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PHYSICAL AND TECHNICAL ENERGY PROBLEMS

SMART CITY THROUGH A FLEXIBLE APPROACH TO SMART ENERGY

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The paper provides an overview of the development trends of the smart city. Over the past decades, the trend of the new urban model called smart city has been gaining momentum, which is an aggregate of the latest technologies, intelligent administration and conscious citizens, which allows the city to actively develop, and effectively and efficiently solve the problems it is facing. Profound changes are also taking place in the energy sector. Researchers and other specialists offer a wide variety of innovative solutions and approaches for the concepts of intelligent cities. The paper reviews and analyses the existing methodological solutions in the field of power industry, as well as provides recommendations how to introduce the common platform on the basis of disparate sources of information on energy resources existing in the city as an optimal solution for developing the city's intelligence, flexibility and sustainability based on its starting conditions.

Keywords*: energy management, multi-energy city, smart city, smart city model, smart energy city, platformization*

1. INTRODUCTION

According to [1], in 1950, 30 percent of the world's population was urban. However in 2050, two-thirds of the world's population is projected to be urban. It is estimated that more than six billion people will live in urban environments, i.e., nearly 70 percent of the Earth's population and with nearly 90 percent of the increase concentrated in Asia and Africa. In recent decades, cities around the world have been experiencing in a very active form the process of transformation of the urban environment, forced to solve large-scale tasks and take serious challenges: demographic (including population aging and migration) [2], technological [3], green lifestyle [4], etc. technologies; environmental and social-economic [5]. The need to adapt cities to these processes and challenges has led to the emergence of a

number of concepts and urban development strategies based on them, which can be treated as a gradual transformation of cities into a smart / intelligent city leading to more efficient urban planning and management and, ultimately, ensuring the high quality of life of the inhabitants by introducing advanced technologies, improving the environmental situation, maintaining the continuity and quality of urban life support systems.

In this process, central place is taken by the innovative development of urban infrastructure – energy, transport and communications. Scientific and technological progress in recent decades has revealed a number of fundamentally new opportunities for improving the quality of life in megacities, including the growth of population mobility, the reduction of environmental pollution, the transformation of urban space (for example, the introduction of intelligent street lighting systems, smart water or electricity metering, etc.). Especially strong progress is observed in green energy technologies: smart energy systems and renewable energy sources (RES), which can radically change the urban environment of big and small cities in the future.

It is well known that energy resources are not infinite; to solve the problem with their exhaustion, smart management of energy supply, infrastructure and energy flows is necessary. Among other systems and elements of the future, economists, environmentalists, energy specialists and engineers identify the following energy elements/components: smart household appliances, home energy management systems, building energy management systems, consumer/ prosumer, energy storage, electric vehicles and microgrids.

Currently, the well-known concept of the Smart City, presented in the form of wheel with six development vectors [6], is supplemented by the term "Smart Energy City" [7] as a city of smart energy, resource efficient, where intellectual energy is based on a variety of sources, integrated and sustainable in the general infrastructure of the city, which also contains innovative approaches to strategic planning. However, the abundance of different definitions of a smart city, as well as a lot of approaches to the interpretations of ways how a city can become smart, and different understandings of the importance of separate vectors of development do not give a clear picture of methodology or approach, which is most rational moving to the smartness.

Megapolises with a multi-million population as well as small towns, cities with developed infrastructure and just starting their way to develop intelligence, cities in warm countries and in countries with a cold climate, cities with a developed transport system and electric vehicles or lack thereof – they all want to become smart, and all they need their own methodology and ways to achieve smartness, suitable for their starting conditions.

Based on the above-mentioned considerations, this definition of "smart" city can be given: a city whose all resources are spent most effectively on the basis of the analysis of the information received from all structures, organisations and inhabitants of this city.

The paper presents an analysis of approaches to energy management and planning in smart cities, their strengths and weaknesses, as well as recommendations for the holistic and effective planning of urban development towards sustainable growth of intelligence.

2. ROLE OF ENERGY IN THE SMART CITY CONCEPT

Moving toward intelligent cities and improving the quality of our life in cities, we need to understand clearly, what we are speaking about. We need to keep in mind the whole concept of a smart city, its separate aspects and vectors of developing. Smart City is an urban development that unites the needs of the citizens in a sustainable and secure way along six vectors:

1. Smart Governance: Public and private organisations, transparency of city management and its infrastructures, open data.
2. Smart Economy: on the basis there are the processes that support the sustainable growth of the city, its individual parts and infrastructures.
3. Smart People: people who contribute to creativity, have critical thinking and are able to apply innovative ICT for their everyday life.
4. Smart Mobility: integrated transport and logistic systems, innovative transport solutions.
5. Smart Living: healthy and safe living through smart technologies and applications that enable responsible lifestyles, behaviour and consumption.
6. Smart Environment: sustainable increasing of renewable energy sources and green energy managed by ICT control and monitoring, waste and pollution control and smart management.

Despite the fact that the term "energy" in the above-mentioned concept is hidden, it is obvious that energy is the key to the sustainable development of the smart city as is shown in Fig. 1.

All six vectors need energy in its different forms and ways, which requires the development of its intelligent, efficient production, transformation, storage, distribution and consumption in all areas of the smart city. Therefore, it is necessary to find a way of an effective interaction between the dimensions of a smart city and the energy which participates and interacts with each of the areas of development.

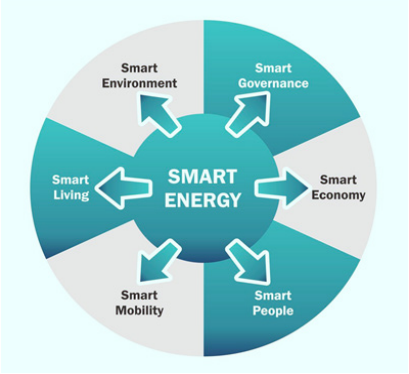

Fig. 1. Smart city and smart energy interaction model.

Whereas energy has the most influence on other vectors for the development of a smart city and its fundamental base, an important factor is the understanding of the clear and successful methodology for the development of smart energy in city. To streamline the approach to understanding smart energy in the city, the concept of "Smart Energy City" (SEC) has been created, which makes possible to be aware of the need for an integrated approach to energy in a smart city.

The way to develop the sustainable smart energy city is considered by [8], providing the definition for SEC, as well as giving a set of smart energy practical solutions and technologies, considering interconnections between such concepts as smart city, smart energy, sustainability and its management and stressing that interaction between these basic areas is not enough clear delineated.

A more holistic SEC definition is provided by [9]: “The Smart Energy City is highly energy and resource efficient, and is increasingly powered by renewable energy sources; it relies on integrated and resilient resource systems, as well as insight-driven and innovative approaches to strategic planning. The application of information, communication and technology is commonly a means to meet these objectives. The Smart Energy City, as a core to the concept of the Smart City, provides its users with a liveable, affordable, climate-friendly and engaging environment that supports the needs and interests of its users and is based on a sustainable economy.” Such approaches to smart energy are really diversified and make clear enough the whole picture of the smart city and the role of smart energy in it.

In addition, since initiatives aimed at the effective implementation of renewable energy sources have an advantage in the development of cities, the issue of the ecological introduction and use of smart energy is more acute than ever in all spheres of city life. As stressed in [10], the transition to renewables happens all across the entire urban energy landscape from buildings to transport, industry and power. Renewables can bring tremendous benefits to cities, including cleaner air, modern services and improved living spaces. At the same time, cities are crucial to the world’s transition to a low-carbon economy, accounting for 65 % of global energy use and 70 % of man-made carbon emissions. The intermittency of renewable sources, the increasing demand, and the necessity of energy-efficient transport systems, among other things, represent important energy challenges that are better addressed as a whole rather than separately, as is usually the case [11].

As a brief summary of the main points, it is necessary to mention that the concept of a smart city, including the six development vectors, covers all major interconnected areas of the city. This city model is appropriate to use for a general overview of trends, overall development planning and identifying areas required for transformation. On the other hand, the concept of smart energy city implies a more professional, more focused approach to selecting and adopting solutions that are necessary for city development, based on an integrated approach to energy issues as the most influential factor in the sustainable development of a smart city. Cities’ energy requirements are complex and abundant. In consequence, modern cities should improve present systems and implement new solutions in a coordinated way and through an optimal approach, by profiting from the synergies among all these energy solutions.

The complexity of the approach to smart energy city is illustrated in Fig. 2.

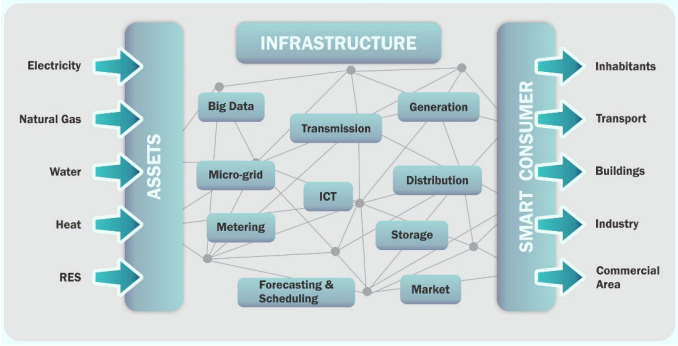

Fig. 2. Smart energy structure.

Between the energy sources and their final smart consumers, there is an infrastructure that includes a variety of different positions, from production and conversion of energy, to the use of ICT solutions, micro grids, and others that make energy consumption smart, economical, sustainable, meeting the needs of the environment and raising awareness of consumers and prosumers.

3. REVIEW OF APPROACHES TO SMART CITY

The research questions involved in transforming cities into smart cities are highly complex and can only be solved by taking an interdisciplinary, transnational approach [12].

We propose to consider different methods of the smart city dimensions. Table 1 provides an overview of approaches to modelling and developing smart energy and smart city.

Table 1

Approaches to Smart City Development

Approach	Short description
Employment of optimisation to single sectors of development	Innovative solutions aimed to develop separate vectors and areas solving local problems. Use of indicators, city ranking, standardisation, IT-based innovation approach to create a suitable solution
New city planning	Methodologies with recommendations on what is needed to plan and implement any new development (smart district, smart city)
Development of smart energy city (SEC)	At the forefront, there is smart energy as one of the most important aspects of the development of a smart city
Energy hubs, multi-energy systems	Prospective development of a smart city through integrated multi-energy systems
Smart city infrastructure architecture model (SCIAM)	Complex approach to a smart city by considering city layers with various indicators and their interactions
Blockchains	Applicable to smart city, the blockchain is the right network to succeed in the delivery of codes (policies, planning, regulations and standards) since it is universal and decentralised, allowing for a bottom-up delivery of codes owned and implemented by the citizen and not by a central authority.
Platformization	Unification of disparate resources of a smart city on the platform basis

A large group of methods and approaches concentrate on making a study, planning and development of smart cities in a gradual, step by step, improvement of each city sphere, moving toward smartness. The article [13] considers energy-intervention areas within the city and their relations, as well as compares different currently available energy models, energy-efficient facilities, control systems, and demand-response schemes. The paper [14] explores the relations existing among urban and territorial networks, actors and stakeholders, functions and activities, suggesting a way to integrate various aspects of a smart city.

An approach called Smartainability, with the help of quality and quantitative indicators, assesses the extent to which enabling technologies for intellectual solutions contribute to improving energy efficiency and environmental sustainability in the city [15]. Thus, the presented group of studies offers options for moving towards smart city, starting with the selection of a separate area of development, for example, an increase in the efficiency of electricity use in smart buildings, or decision to cut traffic congestion in the city, etc., till planning simultaneous implementation of effective solutions in various areas. It is also proposed to use indicators, standards, comparison of development indicators and the rating of cities to determine the areas with the greatest need for improvement.

Another group of smart city studies argues that the most optimal solution is the planning of separate regions, districts or even a whole city in advance by including in the plan all the necessary infrastructure and possibilities for smart building and using smart technologies of a smart city. It is claimed that cities generally have no clear idea as to their precise future smart city requirements at the present time, and specify few models in order to effectively meet potential future requirements, and give guidance on what is needed to plan for any new development to support the smart city plans for a chosen area [16].

Some authors focused on the issues of smart city through the prism of smart energy, believing that energy management is the most influential means of developing smart cities [8], [17]. The overall approach of the Sustainable Urban Regeneration Model [18] describes an approach to the Sustainable Urban Regeneration Model, stressing that cities need to become 'smarter' with respect to energy optimisation. The added value of the proposed methodology lies in the combination of energy efficiency and energy management using multidisciplinary data sources.

Another area of consideration of smart city issues, which has become very relevant in the past few years, is the use of energy centres (energy hubs) for the optimisation and efficient management of energy flows throughout the city. The use of various models, including energy hubs, as well as the possibility of their use for different conditions and needs of the city, its flexibility and management is considered in [19] and [20]. In [21], the idea is discussed that a smart city can be considered to be an open complex giant system, from which consensus emergence can be demonstrated and handled by meta-synthesis method, and clarify the differences between smart city management and traditional city management.

An example of considering a city as a multi-dimensional system and an approach to modelling solutions through the construction of a model for each layer is presented in smart city infrastructure architecture model (SCIAM) [22].

In recent years, one more approach has become increasingly popular and topical – the so-called blockchain technology – a continuous sequential chain of blocks, containing information built according to certain rules. Most often, copies of blockchains are stored independently of each other (extremely parallel) on a variety of different computers. The technology of blockchains can be extended to any interconnected information blocks. The source [23] expresses assurance that the blockchain networks will disrupt the urban context as well, similarly to what is happening with the previous application domains, and put forward Future Living Framework as the meta use case of a wide research called Blockchain4Cities. The

benefits of using blockchain in the urban field was shown. “Blockchain is here to take on and be the next network for cities.” Article [24] discusses a model for service the prosumers using blockchain technology, which allows connecting different sources of energy to different users and manufacturers. Analysing the energy picture of users, the authors argue that this technology leads to increased energy efficiency. Blockchain technology and energy issues are combined to integrate the power and information infrastructure.

Platformization – a holistic approach to smart city vision – will be described in more detail in the further section of this paper.

According to the above-mentioned considerations, there are many approaches to consider smart cities, which we tried to classify. Each of them has a right to exist, and was developed based on a certain vision of an intelligent city. Based on these different visions, methodologies and tools for achieving smart results were developed. Can we consider the development of one particular area or the solution of one particular task a result? Of course, yes. However, a smart city is the widely branched infrastructure with multiplicity of functions and multivariate conditions for their interaction. Therefore, we believe that some of the approaches to the development of a smart city are better suited for a holistic transformation of the city into an intelligent one, while the other approaches to a less degree serve this purpose.

4. SMART SOLUTION FOR CITY STRIVES FOR INTELLIGENCE

In the forefront of the city development, there are multidisciplinary methods and innovative decisions of production, transmission, accumulation and consumption of energy resources, with the purpose to optimise the already existing technologies and equipment, and there are approaches to flexible switching to new, such as mini-generators, micro-grids and the use of the energy of wind, sun, hydrogen and renewables.

Emiliano Dall’Anese, Pierluigi Mancarella, and Antonello Monti in [19] consider energy production-transforming-storing-consumption aspects with the so-called hubs – the energy centres. By means of hubs it is suggested to solve a problem of delivery and consumption of energy resources, such as electricity, gas, water, district heat, etc. Nowadays, the policy of decarbonisation is on the top, as well as implementation of production and electricity consumption from small generation from renewable energy sources. Therefore, the increasing relevance is acquired by the need to shift supply of energy resources and their consumption, e.g., by means of energy accumulation, or a pre-discretion of additional power sources. Energy centres (hubs), depending on the needs of a network and load consumption, can have a variety of inputs/outputs and conversion stages, along with the storage of different energy types. Relevant optimisation problems can be used to compute the optimal energy mix for the hub to minimise operational costs or to optimise the operation of an interconnected system of energy hubs.

The principal advantage of such a system is its flexibility, as well as an ability to use energy resources economically and operationally; it is trouble-free in deliveries taking into consideration the possibilities of energy producers and consumer demands for different types of energy.

The examples of transmission-level and distribution-level modelling and applications were considered, stressing that the new approach to multilevel energy flexibility could be available in gas, electricity, heat and water networks through emerging technologies that could be accounted for in the development of integrated optimisation and control strategies considering not only potential flexibility benefits but also relevant flexibility constraints.

This picture is not complete without citizens or local residents, who are supposed to participate in the innovation process through platforms.

Platformization is also a relatively new trend in the development of the infrastructure and the city as a whole. Since all the advantages of smart cities with new technologies, devices and approaches to solving problems arising in cities are associated with people living in them, with their awareness and willingness to promote city development, efficiency and care of the environment, special attention should be paid to creating the opportunity for citizens directly participate in the life of the city, managing its processes and actively influencing all structures. The issues [25], [26] and [27] raise problems of the effectiveness of the development of any city through the creation of a common infrastructure through open data in the form of a platform where multiple sources of information from all over the city, its most important functions and objects are collected. This approach to the development of the city, based on the human resource, raising awareness of citizens, the perspective of transforming consumers into prosumers, deserves close attention in the perspective and current trends in energy, transport, ICT and other areas.

Platformization means the unification of disparate sources of information, for example, in the case of energy, the production, distribution and sale of electricity and heat, the supply of gas, hot water, the weather forecast, the price of energy services offered by various sellers, the forecast of the cost of electricity on the exchange, the data concerning customers' consumption of electricity, and much more, gathered under one "roof" – on the basis of a common platform, where data from each information source are collected and constantly updated.

Unlike solutions based on the introduction of more and more advanced technologies to enhance the city's intelligence, the work [25] proposes a way to achieve an intelligent and sustainable city by combining existing infrastructure, i.e., open government data and data from large energy companies and sensory networks deployed in cities, by providing a mechanism for sharing the heterogeneous data sources offered by the city, which reduces the complexity of access to city data while bringing citizens closer to the role of prosumer and allowing for integration of data into the city's ecosystem.

As stressed in [28], an open data portal is the gateway to a city's open data resources. The open data portal becomes a progressive way, through which the city can provide its citizens and specialists with extensive data concerning economy, management, as well as special areas such as energy, transport, buildings, etc. Besides, it would be good practice to maintain an open data portal independent of the control of city authorities, large management companies and other interested parties. Open access to data is the right of all citizens of the city. Raising the awareness of citizens by keeping them informed allows the city to have the opportunity to make serious and qualitative steps towards enhancing the effectiveness, sustainability of

all indicators and actions performed in it. The more open data from different areas of functioning are available, the more opportunities are available for a diverse combination of them, the more effectively and powerfully the combined platform performs its functions, the more professionals and residents will turn to it to solve their problems, the greater the consensus can be found in resolving any issue related to the topic of a smart city.

Thereby, an acceptable way to reach flexibility is to organise an open and protected data space such as a smart platform, including an ordered data structure from multiple sources such as energy producers, distributors and sellers of energy resources, the data from consumers and prosumers, as well as possible additional sources of useful information, e.g., weather forecast, data from the electricity exchange at the moment, its statistics by month and by year etc. The examples of such platforms can already be seen in many European countries, e.g., [29] (Estonia), [30] (Denmark), [31] (Norway), [32] (Austria).

Open data allows expanding the management and development of smart cities, including among others the possibilities of navigating open data sources, transparency and accountability, performance management, transportation and infrastructure, resilient city planning, IoT of smart cities, civic engagement, etc.

5. CONCLUSIONS

Small and large cities collect a huge amount of information about what is happening to them. Much of this information has been collected over the years, and some of it is available for public review. Nevertheless, to work effectively, we need more than some separate resources we can find on the Internet, for a fee or without it to get acquainted with certain information, for example, on energy consumption, or the possibility of using different tariff plans for electricity consumption, etc. By unlocking data and making them open with the help of a common data platform, we can achieve much greater efficiency in managing resources, increasing citizen awareness and ultimately in accelerating the development of each city towards its sustainability and intelligence.

Leading experts in a smart city theme believe that energy, transport and information and communication technologies are the key challenges for the further development of smart cities. Electricity, natural gas, water and district heating systems are predominantly planned and operating independently from each other. However, it is getting recognised more and more that integrated optimisation and control of these resources will make it possible to achieve greater efficiency and environmental benefits. Integrated actions across multiple infrastructures can balance costs while increasing safety and access to energy (both by limiting greenhouse gas emissions and by optimising the use of natural resources).

It is evident that nowadays energy solutions based on a rigid, non-variant approach to the production, distribution and consumption of resources or using the data have lost their relevance. The urban environment of modern cities requires a different approach based on flexibility, the possibility of combining different spheres, services and proposals, as well as the ability to control and manage infrastructures with high speed of response and making the right decisions.

The viability of any system is determined by its flexibility, i.e., the ability to timely and adequately respond to any tasks that have arisen in connection with the system during its operation. Another crucial feature is the ability to solve issues related to its functioning in a comprehensive manner, making the right decisions not only based on the current situation but also taking into account the prospects for the development of this and neighbouring areas. Such a system can develop steadily and purposefully in any circumstances, flexibly adjusting to the changes that have occurred. It is the qualities a smart city needs now most of all.

Based on the above-mentioned considerations, a conclusion can be made regarding the topic under consideration, i.e., smart energy in a smart city. The creation of a unified open data platform based on numerous sources of energy and related information will make it possible to develop a smart energy city in an efficient, sustainable, economically viable and environment-friendly way to promote active involvement of citizens in the life of the city and contribute to its intelligence.

The complex approach to solving the multivariate questions of the development of a smart city is undoubtedly in the collection of all the data of a smart city (big data) into a unified platform. This would allow solving at once many tasks on the way to the formation of an intelligent city, at whatever stage of development it is now. These tasks are the efficient and rational use of energy resources, the transparency and accessibility of data, the increase in citizens' awareness through their active involvement in the management of the city and its resources, as well as solving transport problems, reducing CO2 emissions and introducing green energy sources into the urban environment.

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VIEDĀ PILSĒTA: ELASTĪGA PIEEJA VIEDAI ENERĢIJAI

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K o p s a v i l k u m s

Pēdējo desmitgažu laikā arvien populārāks kļūst jaunais pilsētvides attīstības modelis, saukts par "viedo pilsētu", kas ir jaunāko tehnoloģiju konglomerāts, kā arī inteliģenta un apzināta pārvaldība un dzīvesveids, kas ļauj pilsētai efektīvi attīstīt un risināt problēmas, ar kurām tā saskaras.

Milzīgas pārmaiņas notiek arī pilsētu enerģētikas nozarē; pētnieki un citi speciālisti piedāvā visdažādākos inovatīvus risinājumus un pieejas viedo pilsētu koncepcijām. Raksts ir veltīts esošo metodisko risinājumu pārskatīšanai un analīzei enerģētikas jomā, kā arī ieteikumi apsvērumu apskatei kopējās platformas ieviešanai, pamatojoties uz esošajiem pilsētas atšķirīgajiem informācijas avotiem par enerģijas resursiem. Šajā rakstā tiek pētītas "viedo pilsētu" attīstības tendences un pieejas, ir piedāvāti optimālie risinājumi pilsētas elastīgas un ilgtspējīgas attīstībai.

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