive regional structure. The extensive regional structure requires an in-depth approach to the deployment of DSM, taking into account the specifics of

the regions (territorial entities) that make up the country's total electricity consumption.

The study used hourly consumption data from 65 regions that are part of the price zones on the wholesale electricity market in

Figure 10: Average annual share of electricity consumption by industry in different regions of Russia

Russia. For each region, we collected and prepared hourly demand data for 1 year. Next, we calculated annual demand volatility factor, daily load factor and demand volatility coefficient for each region. Figure 8 shows the rating of Russian regions according to the value of their demand volatility coefficient.

As seen from the chart above, the demand volatility coefficient differs significantly between different regions. Given the analyzed set of regions, the average demand volatility coefficient is 0.479, with a range of variation from 0.052 to 0.822. The result indicates a significant difference in demand volatility between different regions of Russia.

Figure 11: Demand volatility map of different regions of Russia

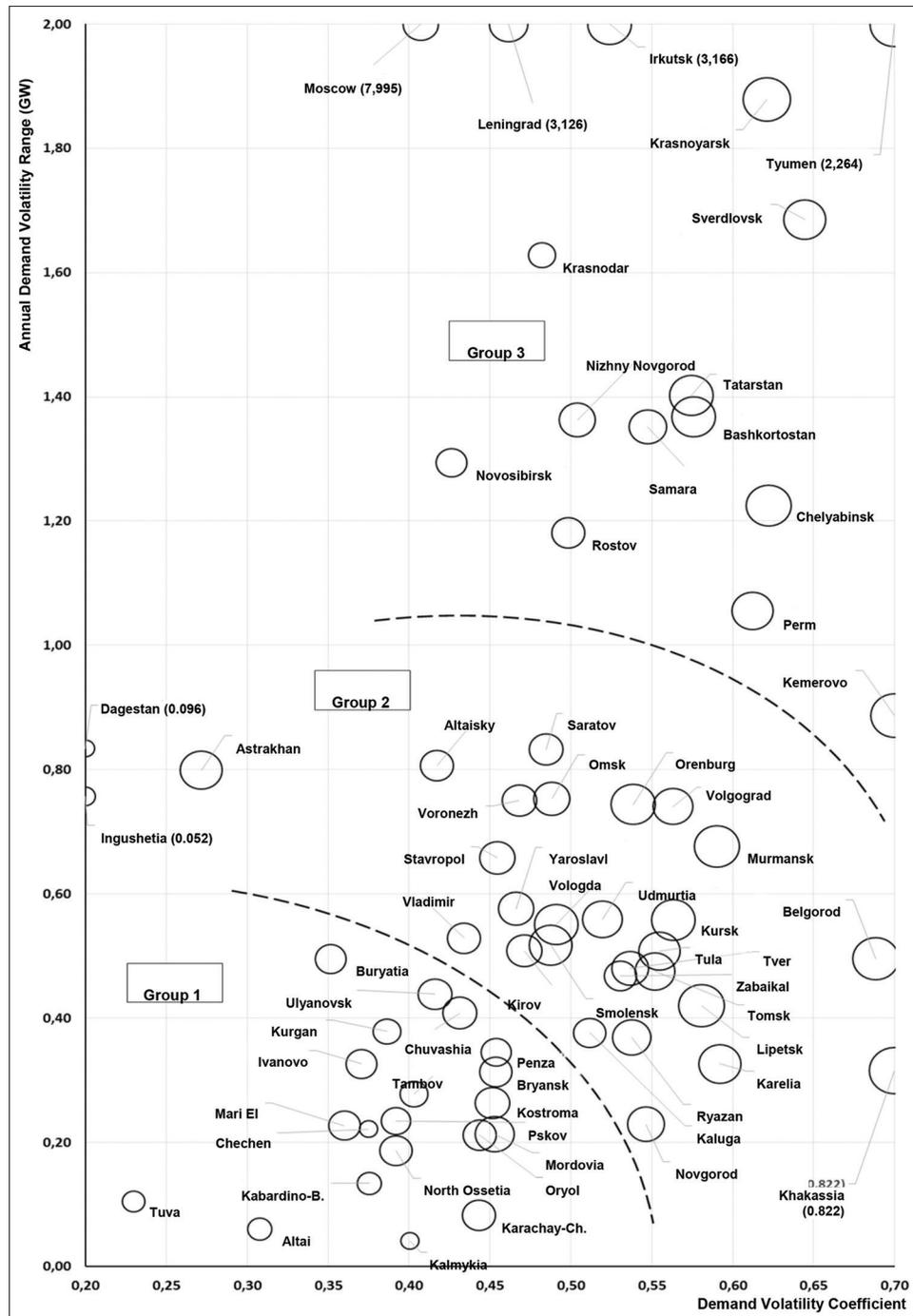


Figure 9 shows the results of calculating the volatility variation range of all regions of the Russian Federation. The variation range of power consumption is also substantially different between the regions. Given the analyzed set of regions, the average variation range is 838 MW, while the indicator itself varies from 41 MW to 7,995 MW, which corresponds to a 195-fold multiplication.

Also, for each of the studied regions of the Russian Federation, we calculated the average annual share of electricity consumption by industry (Figure 10).

Based on the calculation of demand volatility coefficients, annual demand volatility range and the average annual share of electricity

consumption by industry in Russia's regions, we built a demand volatility map as shown below (Figure 11). From our point of view, analysis of the map allowed us to distinguish three groups (clusters) of regions with similar parameters of demand volatility.

- Group 1 – regions with a high level of relative demand volatility and a low level of absolute change in demand.
- Group 2 – regions with an average level of relative demand volatility and an average level of absolute change in demand.
- Group 3 – regions with a low level of relative demand volatility and a high level of absolute change in demand.

Table 1 below contains the list of regions and general volatility parameters of each group. For the sake of convenience, Table 2

includes demand volatility parameters of each of the selected groups.

Despite the fact that the number of regions in each group is almost the same, their demand curves differ significantly. Group 1 regions have the highest rates of relative variation in both annual and daily demand but their contribution to the absolute change of the electricity demand on the scale of Russia's grid, on the contrary, is the lowest (9% in annual terms). Conversely, the regions of the 3rd group, which have the lowest rates of relative variation in demand, contribute the most to the absolute change in demand across the country (60%) (Table 3).

The regions included in Group 2 are characterized by an average level of relative variation in demand and an average contribution to the absolute change in demand (31% on an annualized basis). Group 1 consumes 12% of Russia's total power and comprises 20 regions. Group 2 consumes 38% of Russia's total power and comprises 29 regions. Group 3 accounts for the largest consumption volume and amounts to 50%, while comprising only 16 regions. The shares of electricity consumption by industry as shown on the map of regional demand suggest a direct relationship between the absolute changes in demand and the share of electricity consumption by industry in the region. The analysis suggests that Group 3 regions, especially in the industry sector, offer the most opportunities for DSM.

4. CONCLUSIONS

Our concluding considerations are the following:

- 1) Electricity demand varies significantly between different countries of the world, which manifests itself both in absolute terms and in the annual, weekly and intraday volatility.
- 2) Given the difference in the electricity demand in different countries of the world, it is advisable to use a differentiated approach to DSM, which would take into account the specifics of the local demand and other factors affecting the demand in a given country or territorial entity;
- 3) Accounting for individual parameters of demand in individual countries that deploy DSM initiatives and territorial entities which constitute a single country is one of the areas for improving DSM.
- 4) This methodology, developed by the authors and accounting for multiple demand volatility parameters when building demand volatility maps of individual territorial entities, is recommended for the analysis and differentiation of territorial entities by their demand volatility.
- 5) The methodology of demand volatility mapping includes a sequential calculation of the indicators developed by the authors: "annual volatility factor," "daily load factor" and "demand volatility coefficient," which are the basis for building the resulting map of demand volatility. The methodology is universal and allows analyzing any groups of countries or territorial entities of a single country;
- 6) The developed demand volatility map allows assessing demand parameters of individual countries and territorial entities and reveal similar country clusters with similar demand trends.

This can be used as input for building better differentiated DSM programs and energy efficiency improvements;

- 7) Building a demand volatility map of the EEC countries allowed us to identify clusters with similar volatility trends. The developed grouping allowed us to offer recommendations for DSM programs in the respective countries;
- 8) Building a demand volatility map of Russia's regions allowed grouping the regions along similar trends, while also taking into account the share of electricity consumption by industry. The resulting grouping allowed us to offer recommendations for DSM programs in the respective regions;
- 9) The results of the study have high theoretical and practical importance which manifests in their potential application for the decision-making in the field of DSM in individual countries and territorial entities, aimed at reducing energy consumption and improving energy efficiency.

5. ACKNOWLEDGMENT

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