Smart Approach to Management of Energy Resources in Smart Cities: Evaluation of Models and Methods

Jana Teremranova and Anna Mutule

Abstract A smart city represents a complex approach to the development of all systems, directions and spheres aimed at providing comfortable living conditions for citizens and qualitative management and reliable infrastructure for the city. The paper answers questions about how to estimate the ability of the implementation approach within a smart city, and how the stakeholders, such as energy policy makers, governance, utilities and municipalities, can choose a model that would promote maximum efficiency by the implementation in the energy sector of the city. The paper has three main sections, the first of which provides a literature review with a classification of different approaches to the implementation of a smart city depending on the scope and tasks. The main emphasis is placed on the analysis of the energy component of smart city decisions. The second section proposes a series of criteria for evaluating the existing approaches to a smart city. The ability to flexibly react to the changes in consumption, unpredicted situations, changes in the needs, sustainability in generation and the supply of electricity and heat, as well as considering alterations in the legislative base, has been taken into account when analysing smart city infrastructure. Finally, the third section presents a decision-making scheme related to choosing the development methodology in a smart city that enables accounting of multifaceted nature of urban environment development, as well as describing a scheme of the block-integrated approach to the methodology of smart city development. In the authors' opinion, it can have the largest potential for flexible, sustainable and stable development and will produce the greatest qualitative impact on smart city development. As a result, convolving the approaches to the development of a smart city according to various criteria makes possible highlighting the most optimal decision-making process.

Keywords Assessment of approaches · Platformization · Smart city · Smart energy

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A. Bisello et al. (eds.), *Smart and Sustainable Planning for Cities and Regions*,
Green Energy and Technology, https://doi.org/10.1007/978-3-030-57332-4_1

1 Introduction

At the moment, there is a wide variety of definitions and approaches to resolving issues within the so-called smart city. Comfortable living conditions (Jiménez et al. 2016; Bornholdt et al. 2019), high-quality and reliable management (De Filippi et al. 2019; Suwa 2020) are the key characteristics of a city that can call itself "smart", "intelligent". Over time, not only the definitions of a smart city have changed, but also have the ways to implement this sphere of development (Lim et al. 2019). Nevertheless, the multitude of approaches to solving smart city tasks is not only an advantage; it also brings difficulties in choosing the most appropriate model or solution.

In addition, it should be noted that the task of smart city modelling and evaluating is so complex that it requires a breakdown by application areas, namely, energy, economics, education, etc., in order to find a clear and unambiguous solution. There is a lack and ambiguity in assessing models of the urban environment as a whole in existing empirical literature on the energy sector of a smart city. Furthermore, assessment approaches are usually used for local purposes, limited by separate initiatives. This has served as an incentive for research with the development of a system of criteria for assessing the energy sector of a smart city. What can contribute to improving the feasibility of projects within the framework of a smart city? What should be taken into account when choosing a model that can bring the greatest results at the lowest cost? These problems have been solved by creating a spectrum of criteria for evaluating approaches to the energy aspect of a smart city, followed by the proposed decision-making scheme for choosing the best development methodology.

2 Description of Existing Smart City Models: Literature Review

There are many general models that use an integrated approach to transforming a city into a smart city. The present paper focuses on one of the various aspects, namely, energy. Undoubtedly, each specific model should be chosen in accordance with the tasks facing the city. Nowadays, a plentitude of approaches, methods and algorithms are available for solving tasks related to ensuring the sustainable operation of the energy sector of a city. Nevertheless, a shortage of systematization and assessment can be observed that are aimed at ensuring assistance to the stakeholders such as municipality and energy city planners that could help choose an optimal approach to implementing a plan of urban development and making changes towards a smart energy city. To achieve this goal, a table taken from Mutule et al. (2018) was further elaborated to create Table 1 in order to discuss existing approaches to the development of a smart city.

In order to encompass changes in a specific sector or part of an urban structure, local solutions to various energy issues are acceptable and sufficient (Calvillo

Table 1 Regimentation of the approaches to smart city development

Smart city approach	Description	Sources
Employment of optimization or automation to single sectors of development	Smart solutions aimed at solving the energetic problems of individual areas of the city. Additionally, the KPI sets, standardization and innovative IT-based approaches are used to create a suitable solution	Calvillo et al. (2016), Mattoni et al. (2015), EU Smart Cities Information System
Smartainability	This approach uses qualitative and quantitative indicators of technology assessment for intelligent solutions that are designed to improve energy efficiency and environmental sustainability in the city; it is more focused on integrated intelligent mobile platforms	Girardi and Temporelli (2017), Bounazef and Crutzen (2018), Ambrogi et al. (2016), Giordano et al. (2012)
New city planning	Planning and implementation of new smart districts or a city with pre-laid smart energy infrastructure (e.g. the use of 100% renewable energy sources for energy consumption and heating/cooling of buildings and the use of electric vehicles only, use of sensors, etc.) for further development and expansion. The approach considers state-of-the-art technologies and requirements for the level of comfort of residents and the preservation of the environment	BSI (2014), Farag (2019)
Smart city infrastructure architecture model (SCIAM)	Multi-level holistic approach to energy in a smart city; it uses separation of the energy infrastructure of the city into layers, levels and zones, considering their interactions	Uslar and Enge (2015), Bawany and Shamsi (2015)
Development of smart energy city (SEC)	Smart energy is presented as the most important and necessary aspect of the successful and sustainable development of a smart city	Mosannenzadeh et al. (2017), Nielsen et al. (2013), García-Fuentes et al. (2017), Papastamatiou et al. (2017)

(continued)

Table 1 (continued)

Smart city approach	Description	Sources
Energy hubs, multi-energy systems	Development and operation of a smart city through the creation of the so-called energy hubs aimed at the flexible integration of the diversity of the city's energy resources for the most efficient, cost-effective and stable resource management	Dall'Anese et al. (2017), Mancarella et al. (2016), Weisi and Ping (2014), Yu et al. (2014), Rayati et al. (2015), Si et al. (2018)
Blockchains	Considers blockchain technology application in a smart city context and in energy aspect as a focused task, by using for energy supply operations, measuring the amount of electricity consumed, billing for consumed resources and making payments	Marsal-Llacuna (2017), Hwanga et al. (2017), Li (2018), Kotobi and Sartipi (2018), Qian et al. (2018), Lazaroiu and Roscia (2018a), Guan et al. (2018), Xie et al. (2019), Shen and Pena-Mora (2018), Lazaroiu and Roscia (2018b)
Platformization	Combining information resources on energy generation, transmission, distribution and use in a smart city, which usually are not connected to each other on a unified platform; therefore, it makes it possible to simplify and clarify the procedure for monitoring and managing energy resources for both citizens and the administration of the city	Aguilera et al. (2017), Smart Cities Councel; International Electrotechnical Commission (2014), Bollier (2006), Elering; Energinet; Elhub; APCS; Anttiroiko (2016), Thornton (2016), Anttiroiko (2015), Kaulio (2010)
Frugal social smart city	A new concept for smart city proposed for Casablanca, Morocco. It is based on a global bottom-up multidisciplinary approach that relies on the informational and functional cost-effective integration of various urban complex systems such as energy, transport, health and governance	Hayar and Betis (2017), Ramesh (2015)

et al. 2016; Mattoni et al. 2015; EU Smart Cities Information System). However, the expansion of the area of influence, aimed to create integrated progress towards a smart city, has led to the formation of a special area called smartainability (Girardi and Temporelli 2017) which originated in Italy. One of the main priorities for the development of smart energy city highlights mobility as having a strong impact on the energy sector of the city as a whole (Bounazef and Crutzen 2018). Ambrogi et al. (2016), apart from the mobility, also include energy and telecommunication to the model under study, which helps to expand the view on smart city energy problems and solutions. The topics of methodology and the smartainability strategy were developed by Giordano et al. (2012). Along with more traditional approaches to changes in the direction of a smart city, the articles (BSI 2014; Arab News 2019) present an approach implementing modelling of an entire district or city, which makes possible, despite the high cost of such projects, integrating the advanced innovative energy developments into the model. Another way to approach the modelling of a smart city as a holistic structure is presented in the Smart City Infrastructure Architecture Model (SCIAM) (Uslar and Enge 2015; Bawany and Shamsi 2015). The main idea is to integrate the city information systems into the developed multi-level architecture in order to effectively provide public services to citizens. Investigating the concept of a smart energy city (Mosannenzadeh et al. 2017; Nielsen et al. 2013; García-Fuentes et al. 2017) primarily aims at optimizing urban energy systems and improving the quality of life of citizens, thus clarifying the relationship between a smart energy city, a smart city and a sustainable city, and offers a set of solutions and technologies in the energy field. Cooperation of multiple stakeholders and the integration of urban energy areas included in specific energy goals enable devising the most effective energy solutions to promote the sustainable development of smart cities (Papastamatiou et al. 2017). A different view on the solution of the flexibility and sustainability of the city energy structure is presented in research (Dall'Anese et al. 2017), where the authors propose integrating the so-called energy hubs into the city energy structure. In turn, Mancarella et al. (2016), Weisi and Ping (2014), Yu et al. (2014), Rayati et al. (2015) and Si et al. (2018) suggest applying a multi-energy management framework, thus making it possible for the city to achieve a new level of development of flexibility, sustainability, security and efficient use of energy resources through their optimal combination and solving critical issues. The same issues have been given the opportunity to be resolved with the help of the blockchain technology, which has gained popularity in recent years: from a literature review (Shen and Pena-Mora 2018) and the possibilities of the blockchain technology in an urban environment (Marsal-Llacuna 2017; Li 2018; Smart Cities Council), architecture models for the interaction of energy prosumers (Hwanga et al. 2017) to issues of effective communication in an urban environment using blockchain technology (Kotobi and Sartipi 2018; Xie et al. 2019) and the application of the blockchain technology and smart metres to help prosumers in energy production and consumption management (Lazaroiu and Roscia 2018b). In this case, it is also necessary to take into account possible negative aspects of this technology that may be encountered (Kiran et al. 2019).

To develop effective approaches to handling big data, both from city services and the individual data of city residents, Aguilera et al. (2017) use the idea of a city-wide platform architecture, while the Smart Cities Council report presents the advantages and benefits of open data, which are an integral part of the urban infrastructure platformization that is revealed by International Electrotechnical Commission 2014 in terms of collaboration, integration and interoperability. The user-centric city model focuses on citizens who are "co-designers, co-producers and co-learners" (Bollier 2006) with the government, while the Aguilera et al. (2017) study developing this topic also emphasizes the interaction of smart city management and the activity of its citizens and provides recommendations for state policy. In recent years, there have been an increasing number of examples regarding the practical application of existing platforms (Elering; Energinet; Elhub; APCS), combining various city infrastructures under one "roof" and considering a number of theoretical and practical issues for using platformization to improve the citizens' life in a smart city (Anttiroiko 2016, 2015; Thornton 2016; Kaulio 2010).

Another area that has deserved attention in recent years has made the frugal social smart city (Hayar and Betis 2017; Ramesh 2015) its main goal, making changes in the urban environment affordable and feasible with small means, which makes possible extending the experience of changes to a wide range of cities with small financial opportunities, owing to competent administration and increased activity of citizens. However, it is less focused on the use of new advanced technologies and thereby limits the range of possibilities for solving total tasks.

A wide variety of approaches to solving the problems of a smart city provides, on the one hand, the opportunity of applying an individual approach to a specific task for specific conditions of the urban environment and the present stage of development, and on the other hand, it creates a difficult situation for those who are forced to make the final decision on the use of tools that are most relevant to the needs of the city. For a clear and balanced choice, it is necessary to classify approaches with the subsequent methodology, allowing an optimal choice of a tool.

3 Methodology

To understand the choice of the appropriate model for the implementation of the planned development of the city, many aspects should be taken into account. To promote an understanding of the strengths and weaknesses of the approaches (see Table 1), a variety of criteria has been proposed that enables a comprehensive assessment of each of the approaches. The evaluation is provided for each criterion based on the frequency of occurrence in the literature and the importance of a particular criterion given by experts.

Flexibility is one of the main parameters that meets the modern requirements of a smart city, according to the literature review provided in Table 1. It manifests itself heterogeneously in the selected approaches, prevailing as much as possible in new city planning, energy hubs, blockchains, platformization and frugal social smart

city. A vast majority of sources indicate the presence of flexibility in the mentioned approaches, while in the description of single sector optimization, smart energy city and SCIAM, the flexibility to respond to changes in needs is mentioned to a lesser extent, though it is present in these tools.

Transparency, as a tool for data openness, accessibility, and data-based operations, is part of a smart city system and is presented moderately among the selected sources. The platformization-based approach differs in the role of transparency that is put at the forefront, being one of the cornerstones of this method.

The economic affordability of the selected model ranges from low (with significant financial investments requiring a long payback time) in new city planning to high (requiring relatively low costs) at a separately selected optimization point, as well as in platformization and frugal social smart city, which originally incorporated the idea of low financial investments.

Attracting citizens to active participation (see Table 1) is becoming an increasingly valuable and necessary resource for the effective operation of a smart city. Many authors of publications point out the need for the active participation of citizens in urban management. The positions occupying the last three columns in Table 1 gained the maximum number of references about the possibility and desirability of participation of citizens in the formation of the urban environment. Accessibility of standardization and unification was mentioned in the literature as a significant and necessary criterion for the quality and sustainable development of the city.

The use of ICT has firmly entered the concept of a smart city, and without it, the development of a smart city is impossible. In most models (see Fig. 1), the readiness and necessity of transformations are noted, taking into account innovative information technologies. Only the frugal social smart city model, due to its specificity and initially set goal, focuses to a great extent on the human resources and to a lesser extent on computerization and technology.

The top–bottom and bottom-top criteria in the context of the approach to solving smart city issues can be considered in relation to the specific tasks set for the city and can serve as an additional support for clarifying the choice of the model. To a great extent, it depends on the institution initiating the transformation in the city: utilities, government, municipalities, electricity generation or distribution companies, energy efficiency projects and initiatives, etc. The consideration of these criteria also becomes important when applying some innovative technologies (e.g. blockchain, which involves the foundations of interaction on the basis of partnership and an equal contribution of the resources of the participants of the chain to the process).

To coordinate urban changes with the requirements of the EU, UN and others, for example, on energy efficiency or reducing CO_2 emissions in the atmosphere, many authors highlight an environment-friendly criterion. Its application will enable the city to successfully claim high positions in the ranking of smart cities in the future. To evaluate the approach from the prospects for further development, it is worth taking into account the criterion “opportunities for further development after the implementation of the model” (e.g. when planning a smart city, prospects for development are already considered in advance, as well as opportunities are envisaged

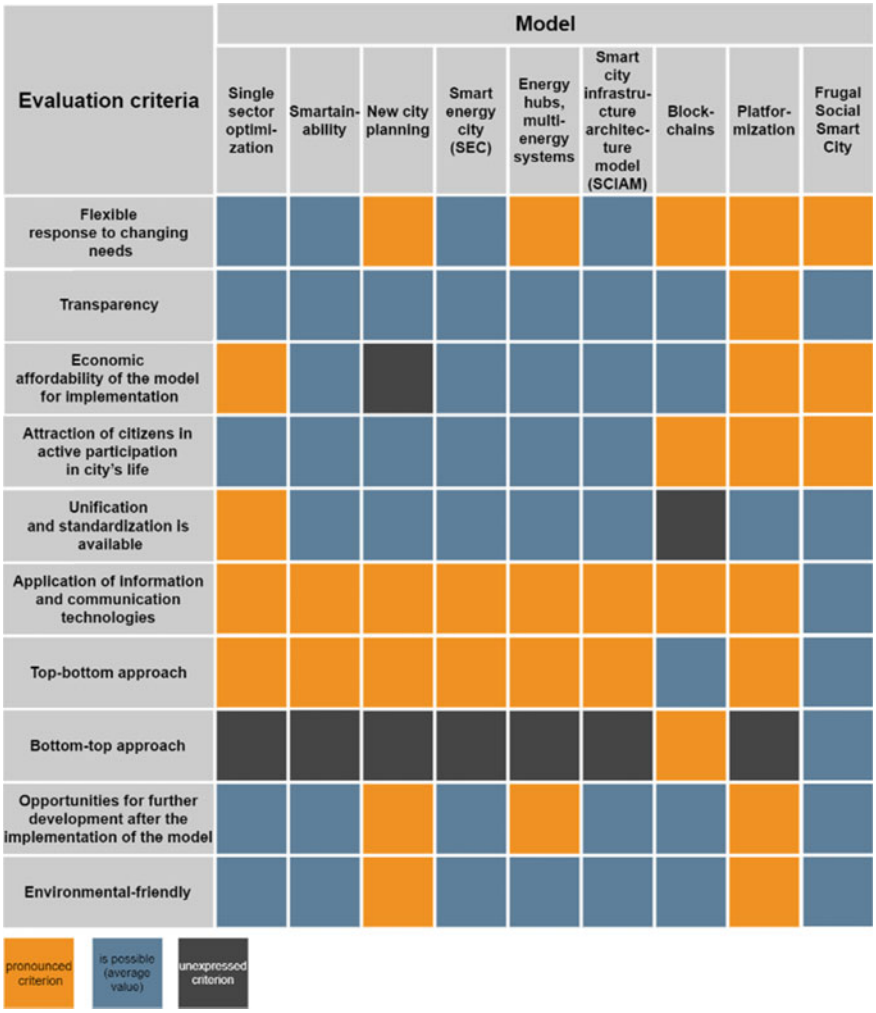

Fig. 1 Evaluation of various models of smart city development according to the criteria selected

for embedding the latest technologies that may appear after the implementation of the project of a new smart city).

The evaluation of all the criteria mentioned is illustrated in Fig. 1.

A general analysis of the evaluation criteria of the approaches demonstrates that platformization has a strong position in almost all criteria, which means that this approach can be highly recommended for the implementation of almost any activity within the framework of the development of a smart city. Platformization will allow naturally integrating the additional data, as well as the requirements for new methods of processing and presenting information into the existing structure. The blockchain approach also confidently leads in the number of functions shown, being a progressive

and promising factor in the successful development of the city, where standardization and unification will follow the technology as it develops. Economic affordability (availability of the necessary financial resources) of the model for implementation certainly does not occupy the last place in the list of criteria, without which it is impossible to reasonably and responsibly plan any changes in the urban infrastructure. Although planning of a new city with the latest technologies and opportunities for environmentally friendly and active participation of residents is very attractive, the economic factor is the strongest negative factor for the wide implementation of this approach. In contrast, single sector optimization, platformization and frugal social smart city are examples of cost-effective spending, which are suitable for almost all cities, irrespective of the initial conditions and amount of resources. The optimal, from the point of view of the authors, model of development of a modern city is considered in the next section.

4 Findings

It would be improper to consider a certain model of the development of a smart city without considering the needs of the city, to which it should be applicable. The available resources, legislation, the degree of resident activity and the existing and proposed development plans should be considered, as well as the previous urban initiatives must be taken into account. Only after fulfilling the just-mentioned tasks, does it becomes possible to set an achievable city development goal, which implies the selection of an optimal methodology (see Fig. 2) that meets the requirements of all stakeholders. The coordination of interests of all stakeholders of the city will contribute to concretization of the necessary requirements and confidence that all opinions are maximally considered in an integrated approach.

The development of the urban environment is an ongoing cycle of changes that is based on the same algorithm each time, but with the use of an individual approach (methodology) for an urgent task, in order to advance to a smart city.

5 Discussion

Based on the analysis of evaluation criteria of approaches to the development of a smart city (see Fig. 1) and elaborated decision-making scheme (see Fig. 2), the authors conclude that the block-integrated approach, combining platformization, blockchain and one of the specific industry approaches (energy, transport, health care, economics, etc.), can have the greatest potential to flexible, sustainable and stable development and will enable the greatest possible quantum leap towards the development of a smart city (see Fig. 3). Such a developmental method presupposes the necessary transformation of the industry (using specific knowledge gained, indices and standards, attracting high-level professionals), enables accessibility, convenience

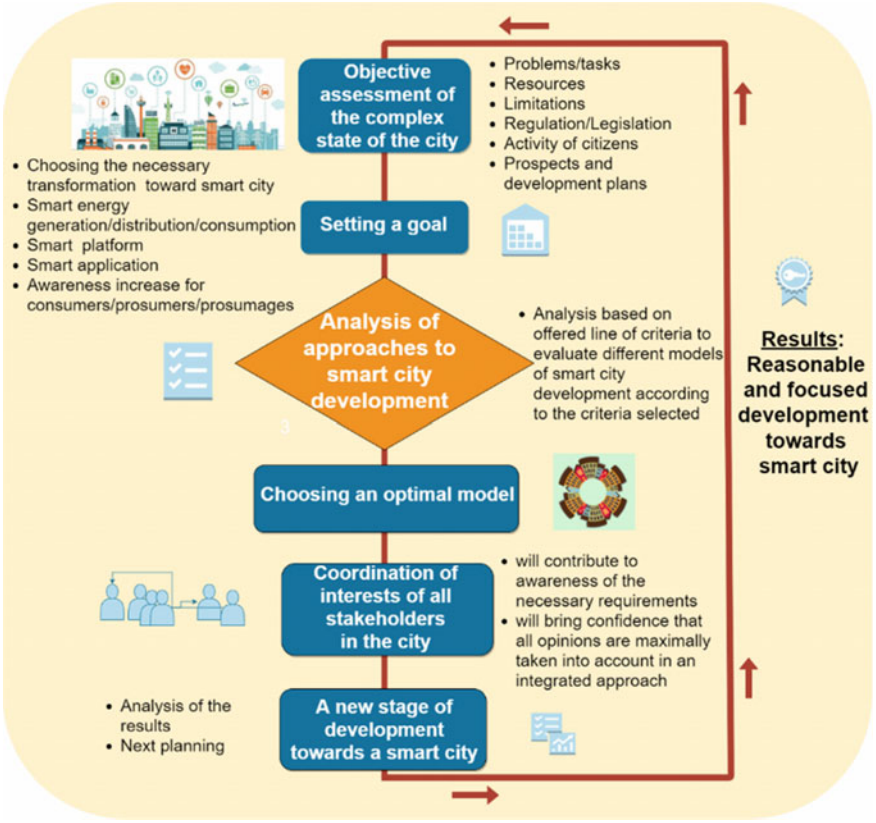

Fig. 2 Decision-making scheme for choosing the developmental methodology in a smart city

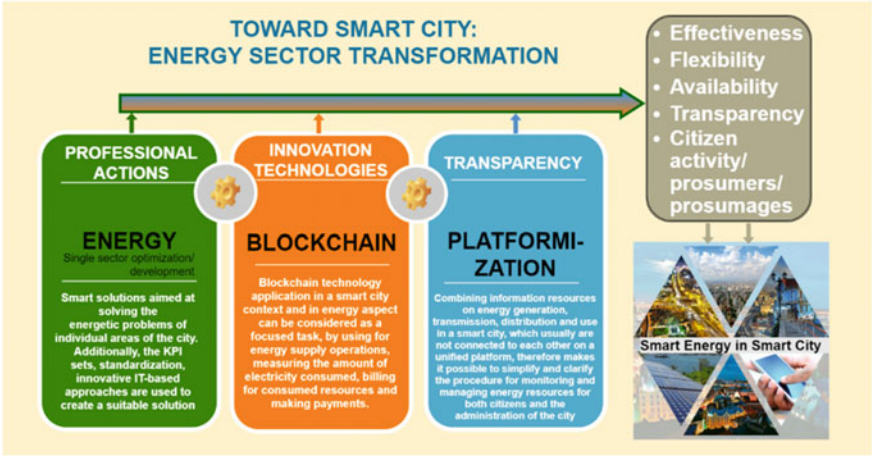

Fig. 3 Block-integrated approach to the developmental methodology of a smart city

and transparency of the data approach through an open platform and enables implementing plans with the help of modern reliable and fast blockchain technology as an effective platform for transactions within the network combining equal partners. A successful experience introducing blockchain technology into the energy industry can be illustrated by initiatives in Chile on a governmental level (CNE 2018), as well as in France, Italy, Germany, Japan and other countries where large energy companies or government organizations are already transferring energy data to the blockchain. They are interested in developing this concept from the conceptual level to a practical result, sharing the views of many world-class experts that blockchain is the advanced technology of the past decade and can become part of everyday life in the next few years. Potential options for using blockchain in the energy sector include not only the possibility of improving security, but also the use of peer-to-peer (P2P) distribution networks, customer billing (tracking of paid work and costs and billing and payment control) and renewable energy certificates.

The developed energy infrastructure of the city intends to use the advanced technologies in the field of energy, e.g. a smart approach, the organization of sustainable and flexible energy supply in the context of the country's specifics, where much attention is paid to training programs for residents on energy efficiency. In this case, the block-integrated approach will serve the replication of experience in a competitive environment and address the needs for flexible, sustainable and transparent city, e.g.

- the use of big data in the design of the platform: the necessary and sufficient amount of data, correct use of data, perception of different types of processed data by users, the ease of adding new data and the ease of handling them;
- combination on one platform of all available energy sources in the city and the ability to add new sources;
- the impact of the blockchain technology on the consumer market and the activity of residents, the accumulation of successful experience of its use, understanding of areas where blockchain can be used to the greatest benefit, etc.

6 Conclusions

The proposed decision-making scheme for selecting a smart city developmental methodology will consider all the results achieved by the analysis of opportunities and resources of the region, as well as will contribute to the accumulation and replication of best practices. This is the key to a successful, qualitative and long-term development. Serving as a guideline for optimal model selection, the evaluation criteria for a model of smart city development help administrators, urban planners and stakeholders. The most viable, efficient and stable smart city model must be flexible and adaptive to the resources and current needs of the city. Such a reliable model, along with a qualitative assessment using the multifunctional criteria proposed in the paper, can satisfy the needs of residents and participants in the urban infrastructure at

any request and affordability level, and the positive experience can be disseminated and replicated to other cities and areas.

Acknowledgements This work has been supported by a project of the Latvian Council of Science: Management and Operation of an Intelligent Power System (I-POWER) (No. Izp-2018/1-0066) and the Latvian State Education Development Agency (VIAA), project "An ICT Platform for Sustainable Energy Ecosystem in Smart Cities" (ITCity), ID: ELAC2015/T10-0643.

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