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## Economic efficiency and energy security of smart cities

Wadim Strielkowski<sup>a</sup>, Tatyana Veinbender<sup>b</sup>, Manuela Tvaronavičienė<sup>c</sup>  and Natalja Lace<sup>d</sup>

<sup>a</sup>Faculty of Economics and Management, Department of Trade and Finance, Czech University of Life Sciences Prague, Prague, Czech Republic; <sup>b</sup>Institute of Service and Sectoral Management, Department of Economics, Organization and Management of Production, Federal State Budget Educational Institution of Higher Education, “Industrial University of Tyumen”, Tyumen, Russian Federation; <sup>c</sup>Department of Business Technologies and Entrepreneurship, Vilnius Gediminas Technical University, Vilnius, Lithuania; <sup>d</sup>Department of Engineering Economics and Management, Riga Technical University, Riga, Latvia

### ABSTRACT

The aim of this paper is to provide an analysis of the determinants of economic efficiency and to assess the prerequisites for the energy security of smart cities. The main methods of the paper include an economic analysis of the infrastructure improvements that result in reducing the energy demand of the smart cities represented by the intelligent light-emitting diode (LED) street lighting system. Smart LED streetlights are getting increasingly popular in the world’s major metropolises as one of the leading components of the “smart” city. We compare the efficiency of LED street lighting used in smart cities with a commonly used lighting system based on sodium lamps. Our results demonstrate that LED street lighting system can significantly reduce the energy demand of any modern city. Moreover, we show that smart grids might help distribution systems within smart cities to better integrate intermittent renewable energy sources such as wind and solar. The main research novelty of our study compared to previous studies from the literature is the estimation of net profit (NP), Net Discounted Savings (NDS), as well as the total savings (TS) using the example of an average European metropolis. Our findings show that there is a need for better management including strong networks of leaders to drive smart city policies and investments and to cover wider city areas with economically sustainable projects and plans. In addition, our findings yield that smart city projects should aim at finding solution for smart connected local energy storage systems to support more renewable energy sources on the power grids. Our results might be of a special interest for city planners, local government stakeholders, as well as urban policy makers dealing with planning and managing smart cities.

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**CONTACT** Manuela Tvaronavičienė  [manuela.tvaronaviciene@vgtu.lt](mailto:manuela.tvaronaviciene@vgtu.lt)

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## 1. Introduction

Large urban centres and world's major metropolises are capable of sustaining the reliability and security of their energy supply based on the advancements in the development of their energy sectors as well as on enhancements in social efficiency and the quality of life of their dwellers (see Urbaniec, Mikulčić, Rosen, & Duić, 2017; Zeibote, Volkova, & Todorov, 2019; Snieska, Zykiene, & Burksaitiene, 2019; El Iysaouy, El Idrissi, Tvaronavičienė, Lahbabi, & Oumnad, 2019; Tvaronavičienė, & Slusarczyk, 2019; Al Badi, Ahshan, Hosseinzadeh, Ghorbani, & Hossain, 2020). However, all of the above requires massive investments into the novel managerial and information and communication technological solutions that would create the prerequisites for the decent level of the quality of life, ensure the focus on the socio-economic direction of the city economy, as well as the enable the smart cities to play their key functional roles.

Smart city applications are designed to manage urban flows and provide real-time answers to such issues as energy efficiency, demand side response, as well as energy management, just to name a few (Jindal, Kumar, & Singh, 2018; O'Dwyer, Pan, Acha, & Shah, 2019; Petrenko, Vechkinzova, & Antonov, 2019; or Deveci, Pekaslan, & Canitez, 2020). Different concepts of smart cities are based on the existing technology (Li, Cursio, Sun, & Zhu, 2019).

The main methods of this paper convey an economic analysis the economic efficiency. They are doing so using the smart city infrastructure improvements leading to decreasing energy demand when it comes to city lighting system represented by the smart light-emitting diode (LED), a technology that is taking over many world metropolises. It becomes clear that a technology-based intelligent city is not only a concept but there are several combinations of technological infrastructure that constitute the concept of smart cities. A smart city has social capital and it could be possible and easier to create an intelligent urban concept if there is a mix of education and education, culture and arts, business, as well as commerce. In addition, it can become a source of entrepreneurial opportunities (Barba-Sánchez, Arias-Antúnez, & Orozco-Barbosa, 2019; Sousa, Melé, & Gómez, 2020).

Thence, it is logical that all of the features mentioned above and having an impact on the city itself, its dwellers, the socio-economic, technological, entrepreneurial, as well as managerial spheres, should take into account the interests of all involved parties in general and the interest of the society and individual in particular. All of these constitute a concept of the "smart city". The "smart city" is a broad definition that consists of a multitude of elements including "smart" power supply, smart grid system, "smart" environment, "smart" transport, "smart" home, as well as "smart" management. The key principles of the smart city embrace the following parameters:

Planning and construction of houses, neighbourhoods and areas as urban planning and energy levels-units (Sarma, Karnitis, Zutters, & Karnitis, 2019).

- Sustaining the autonomy of the levels of the city;
- Providing the social, business and cultural self-sufficiency of the city (Smaliukienė & Monni, 2019)
- Ensuring the development of standards for green building;

- Employing the information and communication technology;
- Introducing the innovative energy technologies (the key energy efficiency), transport and construction (see Tvaronavičienė, 2018; Taveres-Cachat, Grynning, Thomsen, & Selkowitz, 2019).

Infrastructure scheme of the typical smart city involves the connection of individual sectors through information and communication technologies which is carried out according to the principle of “a system of a sub-systems” that means achieving a compliance of the mechanism of integrated management (see Minoli, Sohraby, & Occhiogrosso, 2017; De la Hoz-Rosales, Camacho, & Tamayo, 2019). A characteristic feature of “smart” systems is that their degree of intelligence which is ensured by a variety of infrastructure options providing a controlled adaptation of the structure to changing external conditions, the active development of systems based on the information and communication technologies, as well as the presence of man as a subject and object of functioning and development of the “socially oriented meta-system” (SoM). This “triple SoM” (which is a system based on the three pillars - infrastructural, informational, and intellectual) represents a framework of the “smart” metropolis, and energy as a system of not only life support, but also the life of the city as a “living” organism, should develop as a meta-system (see Hefnawy, Bouras, & Cherifi, 2016).

With regard to the above, it becomes clear that the concepts of the Internet of Things (IoT), in which all devices are interconnected via networks, as well as the Internet of Energy (IoE), in which each subject (consumer) not only selects the information she or he needs, but also making a decision about his or her own or collective energy supply, taking into account the interests of other members of society and the entire socio-natural environment, becomes a key requirement for the smart cities (Bibri, 2018).

In addition, smart grid also becomes part of the overall smart city model, while not only uniting physical infrastructure objects (power system, traffic, communications) and high-level Internet information into a single intellectual complex, but also forms the systems’ energy information system as a single human-machine ecosystem (Strielkowski, 2017; Ragulina, Semenova, Zueva, Kletskova, & Belkina, 2018; Gulati & Kaur, 2019; Dudin, Frolova, Protopopova, Mamedov, & Odintsov, 2019; Vlasov, Shakhnov, Filin, & Krivoshein, 2019; or Praharaj & Han, 2019).

Therefore, it is impossible in the smart grid system to consider the physical level of the power supply separately and separately - the automatic control as a superstructure of physical objects.

This is a single SoM that integrates individual infrastructure subsystems according to the types of energy used as well as the degree of their localization and centralization. The main idea, however, is that they manage (independently) the management of individual objects by several agents and coordinate these actions at the level of coordinating common goals, strategic plans and risk assessment of decisions taken.

The uniform energy information system smart grid offers a compromise solution in the interests of all actors involved in the general life support system and in the life of the metropolis. The principle of autonomy and network-centric unification of the

two physical objects and their information models is based on the multi-agent management of individual blocks and systems of group management of the energy supply in the smart grid system.

Smart grid systems are actively developed in practice for powering local facilities and areas. Their introduction has been prompted by the need to harmonize the conditions and modalities of decentralized production, mainly with the aid of renewable energy sources, into the general network structure.

Decentralized systems are not autonomous, and their interconnection to a common power grid structure requires a sufficiently developed information and control network built on the smart grid-based method (He, Pan, Liang, & Wang, 2018). With regard to the power scheme of large world megapolises, the problem of using the smart grid taking into account the adjoining areas both with regard to the development of decentralized systems and their integration into the general infrastructure SoM, as well as with regard to the increase in the social efficiency of the energy saving.

The aim of the paper is to search for the determinants of economic efficiency and to assess the prerequisites for the energy security of smart cities in Europe and beyond. Smart cities are becoming crucial centres of innovation and economic growth and therefore require special attention and focus.

When it comes to the originality and objectives of this paper compared with the existing research literature and recent findings reported in the similar studies from various cities around the world, our methodology and results provide the estimation of net profit (NP), Net Discounted Savings (NDS), as well as the total savings (TS) on the case study of an average European metropolis. Our results might help city planners to optimize such issues as city lighting in the context of the sustainable growth and development of the smart cities that would constitute intellectual and economic hubs of the 21<sup>st</sup> century.

Based on our results, few recommendations can be drawn: first of all, it can be stated that street lighting systems in large urban centres are good for optimising energy usage and balancing demand side response, especially in a mix with renewable energy sources. Second, intelligent LED street lighting system are crucial for reducing energy demand and mitigating energy use in world's fast-growing metropolises.

This paper is structured as follows: [Section 2](#) describes an overview of the literature of the energy efficiency and information infrastructure of smart cities. [Section 3](#) outlines the main features of our empirical model that focuses on comparing energy demand stemming from the usage of different city lighting systems. [Section 4](#) provides the results and main outcomes of the empirical model and elaborates its results. [Section 5](#) concludes the paper summarising the main findings and highlighting some relevant policy implications.

## **2. Energy efficiency and information infrastructure of smart cities**

The growing role of human beings in creating the Internet of Energy (IoE) requires the development of the new information technology and intelligent network-centric control algorithms. Network-centric management is a multi-agent management of

individual (local) objects while coordinating their operation with the help of the network energy-information infrastructure. At the same time, it is not the control actions themselves that are centralised, but only the general idea of management and risk assessment of the decisions made.

The presence of a single target network-centric architecture is a distinctive feature of most foreign projects in smart city and smart grid in major cities of the world (Su, 2019). With regard to the above, it is useful to recall the spectacular large-scale projects of the smart cities that were implemented in Masdar (Abu Dhabi), Stockholm (Sweden), Amsterdam (the Netherlands), and Yokohama (Japan) (Madu, Kuei, & Lee, 2017). Most of these projects focus on the development of “green” energy using renewable energy sources (RES), passive (zero-power) homes, the use of incineration, the development of electric lighting systems, electric vehicles and energy saving.

For example, Mirkovic and Alawadi (2017) describe the process of transforming oil dependency into renewable energy leadership and a transition from a 20<sup>th</sup> century, carbon-based economy into a 21<sup>st</sup> century sustainable economy. They are using an example based on the case study of “Masdar City,” a carbon-neutral, zero-emission town located in Abu Dhabi which is almost solely based on solar photovoltaic (PV) energy. Their paper outlines the major characteristics of Masdar City, analyses the key features behind the project, describe the main actors for its implementation, and identify the main obstacles to creation and development as well as the urban policy defining Masdar City. The project is still on-going (due to the constraints imposed by the financial crisis in 2008) but it raises many important concerns and sets up a good example for other smart cities around the world to follow. Their results show that in Masdar building energy demand was reduced by up to 10.5%, while solar heat gains dropped by more than 50%, depending on the urban density.

The suburb of Stockholm - Hammarby Sjostad - is to become an innovative “city of the future” - with a complete renovation of the former industrial estate to create a “green city” in the big city (Glazebrook & Newman, 2018)

The concept of a new urban project focuses on creating a district heating and cooling system with electrical installations, using solar panels on the roofs of “passive houses” for local electric heating to reduce the number of cars that will be replaced by bicycles transportation and electromobility.

The megaproject “Smart City of Amsterdam” also deals with the creation of a “green” energy company (an intelligent energy city). It is estimated that by 2025 up to 30% of the city’s energy consumption (only 6% in 2012) will come from environmentally friendly sources of energy.

Over 10 million square meters of roof space will be equipped with solar panels and the office buildings of the Zuidas Business Park will be equipped with autonomous fuel and energy elements. The city becomes an independent part of Amsterdam with its own energy complex and a developed intellectual network that integrates the transport, social and energy infrastructure of the region. The “Old South” district, considered to be one of the dirtiest and poorest districts in Amsterdam, is being rebuilt: the site is creating a new “city in the city” with innovative business centres, office apartments and luxury apartments of former factories and slums. It also requires the conversion of the local power supply system, with the main electricity

supply transition, both via external cables and via its own power plants (Van Winden, 2016).

One of the most ambitious projects for an energy-efficient smart city is the reconstruction of Yokohama's power system in Yokohama, Japan. The project includes various household energy management systems (HEMS), building energy systems (BEMS), municipal energy services (CEMS) and a dispatch control and data acquisition system (SCADA).

A peculiarity of the Yokohama Smart Grid model is the widespread use of storage devices as an interconnection between consumers and the urban power grid from autonomous and external sources. The implementation of this system is expected at the expense of funds from electricity companies supplying equipment, including control systems for power plants. The city administration guarantees the companies a nationwide implementation of the smart grid system with positive operating experience in pilot projects.

Innovative development of energy in the cities of the world is on the way of the development of electric transport, fuel cells for autonomous power supply, the transition from the initial technology to the use of autonomic power systems and system batteries. And all these innovations are included in the structure of modern smart grid-powered cities. In addition, innovative smart city applications also offer a new frontier for cyber-security (Jin et al., 2016).

One can see that over the past 3 years, 300 thousand electric vehicles (EV) were sold in the United States, and 100 thousand electric vehicles each in China and Japan, with most of the sales in 2015. Moreover, half of sales accounted for "clean" electric cars, and the other half - on "hybrids". This is facilitated by a 4-fold reduction in the cost of lithium-ion batteries (from \$1,200 per 1 kWh in 2009 to \$300 in 2015), with a further decrease to \$80 per 1 kWh by 2020 (Statista, 2019). Due to this, the total cost of Nissan Leaf electric vehicle can be reduced from 35 thousand dollars to 15 thousand dollars, and the total number of sold electric vehicles will increase by 2020 to 17 million units.

Progress in the development of lithium-ion batteries stimulates their widespread use as household and network energy storage. In the world, the production and use of fuel cells (FC) for autonomous power supply, especially in the fixed version, is actively growing. Their efficiency is 3.5 times higher than that of the internal combustion engine and 2 times higher than that of the best gas turbines. Therefore, the production of fuel cells in the world in 5 years increased from 7 to 35 thousand units, and their capacity - from 60 to 170 MW. These fuel cells are supposed to be actively used as backup power sources for the most responsible consumers (in hospitals, business centres, banking structures, etc.). It is possible that they will find application for the power supply of individual objects in the zones of decentralized power supply.

All innovative solutions lead to the need to revise the infrastructure of the urban energy sector. In the world, this work is accompanied by the active development of a smart grid-based systems. The cost of implementing intelligent networks has reached \$20 billion, including the growth in the EU countries estimated to be at a rate of about 27-25%, about 16% in the USA, around 12% in China, and about 30% in other Asia-Pacific countries. It is assumed that the development of smart grid technologies,

among other things, will reduce the needs of energy-deficient regions in fuel and energy resources.

In the Russian Federation began the development of a smart city concept in its largest city and its capital Moscow in 2014 the concept of an energy-efficient megacity Smart City called “New Moscow” and was carried out according to the instructions of the city administration in Moscow involving a wide range of specialists and urban planners. The concept leverages global experience in creating smart grid systems as the infrastructure foundation for smart cities, using the examples from other smart cities around the world described above. At the same time, special attention will be paid to the territorial hierarchy of the smart city model, taking into account the new scheme for infrastructure development of a megapolis with adjacent areas (Drozdova & Petrov, 2018).

The scheme of territorial development of smart cities contains the steps that determine the volumes and places of public and residential development, the development of the production sector in the associated areas and its transformation within the boundaries of the “old” city and the city. Development of transport, engineering, energy and social infrastructure.

One of the qualitatively new principles of the organization of the development of the adjacent areas is the cluster approach, which helps to integrate the social production and the infrastructure integration of the settlements. The development of the cluster principle of territorial production development of the economy also implies the corresponding development of its energy supply systems.

Previously, connecting all systems to the unified power distribution network was an indication of an extension of the grid and additional costs for the construction of these networks, an increase in light load losses and an increase in the accident rate of the power grid complex (Bunning, Wetter, Fuchs, & Müller, 2018). In clusters, due to a combination of adequate energy use and adequate energy production, the emphasis is placed on the energy balance of these units, eliminating the need for a major expansion of the distribution network complex.

At the same time, there is still a need for inter-cluster integration of these energy centres along limited and high voltage network routes, with a focus on the future evolution of the load in new geographical nodes. All clusters have their own power scheme that takes into account the characteristics of local consumers, including the use of micro - cogeneration plants, while the centralized electricity and heat supply from the power plants is operated in the territory of the EU “old” city (Farzaneh, Doll, & De Oliveira, 2016; Sarma et al., 2019).

In addition to the cluster approach, the interrelation of social-industrial settlements and their energy supply systems will be considered using the example of the central links (objects) of a megapolis, such as individual buildings, quarterly and district formations.

At the same time, the centralization of the external power supply (both from local energy complexes and from the CHP of the city) and the autonomous power supply of a given load of objects from local sources are combined.

Among the practical comments to introduce the methods of research, it appears that the integration of energy sources and responsible consumers require the creation



of appropriate multi-agent management systems for energy information systems, as well as the development of an integrated smart (multi-functional) smart grid, linking these centres into a common system. For various standard units of large cities, these future systems will be universal (in terms of reliability and energy supply requirements) and qualitatively individual, depending on the structure of the objects themselves and the role of the human being as the subject of management. At the level of a single consumer, the intelligent infrastructure can be represented as an integrated power system of a typical smart home.

### 3. Empirical model of economic and energy efficiency

Smart technology can be used to maximize efficiency and reduce costs in terms of urban security, administrative procedures, municipal maintenance, education and more. The innovation of public services in smart cities, for example by upgrading buildings to optimize energy consumption or improve the efficiency of public transport, can be combined with the use of technology tailored to the needs of companies to reduce operational costs. In today's knowledge-based economy, digital connectivity and solutions are key factors in terms of efficiency and profitability, new and innovative economic activity and ultimately a sustainable competitive advantage.

Different concepts of smart cities are based on technology, a technology-based intelligent city is not only a concept, but there are several combinations of technological infrastructure and management (e.g. waste management) that are built into the concept of smart cities (Esmailian et al., 2018). One of these technologies is city street lighting that represents a public good provided and paid for by the city administration (Petritoli, Leccese, Pizzuti, & Pieroni, 2019).

Generally speaking, some authors report that infrastructure improvements, such as intelligent LED street lighting, can significantly reduce the energy demand of a modern city. Smart grids have the potential to help distribution systems to better integrate intermittent renewable energies such as wind and solar, and smart city projects are investigating how smart, connected local energy storage systems can support more renewable energy sources on the grid. In the report on the Black and Veatch, municipalities were asked to draw up a list of the top three restrictions for cities that want to make energy systems more intelligent and integrated, more than 70 percent quoted budgetary constraints, with a lack of resources and expertise (BV, 2018)

Let us look closer at the city lighting systems in existence. At present, the night lighting system based on sodium lamps and gas discharge lamps that has traditionally been used is not considered sufficiently convenient, and because of its low efficiency, this design is abandoned. The main disadvantages that affect its effectiveness are short service life (about 1000 hours), the circular illumination of lamps requires the use of shades which leads to additional costs, as well as the fact that the lamp life dramatically decreases during power surges. In addition, as the insulation of the wires ages, their replacement is required over time. Sodium lamps consume a sufficiently large power, which requires the use of a larger cable with a larger cross section. In addition to all of the above, the main disadvantage of sodium lamps is low light output, because the ratio of the power of the visible spectrum to the power of the consumed

network is very small and does not exceed 4%. Thence, a modernisation and innovation has long been required and light-emitting diode (LED) streetlamp became a viable and more sustainable alternative (Park, Kang, Choi, Jeon, & Park, 2018).

With regard to the above, it needs to be stressed that street lighting is very different from indoor lighting in terms of technical requirements, plant design and safety standards. The power of the lamp is of a great importance, and, therefore, its light output is also crucial. Luminous efficiency is the ratio of luminous flux to power consumption, that is, the efficiency of a streetlamp. This energy efficiency is very low for sodium lamps.

The technical characteristics of the LED streetlamps are, in fact, much superior to their 20<sup>th</sup> century counterparts: the average power consumption is about 60 W (at a current of 350 mA); they do not require service, their service life constitutes at least 50,000 hours (12 years with 12 hours of operation), they operate at sub-zero temperatures ( $-50^{\circ}$  C), and ignite instantly (Alstone & Jacobson, 2018). Moreover, their ecological impact is almost non-existent, since LED lamps do not contain any chemicals or chemical solutions that need to be disposed with great care.

In our empirical model, we would aim at finding out whether the replacement of street lighting using sodium lamps with LED streetlamps operating on solar panels would yield a greater economic effect. In order to do that, it is necessary to determine the parameter on which the battery performance depends on the amount of sunlight, in other words, daylight hours. Of course, there are limits and advantages of this research method. For example, some alternative measures such as the lifetime of an average city light can be used. Moreover, one can look into different cities in different time zones (e.g. places in the Arctic regions where daylight is extremely short in winter and extended in summer). However, for the sake of objectivity, we would focus on the case of an average European country that yields no such extremes. This approach seems to provide a balanced and better approach to the subject of our research.

Let us take a typical value of daylight hours for a typical European city - the values range from 8-9 hours in winter months (December and January) to 17-18 hours (June and July) (see e.g. Lobaccaro et al., 2019). Recharging the PV batteries for LED streetlamps to 100% requires about 9-10 hours which makes them economically viable (Filimonova, Barbasova, & Shnayder, 2017; Mohandas, Anni, & Gao, 2019). Our data one light come from the Timebie (2019) and include the accurate logs of sunrise sunset daylight hours in various world's destinations (in fact yielding sunrise and sunset times around the world). Our technical data on the street lamps and various types of lights come from the energy consumption and lighting levels data for commercial and industrial lighting installations.

Next, we should calculate the net profit which is determined by the characteristic year of the billing period when the design level of production has been reached, but capital return is still ongoing. When using methods to assess the financial and economic efficiency of an investment project taking into account the time factor, the following indicators are determined: net income, net present value, discounted payback period and internal rate of return. The formula (see Equation 1) that follows provides the economic framework for the estimation of the net profit (NP):

$$\Sigma NP = \Sigma(EL_{old} - EL_{new}) + \Sigma(EXP L_{old} - EXP L_{new}) + \Sigma AM_{new} - INV_{new} \quad (1)$$

where:

*EL* - electricity consumed by the installation;

*EXPL* - system operation costs;

*AM* - depreciation rate;

*INV* - investment investments (taken into account only for 1 year of exploitation)

It will take about 2 months to install a street lighting system, so when calculating net income for the first year, we will take into account electricity consumption, operating costs and depreciation for 10 months. Let us start by calculating the savings from reducing energy consumption.

Sodium streetlamps consume 170 watts of energy which is much more than the consumption of LED streetlamps (consuming 65 watts) (see e.g. Greenbusinesslight, 2019). As a result, the energy saving is 105 W which is, undoubtedly, a plus of replacing one lighting system with another. Therefore, for a calendar year (provided that the lamp works 12 hours a day) the savings will be as follows (see equations (2) and (3) that follow):

$$(12 * 365 * 170) - (12 * 365 * 65) = 459.9kW \quad (2)$$

In addition, the costs can be computed for 10 months. In that case, the savings will be as follows:

$$(12 * 305 * 170) - (12 * 305 * 65) = 384.3kW \quad (3)$$

Thence, for an average European metropolis, the total saving of electricity consumption by 5642 lamps per year is 2594755.8kW and for a 10-months period the savings would be around 2168220.6kW.

In addition, let us calculate the Net Discounted Savings (NDS) stemming from the use of novel energy-efficient street lighting, NDS represents the sum of the current effects for the entire settlement period  $t$ , reduced to the initial planning interval (calculated as a step), or as the excess of the integrated results over the integrated costs. Let us assume that during the billing period there is no inflationary change in prices, or the calculation is made at base prices. In that case, NDS for a constant discount rate can be calculated as expressed by the following formula (Equation 4):

$$NDS = \sum_{t=0}^T (E/(I + D)) = \sum_{t=0}^T (R_t - E_t)/(1 + D)^t \quad (4)$$

where:

$R_t$  - results achieved at the  $t$ -th step;

$E_t$  - costs incurred at the same step;

$T$  - horizon of calculation planning (equal to the number of the calculation step at which the object is liquidated);

$D$  - rate of return (discount rate).

For the discount rate, let us take the rate of long-term government bonds equal to about 10%. In this case, the computation of Equation (4) would yield us savings in

the range of 50 million EUR in the time range of 2-3 years and 40 million EUR in a time range of 5-6 years (due to amortisation).

As one can observe, the savings and the economic reasoning for the new smart lighting system support its energy efficiency and economic viability. Moreover, one has to consider the option of “smart” function of LED streetlamps (e.g. turning on and off using sensors when a vehicle or a person is nearby). Such additions would dramatically increase the energy savings and NDS alike.

#### 4. Overview of result and outcomes

All in all, the results of our empirical model show the pressing need for replacing the old lighting system with a new one (solar-powered LED streetlamps). The outcomes seem to be fully economically justified. Table 1 that follows provides the results of the numerical analysis for the better comparison of results.

The rationale for this conclusion lies in the important indicators such as net savings, project payback period in a range of 3-4 years, as well as energy saving (2594755.8 kW). These indicators indicate the effectiveness, feasibility, vitality and investment attractiveness of this project.

In addition to the economic effect, the project of replacing the city lighting system of sodium lamps with an LED solar-powered lighting system has a considerable social effect. Some psychological studies describe that the soft and even light of LED lamps has a positive effect on the emotional background of a person and even has the potential of supporting and sustaining mental health (see e.g. Wang, Sun, Jiang, & Li, 2017). All office parks and business centres are highly recommended to switch to LED lighting systems. It is envisaged that this might help to significantly increase the efficiency of employees, reduce stress resilience in a team, improve mood, and even help to relieve eye redness and fatigue. A number of studies in the field of medicine show that LED lighting accelerates the regeneration of tissues and neurons, and therefore can be successfully used in the treatment and prevention of many diseases (see e.g. Machado, Peserico, Mezzaroba, Manoel, & da Silva, 2017; or Pereira dos Reis et al., 2019).

In addition, it is worth emphasizing that hazardous compounds of mercury and other heavy metals are not used in the manufacture of LED. Therefore, they appear to be much safer for the environment than the sodium arc lamps and do not require special disposal rules (or even can be utilised and used as a basis for (or as spare parts of) producing some other simple consumer electronics).

**Table 1.** Results of the numerical analysis.

Savings from reduced energy consumption		
Net income for the first year	1 calendar year 459.9 kW	10 months 384.3 kW
Total saving of electricity consumption		
Average European metropolis (5642 lamps per year)	1 calendar year 2594755.8 kW	10 months 2168220.6 kW
Net Discounted Savings (NDS)		
Excess of the integrated results over the integrated costs	2-3 years 50 million EUR	5-6 years 40 million EUR

Source: Own results.

Our results prove that infrastructure improvements in the smart cities, even though they might be small and involve modernisation of street lighting systems or energy generation for this system, might result in substantial energy savings which would in turn foster the economic development, sustainable growth and competitiveness of these cities.

Taking a bit more critical position, we might also say that surely energy savings in smart cities of today and of the future might also result from other forms of economic efficiency, and not just from the modernization of smart city lighting. There are other areas of energy consumption and saving that might be economically more beneficial (e.g. heating, smart metering, using of renewables, etc.). However, in the context of this research and its specific focus, it appears that LED lighting systems might result in increasing economic gains and contribute to sustainable development of urban centres which makes them a good element in the worldwide strategy leading toward sustainable economic development and efficiency.

## 5. Conclusions and implications

Overall, it becomes obvious that energy management witnessed the emergence of “smart” everything: intelligent networks, intelligent water, as well as intelligent energy. All of these elements become integral parts of the Internet of Energy (IoE), a new smart network that is capable of a two-way of exchanging data, information, and energy. Big Data in smart cities of the future can help coordinate wind and solar energy with traditional energy sources. In order to work effectively with large data and smart cities, government and public efforts should create infrastructure to prevent energy depletion and loss. Fertile land for business owners, data - based smart cities are where technology can ultimately increase the quality of life, improve security and protect the environment of large urban hubs.

Smart cities use data and technology to create efficiency, improve sustainability, foster economic development and ameliorate the quality of life of the people who live and work in the cities. Electric companies, in collaboration with city officials, technology companies and a number of other institutions, are among the main players to help to promote the development of smart cities worldwide. However, one needs to remember that most of the electric companies are private entities seeking for profit. Therefore, a strict control and monitoring should be established in order to make them deliver public goods.

Today, smart city technology is paving the way for the next generation of investments and services for consumers. In order to function properly, smart cities need information on lighting, intelligent neighbourhoods, microgrids, electric vehicles, fibres and other intelligent solutions. All of these involves multiple complexities of delivering products and services in the areas of distributed production, solar, energy efficiency and infrastructure that still need to be solved.

Smart city uses a combination of data collection, processing and dissemination technologies, as well as network and computer technologies and data security and privacy measures that encourage application innovation to improve the overall quality of life for its citizens and include utilities, healthcare, transport, entertainment and government services. Whether it is improving security, resilience, sustainability, traffic

jams, public security or municipal services, every community can have several reasons to invest into building smart cities based on smart systems. Such improvements contribute to increasing energy security, energy efficiency, as well as economic stability of large urban centres that are slowly but gradually becoming the hubs for economic and social development of the 21<sup>st</sup> century.

On the critical side, we have to stress that all of the above should be supported by the strong technological solutions including stable networks enabling steady and fast data transfer. Currently, there is a big debate on using 5G networks for enhancing the productivity and energy efficiency in smart cities. However, the standards for 5G still remain unclear and the implementation hinders due to various economic and even political reasons. Moreover, there is still a pressing issue of compatibility. Currently, there are many devices and appliances that might be included into the smart grids of the smart cities, however all of them come from different manufacturers and quite often do not match and cannot be connected or paired with each other or the smart networks. Thence, there is a need for unifying standards for smart grids and IoE before we can move forward.

In the conclusion to our paper, we can state that it appears that while local governments are the key actor of the public sector in smart city space, not all projects and plans should cover the whole city. In the view of the management, scale and other implementation barriers, there is pressing need for strong networks of leaders to drive smart city policies and investments which might become a leading element of economic sustainability.

Our study has some limitations which are given by the nature of our research approach. We focused solely of LED street lighting system and its comparisons with the commonly used sodium lamps. Some novel alternatives might also be considered to make the comparison complete, however this is out of the scope of this paper.

As for the suggestion based on empirical findings, we would support the smart street lighting systems in large urban centres as they help to optimise energy use and effectively manage demand side response, especially in a combination with using renewable energy sources for producing electricity. Our results show that the intelligent LED street lighting system might help to reduce energy demand and mitigate energy use in large cities. This is of a particular importance nowadays when metropolises all around the globe are embarking on the path of going green and making themselves a better place to live for millions of residents.

Last but not least, when it comes to the future research work directions in the area of reducing the energy demand of the smart cities using sustainable street lighting system, it appears to be interesting to extend our research further and to look into the energy efficient smart street lighting systems. These systems are based on artificial neural network and equipped with motion sensor and lighting sensors. Their implementation might ensure efficient decision-making process for demand-based utilisation helping to avoid excessive exploitation of streetlights.

### **Disclosure statement**

No potential conflict of interest was reported by the author(s).

**ORCID**

Manuela Tvaronavičienė  <http://orcid.org/0000-0002-9667-3730>

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