LATVIAN JOURNAL OF PHYSICS
AND TECHNICAL SCIENCES
2020, N 6

DOI: 10.2478/lpts-2020-0031

THE DEVELOPMENT OF THE SMART GAS DISTRIBUTION: GENERAL TRENDS AND THE LATVIAN CONTEXT

J. Savickis[1], L. Zemite[2*], L. Jansons[2], I. Bode[2], E. Dzelzitis[2],
A. Broks[2], L. Vempere[2]

[1]ITERA Latvija
50 Skanstes Str., Riga, LV-1013, LATVIA
[2]Riga Technical University,
Faculty of Electrical and Environmental Engineering,
Institute of Power Engineering
12-1 Azenes Str., Riga, LV-1048, LATVIA
*e-mail: laila.zemite@rtu.lv

A necessity to reduce greenhouse gas (hereinafter – GHG) emissions and energy import dependency, while coping with increasing energy demand, affordability issues and many other factors, causes the European Union (hereinafter – EU) energy policy makers to identify development trends that would help harmonize future energy market and technological changes with ever growing pressure of universal data processing digitalisation. In order to stimulate data processing digitalisation in energy, the European Commission has proclaimed a support to the development of all kind of the smart energy systems, where simultaneous use of the natural gas and renewable gases (hereinafter – RG) will play one of the major sustainability ensuring roles. Firstly, it will help achieve designated energy efficiency goals and, secondly, enable cost saving synergetic solutions at the early stages of the energy supply chain decarbonisation.

Synergy of the natural gas and RG emphasises the need for a modern, smart and sustainable energy infrastructure to allow developing more flexible back-up and balancing power capacity, storage solutions and innovative demand-response mechanisms.

This paper addresses some trends in development of the smart gas distribution (hereinafter – SGD) as part of the smart energy systems both in the EU and Latvia, with a particular focus on smart energy concepts, smart gas metering and grid modernisation.

Keywords: *Natural gas, smart energy systems, smart gas distribution, smart gas metering, synergy.*

1. INTRODUCTION

The natural gas is the second largest source of energy in the EU, which has provided between 23 % and 26 % of the European energy mix over the past two decades [1]. Its consumption is a subject to change on a yearly basis, and the greatest drivers of these changes are typically economic factors and weather conditions rather than structural energy supply chain transformations. Therefore, the present stability of the natural gas in the EU energy sector is determined by several key factors, such as cost competitiveness, security of supply, overall accessibility and sustainability [2].

The statistics shows that consumption of the natural gas in the EU has been quite stable also in recent few years, even demonstrating signs of some positive dynamics. In 2017, gross consumption of the natural gas in the EU increased by 3.7 % in comparison with 2016, to reach 18 587 thousand terajoules, but its use in the European energy production continued to demonstrate a downward pattern [3], [4].

For large-scale natural gas infrastructure in the EU, in order to stay relevant, fulfillment of additional functions beyond its traditional role of transporting fossil fuel is expected. Sustainability of the future natural gas networks will increasingly depend on their versatility, flexibility, and pricing of such commodities as carbon dioxide (hereinafter – CO_2) emissions and land use. Europe's natural gas infrastructure is a valuable asset, which should not be only preserved for sake of preservation, but used rationally to increase energy sector overall sustainability and enhance security of energy supply. The possibility to establish dynamic, integrated synergy between natural gas – regardless of its transportation means and final consumption sector – and RES in form of the RGs till 2030 and beyond will define its role in the EU's decarbonised energy future for decades to come [5], [6].

The average natural gas price at key trading hubs of Europe normally ranges between 5 and 8 US dollars per million British thermal units or 17 and 27.2 US dollars per megawatt hour, which refers both to pipeline supply routes and liquefied natural gas (hereinafter – LNG) import [7]. In power generation, the natural gas has been cheaper than coal across the EU energy markets since late 2018, when the prices of CO_2 emission allowances began to increase after several years of freefall [8]. The natural gas is cost effective and can present a viable alternative not only to coal, but also to growing role of electricity in industrial, commercial and residential power supply. In 2018, the average natural gas price for household consumers in the EU was 0.06 euro per kilowatt hour (hereinafter – EUR/kWh), while electricity price in the same sector averaged 0.21 EUR/kWh. Similarly, the natural gas price for commercial customers averaged 0.04 EUR/kWh and electricity price for commercial customers – 0.14 EUR/kWh [9]. In all, on a levelised cost of service basis, the price of the natural gas in Europe for different groups of consumers was 30 to 50 % less than the price of electricity [10].

In regard to security of supply, it must be pointed out that half of all the natural gas supplies in Europe come from outside the EU region. Given the declining local natural gas production, the share of supplies from the Russian Federation to the EU Member States alone has grown from 35.2 % in 2010 to 40 % in 2018 [11]. However, supply of the natural gas in Europe is relatively flexible, as multiple pipeline and LNG supply routes are available from the other third countries, including Algeria, the US, Qatar, Azerbaijan, and Libya. Notably, the share of LNG in the EU's natural gas supply structure is increasing rapidly: six new European countries have started importing LNG since 2010, but utilisation of regasification capacity has remained low, averaging less than 30 % over the past five years [1].

As for sustainability, the natural gas has already contributed to lower GHG emissions in Europe, but air pollution still remains one of the key environmental challenges, especially within cities. The latest European Environment Agency estimates show that fine particulate air pollution alone was responsible for about 400 000 premature deaths in European countries in 2016. Nitrogen dioxide emissions are also estimated to have caused 79 000 premature deaths in the same countries [12]. Fuel switching to the natural gas from coal in the power sector and diesel in the transport sector is widely acknowledged as one of the potential solutions to these problems. Since 2010, coal-to-gas switching has saved around 500 million tonnes of CO_2 as well – an effect equivalent to putting an extra 200 million EVs running on zero-carbon electricity on the road over the same period [13].

In mid- and long-term perspective, in order to ensure further utilisation of the existing natural gas infrastructure and decarbonisation of the EU energy sector, smart solutions and simultaneous use of RGs and the natural gas, with gradually decreasing percentage of the latter, are expected to be the key development drivers. Given that the necessity for smart transformation will be valid not only to the natural gas transportation and storage but also to the distribution level, the natural gas distribution industry will have to prepare itself to face the major novelties in the next two or three decades. Enabling technologies for data collection, analytics, and automation must motivate utilities to step back and take a comprehensive, critical view of their present infrastructure and operational activities, and thus welcome unavoidable modernisation of the natural gas distribution with regard to gradual transition to SGD [14].

It is quite challenging to predict with absolute certainty what the future may hold, once SGD becomes a reality because at the moment none of the EU Member States has a natural gas distribution system, which could be called truly smart. In fact, concepts of "smart energy systems" and "smart gas distribution" are still being defined [15]. Currently, only some elements of the SGD are present at the natural gas distribution level in Europe, such as more or less advanced smart metering and partial incorporation of RG production units into the natural gas grids. Moreover, incorporation of RG production units into the natural gas grids almost exclusively relates to biomethane production and injection into the natural gas grids at the distribution level. The RG supply diversification inputs of hydrogen are rare and sporadic [16].

The natural gas industries in many EU Member States are keen to gain more clarity and begin making necessary preparations for capturing the benefits from implementation of the SGD. It is important to be aware of the way the future of the natural gas distribution sector could look like when all major components of the SGD are puzzled together, and of the way the utilities get started with building out local SGD systems themselves. In addition, they should be developed with maximum preservation of the existing natural gas distribution infrastructure and benefits to consumers. These aspects are important not only at the energy policy and strategy planning level in the leading EU Member States, but also in small countries, such as Latvia.

2. CONCEPTS OF THE SMART ENERGY SYSTEMS AND THE SGD

2.1. Definition and Content of Concepts

The concept "smart energy systems" is widely used by energy professionals in numerous contexts as it was introduced in order to identify potential synergy points among different segments of the energy sector. Some researches specify that smart energy systems are cost-effective, sustainable and secure energy systems in which renewable energy (hereinafter – RE) production, infrastructures and consumption are integrated and coordinated through energy services, active consumers (prosumers) and enabling technologies [15], [17]. Smart energy systems can be all inclusive or entirely based on the use of RE. The principal differences of conventional and smart energy systems are shown in Table 1.

Table 1. Principal Elements of Conventional and Smart Energy Systems

Conventional energy system	Smart energy system
Electromechanical meters	Digital meters
One-way communication	Two-way communication
Few sensors	Multiple sensors
Fully manual maintenance	Mostly automatic maintenance
Manual monitoring	Automatic monitoring
Limited control	Unlimited control
Impossible dynamic system and energy consumption data access	Possible dynamic system and energy consumption data access, including near real-time and real-time remote meter performance analysis
Manually generated bills	Automatically generated bills
Impossible use in the SGD and integrated energy systems	Unlimited use in the SGD and integrated energy systems

Unlike "smart grid" and "smart networks", which mostly deal with grid automation only, the smart energy systems cover the entire spectrum of energy production, transportation, distribution, storage and consumption. [15] In case of natural gas, smart energy systems may also hold significant exploitation potential of the Internet of Things (hereinafter – IoT), which can initiate new correlation models by supporting not only methodological and engineering, but also economic synergy across different segments of the energy sector [18].

One of the pathways currently demonstrating dynamic synergy of two energy sector segments, namely, electricity and gas, is power-to-gas (hereinafter – P2G) technology, which mostly defines RE storage in a form of such gaseous fuels as biomethane and hydrogen. In all, P2G is a technology that uses electricity to produce a gaseous fuel and allows electricity to be stored and transported in the form of compressed gas, often using existing natural gas transport, storage and distribution infrastructure. P2G is often considered to be one of the most promising technology for seasonal RE storage [19].

A concept of the SGD therefore should be perceived as an integral part of emerging smart energy systems, and major estimated benefits of the SGD are as follows:

- lowering GHG emissions;
- decreasing the natural gas import dependency and improvement of the energy security of supply [20];
- increasing a share of RE (biomethane, hydrogen, syngas etc.) in the overall energy mix;
- improving energy efficiency by enabling active participation of the energy consumers (prosumer strategy) [21];
- creating conditions for efficient use of energy grids, thus giving consumers the ability to choose the most economic energy source in near real-time regime;
- avoiding additional investments in electricity networks by effective usage of existing gas grids, technologies and appliances;
- enabling synergies between gas and electricity sectors through encouragement of distributed generation [22].

There is not a widely accepted definition of the SGD either in the EU member states or in other countries of the world. For the purpose of clarity, in this paper a concept of the SGD is presented as a blend of three conjoined elements:

- the implementation of a range of new technologies to provide near real-time information about the end-to-end distribution system;
- analytics that allows for rapid decision making aligned with both a proactive approach to pipeline safety and overall operational efficiency;
- automated controls to help optimise both pipeline safety and efficiency [14].

The principal elements of the SGD are listed in Fig. 1. This scheme does not include multi-dimensional communication links among single elements of the system.

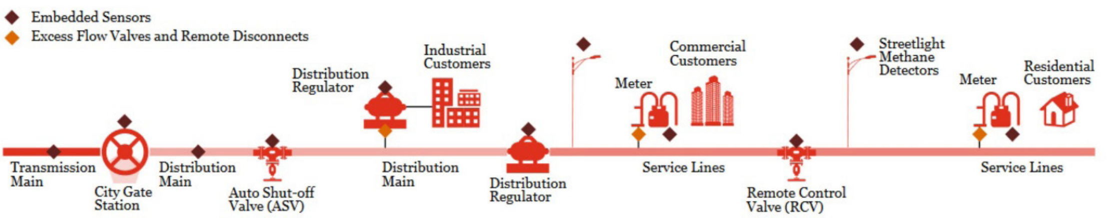

Fig. 1. Principal scheme of the SGD.
Source: *PwC*

2.2. Potential Disruptors of the SGD

New technologies are expected to change gas distribution operations fundamentally: smart sensors, controllers, and inspection technologies are being integrated with pipelines, valves, regulators, gas metering points/stations and gas meters to provide comprehensive, near real-time system information and unprecedented control of system operations. In addition, data from single smart system components, consolidated and analysed in the cloud, feed the SCADA system to allow for real-time optimisation of system operations as well [23]. It means that the SGD should not be evaluated in isolation, as system and data integration may be the most challenging aspect in its creation and enhancement. On the other hand, at the level of hardware, individual sensors or controllers cannot have a system-level impact without being integrated.

However, integration of data with operation, maintenance, and inspection information in the systems could trigger certain risks and challenges of integrity management, as well as better work planning and execution. Risks or potential disruptors of the SGD listed below fall into four main categories: smart pipeline and mobile technologies, advanced controls and automation, systems and records, and data processing and analysis.

Table 2. Potential Disruptors of the SGD

Category	**Potential source of disruption**
Smart pipeline and mobile technology	• Embedded sensors, inline robots – pipeline inspection gauges and ultrasonic inspection devices connected to SCADA • Remote leak detection by means of a car or other mobile technology, such as drones • Smart gas meters with expanded functionality and connectivity to other transmission networks • Mobile devices with secure connection to cloud-based information exchange and storage systems
Advanced controls and automation	• Remote control valves and automated shut-off valves connected to SCADA • Excess flow valves and remote disconnects integrated into smart gas meters • Natural gas distribution system visualization in the natural gas operations control centre
Systems and records	• Materials traceability • Enterprise system integration, including geographic information system, enterprise asset management, etc. • Data, records, and information management, including automated validation to ensure ongoing information quality
Data processing and analytics	• Analytics for all sources of information and relevant external sources of environmental information (e.g., weather, soil, seismography, traffic, etc.) • Tools for dynamic risk modelling and work prioritisation based on threat probability and consequence • Data archiving, safe keeping and on-demand traceability hubs

3. KEY EVALUATION FACTORS OF THE SGD AND SMART METERING

3.1. Key Evaluation Factors of the SGD

Emerging SGD calls for comprehensive planning that considers development of the natural gas distribution along three dimensions, which, at the same time, pose themselves as its key evolution factors: pipeline safety, risk-based integrity and asset management, and efficient, smart-tech-enabled consumer operations.

The impact of these three factors are described in Table 3 with regard to comparison of the current situation and theoretical estimates after implementation of the SDG.

Table 3. Key Evolution Factors for the SGD

Key factor	Current situation	Estimates after implementation of SGD
Pipeline safety	• Compliance-driven risk and activity management • Pipeline replacement, pressure testing, and capital projects carried out as special programmes • Mid-term investment programmes based on historical trends with a reduced linkage to current priorities and risks	• Proactive asset and integrity management • Safety enhancements and capital projects managed in line with regular everyday activities • Interaction with regulatory authorities based on a current view of systemic risks and actual performance efficiency
Risk-based integrity and asset management	• Asset, system, and consumer data are kept in disparate legacy databases • No formal asset management standards are enforced • Multi-annual investment planning and budgeting • Limited linkage between integrity management and work prioritisation	• Asset, system, and consumer data are validated and kept in enterprise systems/data warehouses • Strategic (annual and quarterly) and tactical (monthly and weekly) asset and work planning cycles are introduced • Analytics and risk modelling linked with monitoring technology and enterprise asset management systems to enable dynamic work identification and prioritisation
Efficient, smart-tech-enabled consumers operations	• Leak survey, corrosion and other inspection performed once every 3–5 years using traditional technologies and approaches • Low degree of system control and automation • Decentralised field and district operational model • Limited utility interaction with consumers "beyond gas meter"	• Frequent inspection and continuous monitoring of asset condition enabled by mobile technology and smart sensors • SCADA connected to a wider array of remote-control valves, automated shut-off valves and sensors with real-time system visualization at a common control centre • Centralised field and district operation model • Utilities provide a wider spectrum of services, including 3rd party vendors and partners, with greater consumer involvement

Source: *PwC*

However, in addition to three key evolution factors listed above, one more factor should be mentioned that most likely will have a significant impact on development trends of the SGD: information privacy. The requirements for the protection of personal data in the EU Member States derive from Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) [24], which Latvia enforced by the Personal Data Processing Law. It, inter alia, provides that SSOs, as data controllers or processors, must also guarantee data security of the smart metering system and energy consumers [25].

Current data protection strategies are built around a notion that the communication network used in the SGD should be private to ensure total consumer and utility data security. Even when a communication network is private, but shared among different service providers, it is critically important that security firewalls are impenetrable and the system can handle ever-growing use.

3.2. Smart Gas Metering and its Role in Creation of the SGD

Smart gas metering is one of the crucial elements of the SGD as it provides the possibility of uninterrupted, bidirectional data communication in near real-time between consumers and the distribution system operator (hereinafter – DSO) without human intervention [26]. It means that there is no need to send a technician to read gas meters at the consumers' residences or businesses, and therefore expenses of the system management are significantly reduced. Data exchange from the smart gas meter to the central system can be wireless or conducted via fixed wired connections. Wireless communications include cellular communications, Wi-Fi, wireless ad hoc networks over Wi-Fi, wireless mesh networks, low power long-range wireless etc. Wireless mesh networks are currently one of the most reliable and cost-effective IoT connectivity solutions available for a wide range of smart metering applications [27].

Smart gas meters allow for better measurement of energy use, and therefore provide greater opportunities to manage energy demand and improve utilisation of the energy system as well. If smart meters are not deployed, the energy transition and GHG reduction will be more expensive, less supportive of the RE generation, and less well co-ordinated. Without or with very limited smart metering in the EU, CO_2 reduction in Europe's gas sector will be slower and risks of limited participation of the natural gas and RGs in smart energy system development – much higher [28].

The introduction of smart metering in the EU Member States have different timing. In comparison with smart electricity metering, the deployment of smart natural gas meters was and still is much slower. However, benefits of the smart metering system in the natural gas sector are obvious: it not only contributes to more efficient energy use, but also significantly optimises the management of the natural gas supply system and collection, analysis and archiving of data [29], [30].

It is expected that by the end of 2020, the EU countries would invest around EUR 45 billion in installation of around 45 million smart natural gas meters and almost 200 million smart electricity meters. As a result, around 40 % of the natural gas consumers and 75 % of electricity consumers in the EU will use smart electricity and gas metering devices in their households, businesses or public buildings. In most EU Member States, full replacement of mechanical electricity meters has already been introduced or is planned for next 3–5 years, but the use of smart natural gas metering in all segments of consumption is expected in just a few countries, for example, Italy and Finland [30]–[32].

Smart natural gas metering meets requirements for fast and accurate collection, analysis and archiving of the natural gas consumption data, as well as provides opportunities for SSOs to perform more effective evaluation and planning of the natural gas supply system development in various regions of Latvia and other EU Member States. It may also contribute to the achievement of energy efficiency and system security targets [33], [34], which ensure sustainable economic development and prevention of further climate change. Moreover, with the introduction of SGD, costs for smart metering and data processing, archiving and storage are expected to decrease at a rate of approximately 7 % per year.

There is a wide range of smart natural gas meters in use in the EU, which all could be integrated into the smart energy systems and therefore – SGD. Diaphragm or membrane natural gas meters, which can also be equipped with a data transmission module, are mostly used for a low natural gas flow. In cases where natural gas has to be supplied to a small industrial enterprise or merchant, rotary natural gas meters are preferred. Turbine gas meters are designed to supply natural gas to industrial consumers at a massive, steady flow regime. However, under non-uniform load conditions, turbine meters generate metering errors [35]. Ideally, turbine meters should operate under stable and constant conditions of the natural gas flow in order to avoid pulsations and thus metering inaccuracies. If the flow of natural gas changes or is stopped altogether, the mechanism will continue to rotate for some time; thus, the metering inaccuracies are almost inevitable [36]. The effect of flow disturbances on the readings of the natural gas meter shall not exceed 1/3 of the maximum permissible error of metering instrument of a particular type and technological design.

Diaphragm natural gas meters are used in Latvia up to G25 level because other types of the natural gas meters with a higher performance rate have rather large dimensions and lower accuracy. For example, at times of pulsation of turbine natural gas meters, the inertia of the turbine wheel and subsequent metering error may occur during on and off mode [37].

Ultrasonic and microthermal natural gas meters are an alternative to diaphragm, rotary and turbine natural gas meters. They are used when exclusively high measurement accuracy is required [38]. Microthermal meters can keep an accurate metering rate even at very low initial flows. If correct functioning of diaphragm natural gas meters largely depends on the temperature and pressure, which can be seriously jeopardised without temperature and pressure correction, microthermal meters adjust metering specification to these factors automatically [30]. In contrary to diaphragm natural gas meters, the membranes of which may lose their elasticity over time, microthermal meters do not have moving parts that are subject to wear and tear and can affect the accuracy of metering.

In absence of strict requirements for the choice of technical equipment and software, there is a situation where different data reading systems with different makeup and functionality coexist in the different EU Member States. At some extent it hinders effective, comprehensive development of the SGD. There are also no requirements set for external power supply to smart meters in high gas consumption facilities, where big amounts of data need to be read and transmitted several times a day [30].

In the Latvian natural gas distribution system about 85 % of all consumption data are automatically processed. Data transmission is carried out via GSM communication system by inserting a SIM card into the data transmission device. Around 3,100 pressure and temperature correctors have been installed, of which 510 are equipped with telemetry. According to technical and functional parameters, uniform requirements for the smart meters for natural gas in Latvia have not been determined yet. However, Section 16, Paragraph four of the Energy Efficiency Law (hereafter – EEL) allows the system operator, taking into account the needs and potential benefits of the energy consumers, to determine the minimum functions of a smart commercial metering device, including the possibility to obtain information on actual energy consumption in a specific period of time. The EEL also stipulates that the system operator, when installing a smart commercial metering device, must provide energy consumers with information on the possibilities of meter management and energy consumption monitoring [39].

The importance of smart metering in the SGD is also determined by the detection and classification of the so-called bad data, which can be represented both by missing data or unusual information exchange patterns caused by unplanned events or failing data collection, communication or entry. As more and more information is fed into the system from different points of origin, the likelihood that mistakes will occur automatically increases. Bad data detection can be divided into probabilistic, statistical, and machine learning methods [40], and all are applicable to the smart energy systems and in part – to the SGD.

4. THE USE OF RGS AND RECONSTRUCTION OF DISTRIBUTION SYSTEM

4.1. RGs as Part of SGD

Increasing sustainability and carbon neutrality of the natural gas infrastructure all over the EU means growing presence of RGs in the natural gas sector. Here biomethane stands out as one of the most promising RGs to be blend with natural gas in large volumes, which can be done in a relatively short period of time [41]. Biomethane is flexible and easily storable fuel that can be used wherever natural gas grids exist without significant improvements to any parts of the natural gas transportation and distribution networks. In those EU regions where a natural gas grid already exists, there is a system suitable for the distribution of biomethane as well. It can be used as a direct substitute for natural gas and as fuel in heating, transport and electricity generation since it has the same properties as natural gas – achieving methane content levels greater than 96 % [42]. However, this methane content level benchmark is not legally or technically binding to all the EU Member States, as they can make their own decisions on how pure biomethane must be in terms of methane content to be injected into the grid [16].

More active use of RGs – mostly, biomethane and hydrogen – and their injection into natural gas distribution grids are important elements in the creation of the SGD. The SGD in principle is meant to be a primary recipient of these injections, as for the natural gas transport infrastructure, much higher injection pressure regimes are required. In Germany that is one of Europe's pioneers in the RG injection into the natural gas grids, several projects were carried out already in the mid-2010s, with biomethane facilities connected to the natural gas transport, instead of the distribution network. However, it must be pointed out that facilities connected directly at the natural gas transport level presented rather significant biomethane production capacities and were able to maintain the required high-pressure injection regime. For instance, it relates to Bioenergie Park in Güstrow, which provided the natural gas transportation grid with biomethane input at a maximum rate of up to 5000 m^3/h [43].

In Latvia, the injection of biomethane is also legally allowed in both natural gas transmission and distribution networks. Paragraphs 6 and 7 of Regulation of the Cabinet of Ministers No.650 "Requirements for the Injection and Transport of Biomethane and Gaseous Liquefied Natural

Gas in the Natural Gas Transmission and Distribution System" states that if biomethane is injected into the natural gas transmission system, where a minimum pressure at the moment is 25 bar, but most likely will be risen to 50 bar in the nearest future, its pressure must not exceed the actual pressure of the system by more than 5 bar. On the other hand, if biomethane is injected into the natural gas distribution system, its operating pressure must exceed the pressure of the system by not more than 10 % of the actual pressure at the connection point [44], [16].

It means that in future, when actual biomethane injections into the Latvian natural gas distribution network begins, the grid automation will need to address not only existing elements of the system in use today, but also those that will come online with grid introduction of the RG.

4.2. Modernisation of the Natural Gas Distribution System in Latvia

Successful implementation of the SGD in Europe as a whole and in Latvia in particular is hardly possible without complex, strategic enhancement of current natural gas distribution systems. DSOs have to modernise grids in order to preserve their technical capabilities and to make them more suitable for integration of new automated elements. Given the monopolistic status of many European gas DSOs, in future it will be necessary to couple their traditional regulated service functions with new market and systemic demands. The gradual natural gas distribution automation is about improved efficiency in grid operation, reducing operation costs and increasing grid reliability by introduction of a higher degree flexibility and autonomy.

In case of Latvia, the implementation of at least several elements of the SGD is fully up to the DSO JSC Gaso that, since its creation in late 2017, owns and manages all the natural gas distribution infrastructure in the country [45]. The major part of the natural gas distribution infrastructure in Latvia was built more than fifty years ago. Many of its elements are physically and morally outdated, so planned replacements are unavoidable. Complex repairs are not always possible without interruption of natural gas supply to consumers, but reduction of interruption duration, along with the modernisation of the natural gas supply system itself, is one of the strategic priorities defined by the Latvian gas DSO.

Both in the case of natural gas and electricity, several technical references are used to determine the level of system functionality, which characterise the number and duration of supply disruptions, as well as renewal of supply after unplanned disruptions. In 2019, the number of the natural gas supply interruptions (SAIFI) and duration (SAIDI) per consumer in the natural gas distribution system was 0.48 times and 56 minutes, respectively. In total, unplanned natural gas supply interruptions occurred 425 times. Additionally, the time for renewal of natural gas supply after unplanned interruptions (CAIDI) in 2019 corresponded to 88 minutes or 1.5 hours [46].

By comparing the information on the natural gas distribution SAIDI indicators of the Finnish, German, Lithuanian, Austrian and Latvian natural gas DSOs, it can be concluded that the performance of the Latvian DSO almost fully correlates with them. On average, during scheduled repairs, the natural gas supply outages last from 4 to 6 hours, and they are implemented on workdays – when the economically active part of the society is absent [46]. In very rare situations, while carrying out large-scale replacement of the technological equipment or reconstruction of the major system elements, it is necessary to disconnect customers for several days or even a week. However, the proportion of such works corresponds only to 5 % of all planned repairs carried out by JSC Gaso [47].

Annual investments in repairs and modernisation of the natural gas distribution system for next five years are equal to about EUR 5.5 million. These funds mainly go to activities, which, inter alia, will be of the utmost importance for further system automation and digitalisation as well, and they are: stabilisation of the natural gas network, reconstruction of regulation equipment, water seals, syphons and improvement of cathodic protection of natural gas pipelines. These investments, without which it is impossible to ensure the secure and stable development of natural gas supply in Latvia in a mid- and long-term perspective, fall into six main categories listed in Table 4 in descending order.

Table 4. Average Investments of Natural Gas Distribution System Modernisation (by category, in EUR per year)

Reconstruction of pipelines (cross-connection (looping), stabilisation, security of supply)	1.950.000
Reconstruction of gas regulation points	1.145.000
Shutting-off device replacement programme	800.000
Water seal and syphon replacement programme	350.000
Renovation of gas inlets of buildings	950.000
Improvement of cathodic protection	300.000
Total	5.495.000

Source: JSC Gaso

As it has been mentioned before, many elements of the Latvian natural gas distribution system are outdated, so their replacement needs to be carefully planned and implemented step by step. For instance, system looping significantly reduces risks for the stable operation of all types of natural gas distribution pipelines. It ensures that pressure stabilisation is achieved in the loaded sections of a system, and natural gas supplies from several directions can be carried out. There are also additional possibilities of the natural gas flow variation by using independent natural gas supply sources, when repair or reconstruction of individual gas pipeline sections is required, or in case of emergency. As a result, the level of security of the natural gas supply and system accessibility for new natural gas consumers increase significantly.

Works are also underway on the reconstruction of the equipment ensuring the stability of the natural gas supply itself, namely, gas control points (hereinafter – GCPs). At present, there are about 180 GCPs located in buildings in Latvia and several thousand cabinet-type GCPs. Every year, 5–6 GCPs in buildings, as well as several dozen cabinet-type GCPs are renovated.

During routine maintenance of GCPs, various technical problems and defects are often identified, and many of them are eliminated without delay. On the other hand, problems, which cannot be solved immediately, are included in capital investment and reconstruction programmes of JSC Gaso. The urgency of repairs mainly depends on the nature of defects, as they can vary from damaged fence to significant malfunctions in the major components of equipment, which require immediate replacement of damaged parts or even a complete reconstruction of GCPs. Where technically possible, GCPs are replaced by cabinet-type GCPs. It helps optimise the system and make it more compact: the GCP in a building normally takes up a large amount of space, but a cabinet-type GCP does not require more than a few square meters. In addition, both GCP and cabinet-type GCP can be equipped with telemetry, which allow obtaining data on the operation of the natural gas distribution network, thus increasing its operational safety and ensuring timely detection of non-standard situations and accidents.

During routine inspections of the shut-off devices (valves) located in wells or on the ground surface, various types of damage are detected regularly. Many of them can be immediately eliminated. But, if it is not possible, decisions are made to replace or liquidate the shut-off devices, by including these activities in the corresponding capital investment programmes [47].

Dismantling of the water seal and syphon installed during the Soviet era is also carried out gradually. Water seals of a low-pressure gas supply systems are used to interrupt the supply of natural gas, but syphons are designed to eliminate the liquid in gas pipelines. The usage of water seals is relatively safe, but their exploitation is rather complicated – during the shutting-off process water can enter the system, which can interfere with the normal operation of the natural gas supply. In addition, maintenance of a water seal is quite expensive in comparison with other shut-off technologies, and it cannot be automated. Syphons are mainly built in the former liquefied gas systems, and the necessity to preserve them is rarely justified. To some extent water seals and syphons pose one of the main hazards in terms of safety and integrity of the distribution pipeline system, because they are up to sixty years old, manufactured in workshops, their welds are not radiated and they are located in densely populated areas – mainly, in the courtyards of multi-storey apartment buildings.

In context of developing SGD, one of the future priorities for the European natural gas DSOs, including JSC Gaso, would be a necessity of further automation of the system, starting from consumption side and smart metering, and ending with the most robust parts and equipment used in the natural gas distribution in Latvia. It would allow following the actual trends of the DSO activities in Europe, improving sustainability of the system and optimising future inspection and maintenance costs.

5. CONCLUSIONS

The importance of gaseous fuels and the SGD in the future production, transportation and use of energy in the EU should not be underestimated. Gas grids will play one of the central roles in the overall shaping of the energy strategy thanks to their flexibility and compatibility with RE, including such RGs as biomethane and hydrogen. Storage abilities of the natural gas network, as well as RG and P2G technologies, will help solve many problems to attain to future energy efficiency in a sustainable way.

Although the SGD is not the first priority in the European debate concerning energy efficiency and development of the smart energy systems, the natural gas industry has been an active promoter of the synergic potential of the natural gas sector, and it refers to the gas distribution infrastructure, too. Furthermore, the existing natural gas infrastructure allows implementing cutting-edge innovative solutions for wider use of RGs. For instance, P2G shows that SGD can be used to store and transport the excess production of RE. RGs have been injected into the existing natural gas grids throughout the EU for more than ten years, and the potential for growth in this area is very large. Even in Latvia, it is estimated that biogas production potential is very substantial, including biomethane yearly production of about 300 gigawatt hours [48].

Natural gas networks have the ability to store a large amount of energy without additional storage improvement investments, and thus are much more flexible than electricity networks.

The potential of the SGD in Latvia is significant, as many elements of the system are currently digitalised, remotely controlled and inspected, so their integration into a single network, with gradual widening of its smart segment, resonates well not only with a universal need for modernisation, but also with investment in reasonable enhancement of flexibility, sustainability and future competitiveness of the existing natural gas distribution infrastructure.

ACKNOWLEDGEMENTS

The research has been supported by the National Research Programme, project "Trends, Challenges and Solutions of Latvian Gas Infrastructure Development" (LAGAS) (No. VPP-EM-INFRA-2018/1-0003).

REFERENCES

1. International Gas Union. (2020). *Global Gas Report 2020*. [online]. [accessed 14 November 2020]. Available at https://ceenergynews.com/reports/igu-global-gas-report-2020/
2. Stern, J. (2017). *The Future of Gas in Decarbonising European Energy Markets: The Need for a New Approach*. OIES Paper: NG 116.
3. Eurostat. (2018). *Natural gas supply statistics*. [Online]. [Accessed: 8 October 2020]. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_supply_statistics&oldid=401136
4. Savickis, J., Zeltins, N. & Jansons, L. (2019). Synergy between the Natural Gas and RES in Enhancement of Security of Energy Supply in the Baltic Countries (problem statement): The Latvian Perspective. *Latvian Journal of Physics and Technical Sciences, 56* (6), 17–32. DOI: 10.2478/lpts-2019-0032.
5. Savickis, J., Zeltins, N., Kalvītis, A., & Ščerbickis, I. (2018). Natural Gas Development Prospects in the World, Europe, in the Baltic and Latvia. *Energy and World Special Edition* (dedicated to the 4th World Latvian Scientists' Congress, June 2018, Riga).
6. Verdolini, E., Vona, F., & Popp, D. (2018). Bridging the Gap: Do Fast Reacting Fossil Technologies Facilitate Renewable Energy Diffusion? *Energy Policy, 116,* 242–256.
7. European Gas Hub. (2019). *Lowest European gas prices in 10 years*. [online]. [accessed 5 November 2020]. Available at https://www.europeangashub.com/lowest-european-gas-prices-in-10-years.html
8. Interactive CO_2 pricing data hub Embler. [online]. [accessed 12 November 2020]. Available at https://ember-climate.org/data/carbon-price-viewer/
9. ECRB. (2019). *Monitoring Report on the Functioning of Gas and Electricity Retail Markets in the Energy Community in 2018*.

10. Eurostat. (n.d.). *Gas prices by type of user*. [online]. [accessed 3 November 2020]. Available at https://ec.europa.eu/eurostat/web/products-datasets/-/ten00118
11. Statista. (n.d.). *Share of natural gas imported to the European Union (EU) from Russia from 2010 to 2018 (as percentage of total extra-EU natural gas imports)*. [online]. [accessed 22 November 2020]. Available at https://www.statista.com/statistics/1021735/share-russian-gas-imports-eu/
12. European Environment Agency. (2018). *Air quality in Europe – 2018 Report*. [online]. [accessed 1 November 2020]. Available at https://www.eea.europa.eu/publications/air-quality-in-europe-2018
13. International Energy Agency. (2019). *The Role of gas in today's energy transitions*. World Energy Outlook special report. [online]. [accessed 4 October 2020]. Available at https://webstore.iea.org/login?ReturnUrl=%2fdownload%2fdirect%2f2819%3ffileName%3dTheRoleofGas.pdf&fileName=TheRoleofGas.pdf
14. PwC. (2015). *Realizing the benefits of smart gas distribution*. PwC series: The promise and potential of smart gas distribution. [online]. [accessed 20 November 2020]. Available at https://www.pwc.se/sv/energi/assets/realizing-the-benefits-of-smart-gas-distribution.pdf
15. Lund, H., Østergaard, P.A., Connolly, D., & Mathiesen, B.V. (2017). Smart Energy and Smart Energy Systems, *Energy*, *137*, 556–565. DOI 10.1016/j.energy.2017.05.123
16. Savickis, J., Zemite, L., Zeltins, N., Bode, I., Jansons, L., Dzelzitis, E., … & Ansone, A. (2020). The Biomethane Injection into the Natural Gas Networks: The EU's Gas Synergy Path. *Latvian Journal of Physics and Technical Sciences, 57* (4), 34–51. DOI: 10.2478/lpts-2020-0020.
17. Smart Energy Networks. (2015). *Vision for smart energy in Denmark: Research, development and demonstration.* [online]. [accessed 14 November 2020]. Available at http://www.smartenergynetworks.dk/uploads/3/9/5/5/39555879/vision_for_smart_energy_in_denmark.pdf
18. Miller, W.J. (2017) Internet of Things (IoT) for smart energy systems. In Gabbar, H.A. (ed.) *Smart Energy Grid Engineering*. [online]. [accessed 2 November 2020]. Available at https://www.sciencedirect.com/science/article/pii/B9780128053430000115
19. Staffell, I., Scamman, D., Velazquez Abad A., Balcombe, P., Dodds, P., Ekins, P., … & Ward, K. (2018). The Role of Hydrogen and Fuel Cells in the Global Energy System. *Energy & Environmental Science*, *12* (2): 463–491. DOI:10.1039/C8EE01157E
20. Bouhafs, F., Mackay, M., & Merabti, M. (2014). *Communication challenges and solutions in the smart grid*. Springer
21. Sioshansi, F. (ed.). (2019). *Consumer, prosumer, prosumager: How service innovations will disrupt the utility business model.* Academic Press.
22. Smart Energy. (2015). *IGU World Gas Congress 2015*. Grid aspects related to Gas.
23. Sayed, K., & Gabbar, H.A. (2017). SCADA and smart energy grid control automation. In Gabbar, H. A. (ed.) *Smart Energy Grid Engineering*. 10.1016/B978-0-12-805343-0.00018-8
24. Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation). [online]. [accessed 20 October 2020]. Available at https://eur-lex.europa.eu/eli/reg/2016/679/oj
25. Fizisko personu datu apstrādes likums. (2018). [online]. [accessed 6 October 2020]. Available at https://likumi.lv/ta/id/300099-fizisko-personu-datu-apstrades-likums
26. ERRA. (2010). *Regulatory aspects of smart metering*. [online]. [accessed 5 November 2020]. Available at https://erranet.org/wpcontent/uploads/2016/03/KEMA_Issue_Paper_Smart_Metering_FINAL_eng.pdf
27. Geelen, D., van Kempen, G., van Hoogstraten, F., & Liotta A. (2012). A wireless mesh communication protocol for smart-metering. *International*

Conference on Computing, Networking and Communications (ICNC), 30 January–2 February 2012, Maui, HI, USA. DOI: 10.1109/ICCNC.2012.6167440

28. Delta Energy and Environment. (2019). *Smart meter benefits. Role of smart meters in responding to climate change.* [online]. [accessed 9 November 2020]. Available at https://www.smartenergygb.org/en/resources/press-centre/press-releases-folder/delta-ee-carbon-savings
29. Toratti, J. (2020). *Appraising the economics of smart meters: Costs and benefits*. London: Routledge.
30. Savickis, J., Zemite, L., Bode, I., & Jansons. L. (2020). Natural Gas Metering and its Accuracy in the Smart Gas Supply Systems. *Latvian Journal of Physics and Technical Sciences, 57* (5), 39–50. DOI: 10.2478/lpts-2020-0026.
31. Report from the Commission. *Benchmarking Smart Metering Deployment in the EU-27 with a Focus on Electricity* /* COM/2014/0356 final */ [online]. [accessed 1 November 2020]. Available at https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=COM%3A2014%3A356%3AFIN
32. Bianchini, A., Saccani, C., Guzzini, A., & Pellegrini, M. (2018). *Gas smart metering in Italy: State of the art and analysis of potentials and technical issues*. [online]. [accessed 10 November 2020]. Available at https://www.researchgate.net/publication/330260200_Gas_smart_metering_in_Italy_state_of_the_art_and_analysis_of_potentials_and_technical_issues
33. Zemite, L., Kutjuns, A., Bode, I., Kunickis, M., & Zeltins, N. (2018). Consistency Analysis and Data Consultation of Gas System of Gas-Electricity Network of Latvia. *Latvian Journal of Physics and Technical Sciences, 55* (1), 22–34. DOI: 10.2478/lpts-2018-0003.
34. Koposovs, A., Bode, I., Zemite, L., Dzelzitis, E., Odineca, T., Ansone, A., … & Jasevics, A. (2019). Optimization of the Selection Method for Reconstruction of Outworn Gas Distribution Pipeline. *Latvian Journal of Physics and Technical Sciences, 56* (5), 33–44. DOI: 10.2478/lpts-2019-0029.
35. Stoltenkampa, P.W., Bergervoetb, J.T.M., Willemsa, J.F.H., van Uitterta, F.M.R., & Hirschberga, A. (2008). Response of Turbine Flow Meters to Acoustic Perturbations. *Journal of Sound and Vibration*, 258–278.
36. Cascetta, F., & Rotondo, G. (2015). Effects of Intermittent Flows on Turbine Gas Meters Accuracy. Second University of Naples, *Italy Measurement, 69*, 280–286.
37. Platais, I., & Graudiņš, P. (2008). *Gāzapgāde. 1.daļa. Ogļūdenražu deggāzes, to īpašības, metroloģija un sadedzināšana*. Rīga: RTU izdevniecība.
38. Homann, K., Reimert, R., & Bernhard, K. (2013). *The gas engineer's dictionary. Supply infrastructure from A to Z.* Germany: DIV Deutscher Industrieverlag GmbH.
39. Energoefektivitātes likums. (2016). [online]. [accessed 11 August 2020]. Available at https://likumi.lv/doc.php?id=280932
40. Hodge, M., & Austin, J. (2004). A Survey of Outlier Detection Methodologies. *Artificial Intelligence Review, 22* (2), 85–126.
41. Outlook for biogas and prospects for organic growth. (2020). [Online]. [Accessed: 6 October 2020]. Available at https://www.euneighbours.eu/sites/default/files/publications/ 202003/Outlook_for_biogas_and_biomethane.pdf
42. European Biogas Association. (n.d.). *EBA's biomethane fact sheet*. [Online]. [Accessed: 22 November 2020]. Available at https://www.europeanbiogas.eu/wp-content/uploads/files/2013/10/eba_biomethane_factsheet.pdf
43. Green Gas Initiative. (2016). *Gas and Gas Infrastructure – the Green Commitment*. Recommendations for curbing climate change: Biomethane, power to gas and gas as fuel in transport [online]. [accessed 1 November 2020]. Available at https://www.greengasinitiative.eu/upload/contenu/greengas_initiative_report_web_2016_1.pdf

44. Ministru kabineta noteikumi Nr. 650. (prot. Nr. 50 5. §) “Prasības biometāna un gāzveida stāvoklī pārvērstas sašķidrinātās dabasgāzes ievadīšanai un transportēšanai dabasgāzes pārvades un sadales sistēmā”. [Online]. [Accessed: 20 October 2020]. Available at: https://likumi.lv/ta/id/285189-prasibas-biometana-un-gazveida-stavokli-parverstas-saskidrinatas-dabasgazes-ievadisanai-un-transportesanai-dabasgazes-parvades-...
45. GASO. [online]. [accessed 20 November 2020]. Available at https://www.gaso.lv/uznemuma-rasanas
46. *Elektroenerģijas un dabasgāzes sadales pakalpojumu kvalitātes pārskats par 2019. gadu* [online]. [accessed 1 November 2020]. Available at https://www.sprk.gov.lv/sites/default/files/editor/ED-Kvalitates-parskats_2019%20(3)_0_0.pdf
47. AS “Gaso”. (2018). *Piecu gadu investīciju (attīstības) programma*.
48. Bethers, J. (2020). *Enerģētikas sektora izaicinājumi ceļā uz klimata neitralitāti 2030/2050*. Conference presentation.