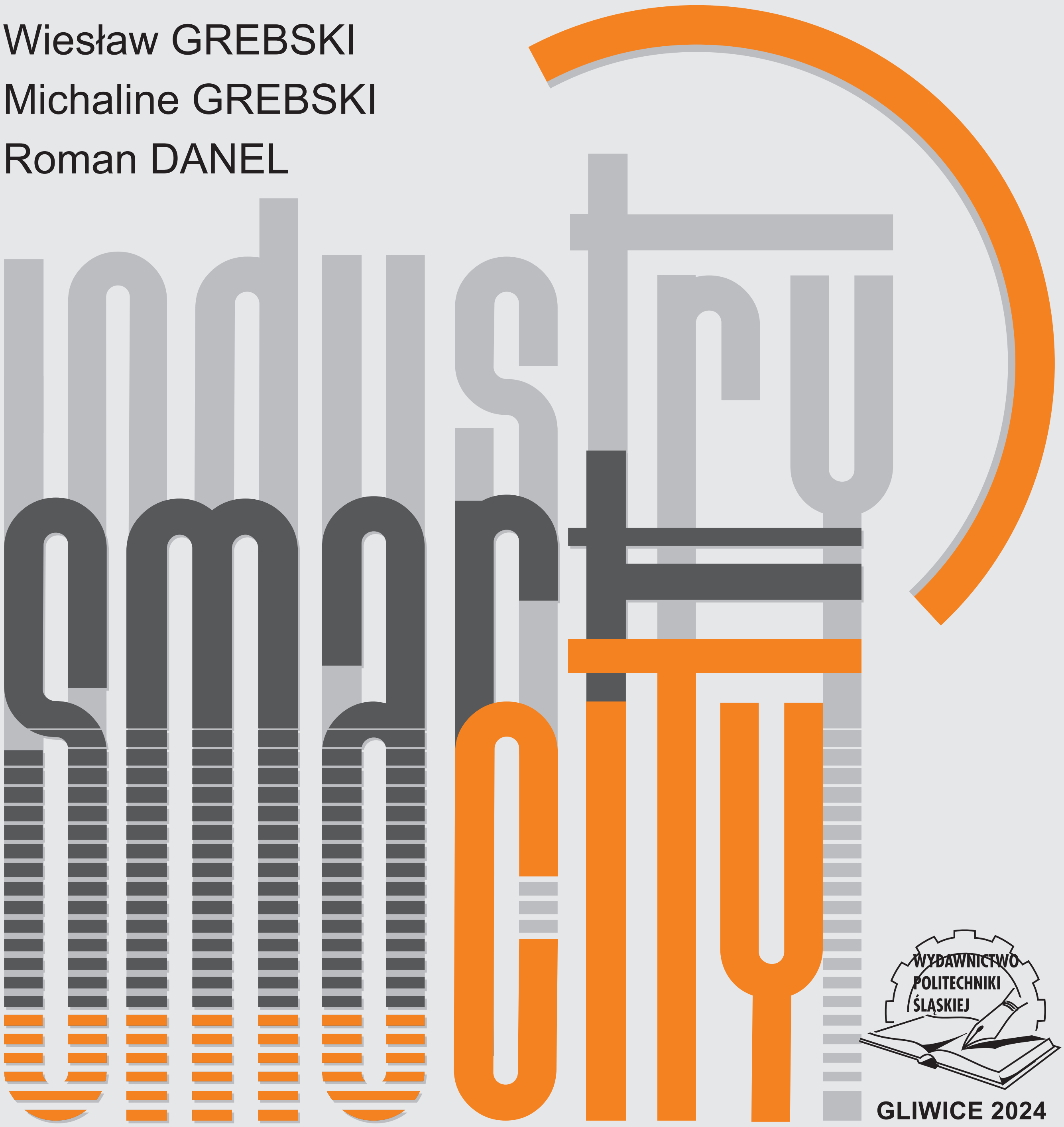
SMART CITIES WITH SMART ENERGY SYSTEMS

KEY DEVELOPMENT DIRECTIONS

Bożena GAJDZIK
Radosław WOLNIAK
Wiesław GREBSKI
Michaline GREBSKI
Roman DANEL



WYDAWNICTWO POLITECHNIKI ŚLĄSKIEJ
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Opiniodawcy
Dr hab. inż. Andrzej PACANA, prof. Politechniki Rzeszowskiej
Dr hab. Barbara PIONTEK, prof. Akademii WSB

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Redakcja techniczna
Ewa TENEROWICZ

Opracowanie edytorskie
Joanna JENCZEWSKA-PAJKA

Projekt okładki
Mgr inż. arch. Agnieszka MĘDREK

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CONTENTS

INTRODUCTION

In an era where urbanization is advancing at an unprecedented pace, the concept of the "smart city" has emerged as a beacon of hope for sustainable development and improved quality of life. At the heart of this transformative vision lies a paradigm shift in the way we approach energy management – the emergence of the "Smart Energy System". This book delves into the pivotal role played by Smart Energy Systems in the realization of a sustainable, efficient, and interconnected urban landscape, where energy resources are harnessed intelligently to meet the evolving needs of citizens and businesses.

The contemporary challenges posed by rapid urbanization, climate change, and the ever-increasing demand for energy necessitate revolutionary solutions that go beyond traditional approaches. The concept of the Smart Energy System offers a holistic and integrated framework that brings together cutting-edge technologies, data-driven insights, and citizen participation to create an energy efficient and environmentally responsible urban environment.

In this book we will unravel the key components that underpin the successful implementation of Smart Energy Systems in the smart city context. From advanced renewable energy sources and smart grids to intelligent energy storage solutions and demand response mechanisms, each component plays a critical role in shaping the future of urban energy management.

The opening chapter sets the stage by providing a comprehensive overview of the evolution and genesis of both smart cities and smart energy systems. Readers will embark on a journey through the historical, economic, and social factors that have led to the rise of these visionary concepts. Exploring the intersection of urbanization, sustainability, and technological advancement, this section highlights the pressing need for smart cities and energy systems in addressing the challenges posed by rapid urban growth and climate change.

The second chapter provides a comprehensive overview of Energy Systems in Smart Cities, highlighting the integration of renewable energy sources, advanced energy storage technologies, and demand response strategies. It explores how these interconnected components work collaboratively to create sustainable, efficient, and resilient urban energy ecosystems. By harnessing renewable energy, optimizing energy consumption through demand response, and implementing innovative energy storage solutions, smart cities can pave the way for a greener and more sustainable future.

At the core of every smart city lies an intelligent and efficient energy management system. In this third chapter, we delve into the intricate mechanisms that drive energy management in urban landscapes. From demand-side management to real-time data analytics and predictive modeling, readers will gain insights into the technologies and strategies employed to optimize energy consumption, reduce wastage, and enhance overall energy efficiency.

The proliferation of electric vehicles (EVs) has paved the way for a revolutionary shift in urban transportation. The 4 chapter explores the role of electric mobility in smart cities, delving into the challenges and opportunities associated with EV adoption. Moreover, it examines the critical aspect of charging infrastructure, discussing the deployment of smart charging stations and their integration into the urban fabric to support a sustainable and widespread electric mobility ecosystem.

Innovative energy-sharing models and peer-to-peer (P2P) trading have emerged as key drivers of smart energy systems. The next chapter explores the concept of energy sharing, where surplus energy generated by prosumers can be redistributed within the community, fostering a decentralized and resilient energy network. Additionally, it delves into P2P energy trading platforms, powered by blockchain technology, enabling individuals and businesses to trade energy seamlessly and efficiently.

The final chapters (six and seven) take a glimpse into the horizon of future energy trends and emerging technologies that hold the potential to redefine the smart city landscape. From advancements in renewable energy to the integration of artificial intelligence, Internet of Things (IoT) devices, and smart grids, this section unveils the cutting-edge innovations that will shape the future of energy systems in smart cities.

The book was written by international team of scientists: Ph.D. (hab.) Eng. Bożena Gajdzik, Professor from Silesian University of Technology, Poland; full professor, Ph.D. Radosław Wolniak, Silesian University of Technology, Poland, Wiesław Grebski – emeritus professor of Pennsylvania State University, USA; Ph.D. Michaline Grebski – Colorado Mesa University, Ph.D. Ing. Roman Danel – Institute of Technology and Business, Budějovice, Czech Republic.

Chapter 1

BACKGROUND OF SMART CITY CONCEPT WITH SMART ENERGY

1.1. Smart City concept in modern economies

Since 2011, when the High Technology Strategy was announced in Germany, the word “smart” has appeared very frequently in business and science. At the end of the year, there were more than 20,000 scientific publications about Industry 4.0 with different smart technologies in the WoS scientific database. The technologies of the 21st century are smart, e.g. smart grid, smart power grid, smart manufacturing, smart product etc. Smart technologies are implemented in all areas of the economy, including energy, industry, cities. The word “smart” in technologies means “intelligent” and “smart”.

With technological advances and the strongly promoted concept of Industry 4.0, Smart Cities are developing. Digital and smart technologies are entering cities. For the past few years, the term “Smart City” has become increasingly fashionable. The new technologies of the Fourth Industrial Revolution are operating more and more products and processes in cities. Smart City is becoming a word that is very capacious. How is the term “Smart City” understood ? How is a Smart City defined? What are the levels of development of the “Smart City” concept? What technologies are used in cities? What objectives are pursued in Smart Cities?

“Smart cities” otherwise known as intelligent cities are cities co-created by citizens. Other terms encountered are “smart neighborhoods”, “smart city functions”, “smart space” and “smart government” understood as “open government”, “smart resident”, “smart life” etc. In last two decades the concept of smart city has become more and more popular in scientific literature and international policies.

The reasons for the appearance of the Smart City concept were the Fourth Industrial Revolution, the growth of cities, the increase in the world's population, the increase in energy consumption (cities consume 60 to 80% of energy), the increase in CO_2 emissions, etc.[1]

The term "Smart City" has many definitions, but most of us equate the term with a city with a creative development strategy with open innovation. A Smart City is flexible, i.e. it adapts quickly to change. A smart city uses a framework of information and communication technologies to create, deploy and promote good development practices according to sustainable principles and according to inhabitants' needs. Table 1 summarises examples of Smart City definitions and synonyms.

Table 1

Definitions and synonyms of smart city

Source	**Definition**
Caragliu et al. (2009)[2]	Smart cities investment in human and social capital and transport and modern (ICT) communication infrastructure etc. Direction of the smart cities is sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.
Hollands (2008)[3]	Smart city as an "urban labelling" phenomenon, and "asking to real smart city to stand up, it emphasis the many aspects which are hidden behind self-declaratory attribution of this label".
Thite (2011)[4]	Smart is used as a synonym of creative. Smart cities have creative strategies.
Nam and Pardo (2012)[5] Deakin and Waer (2011)[6]	Smart city is more than intelligent because smart (smartness) is only realised when the system adapts to the user's needs.

[1] S. Hammer, et al.: Cities and Green Growth: A Conceptual Framework, OECD Regional Development Working Papers 2011/08, OECD Publishing. 2011. Available online: http://dx.doi.org/10.1787/5kg0tflmzx34-en [date of access 17.08.2023].
[2] A. Caragliu, C. Del Bo, P. Nijkamp: Smart Cities in Europe, Journal of Urban Technology, Vol. 18, No. 2, 2011, pp. 65–82.
[3] R.G. Hollands: Will the real smart city please stand up?, City: analysis of urban trends. Culture, Theory, Policy, Action, Vol. 12, No. 3, 2008, pp. 303–320.
[4] M. Thite: Smart cities: implications of urban planning for human resource development, Human Resource Development International, Vol. 14, No. 5, 2011, pp. 623–31.
[5] T. Nam, T.A. Pardo: Conceptualizing Smart City with Dimensions of Technology, People, and Institutions, Proc. 12th Annual International Conference on Digital Government Research, 2011.
[6] M. Deakin, H. Al Waer: From intelligent to smart cities, Intelligent Buildings International, Vol. 3, No. 3, 2011, pp. 140–152.

continue table 1

Source	Definition
Winters (2011)[7]	"Smart cities are metropolitan areas with a large share of the adult population with a college degree."
Chen (2010)[8]	"[…] smart cities will take advantage of communications and sensor capabilities sewn into the cities' infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone." p. 3
Komninos (2011, 2013)[9]	Smart city integrates technologies, systems, infrastructures services, and capabilities into an organic network that is sufficiently complex for unexpected emergent properties to develop.
Zygiaris (2012)[10]	Smart city as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green", "interconnected", "intelligent" "innovating", "knowledge" .
Albino and Berardi (…)[11]	The term "smart city" is sometimes used to discuss the use of ICT for modern transport technologies. Smart systems improve urban traffic and inhabitants' mobility.
Correia, Wunstel (2011)[12]	A smart city is "capable of linking physical and social capital to develop better services and infrastructure. It is capable of collating technology, information and political vision into a coherent programme to improve the city and the services it offers".

[7] J.V. Winters: Why are smart cities growing? Who moves and who stays, Journal of Regional Science, Vol. 51, No. 2, 2011, pp. 253–70.
[8] T.M. Chen: Smart Grids, Smart Cities Need Better Networks, IEEE Network, Vol. 24, No. 2, 2010, pp. 2–3.
[9] N. Komninos: Intelligent cities: Variable geometries of spatial intelligence, Intelligent Buildings International, Vol. 3, No. 3, 2011, pp. 172–188; N. Komninos, M. Pallot, H. Schaffers, Smart Cities and the Future Internet in Europe, Journal of the Knowledge Economy, Vol. 4, No. 2, 2013, pp. 119–134.
[10] S. Zygiaris: Smart City Reference Model: Assisting Planners to Conceptualize the Building of Smart City Innovation Ecosystems, Journal of the Knowledge Economy, Vol. 4, No. 2, 2013, pp. 217–231.
[11] V. Albino, U. Berardi, R.M. Dangelico: Smart cities: definitions, dimensions, and performance, pp. 1723–1738.
[12] L.M. Correia, Wunstel K.: Smart cities applications and requirements, Net Works European Technology Platform White Paper, 2011.

continue table 1

Source	Definition
Caragliu, Del Bo, Nijkamp (2009)[13]	Smart cities invest in human and social capital and in communication and transport infrastructure etc. ICT drives sustainable economic development and a high quality of life with wise, participatory management of natural resources.
Report Maping Smart Cities in the EU adapted from Manville et al. (2014)[14]	A smart city is a city in which public issues are addressed using information and communication technologies (ICTs), involving different types of stakeholders working in partnership with the city government. ICT enables the interconnection of different urban systems and stimulates innovation to facilitate the achievement of urban policy goals. Among these, the so-called low-carbon growth is central.

Source: own elaboration based on V. Albino, U. Berardi, R.M. Dangelico, Smart cities: definitions, dimensions, and performance…, op. cit.

Synonyms for Smart City are “intelligent city”, “wise city”, “efficient city”, “compact city”, “sustainable city”, “coherent city”, “competitive city”, “strong city”, “modern city”, “knowledge city”, “digital city”, “better city”, “comfortable city”, “resilient city”, “awareness city”, “high tech city”, “high-performance city”, “self-determining city”, “independent city”, “city of the future”[15].

The full word “smart” is part of an integrated approach to city management, which consists of both the use of modern technology (automata), as well as striving to improve the quality of life of the inhabitants (humans) and creating a sense that they are the co-creators of the city, i.e. involved (agora)[16]. Figure 1 shows the dimensions of the Smart City.

[13] A. Caragliu, C. Del Bo, P. Nijkamp: Smart cities in Europe, Proceedings of CERS’2009 – 3rd Central; European Conference on Regional Science, Kosice, 2009.

[14] C. Manville, G. Cochrane, J. Cave, J. Millard, J.K. Pederson, R.K. Thaarup, A. Liebe, M. Wissner, R. Massink, B. Kotterink: Maping Smart Cities in the EU, Study, Directorate General for Internal Policies, Policy Department A: Economic and Scientific Policy, European Parliament, Brussels, January 2014.

[15] Ewolucja koncepcji Smart City w krajach grupy Wyszehradzkiej. Przegląd zagadnień związanych z inteligentnym miastem w dokumentach V4. Publisher: Wolański Ego.

[16] Ewolucja koncepcji Smart City w krajach grupy Wyszehradzkiej. Przegląd zagadnień związanych z inteligentnym miastem w dokumentach V4.

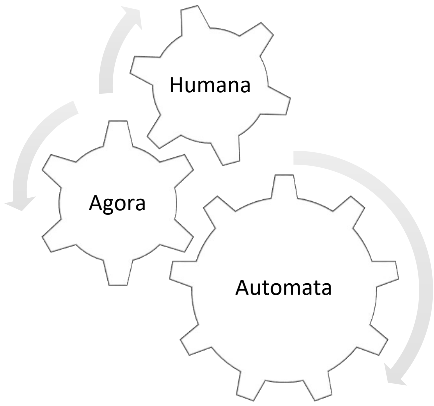

Fig. 1. Dimensions of the concept of Smart City
Source: Ewolucja koncepcji Smart City w krajach grupy Wyszehradzkiej. Przegląd zagadnień związanych z inteligentnym miastem w dokumentach V4.

A smart city is an area, e.g. municipality, county, cluster, city, region. "Smart" cities base their strategy on the application of information and communication technologies (ICT) in areas such as economy, mobility, environment, people, living, governance[17]. Innovations in the smart city create smart economy, smart mobility, smart environment, smart people, smart governance and smart living[18]. Changes improve the standard of living of citizens and increase their participation in urban governance. ICT built on the "smart" combination of endowments and activities of self-decisive, independent and aware citizens"[19]. Broader dimensions of a smart city than in Fig. 1 are presented in Fig. 2. Smart City is essentially a concept strongly associated with innovative technologies that create smart cities. The Smart City uses information and communication technologies to increase the interactivity and efficiency of the urban infrastructure and its components, as well as to raise the awareness of citizens. This part of the definition mainly draws attention to the role of IT in urban development. Investments must be compatible with sustainable economic development and improve the quality of life of city dwellers, and help to manage natural resources wisely[20].

[17] R. Giffender, C. Fertner, H. Kramar, R. Kalasek, N. Pichler-Milanović, E. Meijers: Smart cities: ranking of European medium-sized cities. Vienna: Centre of Regional Science – Vienna UT, 2007. Available online: http://www.smart-cities.eu/download/smart_cities_final_ report.pdf [accessed on 15.07.2023]; A. Di Maio: The Five Dimension of Smart Government. Gartner, 2010. Available online: https://www.gartner.com/en/documents/1485117 [date of access 17.08.2023].

[18] M. Jankowska: Smart city jako koncepcja zrównoważonego rozwoju miasta – przykład Wiednia. Studia i Prace Wydziału Nauk Ekonomicznych i Zarzadzania Uniwersytetu Szczecińskiego, 42, 2015, pp. 173–182; P. Lombardi, S. Giordano, H. Farouh, W. Yousef :Modelling the smart city performance. Innovation – The European Journal of Social Science Research, 25(2). 2012. Available online: http://dx.doi.org/10.1080/13511610.2012.660325 [date of access 17.08.2023].

[19] R. Giffender, et al.: Smart cities…, op.cit. 2007

[20] I. Azkuna (ed.): Smart Cities Study: International study on the situation of ICT, innovation and Knowledge in cities, The Committee of Digital and Knowledge-based Cities of UCLG, Bilbao, 2012; B. Gajdzik, S. Grabowska, S. Saniuk, T. Wieczorek, 2020, *Sustainable Development and Industry 4.0: A Bibliometric Analysis*

IBM defines a smart city as "one that makes optimal use of all the interconnected information available today to better understand and control its operations and optimise the use of limited resources."[21]

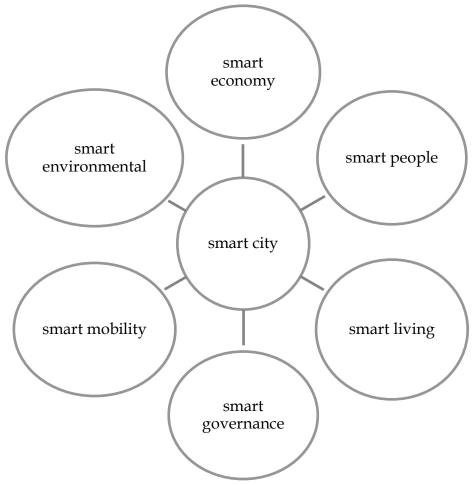

Fig. 2. Broad dimensions of a smart city
Source: Adapted from: A. Di Maio: The Five Dimension of Smart Government. Gartner, 2010. Available online: https://www.gartner.com/en/documents/1485117, [date of access 17.08.2023].

A smart city has:[22]

- competitive economy (smart economy). In a Smart City, the economy is highly efficient because it has advanced technologies. Technologies – ICT – that develop new products and services and new business models. Through the use of IC technologies, people make contacts. The structure of contacts is both local and global. Through IC technologies international exchange of goods, services and knowledge is possible.

Identifying Key Scientific Problems of the Sustainable Industry 4.0, „Energies", vol. 13, iss. 16, (art. no. 4254), p. 1–27, DOI: 10.3390/en13164254; I. Jonek-Kowalska, R. Wolniak: Sharing economies' initiatives in municipal authorities' perspective: research evidence from Poland in the context of smart cities' development, Sustainability, vol. 14, nr 4, 2022, Numer artykułu: 2064, s. 1–23, DOI: 10.3390/su14042064.

[21] Smarter Cities, IBM Global Business Services. Multimedia presentation, IBM Corporation, 2009.

[22] M. Czupich, M. Kola-Bezka, A. Ignasiak-Szulc: Factors and barriers of implementing the concept of smart city in Poland (Title in Polish: Czynniki i bariery wdrażania koncepcji smart city w Polsce). Studia Ekonomiczne. Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach, 276, 2016; T. Nam, T.A. Pardo: The Changing Face of a City Government: A Case Study of Philly, "Government Information Quarterly", Vol. 31, 2014. R Giffinger et al. Smart Cities…, op.cit.; A. Caragliu, Ch., Del Bo, P. Nijkamp: Smart Cities in Europe, "Journal of Urban Technology", Vol. 18(2), 2011; B. Cohen: The Top 10 Smartest European Cities, 2015. Available online: http://www.fastcoexist.com/1680856/the-top-10-smartest-european-cities [date of access 17.08.2023]; I. Jonek-Kowalska, R. Wolniak: Smart Cities in Poland. Towards sustainability and a better quality of life?, 2023, Routledge; R. Wolniak, B. Gajdzik, W. Grebski,: *The implementation of Industry 4.0 concept in Smart City*, Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie, Wydawnictwo Politechniki Śląskiej, nr 178, 2023, s. 174–177, DOI:10.29119/1641-3466.2023.178.42.

- smart transport networks (smart mobility). The movement of cars and pedestrians on the roads is controlled by integrated IC systems. In smart mobility, transport and logistics are realised by using clean energy.
- resource management control systems (smart environment). The systems control the consumption of water, electricity, gas etc. and tell their users how to use them sustainably. In a smart city, natural resources are used sparingly. Innovative technology is also used in renewable energy systems. Solar panels are used to power street lighting and municipal buildings.
- system(s) for the ongoing measurement, control and monitoring of pollution in a city. Based on the level of pollution, city authorities make decisions on environmental alerts.
- subsidy programmes for the renovation of buildings to reduce their energy intensity and others.
- smart governance systems to optimise the environmental and financial costs of city operations.
- high quality social capital (smart people). Residents in the smart city are aware of digitalisation and use IC technologies. Residents are tolerant, creative and involved in the development of the city. In such a city there is public participation in decision-making, including decisions of a strategic nature. The actions taken are transparent.
- high quality of life (smart living). Residents want to live safely and healthily. They choose cities that provide good conditions for working, living and relaxing. Residents enjoy spending their leisure time in museums, cinemas, shops, parks, etc. Wide access to ICT infrastructure enables them to create their lifestyles, behaviour and consumption (work and life). Residents seek a high quality of life and availability of public services.

In a smart city there are[23]:

- creative citizens (population) implementing knowledge-intensive activities or cluster of activities,
- effective institutions and procedures for knowledge creation (acquisition, adaptation and development),

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[23] R. Wolniak, B. Gajdzik, W. Grebski: *The implementation of Industry 4.0 concept in Smart City*, Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie, Wydawnictwo Politechniki Śląskiej, nr 178, 2023, s. 174–177, DOI:10.29119/1641-3466.2023.178.42; R. Wolniak, I. Jonek-Kowalska: The level of the quality of life in the city and its monitoring, Innovation-The European Journal of Social Science Research, vol. 34, nr 3, 2021, s. 376–398, DOI:10.1080/13511610.2020.1828049.

- developed infrastructure, digital space, e-services and online knowledge management tools.
- ability to innovate, manage and solve problems that arise for the first time, as innovation and management under uncertainty are key to assessing intelligence[24].

Every city is unique and has qualities that set it apart from others. However, all cities face similar problems, e.g. social stratification, unemployment, drinking water shortages, healthy food shortages, urban litter, reduced green spaces, increased traffic, etc. Increasingly smart technology is expected to help cities minimise these problems and perhaps even eliminate them.[25]

To nowadays, three levels of smart city development have been identified: smart city 1.0, smart city 2.0 and smart city 3.0. The phrases: Smart City 1.0, 2.0 and 3.0 were first used by Boyd Cohen, a smart city researcher. By analysing smart city initiatives around the world, the author concluded that three types of cities can be identified according to their use of modern technology – depending on the entity inspiring such activities. Smart cities can develop with the development of the IT sector (entrepreneurial actions) or by the city authorities' own actions using technological innovations (technology 4.0) or by and with the participation of residents. According to Cohen, cities can go through successive generations of smart city models. They can also jump, for example, from the 1.0 model straight away to the 3.0 model or remain exclusively in the area of one generation. Table 2 summarises the characteristics of smart city development models.

Table 2

Levels of smart city model

Level	**Characteristics**
Smart City 1.0	Smart City 1.0 inspired by available technologies is the earliest phase of smart city creation. The initiators of the use of technology in city management are companies in the ICT sector, which, having technological solutions. ICT industry themselves created demand for the technologies produced.

[24] N. Komninos: Intelligent Cities and Globalisation of Innovation Networks, London and New York, Routledge 2008.
[25] I. Jonek-Kowalska, R. Wolniak: Economic opportunities for creating smart cities in Poland: Does wealth matter?, Cities, vol. 114, 2021, numer artykułu: 103222, s. 1–16, DOI:10.1016/j.cities.2021.103222.

continue table 2

Level	Characteristics
Smart City 1.0	The creation of demand among cities was easy insofar as most often public administrations were not ready to assess technologies – they lacked appropriate staff, qualifications, instruments. Behaviour of city authorities in the first generation model. Implemented technologies exceeded citizens' expectations. Cities were not ready to create a smart city. Cities built according to the 1.0 model are Masdar in the United Arab Emirates and Songdo in South Korea. Technology has created the ideal cities of the future. These cities are experiments.
Smart City 2.0	Decisions to implement new technologies are made by public administrations (local authorities are the initiators of change). Technologies help remove problems diagnosed in cities. Technologies improve the quality of life for residents. It is a much more conscious and at the same time selective process of using what ICT companies have to offer. It is not just the implementation of technology that counts, but more importantly the effect of that implementation. According to Cohen, most cities implementing smart city projects today belong to level 2.0. Phases of Smart City in level 2.0:
Smart City 2.0	Phase 1: There are a lot of projects and programmes in the city related to the application of smart technological solutions, such as: public WiFi networks, smart traffic control, big data, electric transport (promotion of this form of transport). Phase 2: The city uses the Internet of Things: smart sensors, meters, controllers.
Smart City 3.0	Smart City 3.0 applies modern technologies to improve the quality of life in cities to a greater extent than Smart City 2.0. In addition to the projects that are characteristic of the second generation, there are also social, equality, educational, environmental issues. Smart City 3.0 is also about the sharing economy. In Smart City 3.0, dialogue between authorities and citizens (dialogue, mediation, deliberation) is important.

Source: Own elaboration based M.N. Shah, S. Nagargoje, C. Shah: Assessment of Ahmedabad (India) and Shanghai (China) on Smart City Parameters Applying the Boyd Cohen Smart City Wheel. [In:] Wu Y., Zheng S., Luo J., Wang W., Mo Z., Shan L. (eds): Proceedings of the 20th International Symposium on Advancement of Construction Management and Real Estate. Springer, 2017, Singapore. https://doi.org/10.1007/978-981-10-0855-9_10 [date of access 17.08.2023].

Smart City is a holistic concept. The Smart City is a holistic project to create a suitable living environment for a new society – a smart society, which is primarily "informational", but whose characteristics include all the attributes of modernity: postmodernism, postindustrialism, prosumers[26]. The development of the city through the use of ICT is aimed at increasing the quality of life of its inhabitants[27].

A popular (sustainability concept) smart area is the environment. As the environmental awareness of the population increases, investments in environmental protection are growing. Smart technologies help cities ensure a balance between economic development and environmental protection. Among the key areas of environmental smarts are improved energy efficiency, rational management of natural resources and environmental monitoring. Cities investing heavily in environmental protection are called "green cities". A smart environment is strongly linked to systems for the management of public spaces, the creation of public spaces that are safe for citizens, the development of the city according to (in accordance with) the needs of different stakeholders. Space connects residents, and improved space should strengthen social ties and reintegrate excluded groups into the city. Smart technology can help people with disabilities and older people[28].

A smart city is a liveable city that offers its inhabitants the best quality and comfort of life. In order to proceed with the implementation of the smart city concept, it is necessary to diagnose the problems in the city and look for their solutions. According to the management, it is necessary to start with a diagnosis, then set a strategy for city development and implement it. Smart cities follow four steps to improve the quality of life and enable economic growth through a network of connected IoT devices and other technologies. These steps are as follows (Fig. 3):

1. Collection – Smart sensors gather real-time data
2. Analysis – The data is analysed to gain insights into the operation of city services and operations
3. Communication – The results of the data analysis are communicated to decision makers
4. Action – Action is taken to improve operations, manage assets and improve the quality of city life for the residents.

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[26] A. Bruska. Logistics as a constituent of smart city (Title in Polish: Logistyka jako komponent smart city). Studia Miejskie 2012, no. 6.
G. Andreoli, C.M. Medaglia, Planning for a smarter society, EBR, No. 1, 2010, pp. 31–35.
[27] Smart City Wien Framework Strategy 2019–2050. Vienna Municipal Administration 2019.
[28] S. Żukowska, B. Chmiel, Koncepcja smart city w zamierzeniach strategicznych wybranych miast województwa pomorskiego. Przegląd Planisty, Nr 9, 2022, pp. 19–22.

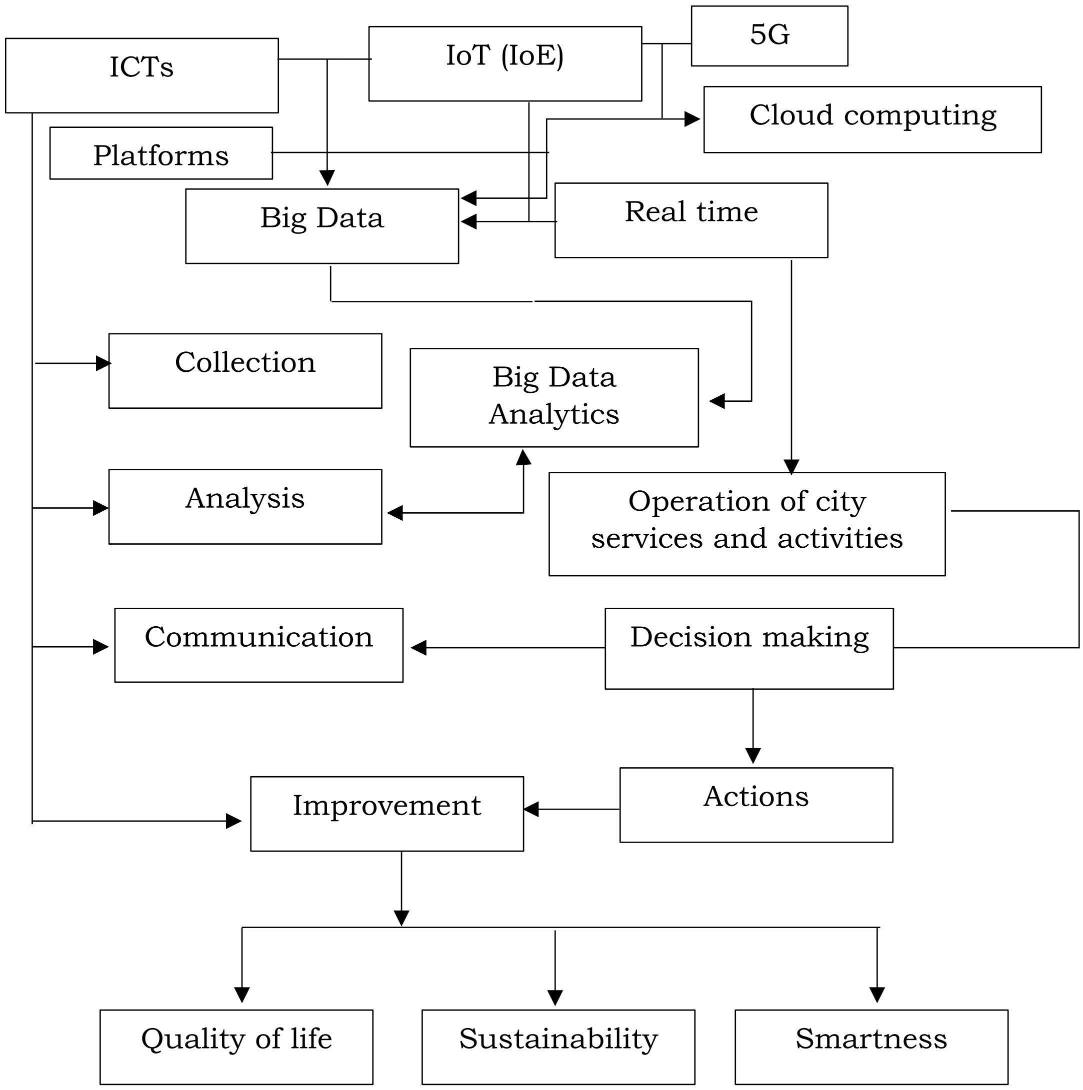

Fig. 3. Steps in smart management in Smart City
Source: Own elaboration (Gajdzik B.).

The Smart City promotes green investments, investments that enhance safety, and economic investments – increasing the competitiveness of the city while focusing on the needs of present and future generations. The Smart City concept is a new way of looking at urban development. In this concept, politicians are paying attention to citizen involvement. Involving citizens who consciously use smart technologies leads to a successful smart city. Benchmarking cities facilitates the implementation of this concept. Cities replicate good practices and adapt them to local conditions. Large cities or clusters of cities (metropolises) co-create smart city technologies (joint investments). There is little information on specific information and communication technologies that can be used in projects within the Smart City concept. There is no information in the overarching documents (European policies and other policies) about the necessary technologies to build a Smart City. Cities are free to decide which technologies to use (mobile applications, intelligent transport systems, smart grids, etc.). Smart technologies need a transmission network (broadband or 5G). Project ideas seem to grow out of the need to improve the situation. The diversity of needs is greater the larger the population of the city[29].

Smart cities use a variety of software, user interfaces and communication networks alongside the Internet of Things (IoT) or Internet of Everything (IoE) to deliver connected solutions for the public. The IoT is a network of connected devices that communicate and exchange data. This can include anything from vehicles to home appliances and on-street sensors. Data collected from these devices is stored in the cloud or on servers to allow for improvements to be made to both public and private sector efficiencies and deliver economic benefits and improvements to the lives of citizens. Many of the IoT devices use edge computing, which ensures that only the most relevant and important data is delivered over the communication network. In addition, a security system is implemented to protect, monitor and control the transmission of data from the smart city network and prevent unauthorised access to the IoT network of city's data platform[30]. Alongside the IoT solutions, smart cities also use technologies including:

- Application Programming Interfaces (APIs)
- Artificial Intelligence (AI)
- Cloud Computing Services
- Dashboards
- Machine Learning
- Machine-to-Machine Communications
- Mesh Networks.

What ICT gives (profits of ICTs)[31]:

- integration of all elements of city logistics and city service providers. Integration eliminates the inconveniences found in the old systems (commercial and municipal). Up to now used systems are incompatible (different software environments and different hardware, computers, networks);
- improving the quality of information exchange between platform users improves the decision-making process, e.g. reduced decision-making time, access to up-to-date information, etc.;
- increasing synergies between different activity areas of the city;
- offering new services and better access to urban infrastructure for residents, tourists, investors etc.;

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29 D. Szymańska, Urbanizacja na świecie, Warszawa 2008.

30 Smart City Reports of any country with Report Linker. Available online: https://www.reportlinker.com › market › reports.

31 A. Bruska: Logistics as a constituent of smart city (Title in Polish: Logistyka jako komponent smart city). Studia Miejskie, No. 6, 2012.

- better use of infrastructure (intensification of its use). Infrastructure-integrated condition sensor systems covering the entire urban system;
- increase in added value in the city by reducing the operating costs of infrastructure, thereby reducing resource consumption and increasing the well-being of residents;
- enhancing both collective (infrastructure fail-safe) and individual safety (indicators of equipment status and necessary maintenance or repair actions). The data provided from the sensors is in real time;
- real-time information can also be used to dynamically modify the conditions of access to resources and services in a city (e.g. change of prices depending on the real resource load, optimal choice of road route in a city, optimal choice of means of public transport (bus, tram, train etc.);
- universal payments for the use of city services (e.g. payment cards, telephones etc.);
- current announcements (current timetables, weather tourists etc.);
- promotion: coupons, vouchers, loyalty programmes etc.;
- fast access to objects (replacement of a building or car key, identification of a person);
- resource management (urban energy, water management systems, etc.);
- public health systems and patient monitoring;
- information on air pollution in the city. Data is collected from sensor indications that signal areas with high CO2 emissions (measuring speed, acceleration frequency, etc.);
- rationalisation of the use of road infrastructure (change from traditional to adaptive street lighting);
- traffic flow control (real-time identification of the traffic situation on the road);
- guidance systems to help find parking spaces;
- car sharing or developing local authority delivery services;
- monitoring all events in the city: from energy and water supply to waste, logistics and telemetry systems for people [32].

Smart Cities are designed according to the requirements of sustainable development, above all the conservation of natural resources. Buildings and their surroundings are elements of sustainable urban development. City management platforms create a virtual city model fed by real data. Linking a complete digitised city model and continuous access to data seems to be a prerequisite for achieving the state of the Smart City[33]. In table 3 there are smart cities grouped into three arrangements: 1. Technology, 2. Ecology/planet 3. People.

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[32] J. Griffiths: Smart city. Plan IT Valley, Portugal 2010, pp. 21–25. Retained from: www.onwindows.com [date of access 17.08.2023].

[33] L.M. Correia, K. Wunstel: Smart cities applications and requirements, Net Works European Technology Platform White Paper, 2011.

Table 3

Examples of smart cities in the world

Fields	**Cities**
Technology	Holyoke, Massachusetts (USA), Kochi (Indie), Malta, Manado (Indonezja), Nanjing (Chiny), Alameda County (Kalifornia), Alcoa (Tennesse), Portland (Oregon), Southampton (Wielka Brytania).
Ecology/planet	Amsterdam (Holandia), Dublin (Irlandia), Glasgow and Peterborough (Wielka Brytania), Lyon (Francja), Malaga (Hiszpania), Sztokholm (Szwecja), Sydney (Australia), Yokohama (Japonia), San Diego i Santa Barbara (Kalifornia), Burlington (Ontario), Dubuque (Iowa), Schenyang (Chiny).
People/ life	Chattanooga (Tennesse), Dublin (Ohio), Eindhoven (Holandia), Issy-les-Moulineaux (Francja), Luksemburg, Queensland (Australia), Stratford (Ontario), Windsor-Essex (Ontario), Chengdu (Chiny), Edynburg, Matosinhos (Portugalia), Syracuse (New York), Wilmington (Północna Karolina), Boise (Idaho), Houston (Teksas), Johannesburg (RPA).

Source: A. Bruska: Logistics as a constituent…, op. cit., 2012; A. Abdullaev, A smart world: a development model for intelligent cities, The 11th IEEE International Conference on Computer and Information Technology (CIT), 2011, pp. 5–6; Smart cities. Ranking of European medium-sized cities, Centre of Regional Science Vienna UT, Vienna 2007.

For many cities, smartness is the future. Cities change because the citizens' needs change. Cities will be green, digitised and friendly. By 2050, more than 75% of the population will be concentrated in cities, so the concept of Smart Cities must be developed[34]. At its core, the smart city concept boils down to the creation of an entirely new settlement unit, reflecting a virtual city model fed by real data. The smart city concept is based on combining the intelligent use of modern technologies and innovative systems facilitating the management of individual agglomeration functions with the potential of companies and institutions and the creativity of citizens. Its implementation is intended to help improve the operation of cities, increase the efficiency of their resources and the quality of life of their inhabitants, all with the help of available solutions based on new ICT technologies[35]. Smart city authorities

[34] ONZ.

[35] B. Gajdzik, M. Jaciow, R. Wolniak, R. Wolny, W. Grebski: *Assessment of energy and heat consumption trends and forecasting in the small consumer sector in Poland based on historical data*, „Resources", Multidisciplinary Digital Publishing Institute (MDPI), vol. 12, nr 9, 2023, Numer artykułu: 111, s. 1–33, DOI:10.3390/resources12090111.

need to take care of many different aspects of urban life in order to ensure the sustainable development of all economic and social areas and to respond immediately to the changing parameters of the city[36].

1.2. Human Factor and Quality of Life in Modern Cities

Quality of Life is a very subjective way to assess the happiness of individuals living in a society. Many factors play a role in affecting the quality of life. Some of the factors are financial security, job satisfaction, physical and mental health, family life, and harmonious relationships with others. Work-life balance as well as free time to do the things we enjoy and pursuing induvial interests or hobbies can also affect happiness and quality of life. Canada and the Scandinavian counties rank the highest in the quality of life of their citizens. In the modern economy, workers pay more attention to the quality of life while making decisions on relocating. Commuting long distances by car or public transportation decreases the quality of life by absorbing time that could be spent with family or pursuing other enjoyable activities. The individual factors increasing the quality of life can be different for different individuals. However, there are some universal markers, such as access to good health care, clean and safe housing, healthy food, jobs paying livable wages, personal safety, and recreational opportunities which affect the quality of life. These factors increase the quality of life for everyone. Meaningful work or volunteering, making time for hobbies, sufficient rest, and enjoyable forms of exercise also increase the quality of life for everyone. State and local governments can improve the quality of life by offering affordable and accessible health services, investing in education at all levels, incorporating family--friendly policies, and providing access to affordable housing. The government needs to promote economic development by creating a business-friendly environment. Government policies supporting creativity, innovativeness, and economic growth are conducive to creating new well-paying jobs. Employment opportunities increase the quality of life for residents. Government policies also need to be conducive toward alcohol and drug use prevention as well as eliminating homelessness by providing

[36] A. Bitkowska, K. Łabędzki: The concept of smart city – definition, assumptions, areas. (Title in Polish: Koncepcja inteligentnego miasta – definicje, założenia, obszary), Marketing i Rynek. Journal of Marketing and Market Studies, XXVIII, No. 2, 2021, pp. 3–11, DOI 10.33226/1231-7853.2021.2.1; N. Komninos, Intelligent Cities and Globalization of Innovation Networks, London-New York 2008, p. 123.

mental health and temporary housing. Affordable and accessible child or elderly care improves the quality of life of residents. Social justice and social equity also improve the quality of life[37].

The different helpful government initiatives conducive to increasing quality of life are as follows:

- Affordable and accessible psychological counseling:

Maintaining mental health for residents is an important human factor of smart cities. Affordable and accessible psychological counseling is an effective method for lowering homelessness and suicide rates, as well as alcohol and drug use prevention. Affordable and accessible psychological counseling increases the quality of life in a city.

- Accessible homeless shelters:

Homelessness is often associated with mental health problems as well as alcohol and drug usage. Smart cities need to be equipped with state-of-the-art homeless shelters. Homelessness, however, can be reduced by the development of accessible and affordable psychological counseling as well as alcohol and drug prevention programs. All those programs increase quality of life in the city.

- Alcohol and drug use prevention:

Alcohol and drug prevention and treatment programs are needed in any community, including smart cities. Making those programs accessible and affordable increases the quality of life of smart city residents. Alcohol and drug prevention lowers homelessness and prevents many social problems. Early detection and treatment increase the effectiveness of the program.

- Intellectual enrichment opportunities:

Innovative individuals are very mobile and gravitates to “Smart Cities”. Smart cities provide individuals with an atmosphere of tolerance, acceptance, and respect for every individual. Innovative individuals are inclined to cluster in certain cities. They need to have other innovative people around them to discuss with them innovative ideas and inspire each other. Innovative individuals need intellectual enrichment opportunities. Smart innovative cities are always located within close proximity to major universities, providing intellectual enrichment opportunities to residents of the community. This is an important factor in attracting highly innovative individuals. In the United States there are smart innovative cities (especially in California) where the number patents per 1,000 resident is 50x the national average. In general, the mobility of the workforce is conducive to innovative behaviour.

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[37] R. Wolniak, I. Jonek-Kowalska: The level of the quality of life in the city and its monitoring, Innovation – The European Journal of Social Science Research, vol. 34, nr 3, 2021, s. 376–398, DOI:10.1080/13511610. 2020.1828049.

- Affordable and accessible childcare:

Affordable and accessible childcare is essential for families living and working in smart cities. There are a lot of opportunities for innovative solutions related to forms and methods of childcare. Childcare in smart cities can be very different than the form to which we are accustomed. Partially remote work developed during the pandemic may help to solve some of the childcare problems. Technology may also help as well.

- Affordable and accessible elderly care:

Affordable and accessible elderly care also requires innovative solutions. Properly managed and affordable care for older individuals improves the quality of life in the city. The technology will be developed and innovated solutions will be introduced. A partially remote work mode may also assist with this issue.

- Integration center for new immigrants:

Modern knowledge-based economies rely to a significant extent on an immigrant workforce. An immigrant workforce can be productive and innovative. For the immigrant workforce to preform to full capacity it is necessary to provide help related to cultural and ethnic assimilation. Local community-based resources need to be identified for this purpose. Integration centers for new immigrants normally provide diverse programs related to language, citizenship, employment, and culture. The integration centers are operating using mostly a volunteer workforce. The activities of the immigrant integration center are coordinated by the Board of Directors. The center provides language classes for adults as well as help in finding employment and legal assistance. The integration centers also organize enrichment activities for children and young adults. One of the goals of an integration centers is to allow immigrant families to adjust to economic conditions within their new location. One of the main objectives of the immigration center is to create and nurture a culture of tolerance and acceptance without a regard to ethnicity, religion and sexual orientation. Cultural and ethic integration centers are also good resources for the development of entrepreneurial skills and attributes. These centers are being established more often. They are also seen as places to provide other resources for integration between native populations and immigrants.

- Affordable and accessible opportunities for further education:

Smart innovative cities need opportunities for quality and affordable education. Innovative individuals need to have access to continuing education. Smart and highly innovative cities have a large concentration of individuals with advanced degrees (table 4).

Table 4

Innovative cities in the United States vs. education of residents

City/Region	Adult Population with a Baccalaureate Degree
Boulder, CO	63.2%
Ann Arbor, MI	54.5%
San Jose-Sunnyvale-Santa Clara, CA	50.8%
San Francisco-Oakland-Fremont, CA	49.3%
Santa Cruz-Watsonville, CA	40.2%

Source: J. Harrington, M.B. Sauter: American's Most Innovative Cities, WALL ST.247, 2020. Available online: wallst.com/special-report/2018/10/30/americas-most-innovative-cities-2/6/ [date of access 17.08.2023].

The concentration of individuals with advanced degrees in some cities is up to 90% higher of the national average of 33.4%. Highly creative and innovative individuals also seek educational opportunities for their families.

- Entrepreneurial centers enhancing creativity and innovativeness:

Entrepreneurial centers are important components of smart cities. Innovative individuals have the tendency to cluster in highly progressive innovative cities. Entrepreneurial centers nurture innovativeness and creativity on many levels and from many different perspectives. Entrepreneurial skills and attributes are need for any business venture. Entrepreneurial centers provide guidance and assistance in exploring business ventures[38]. This type of center has outreach to high school students, college students as well as the adult population. Entrepreneurial centers offer free of charge workshops related to the development of a business idea. A member of the community can approach the entrepreneurial center and ask for assistance in evaluating business ideas and development of a business plan. The Pennsylvania State University has twenty-one entrepreneurial centers spread throughout the state of Pennsylvania [39]. Every entrepreneurial center has one full-time employee (Coordinator of the Center) and a number of volunteers. Mostly volunteers conduct training programs, workshops, and meetings with members of the community to discuss business ideas. Outreach

[38] S. Cyethovska, M. Verkuyten, L. Adelman: Being Tolerated and Minority Well-being: The Role of Group Identification, International Journal of Intercultural Relations, Vol. 74, No. 161, 2020, Available online: http:// www.sciencedirect.com/science/article/pii/S0147176718305852 [date of access 17.08.2023]; M. Verkuyten, L. Adekman, K. Yogeeswaran: The Psychology of Tolerance: Unpacking Diverse Understanding of Intolerance. Current Directions in Psychological Science, Vol. 29(5), paper No. 467, 2020. Available online: http://www.journals.sagepub.com/doi/10.1177/0963721420924763 [date of access 17.08.2023]; A. Sharma: Managing Diversity and Equality in the Workplace. Cogent Business and Management, Vol. 3(1), 2016. Available online: http://www.tandfonline.com/doi/full/10.10.80/23311975.2016.1212682, [date of access 17.08.2023].

[39] H. Qian: Diversity Versus Tolerance: The Social Drivers of Innovation and Entrepreneurship, Urban Studies Vol. 50(13), 2718, 2013. Available online: http://www. journals.sagepub.com/doi/10.1177/004209801347703 [date of access 17.08.2023].

to local high schools and universities is one of the missions of the entrepreneurial center. Entrepreneurial centers conduct workshops for high school students either at the high school location during school hours or during evening hours at the entrepreneurial center. Entrepreneurial centers may also work with university students. High school and university students brainstorm different ideas which would increase the quality of life within the community. The brainstorming ideas are evaluated and implemented as funding becomes available. Some of the workshops offered by the entrepreneurial centers are related to identifying funding resources for innovative projects. The main purpose of the entrepreneurial centers is to empower community members (young and old) to take an active role in improving the quality of life in the area. The entrepreneurial center is creating and promoting a mindset in people to take charge of their own destiny and future (instead of complaining about things they do not like). Working with young people (high school and university) can make a significant difference in their attitude and approach to life[40]. The knowledge-based economy in smart cities requires an entrepreneurial mindset in every individual living within the area. Entrepreneurial centers aim to accomplish this goal. Entrepreneurial centers are one of the resources for the development of entrepreneurial skills and attributes.

- Business incubator centers as facilitators to promote economic growth:

A *business incubator center* is an essential component for creating an atmosphere of entrepreneurship, innovativeness and creativity[41]. The best projects initiated at the entrepreneurial centers are converted into reality at a business incubator center. The role of the entrepreneurial centers is to help generate a business concept and conduct feasibility studies. At a business incubator center those ideas become reality. The following activities are taking place at business incubator centers.

1. Development of a detailed business plan.
2. Identifying funding sources.
3. Development of the product which can includes detailed drawings, structural analysis, etc.

[40] T.H. Cos, S. Blake: Managing Cultural Diversity: Implications for Organizational Competiveness, The Executive Vol. 5 (3), 45, 1991.

[41] B. Hofstra, V. Kulkami, S. Munoz-Najar Galvez, B. He, D. Jurafsky, D.A. McFarland: The Diversity-Innovation Paradox in Science. Proceedings of the National Academy of Science of the United States of America 2020, 117(17), 9284. Available online: https://doi-org.ezproxy.coloradomesa.edu/10.1073/pnas.1915378117 [date of access 17.08.2023]; E.E. Lynch, L.H. Malcoe, S.E. Laurent, J. Richardson, B.C. Mitchell, H.C.S. Meier: The Legacy of Structural Racism: Assicuations between Redlining, Current Mortgage Lending and Health, SSM-Population Health, 14, 2021. Available online: https://doi-org.ezproxy.coloradomesa.edu/10.1016/j.ssmph.2021.100793 [date of access 17.08.2023]; M. Pearcy: The Most Insidious Legacy-Teaching about Redlining and the Impact of Racial Residential Segregation. Geography Teacher, Vol. 17(2), No. 44, 2020.

4. Initiate the procedure for protecting intellectual property and applying for patent, etc.
5. Development of the website for the new company.
6. Development of the marketing strategy.

A business incubator center nurtures new businesses, usually for three years with an option to extend for three more years, if needed. New companies in the business incubator center receive many low-cost services which are needed during the company's development stage. Cooperation of the business incubator center with faculty and students from local universities is highly effective and a cost-efficient method for providing valuable services to startup companies. After the company leaves the business incubator center they become part of the business community contributing to the economic development of the area. Not every company in the business incubator center becomes a success. A significant percentage of startup companies is unsuccessful and close before leaving the business incubator center. This is a reality that cannot be avoided. There is always a risk factor to any business venture. By providing free or low-cost services a business incubator center decreases the financial loss because to business failure.

- Affordable and accessible healthcare system:

Proper healthcare is positioned very high on the *quality-of-life* scale. Canada and Scandinavian counties are rated very high in quality of life mainly because of accessible and affordable healthcare and education. Access to healthcare needs to be one of the fundamental rights of every individual living in a smart city. Many innovative solutions related to healthcare will be introduced and implemented because of technological development.

- Safe and affordable housing:

Young innovative energetic individuals are attracted to the availability of safe and affordable housing. This is also often a factor attracting new businesses to the area. One of the criteria to relocate new businesses to the area (or start a new business) is availability of affordable housing for the workforce. Safe and affordable housing increases the quality of life in an area.

- Efficient and convenient public transport:

Availability of efficient and convenient public transport increases the quality of life for residents. It also attracts new residents. Efficient public transportation also creates a business-friendly environment.

- Recreational areas:

In the knowledge-based economy people have more free time for recreational activities. Smart cities need to have designated areas for recreational family activities.

The forms of recreation are constantly changing. The need for designated recreational areas will always be there.

- Pet-friendly areas:

There will be a need to designate more pet-friendly areas because of the increasing number of people with pets. Areas with pet-friendly hotels, stores, and restaurants are showing an increase in revenue. Pet-friendly recreational parks are gaining popularity. It has been proven that pets increase the quality of life for people.

- Accessible community gardening:

There is a need for accessible community gardening facilities because of the increasing popularity of organic gardening. People are increasingly more concerned with the sources and quality of food that they buy. Gardening is also a form of recreational activity.

- Business-friendly environment conducive to creativity and innovativeness:

The economic development of smart cities relies on success in attracting new state-of-the-art knowledge-based companies. Creating a business-friendly environment is an effective method to attract companies into an area. Availability of a highly qualified workforce is an important factor in attracting new companies. The presence of institutions of higher education also creates a business-friendly environment.

- Pet-related services:

There is a need for pet related services because of the increasing number of people with pets. Pets have a positive influence on the mental and physical health of their owners. Pet walkers, pet sitters, pet groomers and veterinarians are some of the growing businesses in smart cities. The forms and the scope of those services will be changed as technology develops.

Smart cities are hubs of innovation and progress, driven by a vision to improve the quality of life for their residents while fostering economic growth. This text explores various aspects of nurturing new businesses within smart cities and highlights key factors that contribute to their vitality.

A central component of smart city development is the establishment of business incubator centers. These centers play a pivotal role in supporting nascent enterprises, typically for an initial period of three years, with an option for an extension of three more years if necessary. Startups residing in these incubators benefit from a range of cost-effective services critical for their development. Collaborations between these centers and local universities, involving faculty and students, prove to be highly effective and economically efficient, providing invaluable services to budding companies.

While many businesses emerge from incubators to contribute to the local economy, not all succeed. The inherent risk in entrepreneurship is ever-present. However, by offering complimentary or low-cost services, incubator centers mitigate the financial losses associated with business failures.

1.3. Sustainable consumption: Development of “less is more mentality”

Sustainable development is a policy and direction set up by government or management of private industry. The goal of sustainable development is to create products and practices that are sustainable[42].

The United Nations developed seventeen sustainable goals.

1. No poverty in the world
2. Zero hunger in the world
3. Good health and wellbeing for everyone
4. Quality education for everyone
5. Gender equality
6. Clean water and sanitation for everyone
7. Affordable and clean energy for everyone
8. Decent work and economic growth
9. Industry innovation and infrastructure
10. Reducing inequality
11. Sustainable cities and communities
12. Responsible consumption and production
13. Climate action
14. Life below water
15. Life on land
16. Peace, justice and, strong institutions.
17. Partnerships for achieving goals.

Goal 12 is related to achieving sustainable production and consumption as a key to protect the livelihood of the current and future generations. Present patterns of production and consumption are not sustainable and threaten the wellbeing of future

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[42] Sustainable development: Progress Report. Available online: https://www.un.org/sustainabledevelopment/progress-report/ [date of access 17.08.2023]; Sustainable development: Sustainable consumption production. Available online: https://www/un.org/sustainabledevelopment/sustainable-consumption-production/ [date of access 17.08.2023].

generations. Unsustainable production and consumption triggers climate change, biodiversity loss, and pollution. Governments of all countries need to cooperate and work together to protect natural resources, reduce pollution and waste as well as creating a new circular economy.

Sustainable consumption is a choice customers make to buy and use sustainable products. The government and different organizations work on implementing sustainable development. Individual customers work on implementing sustainable consumption. Sustainable development combined with sustainable consumption will make significant impacts on protecting natural resources for future generations. Achieving sustainable consumption and production is essential if we are to overcome climate change, biodiversity loss as well as control pollution and waste. Sustainable consumption requires a fundamental transformation of our society and economy. International cooperation is essential because of an interconnected economic system. This initiative requires involvement of government agencies, businesses, banking, community leaders, as well as all individuals. The existing linear economy using the "make, use, discard" model which based on producing inexpensive short lifespan products is not sustainable. It uses a large quantity of natural resources. After a short time, these products become disposable waste. Often the products with a short lifespan are produced in underdeveloped parts of the world with low labor costs. Sustainable production and consumption must consider the entire supply chain of the product.

Sustainable consumption can be divided into two categories[43]:

- Weak sustainable consumption
- Strong sustainable consumption

Weak sustainable consumption is focused on improving the efficiency of the consumption. By improving the efficiency of the consumption fewer natural resources are being used. Weak sustainable consumption does not eliminate entirely the use of valuable natural resources. A typical example of weak sustainable consumption is replacing energy inefficient car with an energy efficient car. Consumption is in the weak sustainable consumption category because energy efficient cars still use gasoline. Use of energy efficient car is still unsustainable. Natural resources are being used to make and operate the car. Even though the sustainable consumption is weak it is not pointless and has a positive impact on the environment.

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[43] D. Fuchs, S. Lorek: Sustainable Consumption Governance: A History of Promises and Failures, Journal of Consumer Policy Vol. 28(3), 261, 2005. Available online: https://www.researchgate.net/publication/5149362_Sustainable_Consumption_Governance_A_History_of_Promises_and_Failures; Definition: Sustainable consumption. Available online: https://www/beeco.greem/sustainable-consumption/ [date of access 17.08.2023].

Strong sustainable consumption is changing the lifestyle, infrastructure, or choices to eliminate entirely the consumption of particular natural resources. Using the analogy of the car, strong sustainable consumption would be eliminating the car and replacing it with public transportation, shared commuting, or traveling shorter distances. Strong sustainable consumption relies on government organizations or businesses to change the infrastructure. Instead of reducing our use of natural resources we eliminate their use entirely. Bigger environmental difference can be made with strong sustainable consumption. There are some positive signs about the government's initiatives to implement strong sustainable consumption. Most initiatives, however, are on the individual level of changing our behaviour as related to the level of weak sustainable consumption.

The sustainability is connected with circular economy. The concept of a *circular economy* is focused on reducing single-use plastics. The customers are using the same containers that are being refilled at the store. The typical example of circular economy is selling name brand household cleaning products in bulk from a cashless kiosk. The customer can buy "smart" containers and keep refilling it with detergent, shampoo, or other cleaning products. Customers can buy any amount which can avoid overbuying. Customers can come back any time and refill reusable containers. This concept can be expanded to any product and eliminates the need to manufacture a large number of disposable containers. It also reduced the number of disposable containers in the landfill. A process of transition from the current linear economy to a circular economy is a major undertaking[44]. It requires changes in distribution of sales of various products. It also requires a change in mentality and mindset of the customers. Changing the economy into a circular economy needs to be done from the top. There is a need for change in the industry so that the circular sustainable product will be an automatic option for everyone. We are relying on natural resources and cannot overconsume. This applies to everything we buy. Selecting the most sustainable option does not mean downgrading. We need to produce long lasting products from higher quality materials. Consuming better and more thoughtfully needs to be our new mindset. Initially this may be associated with some price increase to be absorbed by the customer. The price increase may be associated with the purchase of a refillable container. Consuming less can require sometime some sacrifices on behalf of the customer.

Circular economy requires the innovation of technology and processes that does not exist yet. By buying a better-quality product, the consumer can save more money in

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[44] Definition: Circular Economy. Retained from: https://www/beeco.green/scp/circular-economy/ [date of access 17.08.2023].

the long term. Better quality products can be repaired and used again. Circular activity and repair shops will stimulate economic growth. Economic growth does not need to be stimulated by natural resource consumption. New jobs will also be created by innovating circular products, repair specialists to fix broken products as well as recycling what cannot be repaired. New technologies will be developed to improve efficiency and circularity of the product. The manufacturing companies will use recycled materials and will not rely on natural virgin materials which are affected by geopolitical crisis. The concept of a circular economy is also promoting sharing, renting, or leasing products instead of buying. Different tools needed in a household including the lawnmower for cutting grass can be leased or rented periodically on an as needed basis. By living in the city, we may want to use the public transportation system and lease a car on an as needed basis for farther trips. Sharing and renting the equipment as needed will reduce the amount of storage space needed in a household. Introducing a circular economy into society will create opportunities for businesses and organizations to come up with innovative solutions to meet sustainability goals and circular economy guidelines. Circular economy and the concept of sustainability are closely related focusing on protecting natural resources, reducing waste and improving the quality of life without sacrificing our planet. The biggest challenges in converting a linear economy into a circular economy is the human factor and our habits developed over the years. This applies to businesses, government agencies, as well as individual customers. A circular economy and the principals of reducing, recycling, reusing, repurposing as well as consuming sustainably requires everyone to participate. Governments need to enhance transformation to circular economy by introducing tax incentives to businesses as well as customers promoting a circular economy.

1.4. Importance of Smart Energy Systems in Smart Cities

Smart City mainly stands for transition in municipal (metropolitan) services based upon implementation of new technologies of the Fourth Industrial Revolution. Smart cities serve new services related to communication, security and sustainability. It is also an approach to face social, spatial and economic challenges in urban areas. On the one hand, “Smart City can be considered as a specific strategic orientation towards sustainable development by using new technologies (interactions between service providers and consumers), but on the other hand, it is a way of implementing technological solutions into existing urban structures by which a real-time (or prompt) response is offered to citizens' and businesses' needs as well as to emerging risks and dangers"[45]. Moreover, there is another concept – deeply involved with saving of energy and using od green energy – the smart energy. In development strategy there are aims about smart energy[46]. Long-term strategy of city development are realized by mid-term or short-term programmes and tasks. Sustainability is supported by new technologies – technologies related to Smart City and Smart Energy[47]. Smart City systems, according to IBM[48], consist of:

- City operations systems: city services,
- City user systems: people and business,
- City infrastructure systems: water, energy, transport, communication.

Smart Energy belongs to city infrastructure systems. The structure of the system is presented in table 5.

Table 5

Energy systems in Smart City

System	Elements	Instrumentation	Interconnection	Intelligence
Energy	• oil, gas, • renewable, • nuclear	Fit sensors to gather data on usage across the energy system	Interconnect appliances and devices between energy consumers and providers	Optimise the use of the system and balance use across time

Source: Smarter Cities (2009): IBM Global Business Services. Multimedia presentation, IBM Corporation.

The implementation of the Smart City concept needs specific policy actions that will provide a push effect, e.g. in an European dimension. EU policy documents clearly shows that the energy efficiency is very important for city development. Looking into the Europe 2050, Smart City strategy is strongly linked to deep decarbonisation [49].

[45] M. Baron: Do we need smart cities for resilience. Economics & Management, Katowice, No. 10, 2012, pp. 32–46.

[46] B. Gajdzik, R. Wolniak, R. Nagaj, W. Grebski, T. Romanyshyn: Barriers to renewable energy source (RES) installations as determinants of energy consumption in EU countries, „Energies", MDPI, vol. 16, nr 21, 2023, numer artykułu: 7364, s. 1–32, DOI:10.3390/en16217364; B. Gajdzik, M. Jaciow, R. Wolniak, R. Wolny, W. Grebski: *Assessment of energy and heat consumption trends and forecasting in the small consumer sector in Poland based on historical data*, „Resources", Multidisciplinary Digital Publishing Institute (MDPI), vol. 12, nr 9, 2023, numer artykułu: 111, s. 1–33, DOI:10.3390/resources12090111.

[47] E. de Oliviera Fernandes et al.: Smart Cities Initiative: How to Foster a Quick Transition towards Local Sustainable Energy Systems. Final Report, FP7 Project THINK, January 2011.

[48] Smarter Cities: IBM Global Business Services. Multimedia presentation, IBM Corporation 2009.

[49] The EU Plan for a Green Transition; European Union: Brussel, Belgium, 2022. Available online: https://www.consilium.europa.eu/pl/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/ [date of access 17.08.2023].

According to Net Zero Strategy (CO_2 emissions)[50], technologies using black energy will be replaced by technologies working on green energy. Decarbonisation will require a profound transformation of industrial activities and urban activities. In addition to the technology replacement associated with decarbonisation, energy efficiency improvements are needed. Energy efficiency can significantly reduce emissions associated with energy consumption. In deep decarbonisation, cities need to switch from fossil fuels to technologies other than those associated with greenhouse gas emissions, mainly to energy from renewable sources. These sources can be wind energy, photovoltaic and solar energy, hydropower, geothermal energy, biomass and biofuels. In order to achieve a deep transformation, particular attention should be paid to encouraging citizens and employees, companies, community organisations and experts to play an active role in the necessary changes in their localities[51]. Public authorities and companies, as part of the social dialogue, must make an effort to use the skills already in place and to achieve decarbonisation targets. Significant investment will be needed to deploy renewable energy, including in energy infrastructure in many cities around the world. Nowadays, the energy and environment notion (energy security, energy efficiency, sustainability) is mainly direction in international, national and regional policies[52]. The EU is changing the energy market towards distributed grids. In this market, the consumer is in a strong position by improving information exchange, ensuring a wide choice of energy market activities related to simplifying switching, increasing flexibility through demand response, reducing bills through energy production (e.g. solar panels), maintaining full consumer protection, making smart homes and networks a reality and data protection. The EU calls for “Clean energy for all Europeans” and sets out new directions for the development of the electricity market (market with smart grids)[53]. The active consumer (prosumer and flex consumer) is promoted in the energy market. Failure to provide consumers with real-time or near real-time information about their energy consumption prevents them from actively participating in the electricity market and in the energy transformation process.

[50] IEA. Net Zero by 2050–A Roadmap for the Global Energy Sector. 2021. Available online: https://www.iea.org/reports/net-zero-by-2050 [date of access 17.08.2023].

[51] B. Gajdzik., M. Jaciow, R. Wolniak, R Wolny, W. Grebski: Diagnosis of the Development of Energy Cooperatives in Poland – A Case Study of a Renewable Energy Cooperative in the Upper Silesian Region. Energies 2024, 17, 647, https://doi.org/10.3390/en17030647.

[52] E. de Oliviera Fernandes et al.: Smart Cities Initiative…, op. cit. 2011.

[53] M. Morawiecka: Pakiet zimowy – czysta energia dla wszystkich Europejczyków czy raczej koniec krajowych polityk energetycznych?. Available online: https://www.cire.pl/item,145414,2,0,0,0,0,0,pakiet-zimowy-czysta-energia-dla-wszystkich-europejczykow-czy-raczej-koniec-krajowych-polityk-energetycznych.html [date of access 17.08.2023].

Technological advances in grid management and renewable electricity generation have opened up many new opportunities for consumers. Action taken by cities regarding the grid should be directed towards promoting investment in renewable energy sources and towards increasing the flexibility of the energy services they offer and use.

Energy smart is a concept for the development of a city based on adapting its functions to a deep decarbonisation strategy and to standards (practices) for optimising energy use in response to market signals. Operators in the energy (electricity) market should offer demand reduction services, propose dynamic pricing, invest in energy storage. For city users with electric cars, access to charging systems for electric cars is important. In addition, city residents expect comprehensive information about energy saving programmes. The Smart City promotes distributed energy networks from renewable sources. All consumer groups (i.e. industrial, commercial and household consumers) should have access to electricity markets to offer their flexibility and generated energy. Smart City promotes different forms of activity by energy market participants, e.g. energy communities. Smart City joins efforts to improve the quality of the network with microgrids[54].

The technological advances that have taken place over the past few years are changing the energy market. Innovations are emerging in this market, which smart energy is building. Network structures are creating both macro grids and microgrids. Energy sources are becoming increasingly diversified. Diversification is determined by the direction from black energy to green energy. Energy market participants (consumers, suppliers, investors) expect real incentives from the municipality to cooperate so that they bear less and less of the costs of the energy transition.

The Smart Energy concept will use blockchain technology. One potential application of this technology in the field of electricity will be its use to create a decentralised energy market model. Transactions for the sale and purchase of electricity can be carried out directly and autonomously between generators and consumers of energy (smart contracts). Blockchain is a big database in a digital form, distributed over the network in identical copies. The technology uses peer-to-peer networks without central computers, management systems or transaction verification. Any computer connected to the network can participate in the transmission and authentication of transactions [55]

[54] G. Materna, J. Król: Szanse i zagrożenia dla uczestników rynku energii. Publisher: INPPAN, Warsow 2021.
[55] J. Węglińska: (Title in Polish: Technologia blockchain w sektorze elektroenergetycznym). Blockchain technology in the electricity sector. Chapter In: G. Materna, J. Król, Szanse i zagrożenia dla uczestników rynku energii. Publisher: INPPAN, Warsow 2021, pp.139–148, DOI: 10.5281/zenodo.5178761 [date of access 17.08.2023].

Blockchain combined with artificial intelligence-based solutions can work very effectively through transaction identification and memorisation applications. Blockchain can predict energy consumption, which in turn allows demand to be matched to supply[56].Data blocks can store data related to energy certificates of origin, emission allowances, etc. Blocks can track changes in the energy market. The use of different system models based on the blockchain network could facilitate the development of energy storage or electric cars and support the integration of current solutions with a variety of smart devices[57].

In Smart Energy concept very important is a prosumer. Bodo et al. introduced six types of prosumers: DIY prosumers, self-service prosumers, customising prosumers, collaborative prosumers, monetised prosumers and economic prosumers[58]. In the field of smart energy, prosumers are households or organisations that sometimes produce surplus fuel or energy and feed it into the national (or local) distribution grid; while at other times (when their demand for fuel or energy exceeds their own production) they consume the same fuel or energy from the grid. Prosumers, or consumers who also produce energy, play an important role in the decarbonisation of the economy. One of the main ways in which prosumers contribute to decarbonisation is through the use of renewable energy sources, also known as RES (Renewable Energy Sources)[59]. Prosumers contribute to the growth of RES by adopting renewable energy technologies such as solar panels, wind turbines etc. Prosumers create demand for green technologies based on RES. In Smart Cities, households and businesses adopt RES technologies, the demand for fossil fuels decreases, which can lead to a reduction in greenhouse gas emissions in cities[60]. The implementation of energy storage systems (ESSs) such as

V. Buterin, A Next Generation Smart Contract & Decentralized Application Platform. Ethereum White Paper. Available online: https://blockchainlab.com/pdf/Ethereum_white_paper-a_next_generation_smart_contract_and_decentralized_application_platform-vitalik-buterin.pdf [date of access 17.08.2023]; M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum, A. Peacock: Blockchain Technology in the Energy Sector: A Systematic Review of Challenges and Opportunities, Renewable and Sustainable Energy Reviews, No. 100, 2019, pp. 143–144.

[56] C. Burger, A. Kuhlmann, P. Richard, J. Weinmann: Blockchain in the Energy Transition a Survey Among Decision-makers in the German Industry, Deutsche Energie-Agentur GmbH, Berlin 2016, pp. 17–19.

[57] J. Węglińska: Blockchain technology in the electricity sector…, op. cit. 2021.

[58] Lang, Bodo; Dolan, Rebecca; Kemper, Joya; Northey, Gavin (2020-01-01). “Prosumers in times of crisis: definition, archetypes and implications”. Journal of Service Management. ahead-of-print (ahead-of-print): 176–189, DOI:10.1108/JOSM-05-2020-0155. hdl:10092/104713. ISSN 1757-5818. S2CID 225379767.

[59] I. Postnikov: Methods for the reliability optimization of district-distributed heating systems with prosumers, Energy Reports No. 9, 2023, pp. 584–593; Y. Liu, Y. Zhang, G. Cheng, J. Zhu, Y. Che: Grid-friendly energy prosumers based on the energy router with load switching functionality, International Journal of Electrical Power and Energy Systems No. 144,108496, 2023.

[60] B. Gajdzik, M. Jaciow, R. Wolniak, R. Wolny, W.W. Grebski: Energy Behaviors of Prosumers in Example of Polish Households, Energies, Vol. 16(7):3186, 2023. Available online: https://doi.org/10.3390/en16073186 [date of access 17.08.2023].

battery storage systems (BSSs) and electric vehicles (EVs) have multiplied the positive effects of RESs on nowadays energy market[61]. Prosumer micro grids (PMGs) as the users of RESs and ESSs are playing an essential role in modern energy systems[62].

There are conscious consumers and energy producers in the Smart Energy market. Conscious market participants use green energy [63]. The level of energy consumption is a key factor in the cost of energy supply. Green energy awareness is very important for the development of Smart Cities. Energy consumption patterns and energy conservation are a challenge for Smart Cities. Cities need to participate in the green energy education of energy market participants because, due to the speed and scale of change in the energy market as a result of progress, they may have gaps in economic and energy knowledge. Public acceptance in the development of smart energy in smart cities is crucial.

In smart energy is sustainable energy consumption. This consumption has forms:

- deconsumption: quantitative reduction of energy consumption levels,
- sharing consumption: sharing of goods, powered by energy,
- responsible consumption: integrating social and environmental aspects into purchasing decisions throughout the product life cycle,
- prosumption: consumers joining the role of energy producers.

Consumer environmental activity in smart cities is increasing. There is a growing conviction among consumers about the need for change in the energy market. The "green consumer" will be a strong participant in smart energy. Energy acceptability has an impact on social welfare. Table 6 shows the components of social well-being according to SSI.

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[61] J. Faraji, H. Hashemi-Dezaki, A. Ketabi: Optimal probabilistic scenario-based operation and scheduling of prosumer microgrids considering uncertainties of renewable energy sources, Energy Science and Engineering, 2020, DOI: 10.1002/ese3.788 [date of access 17.08.2023].

[62] L. Perković, H. Mikulčić, N. Duić: Multi-objective optimization of a simplified factory model acting as a prosumer on the electricity market. J Clean Prod.,167, pp.1438–1449, 2017.

[63] M. Jaciow, E. Rudawska, A. Sagan, J. Tkaczyk, R. Wolny: The Influence of Environmental Awareness on Responsible Energy Consumption – The Case of Households in Poland, Energies, 15, 5339, 2022. https://doi.org/10.3390/en15155339 [date of access 17.08.2023].

Table 6

SSI in the sustainable development

Types of wellbeing	**Index**
social wellbeing	
• basic needs	food, water, sanitary safety
• health	good life, healthy living, education, relaxation
• sustainable society	good governance, income distribution, population growth
environmental wellbeing	
• climate and energy	renewable energy, reduction of greenhouse gas emissions, energy efficiency
• natural resources	renewable resources, conscious consumption, biodiversity
economic prosperity	
• economy	GDP, employment, public finance, stocks for the future, grain reserves etc.

Source: G. Van de Kerg, A.R. Manuel: A comprehensive index for a sustainable society: The SSI – the Sustainable Society Index. Ecol. Econ., 66, 2008, pp. 228–242.

In addition to consumers, energy producers and energy suppliers are important. The energy transformation of cities towards smart energy will require major changes along the entire value chain from electricity generation, through the market, transmission and distribution and end-consumer consumption. Investments in clean energy are a way to grow cities (create jobs) and reduce emissions. Digital and smart technologies help people and companies save energy. Investments, already made in cities, have reduced emissions from municipal power plants, residential heating units and industrial facilities. Now it is time to build smart energy systems, i.e. systems that control, better than humans, energy consumption. Clean energy and smart energy are important for the development of smart cities because they lead to improved air quality and better management of resources (energy sources).

The Smart Energy System concept is essential for cost-effective 100% renewable energy systems. The concept includes a focus on energy efficiency, end use savings and sector integration to establish energy system flexibility, harvest synergies by using all infrastructures and lower energy storage cost[64]. Smart Energy transformation must go far beyond the electricity sector and involve many stakeholders in the city. The electricity sector plays an important role, but a broad (big) strategy is needed

[64] Definition from: https://smartenergysystems.eu/about/ [date of access 17.08.2023].

to address emissions, e.g. powering transport, lighting in cities with renewables. The vision of a net-zero-emissions world is increasingly realistic, but we all need to play our part in achieving it. Technological advances will drive down the cost of low-carbon technologies, and the market for low-carbon products and services will become increasingly important for urban development. Green energy, energy efficiency and behavioural change play an important role in urban development. Every city must change to achieve net zero emissions, globally, by 2050. The European Commission supports various energy transition initiatives focusing on smart grids, energy storage and digitalisation[65]. Smart Energy System is connected with: cost-effective, sustainable, secure, renewable energy production, storage systems, demand side response, electrical vehicles, energy efficiency, active users, and intelligent networking. Smart Energy System is a broader term than Smart Grid, in the sense that it includes more sectors (electricity, heating, cooling, industry, buildings, transportation, water) rather than focusing exclusively on the electricity sector. Smart Energy Systems are closely related to the ongoing energy transition towards a 100% renewable energy system[66]. Smart energy systems connect the energy sources with the customers and adapt via digitisation both the production and consumption of energy, so that the energy is controlled to where it is needed at a given time.

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[65] See: EU initiatives for smart energy systems> web of European Commission: https://energy.ec.europa.eu/topics/research-and-technology/eu-initiatives-smart-energy-systems_en [date of access 17.08.2023].

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Chapter 2

ENERGY SYSTEMS IN SMART CITIES

2.1. Understanding Energy Systems in Smart Cities

Smart cities require a new approach to electric systems due to several reasons. The rapid urbanization and population growth in cities have led to increased energy demands. Traditional electric systems may struggle to meet the rising energy needs, resulting in inadequate supply, blackouts, and inefficiencies. A new approach is needed to optimize energy generation, distribution, and consumption to accommodate these growing demands[67].

Conventional electric systems heavily rely on fossil fuels, contributing to greenhouse gas emissions and environmental degradation. With the urgent need to address climate change, smart cities must transition to cleaner and more sustainable energy sources. A new approach to electric systems emphasizes the integration of renewable energy generation, energy storage, and efficient consumption to reduce carbon emissions and promote environmental sustainability.

Conventional electric grids often face challenges in terms of resilience and reliability. They are susceptible to power outages caused by natural disasters, system failures, or increased demand. A new approach incorporates smart grid technologies that enhance the resilience and reliability of the electric system. Smart grids enable real-time monitoring, automated load balancing, and efficient integration of distributed energy resources, making the grid more robust and adaptive[68].

The traditional model of centralized energy generation and distribution is being challenged by the rise of decentralized energy sources, such as rooftop solar panels and local wind turbines. Smart cities require an approach that accommodates these

[67] S., Maier: Smart energy systems for smart city districts: case study Reininghaus District, Energy, sustainability and Society, Vol. 6, No. 23, 2016, https://doi.org/10.1186/s13705-016-0085-9.
[68] R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin 2016.

distributed energy resources, allowing for their seamless integration into the grid. This involves implementing smart grid technologies and energy management systems that can efficiently manage and optimize the flow of electricity between various decentralized sources and consumers[69].

Advances in digital technologies, data analytics, and artificial intelligence have opened up new possibilities for managing electric systems more efficiently. Smart meters, sensors, and Internet of Things (IoT) devices enable real-time monitoring and data collection, providing valuable insights into energy consumption patterns and grid performance. These technologies facilitate demand response programs, energy conservation, and predictive maintenance, ensuring optimal utilization of resources and reducing costs[70].

Smart cities emphasize citizen engagement and empowerment in energy management. Citizens are encouraged to actively participate in energy conservation efforts, make informed choices about their energy usage, and contribute to a sustainable future. New approaches to electric systems provide tools, platforms, and real-time data access for citizens to monitor and manage their energy consumption, enabling them to actively contribute to a more efficient and sustainable electric system[71].

Energy systems in smart cities refer to the integrated network of infrastructure, technologies, and policies that facilitate efficient generation, distribution, and consumption of energy within urban environments. These systems are designed to optimize energy usage, reduce carbon emissions, and enhance sustainability.

A new approach to electric systems in smart cities is necessary to meet the growing energy demands, address environmental concerns, enhance grid resilience, accommodate decentralized energy generation, leverage technological advancements, and empower citizens. By integrating renewable energy, smart grids, energy storage, and advanced monitoring and management systems, smart cities can create more efficient, sustainable, and resilient electric systems that cater to the evolving needs of urban environments[72].

We can distinguish seven main components of energy systems in smart cities: renewable energy generation, smart grids, energy storage, demand response and energy efficiency, electric mobility, energy management systems and citizen engagement.

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[69] A. Schlüter: Sustainable and Smart Energy Systems for Europe's Cities and Rural Areas, Hanser Fachbuchverlag, Berlin 2022.
[70] Y. Himeur, M. Elnour, F. Fadli, F. Bensaali, A. Amira: Next-generation energy systems for sustainable smart cities: Roles of transfer learning, Sustainable Cities and Society, 85, 2022, 104059.
[71] Ibidem.
[72] V. Pangracius: Smart Energy for Smart Cities, 2022, https://smartcities.ieee.org/newsletter/february-2022/smart-energy-for-smart-cities [access data 19.06.2023].

All those components were characterized in the table 7. By integrating these components and promoting collaboration between stakeholders, energy systems in smart cities aim to optimize energy usage, reduce carbon emissions, enhance grid resilience, and foster a sustainable and liveable urban environment.

Table 7

Components of energy systems in smart cities

Component	**Characteristic**
Renewable Energy Generation	Smart cities prioritize the use of renewable energy sources such as solar, wind, geothermal, and biomass. They integrate various renewable energy systems into the urban fabric, including solar panels on buildings, wind turbines, and geothermal heating and cooling systems.
Smart Grids	Smart grids are advanced electrical grids that incorporate digital technologies, sensors, and automation to optimize the distribution and management of electricity. They enable real-time monitoring of energy demand, efficient load balancing, and integration of decentralized energy sources like rooftop solar panels. Smart grids also facilitate two-way communication between utilities and consumers, enabling demand response programs and energy conservation.
Energy Storage	Energy storage technologies play a crucial role in smart cities. They allow for the efficient capture and storage of surplus energy generated by renewable sources during peak production periods. Batteries, pumped hydro storage, compressed air energy storage, and other innovative storage solutions help balance the supply and demand of electricity, ensure grid stability, and provide backup power during outages.
Demand Response and Energy Efficiency	Smart cities implement demand response programs that encourage consumers to adjust their energy usage during peak demand periods. They leverage real-time data and communication networks to provide incentives for reducing or shifting energy consumption. Additionally, energy-efficient technologies and practices are promoted, including smart appliances, LED lighting, intelligent HVAC systems, and building automation systems that optimize energy usage.

continue table 7

Component	Characteristic
Electric Mobility	Smart cities encourage the adoption of electric vehicles (EVs) by establishing comprehensive charging infrastructure. They deploy charging stations at strategic locations, including residential areas, parking lots, and public spaces. Integration of EV charging with renewable energy sources and smart grid technologies helps manage the increased energy demand and promotes sustainable transportation options.
Energy Management Systems	These systems use data analytics and artificial intelligence (AI) algorithms to monitor and optimize energy consumption across various sectors. They collect and analyse data from sensors, smart meters, and other devices to identify energy inefficiencies, recommend energy-saving measures, and enable predictive maintenance. Energy management systems enable real-time monitoring, analysis, and control of energy usage at the city-wide level.
Citizen Engagement	Smart cities encourage active participation of citizens in energy conservation efforts. They provide access to real-time energy consumption data, user-friendly interfaces, and personalized recommendations for reducing energy usage. Awareness campaigns, educational programs, and interactive platforms empower individuals and communities to make informed choices and contribute to a sustainable energy future.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; A. Schlüter: Sustainable and Smart Energy Systems for Europe's Cities and Rural Areas, Hanser Fachbuchverlag, Berlin 2022; Y. Himeur, M. Elnour, F. Fadli, F. Bensaali, A. Amira: Next--generation energy systems for sustainable smart cities: Roles of transfer learning, Sustainable Cities and Society, 85, 2022, 104059; V. Pangracius: Smart Energy for Smart Cities, 2022, https://smartcities.ieee.org/newsletter/february-2022/smart-energy-for-smart-cities [access data 19.06.2023]; M.G.M. Almihat, M.T.E. Kahn, K. Aboalez, A.M. Almaktoof: Energy and Sustainable Development in Smart Cities: An Overview, Smart Cities, Vol. 5, No. 4, 2022, pp. 1389–1408; B. Li: Effective energy utilization through economic development for sustainable management in smart cities, Energy Reports, Vol. 8, 2022, pp. 4975–4987; R.S. Shudapreyaa, G.K. Kamalam, P. Suresh, K. Sentamilselvan: Smart grid IoT: An intelligent energy management in emerging smart cities, Smart Grids and Internet of Things: An Energy Perspective, 2023, pp. 431–454; F.V. Cerna, M. Pourakbari-Kasmaei, R.G. Barros, M. Lehtonen, J. Contreras: Optimal operating scheme of neighborhood energy storage communities to improve power grid performance in smart cities, Applied Energy, Vol. 331, 2023, 120411.

2.2. Renewable energy sources and their integration

In smart cities, the usage of renewable energy resources is paramount for achieving sustainability, reducing carbon emissions, and ensuring a clean energy future. These cities leverage various renewable energy sources and technologies to power their urban infrastructure and meet the energy needs of their residents. In the table 8 there is a characteristic of main renewable resources from usage in smart city point of view.

The usage of renewable energy resources in smart cities is not limited to a single source but rather encompasses a combination of these resources. By integrating solar power, wind energy, geothermal systems, biomass and biogas facilities, and hydropower, smart cities achieve energy diversification, reduce reliance on fossil fuels, and contribute to a sustainable and low-carbon future. These renewable energy resources are integrated into the urban infrastructure, powering residential, commercial, and public spaces while minimizing environmental impact and ensuring long-term energy sustainability[73].

Table 8

The usage of renewable energy sources in smart city

Energy source	**Characteristic**
Solar Power	Solar energy is a primary renewable resource harnessed in smart cities. Photovoltaic (PV) panels are installed on rooftops, facades, and open spaces to capture sunlight and convert it into electricity. Solar power provides a decentralized and environmentally friendly source of energy, reducing dependence on fossil fuels and minimizing carbon emissions. Smart cities optimize solar power generation by integrating solar panels into buildings, infrastructure, and public spaces, utilizing innovative designs and tracking systems to maximize energy capture.
Wind Energy	Smart cities harness the power of wind to generate electricity through wind turbines. These turbines, either onshore or offshore, capture the kinetic energy of wind and convert it into usable electricity. Wind farms located within or near smart cities provide a substantial and consistent renewable energy source. Smart cities identify suitable locations, implement efficient wind turbine designs, and integrate wind power into their energy systems to diversify their renewable energy portfolio.

[73] N.A. Vukovic, D.E. Nekhorosheva: Renewable Energy in Smart Cities: Challenges and Opportunities by the Case Study of Russia, Smart Cities, Vol. 5, No. 4, 2022, pp. 1208–1228.

continue table 8

Energy source	Characteristic
Geothermal Energy	Geothermal energy is tapped into in smart cities to provide heating and cooling solutions. Geothermal heat pumps use the stable temperature of the earth to provide efficient heating during winters and cooling during summers. These systems utilize the natural heat stored in the ground and distribute it through buildings, reducing the need for traditional heating and cooling methods that rely on fossil fuels. Smart cities incorporate geothermal systems into residential, commercial, and public infrastructure, optimizing energy efficiency and reducing greenhouse gas emissions.
Biomass and Biogas	Biomass and biogas are renewable energy sources derived from organic waste materials. Smart cities employ technologies such as anaerobic digestion and gasification to convert agricultural waste, food waste, and sewage into biogas. This biogas can be used for electricity generation, heating, or as a vehicle fuel. Biomass power plants utilize organic materials such as crop residues, wood chips, or dedicated energy crops to produce electricity and heat. Smart cities implement efficient waste management systems and establish biomass and biogas facilities to harness these resources and reduce landfill waste while producing renewable energy.
Hydropower	Smart cities capitalize on the power of water resources to generate electricity. Hydropower facilities utilize the kinetic energy of flowing or falling water to drive turbines and produce clean electricity. Large-scale hydropower plants are strategically developed near rivers or dams, while smaller-scale micro-hydropower systems are implemented in urban areas with suitable water sources. Smart cities explore the potential of hydropower and integrate it into their energy mix, taking advantage of a reliable and renewable energy source.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; 10; N.A. Vukovic, D.E. Nekhorosheva: Renewable Energy in Smart Cities: Challenges and Opportunities by the Case Study of Russia, Smart Cities, Vol. 5, No. 4, 2022, pp. 1208–1228; C.-H. Hsu, N.M. Eshwarappa, W.-T. Chang, W.-Z. Zhang, J. Huang: Green communication approach for the smart city using renewable energy systems, Energy Reports, Vol. 8, 2022, pp. 9528–9540; J. Huang, D.D. Koroteev, M. Kharun, R.V. Maksimenko: Impact Analysis of Digital Technology on Smart City and Renewable Energy Management, AIP Conference Proceedings, 2022, 2559, 040008; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, pp. 784–800; C.H. Canbaz, O. Ekren, B.Y. Ekren, V. Kumar: Evaluation of fuel production technologies by using renewable energy for smart cities, Smart Cities Policies and Financing: Approaches and Solutions, 2022, pp. 457–470.

In following table 9-13 there is an detailed analysis of advantages and disadvantages of usage of renewable resources in smart city. In the table 9 there are advantages and disadvantages of solar energy usage in smart cities, in table 10 advantages and disadvantages of wind energy usage in smart cities, in table 11 advantages and disadvantages of geothermal energy usage in smart cities, in table 12 advantages and disadvantages of biomass and biogas energy usage in smart cities, in table 13 advantages and disadvantages of hydropower usage in smart cities.

Table 9

Advantages and disadvantages of solar energy usage in smart cities

Advantages of Solar Power Usage in Smart Cities	**Disadvantages of Solar Power Usage in Smart Cities**
Renewable and Sustainable Energy Source	Intermittent Nature: Solar power generation is dependent on sunlight availability, which varies throughout the day and is influenced by weather conditions.
Environmental Benefits: Solar power produces no greenhouse gas emissions or air pollution, contributing to improved air quality and reduced carbon footprint.	Initial Investment Costs: The installation and setup of solar panels can have higher upfront costs, including the purchase of equipment and professional installation.
Energy Independence: Solar power provides cities with greater energy independence, reducing reliance on traditional energy sources and volatile fuel prices.	Space Requirements: Solar panels require sufficient space for installation, which can be a challenge in densely populated urban areas with limited rooftop or open space availability.
Scalability and Modularity: Solar power systems can be easily scaled up or down to meet specific energy demands, making them adaptable to various urban settings.	Storage and Grid Integration: Solar power generation is intermittent and may not align with peak energy demand periods, necessitating energy storage systems or integration with the grid for optimal utilization.
Reduced Transmission Losses: Localized solar power generation minimizes the need for long-distance electricity transmission, reducing energy losses during distribution.	Maintenance and Performance: Solar panels require regular maintenance to ensure optimal performance, including cleaning, inspections, and occasional repairs or replacements.

continue table 9

Advantages of Solar Power Usage in Smart Cities	**Disadvantages of Solar Power Usage in Smart Cities**
Job Creation and Economic Benefits: Solar power infrastructure installation and maintenance create local job opportunities and contribute to the growth of the clean energy sector.	Geographical Limitations: Solar power potential varies based on geographical location, with regions closer to the equator generally receiving higher solar irradiation. Northern latitudes or areas with frequent cloud cover may have lower solar energy potential.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; 10; N.A. Vukovic, D.E. Nekhorosheva: Renewable Energy in Smart Cities: Challenges and Opportunities by the Case Study of Russia, Smart Cities, Vol. 5, No. 4, 2022, pp. 1208–1228; C.-H. Hsu, N.M. Eshwarappa, W.-T. Chang, W.-Z. Zhang, J. Huang: Green communication approach for the smart city using renewable energy systems, Energy Reports, Vol. 8, 2022, pp. 9528–9540; J. Huang, D.D. Koroteev, M. Kharun, R.V. Maksimenko: Impact Analysis of Digital Technology on Smart City and Renewable Energy Management, AIP Conference Proceedings, 2022, 2559, 040008; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, pp. 784–800; C.H. Canbaz, O. Ekren, B.Y. Ekren, V. Kumar: Evaluation of fuel production technologies by using renewable energy for smart cities, Smart Cities Policies and Financing: Approaches and Solutions, 2022, pp. 457–470.

Table 10

Advantages and disadvantages of wind energy usage in smart cities

Advantages of Wind Energy Usage in Smart Cities	**Disadvantages of Wind Energy Usage in Smart Cities**
Renewable and Sustainable Energy Source	Intermittent Nature: Wind power generation is dependent on wind speed, which can vary and be inconsistent, resulting in fluctuations in electricity production.
Environmental Benefits: Wind power produces no greenhouse gas emissions or air pollution, contributing to improved air quality and reduced carbon footprint.	Visual and Noise Impact: Wind turbines may be visually and audibly noticeable, which can be a concern for some residents, particularly in densely populated urban areas.

continue table 10

Advantages of Wind Energy Usage in Smart Cities	**Disadvantages of Wind Energy Usage in Smart Cities**
Energy Independence: Wind power provides cities with greater energy independence, reducing reliance on traditional energy sources and volatile fuel prices.	Space Requirements: Wind turbines require adequate space for installation, including consideration of setback distances, which may pose challenges in urban areas with limited available land.
Scalability and Modularity: Wind energy systems can be easily scaled up or down to meet specific energy demands, making them adaptable to various urban settings.	Wind Resource Variability: The availability and consistency of wind resources can vary across different locations, requiring careful site selection for optimal wind power generation.
Reduced Transmission Losses: Localized wind power generation minimizes the need for long-distance electricity transmission, reducing energy losses during distribution.	Bird and Wildlife Impact: Wind turbines can pose risks to birds and bats, and careful planning and mitigation strategies are necessary to minimize environmental impact.
Job Creation and Economic Benefits: Wind power infrastructure installation, maintenance, and manufacturing create local job opportunities and contribute to the growth of the clean energy sector.	Maintenance and Operation: Wind turbines require periodic maintenance and monitoring for optimal performance, including inspection, repairs, and replacement of components.
Technological Advancements: Ongoing advancements in wind turbine technology have resulted in increased efficiency, reduced costs, and improved performance, making wind energy a viable and competitive energy option.	Grid Integration and Storage: Wind power's variability may require grid integration and energy storage solutions to balance supply and demand and ensure a stable electricity supply.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; 10; N.A. Vukovic, D.E. Nekhorosheva: Renewable Energy in Smart Cities: Challenges and Opportunities by the Case Study of Russia, Smart Cities, Vol. 5, No. 4, 2022, pp. 1208–1228; C.-H. Hsu, N.M. Eshwarappa, W.-T. Chang, W.-Z. Zhang, J. Huang: Green communication approach for the smart city using renewable energy systems, Energy Reports, Vol. 8, 2022, pp. 9528–9540; J. Huang, D.D. Koroteev, M. Kharun, R.V. Maksimenko: Impact Analysis of Digital Technology on Smart City and Renewable Energy Management, AIP Conference Proceedings, 2022, 2559, 040008; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, pp. 784–800; C.H. Canbaz, O. Ekren, B.Y. Ekren, V. Kumar: Evaluation of fuel production technologies by using renewable energy for smart cities, Smart Cities Policies and Financing: Approaches and Solutions, 2022, pp. 457–470.

Table 11

Advantages and disadvantages of geothermal energy usage in smart cities

Advantages of Geothermal Energy Usage in Smart Cities	**Disadvantages of Geothermal Energy Usage in Smart Cities**
Renewable and Sustainable Energy Source	Site-Specific Resource: Geothermal energy availability depends on the geological characteristics of the region, limiting its implementation to areas with suitable geothermal reservoirs.
Environmental Benefits: Geothermal energy produces no greenhouse gas emissions or air pollution, contributing to improved air quality and reduced carbon footprint.	High Initial Investment: Geothermal power plants require significant upfront costs for exploration, drilling, and infrastructure development, making the initial investment relatively higher compared to other renewable energy sources.
Provides Heating and Cooling Solutions: Geothermal systems can efficiently provide heating during winters and cooling during summers, reducing the reliance on traditional heating and cooling methods that rely on fossil fuels.	Geological Risks: The exploration and drilling process may involve geological risks, such as encountering dry or low-temperature wells, which can impact the viability and efficiency of geothermal projects.
Energy Independence: Geothermal energy provides cities with greater energy independence, reducing dependence on traditional energy sources and volatile fuel prices.	Limited Geographical Availability: Geothermal resources are geographically constrained and may not be accessible in all regions, limiting the widespread adoption of geothermal energy in some areas.
Scalable and Modular: Geothermal systems can be scaled up or down to meet specific energy demands, making them adaptable to various urban settings.	Water Usage: Some geothermal power plants require significant amounts of water for cooling and re-injection into the geothermal reservoir, which may pose challenges in water-scarce regions.
Reduced Transmission Losses: Localized geothermal energy generation minimizes the need for long-distance electricity transmission, reducing energy losses during distribution.	Maintenance and Operation: Geothermal power plants require regular maintenance to ensure optimal performance, including monitoring of well integrity, scaling, and corrosion management.

continue table 11

Advantages of Geothermal Energy Usage in Smart Cities	**Disadvantages of Geothermal Energy Usage in Smart Cities**
Job Creation and Economic Benefits: Geothermal infrastructure installation, maintenance, and operation create local job opportunities and contribute to the growth of the clean energy sector.	Risk of Depletion: Prolonged extraction of geothermal energy at a high rate may deplete the heat resource in the geothermal reservoir, requiring careful monitoring and management for long-term sustainability.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; 10; N.A. Vukovic, D.E. Nekhorosheva: Renewable Energy in Smart Cities: Challenges and Opportunities by the Case Study of Russia, Smart Cities, Vol. 5, No. 4, 2022, pp. 1208–1228; C.-H. Hsu, N.M. Eshwarappa, W.-T. Chang, W.-Z. Zhang, J. Huang: Green communication approach for the smart city using renewable energy systems, Energy Reports, Vol. 8, 2022, pp. 9528–9540; J. Huang, D.D. Koroteev, M. Kharun, R.V. Maksimenko: Impact Analysis of Digital Technology on Smart City and Renewable Energy Management, AIP Conference Proceedings, 2022, 2559, 040008; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, pp. 784–800; C.H. Canbaz, O. Ekren, B.Y. Ekren, V. Kumar: Evaluation of fuel production technologies by using renewable energy for smart cities, Smart Cities Policies and Financing: Approaches and Solutions, 2022, pp. 457–470.

Table 12

Advantages and disadvantages of biomass and biogas energy usage in smart cities

Advantages of Biomass and Biogas Energy Usage in Smart Cities	**Disadvantages of Biomass and Biogas Energy Usage in Smart Cities**
Renewable and Sustainable Energy Source	Feedstock Availability: Biomass and biogas energy generation requires a consistent and sufficient supply of organic waste or biomass feedstock, which may not always be readily available or easily accessible.
Environmental Benefits: Biomass and biogas energy can reduce greenhouse gas emissions by utilizing organic waste and biomass, mitigating the impact on landfills and reducing the reliance on fossil fuels.	Land Use and Competition: Biomass production may compete with other land uses, such as food production, and can require dedicated land for growing energy crops, raising concerns about sustainable land use practices.

continue table 12

Advantages of Biomass and Biogas Energy Usage in Smart Cities	**Disadvantages of Biomass and Biogas Energy Usage in Smart Cities**
Waste Management Solution: Biomass and biogas energy production can help manage organic waste, diverting it from landfills and reducing the associated environmental impacts.	Technological Limitations: Biomass and biogas energy technologies may have technical limitations in terms of efficiency, scalability, and reliability, requiring ongoing research and development for optimization.
Distributed Generation: Biomass and biogas energy can be generated at smaller scales, allowing for localized and distributed energy production, reducing transmission losses and increasing energy efficiency.	Emissions and Air Quality: Biomass combustion and biogas production can release pollutants, such as particulate matter, nitrogen oxides, and volatile organic compounds, which need to be carefully managed to ensure compliance with air quality regulations.
Job Creation and Economic Benefits: Biomass and biogas energy projects can create local job opportunities and contribute to the development of a circular economy, promoting sustainability and economic growth.	Storage and Seasonal Variability: Biomass and biogas energy generation may experience seasonal variations and intermittent availability of feedstock, requiring storage or alternative energy sources for continuous supply during low-production periods.
Technology Integration: Biomass and biogas energy can be integrated with other renewable energy systems, such as combined heat and power (CHP) plants or anaerobic digestion facilities, maximizing energy efficiency and resource utilization.	Cost and Financial Viability: Biomass and biogas energy projects often require significant upfront investment and ongoing operational costs, which may affect the financial viability and return on investment, especially in smaller-scale applications.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; 10; N.A. Vukovic, D.E. Nekhorosheva: Renewable Energy in Smart Cities: Challenges and Opportunities by the Case Study of Russia, Smart Cities, Vol. 5, No. 4, 2022, pp. 1208–1228; C.-H. Hsu, N.M. Eshwarappa, W.-T. Chang, W.-Z. Zhang, J. Huang: Green communication approach for the smart city using renewable energy systems, Energy Reports, Vol. 8, 2022, pp. 9528–9540; J. Huang, D.D. Koroteev, M. Kharun, R.V. Maksimenko: Impact Analysis of Digital Technology on Smart City and Renewable Energy Management, AIP Conference Proceedings, 2022, 2559, 040008; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, pp. 784–800; C.H. Canbaz, O. Ekren, B.Y. Ekren, V. Kumar: Evaluation of fuel production technologies by using renewable energy for smart cities, Smart Cities Policies and Financing: Approaches and Solutions, 2022, pp. 457–470.

Table 13

Advantages and disadvantages of hydropower usage in smart cities

Advantages of Hydropower Usage in Smart Cities	**Disadvantages of Hydropower Usage in Smart Cities**
Renewable and Sustainable Energy Source	Environmental Impact: Large-scale hydropower projects can have significant environmental impacts, including habitat disruption, alteration of water flows, and potential negative effects on aquatic ecosystems.
Reliable and Consistent Energy Generation	Land and Habitat Loss: Construction of dams and reservoirs for hydropower plants can result in the loss of land and displacement of communities, as well as the loss of natural habitats and biodiversity.
Environmental Benefits: Hydropower produces no greenhouse gas emissions or air pollution, contributing to improved air quality and reduced carbon footprint.	Initial Investment and Infrastructure: Hydropower projects require substantial upfront investment and the construction of infrastructure such as dams, reservoirs, and transmission lines, which can be financially and logistically challenging.
Energy Independence: Hydropower provides cities with greater energy independence, reducing reliance on traditional energy sources and volatile fuel prices.	Limited Site Availability: Suitable locations for large-scale hydropower plants are limited, and some regions may lack the necessary natural features, such as rivers and elevation changes, for efficient hydropower generation.
Scalable and Modular: Hydropower systems can be implemented at various scales, from large-scale dams to micro-hydropower installations, making them adaptable to different urban settings and energy demands.	Social and Cultural Impact: The construction of large-scale hydropower projects can have social and cultural implications, including the displacement of communities and potential loss of cultural heritage sites.
Reduced Transmission Losses: Localized hydropower generation minimizes the need for long-distance electricity transmission, reducing energy losses during distribution.	Sedimentation and Maintenance: Reservoirs can accumulate sediment over time, reducing their storage capacity, and requiring periodic maintenance and dredging to ensure optimal performance.

continue table 13

Advantages of Hydropower Usage in Smart Cities	**Disadvantages of Hydropower Usage in Smart Cities**
Job Creation and Economic Benefits: Hydropower infrastructure installation, operation, and maintenance create local job opportunities and contribute to the growth of the clean energy sector.	Climate Change and Water Availability: Climate change impacts, such as changes in rainfall patterns and water availability, can affect hydropower generation and the reliability of water resources for energy production.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; 10; N.A. Vukovic, D.E. Nekhorosheva: Renewable Energy in Smart Cities: Challenges and Opportunities by the Case Study of Russia, Smart Cities, Vol. 5, No. 4, 2022, pp. 1208–1228; C.-H. Hsu, N.M. Eshwarappa, W.-T. Chang, W.-Z. Zhang, J. Huang: Green communication approach for the smart city using renewable energy systems, Energy Reports, Vol. 8, 2022, pp. 9528–9540; J. Huang, D.D. Koroteev, M. Kharun, R.V. Maksimenko: Impact Analysis of Digital Technology on Smart City and Renewable Energy Management, AIP Conference Proceedings, 2022, 2559, 040008; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, pp. 784–800; C.H. Canbaz, O. Ekren, B.Y. Ekren, V. Kumar: Evaluation of fuel production technologies by using renewable energy for smart cities, Smart Cities Policies and Financing: Approaches and Solutions, 2022, pp. 457–470.

Renewable resources can be effectively integrated into smart cities through various strategies and technologies. Below we presented some ways in which renewable resources can be integrated into smart cities[74]:

1. Solar Power Integration:
   - Installation of solar panels on rooftops of buildings to generate clean energy for individual consumption or for feeding back into the grid.
   - Implementation of solar farms or solar parks in open areas to generate electricity on a larger scale.
   - Integration of solar-powered streetlights and solar charging stations for electric vehicles.

[74] R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; 10; J. Huang, D.D. Koroteev, M. Kharun, R.V. Maksimenko: Impact Analysis of Digital Technology on Smart City and Renewable Energy Management, AIP Conference Proceedings, 2022, 2559, 040008; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, pp. 784–800; C.H. Canbaz, O. Ekren, B.Y. Ekren, V. Kumar: Evaluation of fuel production technologies by using renewable energy for smart cities, Smart Cities Policies and Financing: Approaches and Solutions, 2022, pp. 457–470; E. Newton: 9 Ways smart cities can use renewable resources, 2022, https://www.construction21.org/articles/h/9-ways-smart-cities-can-use-renewable-resources.html, [access data 19.06.2023].

2. Wind Energy Integration:
   - Construction of wind turbines in suitable locations to harness wind power and generate electricity.
   - Installation of small-scale wind turbines on buildings or in urban areas where wind speeds are sufficient.
   - Integration of wind power into the grid to supplement the energy needs of the city.
3. Geothermal Energy Integration:
   - Utilization of geothermal heat pumps for heating and cooling buildings, tapping into the Earth's natural heat.
   - Integration of geothermal power plants to generate electricity from geothermal reservoirs.
   - Implementation of geothermal district heating systems to provide sustainable heating solutions for urban areas.
4. Biomass and Biogas Integration:
   - Construction of biomass power plants that use organic waste or energy crops to generate electricity or heat.
   - Utilization of biogas produced from anaerobic digestion of organic waste or wastewater treatment processes for heating, electricity generation, or as a fuel for vehicles.
   - Integration of biomass and biogas facilities with waste management systems to effectively process and utilize organic waste.
5. Hydropower Integration:
   - Construction of small-scale hydropower installations in urban areas, utilizing rivers or canals to generate electricity.
   - Integration of hydropower from large-scale dams or run-of-river systems to supplement the energy needs of the city.
   - Implementation of micro-hydropower systems in wastewater treatment plants or water distribution networks to generate electricity from water flow.
6. Energy Storage and Management:
   - Integration of energy storage systems, such as batteries or pumped hydro storage, to store excess energy generated by renewable resources for later use.
   - Implementation of smart grid technologies to manage and balance the fluctuating supply and demand of renewable energy.
   - Utilization of demand-response systems that adjust energy consumption based on availability and pricing of renewable energy.

7. Smart City Infrastructure:
    - Integration of renewable energy technologies into smart buildings, including energy-efficient design, smart lighting systems, and automated energy management systems.
    - Development of electric vehicle charging infrastructure powered by renewable energy sources.
    - Integration of renewable energy generation and distribution systems with smart city management platforms for efficient monitoring, control, and optimization.

The integration of renewable resources in smart cities enables the transition to a sustainable and low-carbon energy system. It promotes energy efficiency, reduces greenhouse gas emissions, improves air quality, enhances energy independence, and creates job opportunities in the clean energy sector. The successful integration of renewables in smart cities requires careful planning, collaboration between stakeholders, supportive policies, and the deployment of advanced technologies for monitoring, management, and optimization of energy systems.

In literature we can spot many example of usage of renewable resources in smart cities. Some examples of them are presented in the table 14

Table 14

Examples of usage of renewable resources in smart cities

Example	**Description**
Smart Street Lights	These automatic lights adjust their brightness according to specific times, resulting in cost savings and a more pleasant environment. Unlike traditional lights that remain bright throughout the night, contributing to light pollution and energy waste, smart lights adapt to the current conditions. They can increase their brightness when necessary, like when people walk underneath them or when cars approach. In emergency situations, police departments and traffic officers have the ability to raise the light intensity to enhance visibility. However, these smart lights are designed to consume the minimum amount of power required for their operation. Solar panels and wind turbines provide the energy needed to power these streetlights, which not only helps save money but also reduces the costs associated with wiring and infrastructure.

continue table 14

Example	Description
Garbage Sensors	The collection of half-empty dumpsters by garbage trucks consumes significant time and energy. However, imagine if the trucks could accurately identify which dumpsters require emptying at any given time. This is made possible through the use of trash sensors that detect the fill level of the cans. As a result, this technology minimizes wasted time, reduces fuel consumption, and lowers carbon emissions. Moreover, it contributes to quieter neighborhoods, as the trucks no longer need to spend prolonged periods in specific areas of the town.
Driving Apps	Rather than engaging in a futile search for an available parking spot, drivers now have the option to utilize smartphone applications linked to parking lot sensors that identify vacant spaces. These applications can effectively direct drivers to an unoccupied spot. Additionally, there are other types of applications that inform drivers about the locations of electric vehicle charging stations. By providing this information, these apps contribute to the reduction of electricity usage and promote smoother traffic flow.
Weather Sensors	Numerous sprinkler systems operate on timers that disregard weather conditions. Consequently, they frequently water plants during the hottest part of the day, resulting in leaf burns and substantial water loss through evaporation. However, the integration of intelligent weather sensors with sprinklers and hoses addresses this issue by adapting watering schedules based on temperature and precipitation. These sensors enable automatic watering at optimal times, effectively reducing water consumption and promoting the overall health of plants.
Smart Utilities	By employing interconnected devices throughout the grid, energy and water utilities can gather a wealth of information surpassing that of traditional meters. These devices encompass smart meters and solar instrumentation. As a result, utilities are able to provide services with enhanced reliability while conserving energy. The implementation of these intelligent utilities contributes to the development of sustainable cities that promote the well-being of their residents. They enable real-time energy purchases, daily monitoring of energy consumption, power-saving practices, and swift grid connections or disconnections. The need for physical meter reading is eliminated as the meters consistently display current electricity usage.

continue table 14

Example	Description
Smart Charging Stations	Smart charging stations establish a data connection with the electric vehicles utilizing them. Additionally, these stations are linked to a smart charging operator, and the entire system is connected to the cloud. This connectivity enables remote management and control of the charging station, with the primary objective of optimizing energy usage. The person overseeing the station can effectively restrict or regulate its usage, encouraging charging activities during periods of low electricity demand. Furthermore, smart chargers have the capability to reduce the charging costs for electric vehicle drivers. Together with the expansion of charging infrastructure, this advancement facilitates a more convenient and dependable experience for individuals driving electric vehicles. It plays a crucial role in the collective effort towards decarbonization.
Smart Heating and Cooling Systems	Due to the significant energy consumption associated with heating and cooling, buildings hold a crucial position in the pursuit of sustainability. In the United States, commercial buildings alone contribute to 35% of the country's electricity consumption, and this doesn't even include residential structures. This is where smart HVAC systems play a vital role. Equipped with real-time data-collecting sensors that transmit information to a cloud-based platform, energy providers can analyse energy usage patterns throughout different times of the day and seasons. This capability is instrumental in reducing costs and preventing energy wastage. Another notable feature of smart heating and cooling systems is their ability to detect early signs of excessive vibration, decreased efficiency, or other issues even before they are noticeable to occupants. This enables technicians to promptly identify and resolve problems within the HVAC system, resulting in substantial savings over time through reduced energy consumption and replacement expenses. Furthermore, smart HVAC systems possess the capability to automatically adjust temperature settings based on occupancy and room usage. Leveraging AI technology, these systems continuously learn and improve their heating and cooling programs over time, ensuring optimal comfort and energy efficiency.

continue table 14

Example	**Description**
Electric or Biogas-Based Public Transportation	In smart cities that rely on wind and solar energy, electric buses and trains can be charged to serve the public transportation needs. Electric vehicles (EVs) offer significant advantages over traditional combustion engine vehicles as they generate zero emissions and operate quietly. Some cities have even introduced electric garbage trucks as part of their sustainable transportation initiatives. Another environmentally friendly option for powering vehicles in smart cities is biogas. In countries like Sweden, smart cities are utilizing biogas derived from various sources such as slaughterhouse waste, manure, sewage, and the food industry. This renewable fuel is used to power cars, trucks, and buses, contributing to the reduction of greenhouse gas emissions and promoting a cleaner urban environment.
Air Quality Monitors	Strategic placement of intelligent air monitors across the city enables city planners to effectively assess and make informed decisions regarding infrastructure and policies. These advanced monitors have the capability to detect various environmental conditions, including air pollution, dust, odors, and weather patterns. The collected data serves as a valuable resource for authorities to identify trends and patterns. For instance, if a specific traffic intersection exhibits severe pollution levels, city planners may choose to construct an alternative route to alleviate congestion and enhance air quality in that area. Moreover, the air monitors enable officials to swiftly issue advisory messages, recommending people to stay indoors or wear masks during excessively dusty days, thereby safeguarding public health. By utilizing smart air monitors, city planners gain valuable insights into the environmental conditions, enabling them to implement targeted measures that improve overall air quality and enhance the well-being of the community.

Source: Authors own work on basis: 15.E. Newton: 9 Ways smart cities can use renewable resources, 2022, https://www.construction21.org/articles/h/9-ways-smart-cities-can-use-renewable-resources.html [access data 19.06.2023].

2.3. Energy storage technologies for Smart Cities

Energy storage technologies play a crucial role in enabling the efficient and reliable operation of smart cities. These technologies allow for the capture, storage, and distribution of energy, ensuring a stable and continuous power supply. The brief description of mainly used technologies in this case is in table 15.

Table 15

Energy storage technologies which can be used in smart city

Technology	Description
Battery Energy Storage Systems (BESS)	BESS are widely used in smart cities to store electricity generated from renewable sources such as solar and wind. They consist of rechargeable batteries that store excess energy during periods of low demand and supply it during peak demand or when renewable energy generation is low. BESS provide flexibility in managing energy supply and demand, enhance grid stability, and enable the integration of intermittent renewable energy sources.
Pumped Hydroelectric Storage	Pumped hydroelectric storage involves pumping water from a lower reservoir to an upper reservoir during times of excess electricity generation. When electricity demand increases, the water is released back to the lower reservoir through turbines, generating electricity. This technology provides large--scale energy storage capacity and is known for its high efficiency and long duration storage capabilities.
Compressed Air Energy Storage (CAES)	CAES systems store excess electricity by compressing air and storing it in underground caverns or containers. When electricity demand rises, the compressed air is released and expands through turbines to generate electricity. CAES is known for its scalability and the ability to provide both short-term and long-term energy storage solutions.
Thermal Energy Storage (TES)	TES technologies store excess thermal energy for later use. This can involve storing heat or cold in materials such as molten salts, water, or phase-change materials. The stored energy can then be used for heating or cooling purposes, reducing the reliance on grid electricity during peak periods and optimizing energy efficiency in buildings and district energy systems.

continue table 15

Technology	Description
Flywheel Energy Storage	Flywheel systems store energy by accelerating a rotor to high speeds and then releasing it to generate electricity when needed. They provide rapid response times and can supply power for short durations. Flywheel energy storage is often used in conjunction with other storage technologies to provide grid stabilization and frequency regulation services.

Source: T. Matsumoto, K. Tanaka: Smart City Design Method for Feasible Energy Storage Introduction toward 100% Renewable Electricity, 21st IEEE International Conference on Environment and Electrical Engineering and 2021 5th IEEE Industrial and Commercial Power System Europe, EEEIC / I and CPS Europe 2021 – Proceedings, 2021; A. Colmenar-Santos, E.L. Molina, E. Rosales-Asensio, D. Borge-Diez: Smart cities and energy storage, The Future of Energy: Challenges, Perspectives, and Solutions, 2020, pp. 33–71; D. Zhao, N. Thakur, J. Chen: Optimal Design of Energy Storage System to Buffer Charging Infrastructure in Smart Cities, Journal of Management in Engineering, Vol. 36, No. 2, 2020, 04019048; A.H. Lone, T. Navid, A.S. Siddiqui: Feasibility Investigation of Energy Storage Systems of Hybrid Power System and Its Benefits to Smart Cities, Lecture Notes in Civil Engineering, Vol. 58, 2020, pp. 219–229; H.U.R. Habib, S. Wang, M.T. Aziz: Renewable Energy Resources and Microgrid Management with Smart Battery Storage Control Considering Load Demand of Smart City, HONET-ICT 2019 - IEEE 16th International Conference on Smart Cities: Improving Quality of Life using ICT, IoT and AI, 2019, pp. 191–192, 8908084.

Battery Energy Storage Systems (BESS) are essential components of smart cities as they enable the efficient utilization of renewable energy sources. These systems consist of rechargeable batteries that store excess electricity generated from sources like solar panels and wind turbines. The stored energy can be used during periods of high demand or when renewable energy generation is low. BESS provides flexibility in managing the supply and demand of electricity, enhancing grid stability and reliability. They play a crucial role in integrating intermittent renewable energy sources into the grid by storing excess energy for later use. This allows for a more balanced and sustainable energy mix in smart cities. Moreover, BESS helps to optimize energy usage and reduce reliance on traditional fossil fuel-based power plants. By storing electricity during off-peak hours when demand is low and utilizing it during peak hours, BESS can help reduce the strain on the grid and decrease the need for additional power generation capacity[75].

[75] I.I. Picioroaga, M. Eremia, M. Sanduleac: Economic Benefits of Energy Storage and Price-aware Demand Response for Future Smart Cities, 2019 54th International Universities Power Engineering Conference, UPEC 2019 – Proceedings, 2019, 8893590.

BESS contributes to the overall resilience of the energy infrastructure in smart cities. In the event of power outages or disruptions, battery storage systems can provide backup power, ensuring continuity of critical services and minimizing disruptions to residents and businesses. Overall, Battery Energy Storage Systems play a vital role in maximizing the efficiency, reliability, and sustainability of energy systems in smart cities. They facilitate the integration of renewable energy, enhance grid stability, and contribute to a more resilient and environmentally friendly energy infrastructure[76].

Pumped Hydroelectric Storage is a widely used energy storage technology in smart cities. It involves using excess electricity during low-demand periods to pump water from a lower reservoir to a higher one. Then, during peak demand periods or when renewable energy generation is low, the stored water is released back to the lower reservoir through turbines, generating electricity. This technology offers several advantages for smart cities. Firstly, it provides a large-scale energy storage capacity, allowing for the storage of significant amounts of energy over long periods. This helps in balancing the supply and demand of electricity and ensures a reliable and stable grid[77].

Additionally, pumped hydroelectric storage is highly efficient, with energy conversion efficiencies reaching up to 80%. It offers quick response times, enabling the system to ramp up electricity production rapidly when needed. This flexibility is crucial for managing fluctuations in energy demand and supply. Pumped hydroelectric storage is also environmentally friendly as it does not produce greenhouse gas emissions during operation. It can complement the integration of renewable energy sources by storing excess renewable energy and releasing it when needed, reducing the reliance on fossil fuel-based power generation[78].

Furthermore, this technology has a long lifespan and requires minimal maintenance, making it a cost-effective energy storage solution in the long run. It can contribute to the overall resilience of the energy grid by providing backup power during emergencies or power outages. In smart cities, pumped hydroelectric storage systems can play a critical role in optimizing the utilization of renewable energy resources, ensuring grid stability, and enhancing the overall efficiency and reliability of the energy infrastructure[79].

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[76] A. Benson: Customized predictions of the installed cost of behind-the-meter battery energy storage systems, Energy Reports, Vol. 9, 2023, pp. 5509–5531.

[77] A. Barbón, Á. Gutiérrez, L. Bayón, C. Bayón-Cueli, J. Aparicio-Bermejo: Economic Analysis of a Pumped Hydroelectric Storage-Integrated Floating PV System in the Day-Ahead Iberian Electricity Market, Energies, Vol. 16, No. 4, 2022, 1705.

[78] R. Abdelhady, D. Abdellatif: Optimal scheduling of Egyptian grid with pumped storage hydroelectric power plant, IET Renewable Power Generation, Vol. 16, No. 15, 2022, pp. 3161–3170.

[79] P.T. Ha, D.T. Tran, T.T. Nguyen: Electricity generation cost reduction for hydrothermal systems with the presence of pumped storage hydroelectric plants, Neural Computing and Applications, 2022, Vol. 34, No. 12, pp. 9931–9953.

Compressed Air Energy Storage (CAES) is an energy storage technology that can be utilized in smart cities. It involves compressing air and storing it in underground reservoirs or specially designed containers. The stored air can then be released and expanded through turbines to generate electricity when demand is high or renewable energy generation is low. CAES offers several advantages for smart cities. Firstly, it has a large-scale energy storage capacity, allowing for the storage of significant amounts of energy over extended periods. This helps in balancing the supply and demand of electricity and ensures a reliable and stable grid. Another advantage of CAES is its ability to convert excess electricity into potential energy in the form of compressed air, which can be stored for later use. This makes it a suitable option for integrating intermittent renewable energy sources into the grid[80].

CAES systems can provide quick response times and can ramp up electricity production rapidly, making them flexible in meeting sudden increases in demand or compensating for fluctuations in renewable energy generation. This flexibility helps in maintaining grid stability and optimizing energy usage in smart cities. Also, CAES is a clean and environmentally friendly technology as it does not produce greenhouse gas emissions during operation. It can contribute to reducing the reliance on fossil fuel-based power generation and promote the use of renewable energy sources in smart cities[81].

Additionally, CAES systems have a long lifespan and require minimal maintenance, making them cost-effective in the long run. They can also provide grid stability and serve as backup power during emergencies or power outages. Compressed Air Energy Storage can play a significant role in the energy storage infrastructure of smart cities. It offers large-scale storage capacity, flexibility, environmental sustainability, and grid stability, contributing to the efficient and reliable utilization of renewable energy resources.

Thermal Energy Storage (TES) is a technology used in smart cities to store and release thermal energy as needed. It involves capturing and storing heat or cold energy in various mediums, such as water, ice, or phase change material In smart cities, TES systems can be used for heating and cooling applications. During periods of excess energy or when energy prices are low, thermal energy is captured and stored for later use. The stored energy can be released when there is a demand for heating or cooling, optimizing energy usage and reducing peak load on the grid[82].

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[80] T. Hai, M. Zoghi, K. Javaherdeh: 4E analysis and optimization of a biomass-fired waste-to-energy plant integrated with a compressed air energy storage system for the multi-generation purpose, Fuel, Vol. 348, 2023, 128457.

[81] X. Zhang, Y. Li, Z. Gao, Y. Xu, H. Chen: Overview of dynamic operation strategies for advanced compressed air energy storage, Journal of Energy Storage, Vol. 66, 2023, 107408.

[82] C. Zhao, J. Yan, X. Tian, X. Xue, Y. Zhao: Progress in thermal energy storage technologies for achieving carbon neutrality, Carbon Neutrality, Vol. 2, No. 1, 2023, 10.

TES offers several advantages for smart cities. It allows for the efficient management of energy consumption by shifting the usage of heating or cooling energy to off-peak hours when electricity demand is lower. This helps in reducing energy costs and minimizing the strain on the grid during peak periods. One of the key benefits of TES is its ability to integrate with renewable energy sources. Excess energy generated from renewable sources, such as solar or wind, can be utilized to heat or cool the storage medium. This enhances the utilization of renewable energy and promotes sustainability in smart cities.

TES systems can also improve the efficiency of heating and cooling systems. By storing thermal energy during periods of high efficiency and utilizing it during periods of lower efficiency, overall energy consumption can be reduced, resulting in energy savings and lower carbon emissions. Moreover, TES can enhance the resilience of smart cities by providing a backup energy source during power outages. The stored thermal energy can be utilized to maintain heating or cooling services, ensuring the comfort and well-being of residents and critical infrastructure. In addition to its energy-related benefits, TES systems can contribute to load balancing and grid stability. By shifting energy demand to off-peak hours, TES helps in leveling out electricity consumption and reducing the strain on the grid during peak periods[83].

Thermal Energy Storage is a valuable technology for smart cities, offering efficient energy management, integration with renewable energy sources, improved heating and cooling efficiency, resilience during power outages, and grid stability. It plays a crucial role in optimizing energy usage, reducing costs, and promoting sustainability in urban environments.

Flywheel Energy Storage is a technology used in smart cities to store and release energy by harnessing the rotational motion of a spinning flywheel. It operates based on the principle of conservation of angular momentum. In smart city applications, a flywheel energy storage system consists of a high-speed rotor, bearings, and a motor-generator. When excess energy is available, the motor drives the flywheel to high speeds, storing the energy in the form of rotational kinetic energy. This energy can be subsequently released when there is a demand or shortage of electricity[84].

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[83] S. Sharma, M. Mortazavi: Pumped thermal energy storage: A review, International Journal of Heat and Mass Transfer, Vol. 213, 2023, 124286.

[84] O. Bamisile, Z. Zheng, H. Adun, N. Ting, Q. Huang: Development and prospect of flywheel energy storage technology: A citespace-based visual analysis, Energy Reports, Vol. 9, 2023, pp. 494–505.

Flywheel Energy Storage offers several advantages for smart cities. One of the key advantages is its high efficiency. The energy conversion process in a flywheel system is highly efficient, with minimal energy losses during charging and discharging cycles. This makes it an attractive option for storing and utilizing energy effectively. Another advantage of flywheel energy storage is its rapid response time. The rotational motion of the flywheel allows for near-instantaneous energy release, making it suitable for applications that require quick power delivery, such as grid stabilization and backup power during sudden outages.

Flywheel systems are also known for their long lifespan and low maintenance requirements. Compared to traditional battery storage systems, flywheels have a longer operational life and do not experience degradation over time. This results in reduced maintenance costs and increased reliability for smart city applications. Also, flywheel energy storage systems have a small footprint and can be easily integrated into existing infrastructure. They do not require hazardous chemicals or materials, making them environmentally friendly and safe for use in urban areas. However, flywheel energy storage does have some limitations. It is typically suited for short-duration energy storage applications due to the inherent energy loss caused by friction and air resistance. Therefore, it may not be suitable for long-term energy storage requirements[85].

Flywheel Energy Storage is a promising technology for smart cities, offering high efficiency, rapid response times, long lifespan, low maintenance requirements, and a small environmental footprint. It can contribute to grid stability, provide backup power, and enhance the overall efficiency and reliability of energy systems in urban environments.

2.4. Demand response and energy efficiency strategies

In a smart city, the changing demand for energy can be effectively managed through demand response strategies. These strategies allow the city to dynamically respond to fluctuations in energy demand by adjusting consumption patterns, optimizing energy distribution, and promoting efficient usage. In the table 16 we put some ways in which a smart city can react to changing demand response in energy usage:

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[85] A.J. Hutchinson, D.T. Gladwin: Capacity factor enhancement for an export-limited wind generation site utilizing a novel Flywheel Energy Storage strategy, Journal of Energy Storage, Vol. 68, 2023, 107832.

Table 16

Strategies smart cities can adopt to react to changing demand response in energy usage

Strategy	Characteristic
Real-time monitoring and analytics	Smart city infrastructure can incorporate advanced metering systems and sensors to collect real-time data on energy consumption. This data can be analysed to identify patterns, trends, and peak demand periods. By continuously monitoring energy usage, city officials can proactively respond to changes in demand.
Smart grid technology	Implementing a smart grid enables bidirectional communication between the utility provider and consumers. It allows for the integration of renewable energy sources, energy storage systems, and demand response mechanisms. With a smart grid, the city can adjust energy supply and distribution in real-time, ensuring a stable and efficient response to changing demand.
Time-of-use pricing	By implementing time-of-use pricing, consumers are encouraged to shift their energy usage to off-peak hours when demand is lower. Smart meters can provide real-time pricing information to consumers, allowing them to make informed decisions about their energy consumption. This helps to flatten the demand curve and optimize energy distribution throughout the day.
Demand response programs	Smart cities can implement demand response programs that incentivize consumers and businesses to reduce their energy usage during peak demand periods. This can be done through financial incentives, such as discounted rates or rebates, or through non-monetary incentives, such as access to special services or rewards. By actively engaging consumers, the city can effectively manage and balance the demand for energy.
Energy storage systems	Deploying energy storage systems, such as batteries or pumped hydro storage, allows the smart city to store excess energy during low-demand periods and release it during high-demand periods. This helps to stabilize the grid, manage fluctuations in demand, and ensure a reliable supply of energy.
Automated demand response	Smart city infrastructure can incorporate automation and intelligent algorithms to optimize demand response. By utilizing data analytics and artificial intelligence, the city can automatically adjust energy usage based on real-time demand signals. This can include controlling street lighting, HVAC systems, and other energy-consuming devices to align with demand patterns.

continue table 16

Strategy	Characteristic
Consumer engagement and education	Smart cities can empower consumers through education and awareness campaigns about the importance of energy conservation and demand response. By providing information on energy-saving practices and encouraging behavioural changes, consumers can actively participate in managing energy demand and contribute to the sustainability goals of the city.

Source: R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; A. Schlüter: Sustainable and Smart Energy Systems for Europe's Cities and Rural Areas, Hanser Fachbuchverlag, Berlin, 2022; M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, 2022, pp. 784–800; R. Krishankumar, D. Pamucar, M. Deveci, M. Aggarwal, K.S. Ravichandran: Assessment of renewable energy sources for smart cities' demand satisfaction using multi-hesitant fuzzy linguistic based choquet integral approach, Renewable Energy, Vol. 189, 2022, pp. 1428–1442; M.M. Hussain, R. Akram, Z.A. Memon, W. Javed, M. Siddique: Demand side management techniques for home energy management systems for smart cities, Sustainability (Switzerland), Vol. 13, No. 21, 2021, 11740; S. Ardabili, A. Mosavi, A.R. Várkonyi-Kóczy: Building Energy Information: Demand and Consumption Prediction with Machine Learning Models for Sustainable and Smart Cities, Lecture Notes in Networks and Systems, Vol. 101, 2020, pp. 191–201; H.U.R. Habib, S. Wang, M.T. Aziz: Renewable Energy Resources and Microgrid Management with Smart Battery Storage Control Considering Load Demand of Smart City, HONET-ICT 2019 – IEEE 16th International Conference on Smart Cities: Improving Quality of Life using ICT, IoT and AI, 2019, pp. 191–192, 8908084; I.I. Picioroaga, M. Eremia, M. Sanduleac: Economic Benefits of Energy Storage and Price-aware Demand Response for Future Smart Cities, 2019 54th International Universities Power Engineering Conference, UPEC 2019 – Proceedings, 2019, 8893590.

Real-time monitoring and analytics of energy usage play a vital role in smart cities. This approach involves the continuous monitoring of energy consumption, generation, and distribution using advanced technologies and data analytics. By leveraging sensors, meters, and smart devices, real-time data is collected and analysed to provide valuable insights into energy patterns and trends[86].

With real-time monitoring and analytics, city authorities and energy providers can[87]:

- Gain immediate visibility into energy usage across various sectors and locations within the city.
- Identify energy inefficiencies, anomalies, or potential issues in real time.

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[86] M. Shu, S. Wu, T. Wu, A. Shanthini, B.A. Muthu: Efficient energy consumption system using heuristic renewable demand energy optimization in smart city, Computational Intelligence, Vol. 38, No. 3, 2022, pp. 784–800.

[87] R. Papa, R. Fistola: Smart Energy in the Smart City, Springer, Berlin, 2016; A. Schlüter: Sustainable and Smart Energy Systems for Europe's Cities and Rural Areas, Hanser Fachbuchverlag, Berlin 2022.

- Optimize energy distribution by identifying peak demand periods and adjusting supply accordingly.
- Detect and mitigate energy wastage, such as equipment malfunctions or excessive consumption.
- Implement demand response strategies by understanding energy usage patterns and adjusting consumption during peak demand periods.
- Monitor the performance of renewable energy systems and optimize their integration into the grid.

By harnessing real-time data and analytics, smart cities can make data-driven decisions to improve energy efficiency, reduce costs, and enhance sustainability. It enables proactive energy management and empowers stakeholders to take timely actions to optimize energy usage and mitigate environmental impact.

Time-of-use pricing is an energy pricing strategy utilized in smart cities to encourage users to adjust their energy consumption based on different time periods throughout the day. Instead of a fixed rate for electricity, time-of-use pricing introduces varying rates depending on the time of day, typically divided into peak, off-peak, and shoulder periods. During peak hours when energy demand is high, electricity rates are set at a higher price to reflect the increased cost of generating and distributing energy. In contrast, off-peak hours, typically occurring during nighttime or early morning, offer lower electricity rates as energy demand is lower. Shoulder periods fall between peak and off-peak hours and have intermediate rates[88].

By implementing time-of-use pricing, smart cities aim to incentivize users to shift their energy consumption to off-peak hours when electricity costs are lower. This helps to balance the overall demand for electricity, reduce strain on the grid during peak periods, and optimize energy distribution. Users can make informed decisions about when to run high-energy-consuming appliances or charge electric vehicles, taking advantage of lower rates during off-peak times. This pricing model encourages energy conservation, as it provides an economic incentive for consumers to adjust their behaviour and reduce energy consumption during peak hours. It also promotes the integration of renewable energy sources by aligning energy usage with periods of high renewable energy generation[89].

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[88] R. Krishankumar, D. Pamucar, M. Deveci, M. Aggarwal, K.S. Ravichandran: Assessment of renewable energy sources for smart cities' demand satisfaction using multi-hesitant fuzzy linguistic based choquet integral approach, Renewable Energy, Vol. 189, 2022, pp. 1428–1442.

[89] M. Hussain, R. Akram, Z.A. Memon, W. Javed, M. Siddique: Demand side management techniques for home energy management systems for smart cities, Sustainability (Switzerland), Vol. 13, No. 21, 2021, 11740.

Through smart meters and real-time data monitoring, users can track their energy usage and costs, allowing them to make more informed decisions about their consumption patterns. Time-of-use pricing is a key element of demand response programs and supports the overall goal of energy efficiency and sustainability in smart cities.

Demand response programs in smart cities are implemented to encourage consumers to adjust their energy consumption based on changes in electricity demand or grid conditions. These programs aim to manage and optimize energy usage during peak periods or when there is strain on the grid. Consumers can participate by modifying their energy consumption patterns, such as shifting usage to off-peak hours or temporarily reducing non-essential electrical loads. Smart technologies and devices play a crucial role in automating and adjusting energy usage based on signals from the grid. Additionally, demand response strategies can be applied to electric vehicle charging to ensure efficient use of electricity resources. By actively participating in demand response programs, consumers contribute to a more sustainable and resilient energy system in smart cities. These programs help balance electricity supply and demand, reduce strain on the grid, and promote energy efficiency and conservation[90].

Automated demand response is a system employed in smart cities to automatically manage and optimize energy usage based on predefined criteria and signals. It enables the city's infrastructure, buildings, and devices to respond dynamically to changes in energy supply, demand, and pricing. Through advanced technologies and communication systems, automated demand response allows for real-time monitoring of energy consumption and the ability to adjust energy usage accordingly. It involves the use of smart meters, sensors, and control systems that can communicate with various energy-consuming devices and systems, such as HVAC (heating, ventilation, and air conditioning), lighting, and appliances.

When the system detects a high demand for energy or an imbalance between supply and demand, it can automatically trigger load-shedding measures or adjust the operation of energy-consuming devices to reduce overall demand. This can include temporarily adjusting the temperature settings in buildings, dimming lights, or cycling certain equipment on and off. The automated demand response system relies on predefined algorithms and rules that take into account factors such as energy pricing, grid stability, and environmental conditions. By responding intelligently to changing energy conditions, the system helps to optimize energy usage, minimize peak demand, and avoid unnecessary strain on the grid.

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[90] S. Ardabili, A. Mosavi, A.R. Várkonyi-Kóczy: Building Energy Information: Demand and Consumption Prediction with Machine Learning Models for Sustainable and Smart Cities, Lecture Notes in Networks and Systems, Vol. 101, 2020, pp. 191–201.

Automated demand response offers several benefits in smart cities. It helps to improve the overall efficiency of energy consumption, reduce peak demand charges, and enhance grid reliability. It also enables energy consumers to actively participate in demand response programs without requiring manual intervention, making it a seamless and efficient process. Moreover, automated demand response supports the integration of renewable energy sources by aligning energy consumption with periods of high renewable energy generation. By automatically adjusting energy usage in response to renewable energy availability, the system contributes to the overall goal of promoting sustainable and clean energy practices in smart cities[91].

Consumer engagement and education play a crucial role in promoting energy efficiency and sustainable practices in smart cities. It involves actively involving and educating residents, businesses, and communities about their energy usage and providing them with the necessary tools and information to make informed decisions. In smart cities, consumer engagement and education initiatives aim to raise awareness about the importance of energy conservation, the benefits of efficient technologies, and the impact of individual actions on the overall energy consumption and environmental sustainability. This can be achieved through various channels, including public campaigns, workshops, community events, and online platforms.

One aspect of consumer engagement is providing real-time feedback on energy usage. Smart meters and energy monitoring systems can be installed in homes and buildings to provide consumers with detailed information about their energy consumption patterns. This empowers individuals to understand their energy usage, identify areas of inefficiency, and make adjustments to reduce their consumption. Education programs can also focus on promoting energy-saving practices and behaviours. This includes educating consumers about the benefits of using energy--efficient appliances, implementing proper insulation and weatherization measures, adopting smart thermostat systems, and practicing energy-conscious habits such as turning off lights and appliances when not in use[92].

Consumer engagement and education initiatives can further encourage the adoption of smart technologies and energy management systems. Providing information and resources about smart home devices, energy-efficient appliances, and automation

[91] H.U.R. Habib, S. Wang, M.T. Aziz: Renewable Energy Resources and Microgrid Management with Smart Battery Storage Control Considering Load Demand of Smart City, HONET-ICT 2019 – IEEE 16th International Conference on Smart Cities: Improving Quality of Life using ICT, IoT and AI, 2019, pp. 191–192, 8908084.

[92] I.I. Picioroaga, M. Eremia, M. Sanduleac: Economic Benefits of Energy Storage and Price-aware Demand Response for Future Smart Cities, 2019 54th International Universities Power Engineering Conference, UPEC 2019 – Proceedings, 2019, 8893590.

systems can help consumers make informed choices and actively participate in optimizing their energy usage. In addition to raising awareness and providing information, consumer engagement and education programs can promote behavioural changes and incentivize energy-efficient practices. This can involve offering rewards or incentives for reducing energy consumption, implementing energy-saving challenges or competitions, or providing access to energy efficiency financing options for home or business upgrades. By engaging and educating consumers, smart cities can create a culture of energy-consciousness and empower individuals to actively contribute to the overall sustainability goals. Through knowledge and awareness, residents and businesses can make informed decisions, reduce their environmental impact, and collectively work towards creating a more energy-efficient and sustainable future.

By combining described approaches, a smart city can effectively react to changing demand response in energy usage. This leads to improved energy efficiency, reduced peak demand, optimized energy distribution, and a more sustainable and resilient energy infrastructure.

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Chapter 3

ENERGY MANAGEMENT SYSTEMS IN SMART CITIES

3.1. Energy Management System in Smart Cities

Investing in renewable energy sources supported by digital technology is a determinant of sustainable economic development. In line with this statement, more and more cities are using modern technology to make life easier for their residents and improve their quality of life. Smart cities, and the smart grid, will develop over the next two decades. Smart Cities, compared to traditional cities, will more fully integrate and use the information collected to improve the quality of services provided to citizens by local authorities and infrastructure operators. This will be ensured through cooperation between cities and modern technology providers. Smart Grids will instead become part of a larger, more flexible urban ecosystem. A smart grid in a city aims, among other things, to improve the city's efficiency, increase the living comfort of its inhabitants or ensure trouble-free delivery of utilities such as water, heat, gas and electricity. Digital technologies coordinate city authorities and infrastructure operators responsible for public safety and society. Smart grids are essential for the reliable operation of a smart city.

State and local administrations (cities, regions), government agencies, distribution system operators (electricity, water, heat, gas), technology companies, households and other organisations are in the structure of the city's energy management systems. Smart city energy management systems are in the smart city ecosystem that makes a city stand out from others.

Although the term energy management has been widely discussed in the academic literature and practice, no cohesive definition exists[93]. In the frame of this assignment, the following definition is used, which is claimed to be structured and summarized by its authors: "Energy management is the targeted deployment of methods and measures

[93] S. Backlund, P. Thollander, J. Palm, M. Ottosson: Extending the energy efficiency gap, Energy Policy, vol. 51, 2012, pp. 392–396.

for energy-related tasks, thereby implementing a continual energy efficiency improvement approach in companies while keeping the costs and uninterrupted energy supply in consideration”[94]. The goal is to guarantee the energy supply under economic andecologic aspects which have to be adequate, efficient and sustainable.

Energy management in the city follows the management functions: planning, organising, controlling and controlling. The E. Deming cycle: Plan-Do-Check-Act (PDCA) is embedded in energy management processes in smart cities. Figure 4 provides an overview of the PDCA methodology in energy management system in city. Within the PDCA circuit, energy controlling plays a central role: it supports the data collection (PLAN), the documentation(DO), the monitoring and the measurement (CHECK), and the conception of improvement measures(ACT)[95].

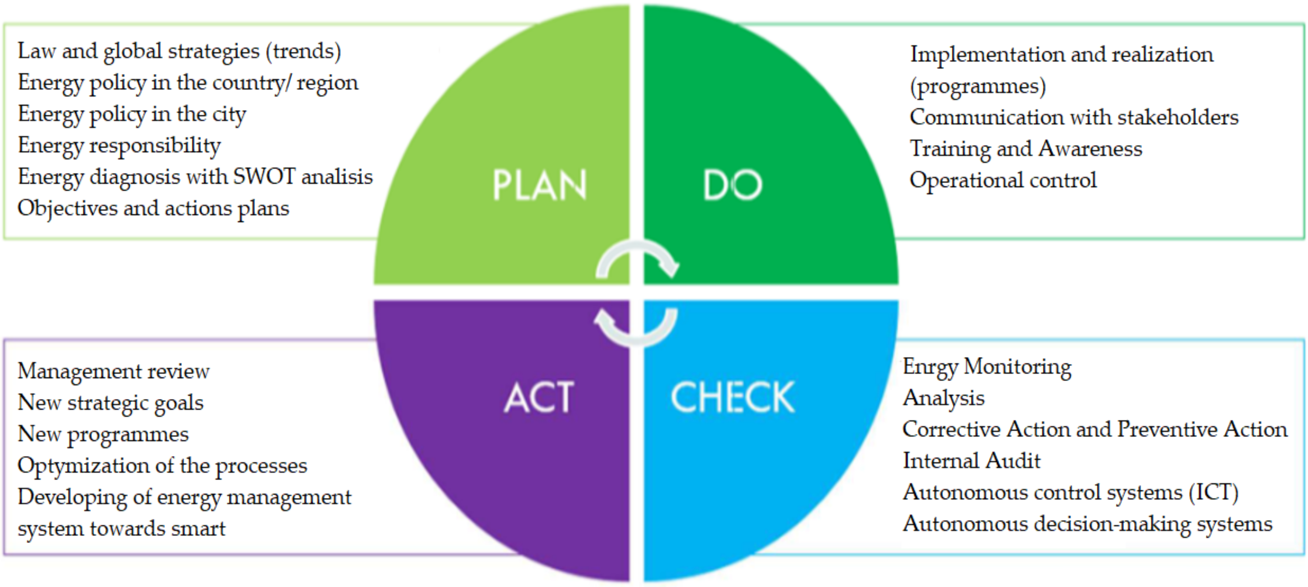

Fig. 4. PDCA methodology in Energy Management System in City according to ISO 50001.
Source: E.G. Huang: Understanding the requirements of the energy management system certification: a discussion about the challenges, impacts and opportunities for energy efficiency, SGS. Adapted from: (PDF) Energy Controlling, 2011. Available from: https://www.researchgate.net/publication/319273390_Energy_controlling [date of access 17.08.2023].

[94] T. Javied, T. Rackow, J. Franke: Implementing Energy Management System to Increase Energy Efficiency in Manufacturing Companies’, Procedia CIRP, vol. 26, 2015, pp. 156–161. Adapted from: (PDF) Energy controlling. Available from: https://www.researchgate.net/publication/319273390_Energy_controlling [accessed Jun 29 2023].
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Economics & Management Luxembourg, 2017. Available from: https://www.researchgate.net/publication/319273390_Energy_controlling [date of access 17.08.2023].

Energy Management System is directed to[96]:

- reducing energy intensity in accordance with legal requirements, standards and the principles of urban economics.
- optimisation solutions for rational energy management in the city. The solutions are aimed at achieving an economic effect, but also at improving the quality of life for inhabitants.

Two categories of sustainable energy management measures can be distinguished in urban management: technical and organisational. An Energy Management System (ESS) is an organisational measure (with elements of the technical area), the successful implementation of which should allow the improvement of the energy result and, consequently, the reduction of energy costs and the degree of environmental impact. The basic elements of an ESA are defined in ISO 50001:2012. The Energy Management System (EMS) is a structure of interaction between actors, technologies and infrastructure, data and information. This system is linked to other management systems in smart cities. The aim of this system is rational energy management. The scope and boundaries of this system are in accordance with the law and energy policy. The system (EMS) is continuously improved by its participants.

An energy management system is designed to achieve the highest possible level of energy efficiency by optimising energy consumption. Newer, cloud-based energy management systems provide remote control capabilities. The systems can collect detailed, real-time data for each piece of equipment and generate guidance on the most attractive energy-saving opportunities. The systems' software has a clear goal of increasing energy and thermal efficiency and improving the city's overall energy performance. A component of the system is technology for remote or automatic control of equipment – for reasons of convenience or security. Energy management is the targeted deployment of methods[97] and measures for energy – related tasks, thereby implementing a continual energy efficiency improvement approach in particular activities of city while keeping the costs and uninterrupted energy supply in consideration. The Energy Management System according to ISO 50001 comprises of definition, implementation, and controlling of measures regarding energy-relevant issues. Here, the approach

[96] E.G. Huang: Understanding the requirements of the energy management system certification: a discussion about the challenges, impacts and opportunities for energy efficiency, SGS. Adapted from: (PDF) Energy Controlling, 2011. Available from: https://www.researchgate.net/publication/319273390_Energy_controlling [date of access 17.08.2023].

[97] T. Javieda, T. Rackowa, J. Franke: Peer-review under responsibility of Assembly Technology and Factory Management, Procedia CIRP 26 (2015) 156–161. Science Direct 12th Global Conference on Sustainable Manufacturing Implementing energy management system to increase energy efficiency in manufacturing companies, Elsevier, 2015, DOI: 10.1016/j.procir.2014.07.057.

is transparent, systematic and continuous. The goal of the System is to guarantee the energy supply under the following economic and ecologic aspects in the way that is adequate, efficient and sustainable.

In the Energy Management System there are a lot of segments (clusters) of methods used in particular steps of management (Fig. 5)[98].

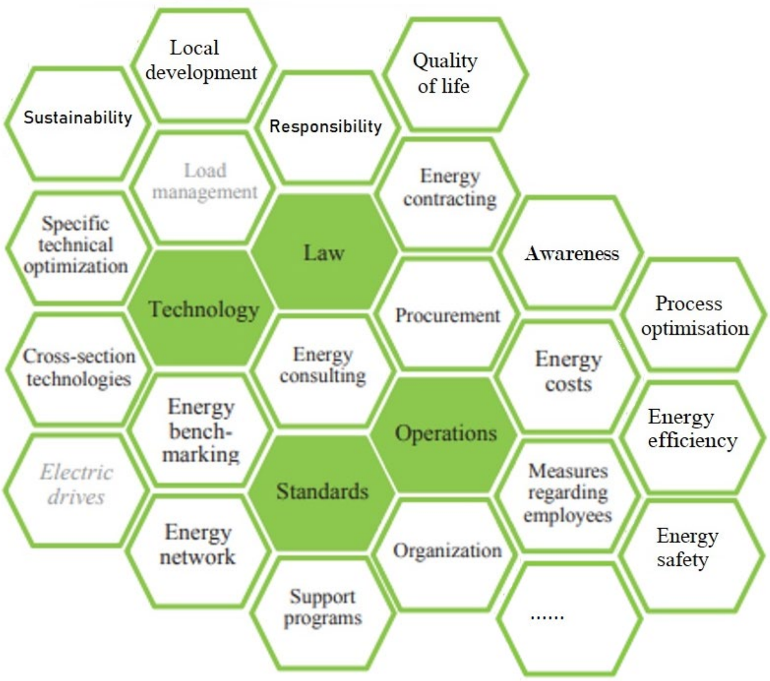

Fig. 5. Segments (clusters) of Energy Smart management in city.
Source: own elaboration based on T. Javieda, et al. 2015.

In general, energy management consists of the following steps, which are implemented sequentially in the process of continuously improving energy efficiency:

- Energy policy: a set of policies set by the local authority (city/town council). The city's energy policy is a document linked to the national energy policy and other European Union documents. The city's energy policy is also linked to the city development strategy and other documents. The energy policy defines the general lines of action to improve energy efficiency It is important to absorb smart technologies so that the built energy system is smart. EMS in smart cities must be integrated into the vision of smart city development[99].

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[98] T. Javieda, T. Rackowa, J. Franke: Peer-review under responsibility of Assembly Technology and Factory Management, Procedia CIRP 26, 2015, pp. 156–161.
[99] M. Swora (ed.) W kierunku nowoczesnej polityki energetycznej. Instytut Obywatelski. Available online: https://www.researchgate.net/profile/Mariusz-Swora-2/publication/264044193_W_kierunku_nowoczesnej_polityki_energetycznej_Energia_Elektryczna_Towards_modern_energy_policy_Electricity_market/links/0046353cab1c82c438000000/W-kierunku-nowoczesnej-polityki-energetycznej-Energia-Elektryczna-Towards-modern-energy-policy-Electricity-market.pdf [date of access 17.08.2023].

- Planning: identifying major energy sources and potential energy saving opportunities, prioritising energy saving measures, identifying targets and developing action plans in line with energy policy, including smart energy systems (smart grids). Smart Cities are part of a huge Smart Energy system. In addition to the local authority, actors in the system are: consumers, communities, distributors, retailers, the ICT sector, etc.

  The Municipal or Communal Energy Programme is approved by the City/ Commune Council (according to the Act on Local Self-Government in Poland). In Smart Energy System planning, the city is both an energy consumer and an energy producer and distributor.

  Examples of city segments as an energy consumer: urban transport, street lighting, municipal buildings.

  Examples of city segments as an energy producer: production of heat and electricity and use of renewable energy sources (RES)[100].
- Implementation/implementation of programmes: involvement of the city (city authorities, public administration staff), citizens, businesses etc. in the implementation of the objectives. The implementation of the SES (Smart Energy System) is based on a number of programmes accompanied by procedures. The city creates many energy standards, e.g. building standards (for example heating technology requirements) and procedures. The city is also a motivator for change. The city/municipality can influence: heating and ventilation of buildings; internal lighting of living spaces; use of electrical appliances (white goods, computers) in households and workplaces; use of urban and interurban transport, as well as private motorised or non-motorised vehicles; technological processes; waste management, etc. The implementation of energy management is done through specific techniques and tools. The key techniques are energy audits, monitoring and benchmarking, while the key tools are energy management systems and related standards.
- control and corrective action: monitoring all relevant processes and activities that cause energy consumption. Taking preventive and corrective action. The forms of control can vary from period to period or on a continuous basis (monitoring). Control is the comparison of input data with output data. Example: data on: (a) the status of the facilities affected by the programme and the city/municipality as a whole from before and after the implementation of the programme; (b) the total

[100] G. Magnin: Planowanie energetyczne w miastach i gminach. Available online: http://www.pnec.org.pl/etykietyenergetyczne/doc/MEP%20Guide%20PL.pdf [date of access 17.08.2023].

amount of energy saved over the whole period of implementation of the programme and projections for a certain future period, made on the basis of measurement data as well as projections based on the actual results achieved – financial expenditure[101]. At this stage there is also evaluation, or assessment. Evaluation is the systematic examination of the value or characteristics of a specific programme, plan, activity (experiment) or object (computer program, curriculum, medicine, technical solution) from the point of view of accepted criteria, with the aim of improving, developing or better understanding it. It is an assessment of the value of an intervention using specific criteria for that assessment, undertaken to determine the effectiveness of the intervention, to evaluate against targets, and to analyse the impact on specific structural problems[102]. In this energy management, there is the systematic, continuous and strategic optimisation of energy consumption. The evaluation looks at energy models that can be benchmarks for other smart cities.

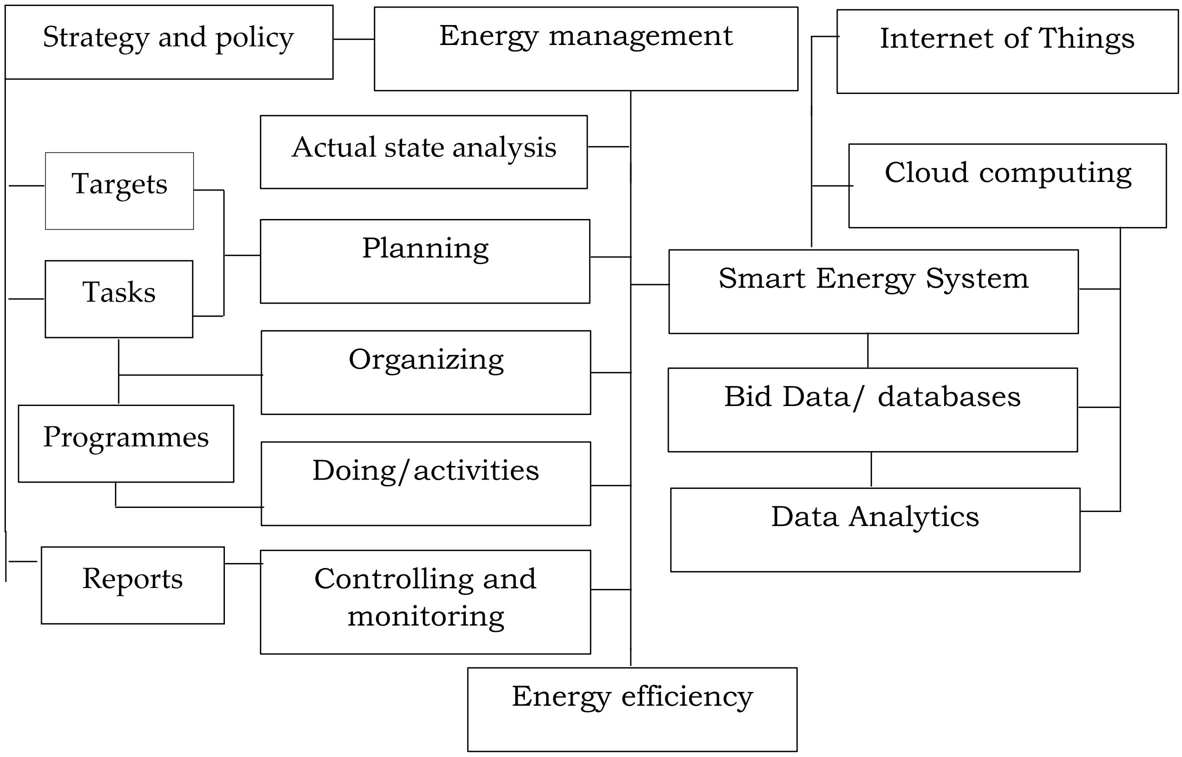

Fig 6. Energy management system: key steps
Source: Own elaboration.

[101] G. Magnin: Planowanie energetyczne…, op. cit.; Rozporządzenie Rady Unii Europejskiej z dnia 21 czerwca 1999 r. wprowadzające ogólne przepisy dotyczące funduszy strukturalnych.
[102] W. Piekarski, M. Stoma, A. Dudziak: Funkcjonowanie systemu zarządzania energią i środowiskiem na przykładzie budynków użyteczności publicznej, Autobusy, Nr 10, 2011.

The city can apply for the ISO 50001 certificate after fulfilling all of the requirements of an energy management system according to the international standard: ISO 50001.

Benefits of implementing a smart energy management system:

- energy savings,
- reduced city running costs,
- reduction in emissions of gases harmful to the environment,
- increased awareness of the inhabitants concerning the reduction of energy use,
- systematisation of activities and structured approach to energy management, improvement of operational efficiency,
- creating and developing the image of a city aware of efficient energy management[103].
- creating and developing the image of a city aware of efficient energy management ,
- energy management system intelligence, including: ongoing data analysis, tracking energy consumption in multiple locations at the same time.

In striving to become a city at the forefront of sustainable and efficient energy management, the pursuit of the ISO 50001 certificate stands as a testament to our commitment to a greener, more responsible future. Once all the requirements of an energy management system aligned with the international standard, ISO 50001, have been met, we will be poised to unlock a multitude of benefits that will not only transform our city but also inspire others to follow suit.

3.2. Optimization of Energy Consumption in Smart Cities

Optimisation of energy consumption must be applied to the development of Energy Management System (EMS) in organisations of all types and sizes, regardless of the type of business, organisational structures or areas of market activity. The system must be designed to save energy, heat and cooling. Energy Management Systems in smart cities should include the following fields (modules):

- financial controlling,
- environmental protection,
- energy sources and energy efficiency.

[103] https://www.bialecertyfikaty.com.pl/systemy-zarzadzania-energia/ [date of access 17.08.2023].

Financial controlling is directed at cost reduction. The system consists of fields (examples):

- reducing energy consumption,
- negotiating energy purchase prices,
- using renewable energy sources.

The key fields of the module: Energy Consumption are (examples):

- choosing the right heating medium in investments,
- thermo-modernisation of public facilities,
- use of energy-efficient lighting,
- replacing light installations with optimal ones,
- monitoring energy consumption (audit)
- cooperation with energy companies on renewable energy sources,
- application of variable energy tariffs and charges,
- smart facilities, etc.

Fields of environmental protection are (examples):

- carbon emissions (direction: less and less gases and dust in the atmosphere),
- renewable energy sources (RES),
- waste and water management (incinerators, biomass boilers, quality of water etc.).

The main objective of optimisation: rational energy consumption reduces the amount of energy produced, and this relationship reduces the amount of gases in the air and waste after energy production. In order for cities to reduce the amount of energy they consume, they must first carry out an energy review and audit. The diagnosis is the starting point for setting energy outcome indicators, as well as related goals and targets. The energy review, developed in accordance with ISO 50001, must include an analysis of the organisation's energy use and consumption and the identification of areas of significant energy use on this basis. To this end, in addition to identifying current energy sources and assessing historical and present energy use and consumption, elements that have a significant impact on energy intensity and opportunities for improving energy performance must be identified with appropriate prioritisation. Optimisation of electricity costs must be preceded by an analysis of all energy consumption points in terms of energy demand and identification of cost-reducing measures in each organisation. Each location in the city that is energy intensive must be accurately and reliably described (diagnosed).

During the analysis phase, cities build a database for energy systems. The database is a set of indicators that can be represented according to optimisation criteria. Examples of criterias in indicators (indices: *i*)[104]:

i_1 – energy saved,
i_2 – money saved,
i_3 – CO_2 emission (reduction),
i_4 – utilisation,
i_5 – quality life,
i_6 – expenditures.

The diagnosis should conclude with a proposal for (variant) measures, e.g. replacement of street lighting in the city, replacement of energy-intensive technologies, diversification of energy sources, negotiating energy purchase prices, changes in local charges, etc. A process approach should be used when optimising energy consumption. Examples of activities in an energy-consuming organisation: analysis of energy consumers, metering of consumers (energy meters, inverters, reading of operating hours), introduction of a system for reading and analysing data (instructions for the procedure with deadlines for reading, ways of recording data); monthly analysis of energy consumption.

Optimising energy consumption in city is based on cooperation between people and technologies. The human factor is based on teamwork and team members include: technologists, energy engineers, government officials, residents' representatives, business people, network administrators, building owners, etc. Energy management systems are installed in municipal buildings, households (Home Energy Management System: HEMS), municipal treatment plants, municipal water and sewage plants, municipal power plants, etc.

Energy optimisation systems are based on modern measurement and evaluation technology. An energy management system usually consists of devices centred around a control panel, which is responsible for communication between all system components and user commands. The panel can be a dashboard, but in cases where the system only operates over a wireless network, it can also be installed in a virtual form. The components of the system are intelligent energy generation technologies, energy storage, light and temperature sensors and other smart technologies. The software used in energy management systems moderates incoming and outgoing data

[104] M. Łagoda: Multi-criterial optimization of energy consumption in a single-family house with modification of entropia preference (title in Polish: Wielokryterialna optymalizacja zużycia energii w domu jednorodzinnym z modyfikacją preferencji entropią). RUTJEE, 38 (1–2), 2020, pp. 51–64, DOI: 10.7862/re.2020.4.

and communication. From the user's point of view, the software is an interface that allows access to monitoring data and control functions of the system. The interface can be an application or a web portal. A system is a technology platform including both hardware and software that enables the user to monitor the consumption and production of thermal energy and to manually control and/or automate its consumption in the organisation. In terms of monitoring, the way data is displayed will vary depending on the system chosen, but will usually include these two elements: device data – that is, which devices are on and off and how much energy each device is using, information obtained and messages - such as notifications to inform the user of trends and problems that may not be detected without analysing the data[105].

General optimisation scheme – cost approach:

$$\boxed{\text{cost of energy service after} < \text{cost of energy service before}}$$

Source:[106]

General optimisation scheme – efficiency approach:

$$\boxed{\frac{\text{results (profits)}}{\text{expenditures (costs)}} \quad >1}$$

There is no one-size-fits-all way of operating an energy and environmental management system for cities. A city has to develop its own system model. Benchmarking (learning from other cities that are already smart cities) can be used to build the system. Each system must be adapted to the way the city works, to its experiences. Each system must be, especially in the first stage of development, supervised by the city (teams of operators, system administrators, system manager). The city can outsource the system development to external companies with experience in designing urban energy and environmental management systems [107].

[105] W. Piekarski, M. Stoma, A. Dudziak: Funkcjonowanie systemu zarządzania energią i środowiskiem na przykładzie budynków użyteczności publicznej. Autobusy Nr 10, 2011.
[106] Jak zarządzać energią i środowiskiem w budynkach użyteczności publicznej poradnik dla samorządów terytorialnych. Publisher: Fundacja na Rzecz Efektywnego Wykorzystania Energii. Katowice 2010.
[107] Ibidem.

3.3. Control system of energy consumption in Smart Cities

Energy controlling is considered as a key function of any effective energy management[108]. Its main goal is to improve the effectiveness as well as the efficiency with regard to energy consumption and costs. Energy controlling is often assimilated to the systematic acquisition and monitoring of energy-relevant data with the aim of limiting or reducing energy consumption and costs. In addition, similarly to financial controlling, energy controlling include planning tasks (e.g. budgeting of energy consumption) and analysis tasks (e.g. actual-target performance comparison) [109]. Energy controlling helps the public government and energy administration to plan, measure and monitor energy-related operational activities such as procurement, conversion, distribution and utilisation[110]. The part of the controlling is monitoring.

The key activities of energy controlling can be summarized in 5 main functions (Gleich 2014, pp. 30–32): planning, coordination, information, control and advisory. More information about the functions of energy controlling in table 17.

Table 17

Function of energy controlling

Functions	**Tasks**
planning	• Participation into the elaboration of the energy strategy and the conception of projects based on it. • The energy performance targets are based on the objectives defined by the governance and the country energy policy. • Budgeting of energy consumption. • Detailed planning of energy efficient projects in city. • Local investment decision making by providing profitability and risk analysis.

[108] W. Schellong: Analyse und Optimierung von Energie Verbundsystem, Springer Science and Business Media, 2016.
[109] T. Wautelet: Energy controlling. Master of Business Administration (2015–2017)European University for Economics & Management Luxembourg, 2017. Available from: https://www.researchgate.net/publication/319273390_Energy_controlling [date of access 17.08.2023].
[110] Definition from: Gleich R.: Energiecontrolling, Haufe Lexware 2014.

continue table 17

Functions	Tasks
Coordination	• Planning, implementation and control of energy efficiency measures. • Continuous implementation of local coordination processes in order to ensure the communication of important information to all the stakeholder involved in energy efficiency projects and to avoid any disturbances. • Continuous tracking of the project progress in order to ensure the achievement of the deadline. • Continuous tracking of the energy consumption in particular sectors of the local activity.
reporting	Data on energy consumption, energy accounting, the energy cost etc.
control	• **Deviation analysis** between actual energy performance and the strategic and operational energy targets. • In case of deviations, investigations are carried out to identify the root causes and to suggest corrective actions. • Time comparisons (actual values vs values from previous periods) in order to identify significant changes over a certain period of time and to address them. • Energy benchmarking to identify potential improvements in energy efficiency.
Advisory	• Service-oriented consulting function for energy customers. • Strengths-weaknesses analysis of energy policy in city. • Development of energy strategy in city. • Negotiations with energy suppliers and investors.

Source: Gleich 2014, pp. 30–32, adapted from (PDF) Energy controlling. Available from: https://www.researchgate.net/publication/319273390_Energy_controlling [date of access 17.08.2023].

Monitoring is a process that collects data, mainly on energy consumption and costs, which is fundamental to the ongoing management of energy consumption. Monitoring is real-time data on the volume of resources consumed, consumers, costs, equipment efficiency, budget, energy purchase expenditure), etc. Monitoring makes it possible to detect any anomalies in the operation of a facility (technology, network, transport, etc.) and to react immediately to blockages (errors) to minimalise losses. With a large number of facilities and technologies, monitoring should be implemented by automatic data collection systems directly into information systems and autonomous error correction systems (equipment settings) to optimise energy intensity.

The benefits of monitoring are as follows (example):

- current analysis of the consumption of energy carriers,
- data on the cost of consumption of energy carriers,
- analysis of expenditure from the city budget on energy purchase, energy distribution, etc.,
- detection of failures and malfunctions of networks, facilities, street lighting, etc.,
- ongoing analysis of decisions,
- correcting technology settings, etc.

A diagram of the procedure during monitoring is presented in Figure 7.

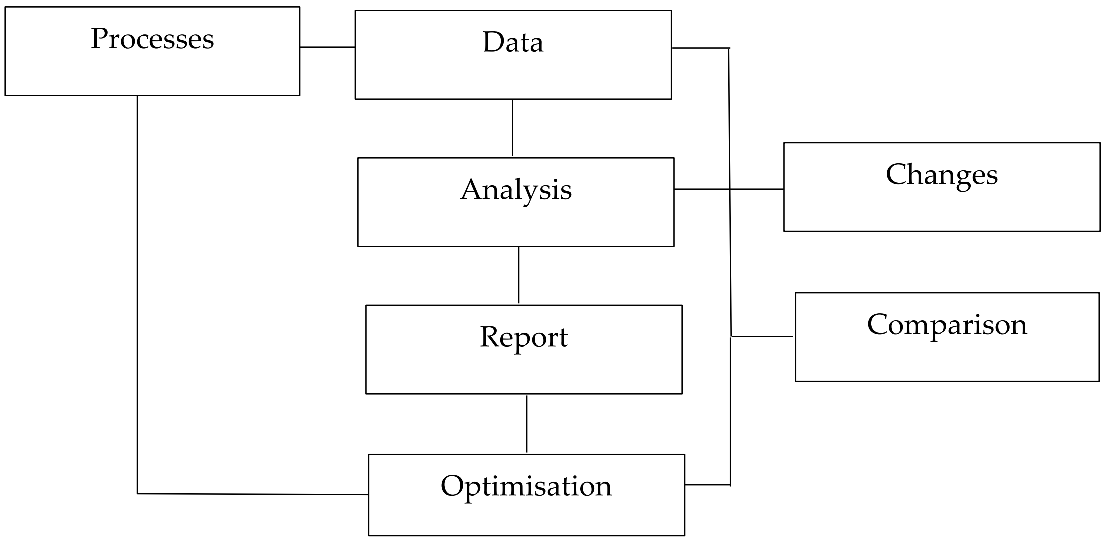

Fig. 7. The algorithm of monitoring

Source: Own elaborate based on: Jak zarządzać energią i środowiskiem w budynkach użyteczności publicznej poradnik dla samorządów terytorialnych. Publisher: Fundacja na Rzecz Efektywnego Wykorzystania Energii. Katowice 2010.

There are many information technologies in the Smart Energy Management System (SEMS) that autonomously optimise processes based on data (Big Data). Smart technologies with computer learning programmes are used to analyse the collected data and make decisions. Increasingly, new technologies are also operating with learning algorithms (algorithmisation of technology towards AI) with autonomous measurement systems. In SEMS monitoring, dedicated applications are being introduced and databases created. Big Data is stored in the cloud. Cities can outsource the implementation and improvement of programmes, as well as the maintenance of databases, the necessary analyses and the generation of reports to IT companies.

Remote use of the system via the Internet is a necessity in the digital economy. Systems operate via a web browser. Technologies work together via IoT or IoE.

The data collection system can be extended by an automatic monitoring system, based on measuring transducers and energy meters, coupled via a transmission system (wireless system and Internet) to the database. Access to the database is limited by the access rights granted to the administrator (internal or external administrator). The data collected in the databases is vast. Access to the Big Data is in the real time. Examples of database modules:

- data module on buildings (data on architecture, installations in buildings, other technical data about buildings),
- data module on public transport (data on public transport, data on transport costs, data on fuel consumption, etc.),
- data module on energy infrastructure (grids, energy stores, etc.)
- data module on energy consumption (dynamics of energy consumption, energy consumers, energy prices, etc.)
- data module on energy costs in the processes: production, distribution, consumption,
- other data modules.

Data is organised and entered into reports. The systems analyse the data, create summaries, determine indicators, organise data, create rankings, compare data within or between groups (benchmarking), make forecasts (identifying potential for possible savings), export the collected data to other systems, etc. Data is collected and analysed continuously. There are many reports and they are varied. Reports are used by facility users, facility managers, system administrators, local authorities, public administration staff and others. The reports may include, among other things: an analysis of the energy situation of the facilities, an estimation of the potential for savings, recommendations for further action and a determination of the order in which it should be taken[111].

Energy monitoring in smart city is one of the tools for energy and environmental management system. Monitoring includes all tasks related to the creation and operation of the energy management system database. IC technologies (systems, programmes) use the collected data to optimise energy management processes.

[111] Jak zarządzać energią i środowiskiem…, op. cit. Katowice 2010; T. Javied, F. Dlugosch, T. Maul, J. Franke: Conformity Check and Optimization of the Energy Management System Based on ISO 50001, Applied Mechanics and Materials, No. 11, 2015.

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4. Huang E.G.: Understanding the requirements of the energy management system certification: a discussion about the challenges, impacts and opportunities for energy efficiency, SGS. Adapted from: (PDF) Energy Controlling, 2011. Available online: https://www.researchgate.net/publication/319273390_Energy_controlling [date of access 17.08.2023].
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6. Javied T., Dlugosch F., Maul T., Franke J.: Conformity Check and Optimization of the Energy Management System Based on ISO 50001. Applied Mechanics and Materials, No. 11, 2015.
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10. Magnin G.: Planowanie energetyczne w miastach i gminach, http://www.pnec.org.pl/etykietyenergetyczne/doc/MEP%20Guide%20PL.pdf [date of access 17.08.2023].

11. Piekarski W., Stoma M., Dudziak A.: Funkcjonowanie systemu zarządzania energią i środowiskiem na przykładzie budynków użyteczności publicznej. Autobusy 10, 2011.
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14. Swora M. (ed.): W kierunku nowoczesnej polityki energetycznej. Instytut Obywatelski, dostęp: https://www.researchgate.net/profile/Mariusz-Swora-2/publication/264044193_W_kierunku_nowoczesnej_polityki_energetycznej_Energia_Elektryczna_Towards_modern_energy_policy_Electricity_market/links/0046353cab1c82c438000000/W-kierunku-nowoczesnej-polityki-energetycznej-Energia-Elektryczna-Towards-modern-energy-policy-Electricity-market.pdf [date of access 17.08.2023].
15. Wautelet T.: Energy controlling. Master of Business Administration (2015–2017) European University for Economics & Management Luxembourg, 2017. Available from: https://www.researchgate.net/publication/319273390_Energy_controlling [date of access 17.08.2023].

Chapter 4

ELECTRIC MOBILITY AND CHARGING INFRASTRUCTURE IN SMART CITIES

4.1. Electric vehicles and their role in Smart Cities

Electric vehicle usage refers to the utilization and operation of vehicles that are powered by electricity rather than traditional fossil fuels like gasoline or diesel. These vehicles are equipped with electric motors and rechargeable batteries, which store and provide energy for their propulsion[112].

When using an electric vehicle, the driver relies on the stored electricity in the vehicle's battery to power the motor, which generates the necessary torque to propel the vehicle forward. The battery is typically charged by connecting the vehicle to an external power source, such as a charging station or a home charger. This charging process replenishes the battery's energy and prepares the vehicle for the next journey. One of the significant advantages of electric vehicles is their environmental friendliness. They produce zero tailpipe emissions, reducing air pollution and greenhouse gas emissions, which are major contributors to climate change. Electric vehicles also have lower operational costs compared to traditional vehicles, as the cost of electricity is generally lower than that of fossil fuels[113].

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[112] E.A. Nanaki: Electric Vehicles for Smart Cities Trends, Challenges, and Opportunities, Elsevier, Berlin 2020; R. Wolniak: Smart mobility jako element koncepcji smart city, Zarządzanie i Jakość, Vol. 1, No. 5, 2023, pp. 208–222; R. Wolniak: Smart mobility in a smart city concept Silesian University of Technology Scientific Papers. Organization and Management Series, Vol. 170, 2023, pp. 679–692;R. Wolniak: European Union Smart Mobility–Aspects Connected with Bike Road System's Extension and Dissemination, Smart Cities, Vol. 6, No. 2, 2023, pp. 1009–1042; https://doi.org/10.3390/smartcities6020049; I. Jonek-Kowalska, R. Wolniak: Sharing economies' initiatives in municipal authorities' perspective: research evidence from Poland in the context of smart cities' development. Sustainability, Vol. 14, No. 4, 2023, pp. 1–23; I. Jonek-Kowalska, R. Wolniak: Economic opportunities for creating smart cities in Poland. Does wealth matter? Cities, Vol. 114, 2021, 1–6; R. Wolniak: European Union Smart Mobility – aspects connected with bike road systems extension and dissemination. Smart Cities, Vol. 6, 2023, pp. 1–32.

[113] A. Bokolo: Integrating Electric Vehicles to Achieve Sustainable Energy as a Service Business Model in Smart Cities, Frontiers in Sustainable Cities, Vol. 3, 2023, https://doi.org/10.3389/frsc.2021.685716.

To maximize the range of an electric vehicle, drivers often consider factors such as driving habits, speed, and efficiency. Additionally, electric vehicle owners can take advantage of regenerative braking, a feature that converts kinetic energy into electrical energy and stores it back in the battery during deceleration, thus extending the vehicle's range. The availability of charging infrastructure is crucial for the widespread adoption of electric vehicles. Charging stations are being installed in various locations, including public areas, workplaces, and residential areas, to provide convenient access to charging facilities. Rapid charging stations, capable of delivering a significant amount of power in a short time, are also being deployed along highways and major travel routes to facilitate long-distance electric vehicle travel[114].

As electric vehicle technology continues to advance, the range and performance of electric vehicles are improving. Battery technology is evolving, enabling larger capacities and faster charging times. Additionally, the development of autonomous driving technology and vehicle-to-grid integration holds the potential to further enhance the convenience and versatility of electric vehicle usage. It can be stated that electric vehicle usage represents a shift towards more sustainable transportation options, promoting reduced dependence on fossil fuels, cleaner air quality, and a greener future. In the table 18 there is a list of main advantages of electric vehicle usage[115].

Table 18

Advantages of electric vehicle usage

Advantage	**Description**
Environmental Friendliness	Electric vehicles produce zero tailpipe emissions, reducing air pollution and greenhouse gas emissions.
Cost Savings	Electric vehicles have lower operational costs compared to traditional vehicles, thanks to lower fuel and maintenance costs.
Energy Efficiency	Electric vehicles are more energy-efficient than internal combustion engine vehicles, converting more stored energy into power.
Renewable Energy Integration	Electric vehicles can be charged using renewable energy sources such as solar or wind power, contributing to sustainability.

[114] Z. Yao, Z. Wang, L. Ran: Smart charging and discharging of electric vehicles based on multi-objective robust optimization in smart cities, Applied Energy, Vol. 343, 2023, 121185.

[115] M. Campaña, E. Inga: Optimal Planning of Electric Vehicle Charging Stations Considering Traffic Load for Smart Cities, World Electric Vehicle Journal, Vol. 14, No. 4, 2023, pp. 104–115.

continue table 18

Advantage	Description
Quieter Operation	Electric vehicles produce significantly less noise compared to internal combustion engine vehicles, offering a quieter ride.
Government Incentives	Governments provide incentives like tax credits and grants to promote electric vehicle adoption and affordability.
Technological Advancements	Ongoing advancements in electric vehicle technology enhance range, battery capacity, charging infrastructure, and performance.
Energy Independence	Electric vehicles reduce dependence on fossil fuels and promote energy independence through diverse electricity sources.
Health Benefits	Electric vehicles contribute to improved air quality, reducing harmful emissions and potential health risks.
Innovation and Job Creation	The electric vehicle industry drives innovation, research, development, and job creation in various related sectors.

Source: E.A. Nanaki: Electric Vehicles for Smart Cities Trends, Challenges, and Opportunities, Elsevier, Berlin, 2020; A. Bokolo: Integrating Electric Vehicles to Achieve Sustainable Energy as a Service Business Model in Smart Cities, Frontiers in Sustainable Cities, Vol. 3, 2023, https://doi.org/10.3389/frsc.2021.685716; Z. Yao, Z. Wang, L. Ran: Smart charging and discharging of electric vehicles based on multi-objective robust optimization in smart cities, Applied Energy, Vol. 343, 2023, 121185; M. Campaña, E. Inga: Optimal Planning of Electric Vehicle Charging Stations Considering Traffic Load for Smart Cities, World Electric Vehicle Journal, Vol. 14, No. 4, 2023. pp. 104–115.

Electric vehicle usage in smart cities refers to the integration and utilization of electric vehicles as part of a comprehensive approach to urban planning and development. Smart cities leverage advanced technologies, data analytics, and connectivity to enhance sustainability, efficiency, and quality of life for residents. Electric vehicles play a crucial role in achieving the transportation objectives of smart cities. In smart cities, electric vehicles are seen as a key component of sustainable mobility solutions. They contribute to reducing air pollution, lowering carbon emissions, and addressing the challenges of urban congestion[116]. The main important aspects of electric vehicle usage which should be taken into consideration when this solution will be implemented we put in table 19.

[116] P. Zhou, C. Wang, Y. Yang: Design and Optimization of Solar-Powered Shared Electric Autonomous Vehicle System for Smart Cities, IEEE Transactions on Mobile Computing, Vol. 22, No. 4, 2023, pp. 2053–2068.

Table 19

Main important aspects of electric vehicles usage in smart cities

Aspect	**Description**
Electric Vehicle Charging Infrastructure	Smart cities invest in the development of a robust and interconnected charging infrastructure network. This includes the deployment of charging stations in public areas, commercial zones, residential areas, and other strategic locations. Charging infrastructure is integrated into the urban landscape, ensuring convenient access to charging facilities for electric vehicle owners.
Intelligent Charging Management	Smart cities leverage advanced technologies to implement intelligent charging management systems. These systems optimize the charging process by considering factors such as grid demand, renewable energy availability, and user preferences. Smart charging solutions enable load balancing and peak shaving, ensuring efficient use of electricity and minimizing strain on the power grid.
Integration with Renewable Energy	Smart cities emphasize the integration of electric vehicle charging with renewable energy sources. They promote the installation of solar panels and wind turbines to generate clean energy that can be used for charging electric vehicles. This integration facilitates a greener and more sustainable energy ecosystem within the city.
Electric Vehicle Sharing and Carpooling	Smart cities encourage the adoption of electric vehicle sharing programs and carpooling services. These initiatives promote efficient utilization of electric vehicles, reduce the number of private cars on the road, and optimize urban mobility. Advanced technology platforms facilitate seamless booking, payment, and real-time monitoring of shared electric vehicles.
Data Analytics and Optimization	Smart cities leverage data analytics to gain insights into electric vehicle usage patterns, charging infrastructure utilization, and energy consumption. This data is used to optimize charging infrastructure planning, identify high-demand areas, and make informed decisions for future expansion and optimization of electric vehicle infrastructure.

continue table 19

Aspect	Description
Integration with Smart Grids	Electric vehicle usage in smart cities involves integration with smart grids. This integration enables bidirectional energy flow, allowing electric vehicles to not only consume electricity but also feed excess energy back to the grid through vehicle-to-grid (V2G) technology. V2G enables energy storage, demand response, and grid stabilization, making electric vehicles valuable assets for the overall energy management of the city.
Mobility-as-a-Service (MaaS)	Smart cities promote the concept of Mobility-as-a-Service, which provides integrated, on-demand, and multimodal transportation options to residents. Electric vehicles are integrated into MaaS platforms, allowing users to access and combine different modes of transport, including electric cars, electric bikes, public transportation, and more, through a single digital interface.

Source: E. Ghorbani, T. Fluechter, L. Calvet, J. Panadero, A.A. Juan: Optimizing Energy Consumption in Smart Cities' Mobility: Electric Vehicles, Algorithms, and Collaborative Economy, Energies, Vol. 16, No. 3, 2023, 1268; T. Chanraksa, J.G. Singh: Benefits of Demand Response with Electric Vehicles in Smart Grid: A Case Study of Pattaya City, Thailand, 2023 International Conference on Power, Instrumentation, Energy and Control, PIECON 2023, 103; H.T. Mouftah, A. Radwan, M.H. Rehmani, F. Al-Turjman, B. Vaidya: Editorial: Prospects of energy and mobility-Connected and autonomous electric vehicles for sustainable smart cities, Frontiers in Energy Research, Vol. 10, 2023, 972084; M. Lotfi, T. Almeida, M.S. Javadi, C. Monteiro, J.P.S. Catalão: Coordinating energy management systems in smart cities with electric vehicles, Applied Energy, Vol. 307, 2022, 118241; P.W. Shaikh, H.T. Mouftah: Intelligent Charging Infrastructure Design for Connected and Autonomous Electric Vehicles in Smart Cities, Proceedings of the IM 2021 – 2021 IFIP/IEEE International Symposium on Integrated Network Management, 9463934, 2021, pp. 992–997.

Electric vehicle infrastructure plays a crucial role in smart cities by providing the necessary support for the adoption and efficient operation of electric vehicles (EVs). It encompasses various components and systems that work together to create a sustainable and reliable charging ecosystem. One of the key elements of electric vehicle infrastructure is the deployment of charging stations throughout the city. These stations serve as the primary means for EV owners to charge their vehicles conveniently and reliably. By strategically installing charging stations in public areas, residential complexes, workplaces, and other high-traffic locations, electric vehicle infrastructure ensures that EV owners have access to charging facilities when and where they need them[117].

A well-developed charging network is another important aspect of electric vehicle infrastructure. It establishes a connected system of charging stations, allowing EV owners to easily find and utilize charging facilities across the city. This network helps address range anxiety concerns and encourages more people to consider and adopt electric vehicles as a viable transportation option. Electric vehicle infrastructure also involves the integration of charging systems with the electrical grid. This integration enables bidirectional energy flow, where EVs can not only draw electricity from the grid but also supply excess energy back to it. By leveraging smart grid technologies, EVs can contribute to grid stability, load management, and the efficient utilization of renewable energy sources[118].

Supportive policies and regulations play a significant role in the development of electric vehicle infrastructure. Governments and local authorities can implement incentives, such as tax benefits or grants, to encourage the installation of charging stations. They can also streamline permitting processes and establish partnerships between public and private entities to accelerate infrastructure development. Furthermore, data and connectivity are essential components of electric vehicle infrastructure. Charging stations equipped with connectivity features can provide real-time information on station availability, charging rates, and user feedback. Data collected from charging infrastructure can be utilized for monitoring, analysis, and optimization of EV charging patterns, helping to improve the overall efficiency and effectiveness of the charging network[119].

Scalability and future expansion are considerations in designing electric vehicle infrastructure. As the adoption of EVs grows, the infrastructure must be able to accommodate the increasing demand for charging services. Planning for additional charging stations, upgrading power grid infrastructure, and incorporating emerging technologies are essential to meet future requirements. Electric vehicle infrastructure plays a critical role in enabling the transition to sustainable transportation in smart cities. By providing reliable and accessible charging infrastructure, integrating with the grid,

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[117] P.W. Shaikh, H.T. Mouftah: Intelligent Charging Infrastructure Design for Connected and Autonomous Electric Vehicles in Smart Cities, Proceedings of the IM 2021 – 2021 IFIP/IEEE International Symposium on Integrated Network Management, 9463934, 2021, pp. 992–997.

[118] C.A. Marino, M. Marufuzzaman: Unsupervised learning for deploying smart charging public infrastructure for electric vehicles in sprawling cities, Journal of Cleaner Production, Vol. 266, 2020, 121926.

[119] S.S. Kadlag, P. Tapre, R. Mapari, D. Kadam, D. Dahigaonkar: Pulse charging based intelligent battery management system for electric vehicle, Bulletin of Electrical Engineering and Informatics, Vol. 12, No. 4, 2022, pp. 1947–1959.

and leveraging data and connectivity, electric vehicle infrastructure supports the growth of electric mobility, reduces emissions, and contributes to the development of smarter, greener, and more sustainable cities[120].

The integration of smart vehicles with smart grids in smart cities involves the seamless coordination and communication between electric vehicles (EVs) and the electrical grid infrastructure. This integration aims to optimize energy management, enhance grid stability, and promote sustainable transportation. In plain text, here's how the integration works: Smart vehicles, equipped with advanced communication and sensing capabilities, can interact with the smart grid infrastructure. They can send and receive real-time data regarding their battery state, charging needs, and availability for grid services. This information allows the smart grid to effectively manage the charging and discharging of EVs while considering grid conditions, electricity demand, and renewable energy availability[121].

The integration of renewable energy sources with electric vehicle (EV) usage in smart cities plays a crucial role in promoting sustainable and clean transportation. By combining EVs with renewable energy, cities can achieve several benefits and contribute to a greener and more efficient urban environment. One of the key roles of integrating renewable energy with EV usage is reducing greenhouse gas emissions. Renewable energy sources such as solar, wind, and hydropower produce electricity without releasing harmful emissions. When EVs are charged with renewable energy, they operate with significantly lower or even zero emissions compared to traditional internal combustion engine vehicles. This integration helps to mitigate air pollution and combat climate change. Moreover, integrating renewable energy with EV usage contributes to energy diversification and reduces reliance on fossil fuels. By utilizing locally generated renewable energy, cities can decrease their dependence on imported fossil fuels, enhancing energy security and resilience. This integration also promotes a shift towards cleaner and more sustainable energy systems.

Integrating renewable energy sources with EVs can also support the efficient use of electricity resources. EV charging can be scheduled during periods of high renewable energy generation, such as during the day for solar power or during windy conditions for wind power. This approach allows EV charging to align with the availability

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[120] S.S. Kadlag, M.P. Thakre, R. Mapari, P.C. Tapre, D.P. Kadam: A novel pulse charger with intelligent battery management system for fast charging of electric vehicle, Bulletin of Electrical Engineering and Informatics, Vol. 12, No. 3, 2023, pp. 1388–1396.

[121] V. Boglou, C.-S. Karavas, A. Karlis, K. Arvanitis: An intelligent decentralized energy management strategy for the optimal electric vehicles' charging in low-voltage islanded microgrids, International Journal of Energy Research, Vol. 46, No. 3, 2023, pp. 2988–3016.

of renewable energy, reducing strain on the grid during peak demand periods. It maximizes the utilization of renewable energy and optimizes the overall energy management in smart cities. Additionally, the integration of renewable energy with EVs facilitates the concept of "vehicle-to-grid" (V2G) technology. V2G enables bidirectional energy flow between EVs and the electrical grid, allowing EVs to not only consume electricity but also supply excess energy back to the grid. During times of high demand, EVs can serve as temporary energy storage units, contributing to grid stability and supporting the integration of intermittent renewable energy sources.

Integrating renewable energy with EV usage requires a supportive infrastructure and smart grid technologies. This includes the installation of renewable energy generation systems, such as solar panels or wind turbines, in proximity to EV charging stations. Smart grid technologies enable real-time monitoring and control of renewable energy generation, storage, and distribution, ensuring optimal utilization and grid integration with EV charging. Overall, the integration of renewable energy with EV usage in smart cities offers numerous benefits. It reduces emissions, promotes energy diversification, optimizes energy management, enhances grid stability, and contributes to the overall sustainability and resilience of urban transportation systems. By combining EVs with renewable energy, cities can foster a cleaner, greener, and more sustainable future for transportation[122].

The integration of smart vehicles and smart grids enables several key functionalities. First, it facilitates demand-side management by allowing the grid to control and optimize the charging patterns of EVs. This means that charging can be scheduled during off-peak hours or when renewable energy generation is high, reducing the strain on the grid during peak periods. Second, smart vehicles can participate in vehicle-to-grid (V2G) systems. In V2G, EVs not only draw energy from the grid but can also feed excess energy back into the grid when needed. This two-way energy flow allows EVs to become valuable grid assets, supporting grid stability, and providing additional energy storage capacity.

The integration also enables EVs to leverage dynamic pricing models. EV owners can benefit from time-of-use rates, where electricity prices vary based on demand and supply conditions. Smart vehicles can adjust their charging behaviour based on price signals, allowing owners to take advantage of lower electricity prices during off-peak

[122] S. Sabzi, L. Vajta: Security and Energy Consumption Considerations of Electric Vehicles Integration in Smart Grids, U.Porto Journal of Engineering, Vol. 9, No. 1, 2023, pp. 134–149.

periods. Additionally, smart grids can provide EV owners with real-time information about the availability and location of charging stations, facilitating efficient route planning and reducing the chances of encountering charging infrastructure congestion[123].

It can be stated, that the integration of smart vehicles with smart grids in smart cities offers benefits such as optimized energy management, reduced strain on the grid, increased renewable energy utilization, and improved charging convenience for EV owners. By leveraging the capabilities of both smart vehicles and smart grids, cities can promote sustainable transportation while ensuring efficient and reliable energy supply.

By incorporating electric vehicles into the fabric of smart cities, urban areas can achieve reduced emissions, improved air quality, optimized energy management, and enhanced mobility options for residents. Electric vehicle usage in smart cities contributes to the vision of sustainable, connected, and liveable urban environments.

Electric vehicles (EVs) can play several important roles in smart cities, contributing to their overall sustainability, efficiency, and quality of life. Electric vehicles produce zero tailpipe emissions, reducing air pollution and improving urban air quality. By replacing conventional internal combustion engine vehicles with EVs, smart cities can significantly reduce greenhouse gas emissions and combat climate change. Those vehicles operate quietly compared to vehicles with internal combustion engines, contributing to a quieter and more peaceful urban environment. This reduction in noise pollution can enhance the quality of life for residents in smart cities[124].

Mobility-as-a-Service (MaaS) refers to a comprehensive approach to transportation in a smart city that offers integrated and seamless mobility solutions to residents and visitors. Specifically, MaaS focuses on providing access to electric vehicles (EVs) as a sustainable and convenient mode of transportation. In a smart city context, MaaS platforms or applications serve as a one-stop solution for users to plan, book, and pay for their entire travel journey using EVs. These platforms aggregate various transportation services, including EV rentals, ride-sharing, public transit, bike-sharing, and more, into a single interface. Users can access these services through mobile apps or web platforms, simplifying the process of finding and using EVs for their travel needs[125].

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[123] S. Aliakbari Sani, O. Bahn, E. Delage, R. Foguen Tchuendom: Robust Integration of Electric Vehicles Charging Load in Smart Grid's Capacity Expansion Planning, Dynamic Games and Applications, Vol. 12, No. 3, 2023, pp. 1010–1041.

[124] P. Tamay, E. Inga: Charging Infrastructure for Electric Vehicles Considering Their Integration into the Smart Grid, Sustainability (Switzerland), Vol. 14, No. 14, 2023, 8248.

[125] Y. He, C. Csiszár: Model for crowdsourced parcel delivery embedded into mobility as a service based on autonomous electric vehicles, Energies, Vol. 14, No. 11, 2022, 3042.

MaaS platforms enable users to search for available EVs in their vicinity and make reservations based on their preferences. They provide real-time information on vehicle availability, charging stations, and pricing options, allowing users to compare and choose the most suitable EV for their travel requirements. Through the platform, users can also unlock and access the reserved EV, eliminating the need for separate rental agreements or transactions. Moreover, MaaS platforms often integrate with payment systems, allowing users to conveniently pay for their EV usage and related services within a single transaction. This streamlines the payment process and eliminates the need for multiple payment methods or accounts for different transportation services.

One of the key advantages of MaaS for EV usage in a smart city is the ability to optimize travel routes and modes of transportation. MaaS platforms can provide personalized journey recommendations, taking into account factors such as traffic conditions, real-time EV availability, and user preferences. By suggesting the most efficient and eco-friendly routes and transportation options, MaaS encourages users to make sustainable choices and reduce reliance on private vehicles. Additionally, MaaS platforms can leverage data analytics and predictive modeling to anticipate travel demand and optimize fleet management. By analysing historical travel patterns and user behaviour, MaaS operators can strategically position EVs and charging infrastructure to ensure availability and efficient usage. This helps reduce vehicle idle time, minimize congestion around popular destinations, and enhance overall transportation system efficiency[126].

MaaS also promotes interoperability and integration between different transportation modes. By combining EV rentals, ride-sharing, public transit, and other services into a unified platform, MaaS encourages seamless transfers between different modes of transportation. This integrated approach simplifies travel planning and encourages a more sustainable and efficient use of transportation resources. Besides many benefits there can be some problems when we implement electric vehicles in smart cities. In the table 20 there are description some of them. When government will implement this solution in smart cities the mentioned problems should be taken into account and overcome[127].

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[126] P. Brezovec, N. Hampl: Electric vehicles ready for breakthrough in MaaS? Consumer adoption of E-car sharing and E-scooter sharing as a part of mobility-as-a-service (MaaS), Energies, Vol. 14, No. 4, 2021, pp. 1088–1105.
[127] P. Cooper, T. Tryfonas, T. Crick, A. Marsh: Electric Vehicle Mobility-as-a-Service: Exploring the "Tri-Opt" of Novel Private Transport Business Models, Journal of Urban Technology, Vol. 26, No. 1, 2019, pp. 35–56.

Table 20

Problems in implementation of electric vehicles in smart cities

Problem	Description
Limited Charging Infrastructure	Insufficient availability of charging stations and limited coverage can hinder the widespread adoption of EVs in smart cities.
High Initial Infrastructure Costs	Setting up a comprehensive charging infrastructure network requires substantial investments in equipment, installation, and maintenance.
Range Anxiety	Concerns about limited driving range and the availability of charging stations may discourage potential EV owners in smart cities.
Charging Time	EV charging time is typically longer compared to refueling conventional vehicles, which can lead to inconvenience for drivers in smart cities.
Grid Overload	A large-scale deployment of EVs without proper grid management could strain the electricity grid and potentially cause blackouts or power disruptions.
Upgrading Power Grid Infrastructure	The existing power grid infrastructure may need upgrades to handle the increased demand from EV charging, requiring substantial investments.
Battery Technology and Recycling	The production, disposal, and recycling of EV batteries pose environmental challenges that need to be addressed in smart cities.
Disruption to Petroleum Industry	A rapid shift to EVs in smart cities can have economic impacts on the petroleum industry and associated sectors, requiring transition planning.
Equity and Accessibility	Ensuring equitable access to EV charging infrastructure and affordable EV options for all residents is crucial in smart city implementations.
Technological Advancements	Ongoing advancements in EV technology require continuous research and development to improve battery efficiency, range, and charging speeds

Source: E.A. Nanaki: Electric Vehicles for Smart Cities Trends, Challenges, and Opportunities, Elsevier, Berlin, 2020; P. Zhou, C. Wang, Y. Yang: Design and Optimization of Solar-Powered Shared Electric Autonomous Vehicle System for Smart Cities, IEEE Transactions on Mobile Computing, Vol. 22, No. 4, 2023, pp. 2053–2068; E. Ghorbani, T. Fluechter, L. Calvet, J. Panadero, A.A. Juan: Optimizing Energy Consumption in Smart Cities' Mobility: Electric Vehicles, Algorithms, and Collaborative Economy, Energies, Vol. 16, No. 3, 2023, 1268; T. Chanraksa, J.G. Singh: Benefits of Demand Response with Electric Vehicles in Smart Grid: A Case Study of Pattaya City, Thailand, 2023 International Conference on Power, Instrumentation, Energy and Control, PIECON 2023, 103; H.T. Mouftah, A. Radwan, M.H. Rehmani, F. Al-Turjman, B. Vaidya: Editorial: Prospects of energy and mobility-Connected and autonomous electric vehicles for sustainable smart cities, Frontiers in Energy Research, Vol. 10, 2023, 972084; M. Lotfi, T. Almeida, M.S. Javadi, C. Monteiro, J.P.S. Catalão: Coordinating energy management systems in smart cities with electric vehicles, Applied Energy, Vol. 307, 2022, 118241.

4.2. Smart charging infrastructure and Vehicle-to-Grid Integration

Smart charging infrastructure and Vehicle-to-Grid (V2G) integration are two important components of electric mobility in the implementation of smart cities. They aim to optimize the charging process for electric vehicles (EVs) and leverage their energy storage capabilities to support the grid. Smart charging infrastructure refers to the network of charging stations equipped with advanced technologies and communication systems. These charging stations are designed to facilitate efficient and intelligent charging of EVs. They can be integrated into smart cities' overall infrastructure, including parking facilities, residential areas, commercial districts, and public transportation hubs[128].

Smart charging infrastructure in a smart city refers to a network of charging stations and supporting technologies designed to enable efficient and intelligent charging of electric vehicles (EVs). It encompasses various components and features that optimize the charging process, enhance user experience, and integrate seamlessly with the overall smart city infrastructure. The most important aspects of smart charging infrastructure in smart city are described in the table 21. By implementing smart charging infrastructure, a smart city can foster the widespread adoption of electric vehicles while ensuring efficient energy utilization, grid stability, and enhanced user experience. It forms a critical pillar in the sustainable transportation ecosystem of a smart city.

Table 21

Important aspects of smart charging infrastructure in smart city

Smart charging infrastructure	**Characteristic**
Charging Stations	Smart charging infrastructure consists of a widespread deployment of charging stations strategically located throughout the city. These stations can be installed in public areas, residential complexes, commercial districts, parking lots, and transportation hubs to ensure convenient access for EV owners.

[128] H.A. Gabbar: Fast Charging and Resilient Transportation Infrastructures in Smart Cities, Fast Charging and Resilient Transportation Infrastructures in Smart Cities, 2022, pp. 1–292.

continue table 21

Smart charging infrastructure	**Characteristic**
Connectivity and Communication	Charging stations are equipped with advanced connectivity technologies such as cellular networks, Wi-Fi, or dedicated communication protocols. This enables real--time data exchange between the charging infrastructure, EVs, and central management systems. Communication capabilities facilitate features like remote monitoring, control, and payment authentication.
Intelligent Charging Management	Smart charging infrastructure employs sophisticated algorithms and software systems to optimize the charging process. It takes into account various factors such as grid demand, electricity prices, EV owner preferences, and renewable energy availability. By dynamically adjusting the charging rate, it ensures efficient utilization of energy resources and reduces strain on the grid during peak periods.
Load Balancing and Demand Response	Smart charging infrastructure integrates with the city's energy management system, allowing coordination and load balancing between EV charging and other energy-consuming devices or systems. It enables demand response strategies, where charging rates can be adjusted in response to grid conditions or signals from the utility company, promoting grid stability and cost optimization.
Payment and Authentication	Smart charging infrastructure provides convenient payment options and authentication mechanisms for EV owners. This may include mobile apps, RFID cards, credit card readers, or even integrated payment systems with electric vehicle service providers. Secure authentication ensures only authorized users can access the charging stations and initiates charging sessions.
Renewable Energy Integration	Smart charging infrastructure supports the integration of renewable energy sources into the charging process. It can prioritize charging from renewable energy or schedule charging during periods of high renewable energy generation. This enables EV owners to align their charging with sustainable energy sources and promotes the utilization of clean power in the transportation sector.

continue table 21

Smart charging infrastructure	**Characteristic**
Data Analytics and Optimization	Smart charging infrastructure collects and analyses data related to charging patterns, energy consumption, and grid conditions. This data can be utilized to identify trends, optimize charging strategies, and provide insights for infrastructure planning and investment decisions.
Scalability and Future-Proofing	Smart charging infrastructure is designed to be scalable and adaptable to accommodate the growing number of EVs in the city. It takes into consideration future technological advancements, compatibility with different charging standards (e.g., AC, DC), and the ability to integrate with emerging technologies like Vehicle-to--Grid (V2G) systems.

Source: P.W. Shaikh, H.T. Mouftah: Intelligent Charging Infrastructure Design for Connected and Autonomous Electric Vehicles in Smart Cities, Proceedings of the IM 2021–2021 IFIP/IEEE International Symposium on Integrated Network Management, 2021, pp. 992–997; J. Ramsebner, A. Hiesl, R. Haas, M. Mühlberger, K. Mühlberger-Habiger: Smart charging infrastructure for battery electric vehicles in multi apartment buildings, Smart Energy, Vol. 9, 2023, pp. 100093; P. Tamay, E. Inga: Charging Infrastructure for Electric Vehicles Considering Their Integration into the Smart Grid, Sustainability (Switzerland), Vol. 14, No. 14, 2022, pp. 8248–8261; L. Phiri, S. Tembo, K.J. Nyoni: Assessing the Ramifications of Electric Vehicle Charging Infrastructure on Smart Grid Systems in Zambia, 2022 International Conference on Information and Communication Technology for Development for Africa, ICT4DA 2022, pp. 175–180; B. Azin, X.T. Yang, N. Marković, M. Liu: Infrastructure enabled and electrified automation: Charging facility planning for cleaner smart mobility, Transportation Research Part D: Transport and Environment, Vol. 101, 2021, pp. 103079.

Charging stations play a crucial role in the electric car usage system of a smart city. They are the infrastructure that enables electric vehicles (EVs) to recharge their batteries, ensuring their availability and usability for city residents. Charging stations are strategically placed throughout the city to provide convenient access for EV owners and support the widespread adoption of electric mobility. By offering a reliable and accessible charging infrastructure, charging stations address one of the main concerns of EV owners: range anxiety. They alleviate worries about running out of battery power by providing a place for EVs to recharge conveniently and efficiently. This encourages more people to adopt electric vehicles, contributing to the reduction of greenhouse gas emissions and air pollution in the city[129].

[129] P.W. Shaikh, H.T. Mouftah: Intelligent Charging Infrastructure Design for Connected and Autonomous Electric Vehicles in Smart Cities, Proceedings of the IM 2021–2021 IFIP/IEEE International Symposium on Integrated Network Management, 2021, pp. 992–997.

In a smart city context, charging stations go beyond basic charging functionalities. They are equipped with advanced technologies and communication systems that enable them to be part of the overall smart city infrastructure. This connectivity allows charging stations to interact with EVs, grid operators, and other components of the smart city ecosystem. Smart charging stations can communicate with EVs in real-time, exchanging data and providing information about charging status and availability. This connectivity also enables remote monitoring and control of charging processes, ensuring that charging stations are functioning properly and allowing for efficient maintenance.

Also charging stations in a smart city can integrate with the energy management systems of buildings, homes, and the overall city grid. This integration facilitates load balancing and demand response strategies. Charging stations can adjust charging rates based on factors like grid demand, energy prices, and the availability of renewable energy. This optimization helps to avoid peak demand periods, reduces strain on the grid, and maximizes the utilization of clean energy sources. Payment and authentication mechanisms are also integrated into charging stations to ensure secure and convenient access for EV owners. Various payment options such as mobile apps, RFID cards, and credit cards are supported, making it easy for users to pay for their charging sessions[130].

Vehicle-to-Grid (V2G) technology plays a significant role in the development of smart cities by leveraging the capabilities of electric vehicles (EVs) to support the power grid. V2G enables bidirectional energy flow between EVs and the grid, allowing EVs to act as mobile energy storage devices and suppliers of power back to the grid. In the table 22 there is a juxtaposition of most important aspects connected with V2G contribution to the smart city infrastructure[131].

It can be stated that Vehicle-to-Grid (V2G) technology enhances the role of electric vehicles (EVs) in a smart city by transforming them into valuable assets that support the power grid. V2G integration offers grid stabilization, renewable energy integration, demand response capabilities, grid ancillary services, energy market participation,

[130] J. Ramsebner, A. Hiesl, R. Haas, M. Mühlberger, K. Mühlberger-Habiger: Smart charging infrastructure for battery electric vehicles in multi apartment buildings, Smart Energy, Vol. 9, 2023, pp. 100093.

[131] P. Tamay, E. Inga: Charging Infrastructure for Electric Vehicles Considering Their Integration into the Smart Grid, Sustainability (Switzerland), Vol. 14, No. 14, 2022, pp. 8248–8261; L. Phiri, S. Tembo, K.J. Nyoni: Assessing the Ramifications of Electric Vehicle Charging Infrastructure on Smart Grid Systems in Zambia, 2022 International Conference on Information and Communication Technology for Development for Africa, ICT4DA 2022, pp. 175–180; B. Azin, X.T. Yang, N. Marković, M. Liu: Infrastructure enabled and electrified automation: Charging facility planning for cleaner smart mobility, Transportation Research Part D: Transport and Environment, Vol. 101, 2021, pp. 103079.

and carbon emission reduction. By leveraging the capabilities of EVs through V2G, smart cities can optimize energy usage, enhance grid flexibility, and promote sustainable and efficient energy systems[132].

Table 22

The role of vehicle-to-grid technology in smart city

Key aspects	**Characteristic**
Grid Stabilization and Flexibility	V2G integration helps stabilize the power grid by enabling EVs to supply electricity back to the grid during periods of peak demand or in emergency situations. By utilizing the stored energy in EV batteries, V2G can alleviate strain on the grid and prevent blackouts or brownouts. It provides an additional source of flexibility for grid operators to manage energy supply and demand fluctuations more efficiently.
Renewable Energy Integration	Smart cities often prioritize the adoption of renewable energy sources like solar and wind power. However, these sources can be intermittent, causing fluctuations in energy supply. V2G technology enables EVs to store excess electricity generated from renewable sources during times of low demand. This stored energy can then be fed back into the grid during high-demand periods, effectively integrating renewable energy into the grid and promoting its utilization.
Demand Response and Peak Shaving	Vehicle-to-grid facilitates demand response programs by allowing grid operators to control the charging and discharging of EVs based on grid conditions and demand signals. During times of high demand, grid operators can temporarily reduce the charging rate or discharge energy from EVs to help balance the grid. By actively managing the charging and discharging cycles, V2G can contribute to peak shaving, reducing the need for additional power plants and infrastructure investments.

[132] H. Klaina, I.P. Guembe, P. Lopez-Iturri, A.V. Alejos, F. Falcone: Aggregator to Electric Vehicle LoRaWAN Based Communication Analysis in Vehicle-to-Grid Systems in Smart Cities, IEEE Access, Vol. 8, 2020, pp. 124688–124701.

continue table 22

Key aspects	Characteristic
Grid Ancillary Services	EVs connected through V2G can provide various ancillary services to the grid, enhancing its stability and reliability. For example, EVs can offer frequency regulation by adjusting their charging or discharging rates to help match supply and demand and maintain grid frequency within acceptable limits. They can also assist in voltage control and grid balancing, improving power quality and stability.
Energy Market Participation	V2G technology opens up new opportunities for EV owners and fleet operators to participate in energy markets. They can sell excess stored energy from their EVs back to the grid or provide grid services, generating revenue and potentially reducing charging costs. V2G enables the creation of aggregator models where a fleet of EVs can be managed collectively to provide grid services and maximize financial benefits.
Carbon Emission Reduction	By integrating V2G technology, smart cities can further promote the transition to a low-carbon transportation system. EVs, already emitting fewer greenhouse gases than internal combustion engine vehicles, can provide additional environmental benefits by storing and utilizing renewable energy and supporting the grid's stability. This contributes to the overall reduction of carbon emissions within the city.

Source: H. Klaina, I.P. Guembe, P. Lopez-Iturri, A.V. Alejos, F. Falcone: Aggregator to Electric Vehicle LoRaWAN Based Communication Analysis in Vehicle-to-Grid Systems in Smart Cities, IEEE Access, Vol. 8, 2020, pp. 124688–124701; A.V. Sahu, E.H.P. Lee, Z. Lukszo: Exploring the potential of the vehicle-to-grid service in a sustainable smart city, ICNSC 2018 – 15th IEEE International Conference on Networking, Sensing and Control, 2018, pp. 1–6; E. Paffumi, M. De Gennaro, G. Martini: Innovative Technologies for Smart Cities: Towards Customer Driven Infrastructure Design for Large Scale Deployment of Electric Vehicles and Vehicle-to--Grid Applications, Transportation Research Procedia, Vol. 14, 2016, pp. 4505–4514; M.S. Mastoi, S. Zhuang, H.M. Munir, M. Alqarni, B.A. Alamri: Study of charging-dispatch strategies and vehicle-to-grid technologies for electric vehicles in distribution networks, Energy Reports, Vol. 9, 2023, pp. 1777–1806; Y. Zheng, Z. Shao, Y. Shang, L. Jian: Modeling the temporal and economic feasibility of electric vehicles providing vehicle-to-grid services in the electricity market under different charging scenarios, Journal of Energy Storage, Vol. 68, 2023, pp. 107579; A. Zar, I. Ahmad, M.S. Nazir, I. Ahmed: Fuzzy optimized conditioned-barrier nonlinear control of electric vehicle for grid to vehicle & vehicle to grid applications, Journal of Energy Storage, Vol. 64, 2023, pp. 107251.

Grid stabilization refers to the ability of V2G to help balance supply and demand in the grid. During periods of peak electricity demand, when the grid is under strain, EVs connected to V2G can discharge the stored energy in their batteries back to the grid. This additional supply of electricity helps alleviate strain on the grid, reducing the risk of blackouts or brownouts. By acting as mobile energy storage devices, EVs connected to V2G can provide flexibility to the grid. During times of surplus electricity generation, such as when renewable energy sources produce excess power, EVs can charge their batteries. This helps to absorb the excess energy and avoid wastage. The stored energy can then be discharged back to the grid when demand is high, providing additional power supply and contributing to grid stability[133].

V2G technology also enables grid operators to have better control over energy resources and respond to fluctuations in supply and demand. By implementing demand response programs, grid operators can adjust the charging or discharging rates of EVs based on grid conditions and demand signals. This dynamic control allows grid operators to optimize energy usage, balance the load on the grid, and maintain grid stability more efficiently. Moreover, V2G technology promotes the integration of renewable energy sources into the grid. As renewable energy generation is often intermittent, EVs connected to V2G can store excess renewable energy during times of low demand. This stored energy can be released back into the grid during periods of high demand, effectively utilizing renewable energy and reducing reliance on traditional power sources[134].

4.3. Intelligent transportation systems and traffic management

Intelligent Transportation Systems (ITS) play a significant role in the development of smart cities by leveraging advanced technologies to enhance transportation efficiency, safety, and sustainability. ITS encompasses a wide range of applications

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[133] A.V. Sahu, E.H.P. Lee, Z. Lukszo: Exploring the potential of the vehicle-to-grid service in a sustainable smart city, ICNSC 2018 – 15th IEEE International Conference on Networking, Sensing and Control, 2018, pp. 1–6.

[134] E. Paffumi, M. De Gennaro, G. Martini: Innovative Technologies for Smart Cities: Towards Customer Driven Infrastructure Design for Large Scale Deployment of Electric Vehicles and Vehicle-to-Grid Applications, Transportation Research Procedia, Vol. 14, 2016, pp. 4505–4514; M.S. Mastoi, S. Zhuang, H.M. Munir, M. Alqarni, B.A. Alamri: Study of charging-dispatch strategies and vehicle-to-grid technologies for electric vehicles in distribution networks, Energy Reports, Vol. 9, 2023, pp. 1777–1806; Y. Zheng, Z. Shao, Y. Shang, L. Jian: Modeling the temporal and economic feasibility of electric vehicles providing vehicle-to-grid services in the electricity market under different charging scenarios, Journal of Energy Storage, Vol. 68, 2023, pp. 107579.

and services that utilize data, communication networks, and automation to improve the overall transportation system. Key aspects of Intelligent Transportation Systems are described in the table 23.

Intelligent Transportation Systems (ITS) form a critical component of smart cities by utilizing technology and data to optimize transportation efficiency, enhance safety, and promote sustainable mobility. ITS applications encompass traffic management, public transportation enhancements, connected vehicles, smart parking, EV infrastructure, safety and emergency management, data analytics, and support for sustainable transportation modes. By integrating these systems, smart cities can create a seamless, efficient, and sustainable transportation network[135].

Table 23

Key aspects of intelligent transportation systems in smart city

Key aspects	**Characteristic**
Traffic Management	Intelligent Transportation Systems employs technologies like sensors, cameras, and data analytics to monitor and manage traffic flow in real-time. This enables dynamic traffic signal control, congestion detection, and optimization of traffic signal timings to reduce congestion and improve traffic efficiency. Advanced systems can also provide adaptive routing information to drivers, guiding them to the least congested routes.
Intelligent Public Transportation	ITS enhances the efficiency and accessibility of public transportation systems. Real-time passenger information systems keep commuters informed about arrival times, delays, and service updates through displays, mobile apps, or automated announcements. Smart ticketing systems enable contactless payment and seamless integration between different modes of public transportation, promoting multimodal travel options.

[135] L. Wang, X. Deng, J. Gui, F. Zeng, S. Wan: A review of Urban Air Mobility-enabled Intelligent Transportation Systems: Mechanisms, applications and challenges, Journal of Systems Architecture, Vol. 141, 2023, pp. 102902.

continue table 23

Key aspects	Characteristic
Connected Vehicles	ITS enables communication between vehicles and infrastructure, creating a connected vehicle ecosystem. Vehicles equipped with sensors and communication technologies can exchange information with traffic management centers and other vehicles. This facilitates the dissemination of real-time traffic and road condition updates, collision warnings, and emergency notifications, enhancing driver safety and efficiency.
Smart Parking	Intelligent Transportation Systems optimizes parking management by providing real-time information on parking availability through sensors and mobile apps. Drivers can locate vacant parking spaces easily, reducing the time spent searching for parking and decreasing traffic congestion. Smart parking systems can also enable cashless transactions and reservation services, streamlining the parking experience.
Electric Vehicle Infrastructure	ITS supports the deployment of electric vehicles by integrating EV charging infrastructure into the transportation system. Smart charging stations equipped with connectivity and payment systems enable efficient charging, demand management, and integration with renewable energy sources. ITS can provide real-time information about the availability of charging stations, optimize charging schedules, and support vehicle-to-grid integration.
Safety and Emergency Management	ITS improves road safety through applications such as intelligent speed control, automated enforcement systems, and incident detection. In case of emergencies, ITS facilitates quick response and coordination by providing real-time information about incidents, traffic diversions, and emergency services. This enhances emergency management and helps reduce response times.
Data Analytics and Decision Support	Intelligent Transportation Systems leverages data collected from various sensors, cameras, and connected devices to generate valuable insights. Advanced analytics and machine learning algorithms can analyse this data to identify traffic patterns, predict congestion, optimize signal timings, and support decision-making for transportation planning and infrastructure development.

continue table 23

Key aspects	Characteristic
Sustainable Transportation	ITS promotes sustainable transportation modes such as cycling and walking by providing infrastructure and support systems. This includes smart bike-sharing programs, pedestrian-friendly infrastructure, and real-time information on alternative transportation options. By encouraging sustainable modes of travel, ITS contributes to reducing traffic congestion, improving air quality, and enhancing the overall environmental sustainability of the city.

Source: L. Wang, X. Deng, J. Gui, F. Zeng, S. Wan: A review of Urban Air Mobility-enabled Intelligent Transportation Systems: Mechanisms, applications and challenges, Journal of Systems Architecture, Vol. 141, 2023, pp. 102902; H. Korkmaz, E. Filazoglu, S.S. Ates: Enhancing airport apron safety through intelligent transportation systems: Proposed FEDA model, Safety Science, Vol. 164, 2023, pp. 106184; A. Barodi, A. Zemmouri, A. Bajit, M. Benbrahim, A. Tamtaoui: Intelligent Transportation System Based on Smart Soft-Sensors to Analyze Road Traffic and Assist Driver Behavior Applicable to Smart Cities, Microprocessors and Microsystems, Vol. 100, 2023, pp. 104830; M. Deveci, I. Gokasar, D. Pamucar, X. Wen, B.B. Gupta: Evaluation of Cooperative Intelligent Transportation System scenarios for resilience in transportation using type-2 neutrosophic fuzzy VIKOR, Transportation Research Part A: Policy and Practice, Vol. 172, 2023, pp. 103666; H. Zhang, G. Luo, Y. Li, F.-Y. Wang: Parallel Vision for Intelligent Transportation Systems in Metaverse: Challenges, Solutions, and Potential Applications, IEEE Transactions on Systems, Man, and Cybernetics: Systems, Vol. 53, No. 6, 2023, pp. 3400–3413; A. Susanty, B. Purwanggono, V.A. Putri: Bibliometric analysis for intelligent transportation system, IP Conference Proceedings, 2023, 2683,050004.

In the table 24 there is a description of selected examples of cities in the word very advanced in Intelligent Transport Systems implementation.

Table 24

Example of smart cities advanced in Intelligent Transport System implementation

City	Characteristic of Intelligent Transport System
Singapore	In 2014, Singapore became the pioneer in establishing a dedicated minister for smart nation initiatives. However, the city-state had already been at the forefront of smart traffic management for over a decade. As early as 1998, Singapore implemented the Electronic Road Pricing scheme as a means to effectively handle traffic congestion. Over the years, Singapore has continued to invest significantly in intelligent traffic management, allocating a substantial budget of $12 billion for transportation development in 2018.

continue table 24

City	Characteristic of Intelligent Transport System
Singapore	This substantial investment has largely been directed towards developing connected infrastructure equipped with sensors for traffic management and proactive maintenance measures. In addition to infrastructure, Singapore is also actively exploring the use of connected vehicles and has plans to introduce automated buses as early as 2022. Recognized by KPMG as the leader in preparedness for automated vehicles, Singapore's intelligent transportation system is data-rich and capable of providing real-time traffic alerts to the public. As a result of these initiatives, Singapore has achieved one of the lowest levels of traffic congestion among cities worldwide.
New York City	New York City, renowned for its outstanding public transportation, is consistently pushing the boundaries of innovation by developing an advanced transportation system. This achievement has positioned the city at the top of IESE's city in motion list for mobility this year. In its pursuit of progress, New York City has been actively investing in connected infrastructure and adaptive traffic signals, with the installation of cameras and sensors at more than 10,000 intersections across the municipality. Furthermore, the city is embracing the potential of connected cars by launching the Connected Vehicle Pilot Program. This initiative aims to gather and analyse data from connected vehicles to drive various technologies and applications. Through the utilization of connected vehicle hardware and software, the program will implement V2X (vehicle-to-everything) initiatives, enabling real-time enhancements in safety and traffic management.
London	London is at the forefront of advancing its infrastructure by leading the charge in 5G technology. The Smart Mobility Living Lab in London (SMLL) is spearheading the deployment of an advanced urban testbed, utilizing the most cutting-edge 5G connectivity available, specifically designed for connected and autonomous vehicles. This initiative enables the city to conduct real-world testing of vehicle--to-infrastructure (V2I) and vehicle-to-vehicle (V2V) capabilities, capitalizing on the high-speed capabilities of 5G technology. O2, the mobile operator responsible for enabling SMLL, has highlighted the significant benefits of 5G for road management systems.

continue table 24

City	Characteristic of Intelligent Transport System
London	These benefits include a potential 10 percent reduction in travel time for motorists stuck in traffic, an estimated annual saving of £880 million for the economy, and a substantial reduction of 370,000 metric tons of CO2 emissions per year. In addition to this, London has introduced Sitraffic Fusion,a program designed to efficiently manage traffic by utilizing data obtained from connected vehicles. This program will play a crucial role in London's Real Time Optimiser system, which has previously managed road networks through data gathered from embedded road sensors, cameras, and other connected infrastructure.
Paris	Paris is dedicated to promoting public transportation and walking as viable modes of transportation. As the city progresses in developing infrastructure for non-motorized forms of travel, it acknowledges the importance of vehicles for certain needs. In its commitment to becoming an eco-friendly city, Paris is embarking on an initiative to replace its entire fleet of buses with electric vehicles. Additionally, the city places significant emphasis on enhancing road safety and managing traffic effectively, resulting in a 40% reduction in traffic-related fatalities since 2010. Paris is also taking strides to further enhance its existing intelligent transportation system and has allocated €100 million to adapt its infrastructure to support the widespread adoption of connected and autonomous vehicles.
Beijing	China adopts a centralized approach to the development of smart cities, with an impressive number of over 800 smart city initiatives implemented across the country. The smart city solutions market in China is estimated to be valued at $1.1 trillion. Among these initiatives, Beijing stands out as a leading example. In 2017, Beijing became the first city in China to authorize the testing of autonomous vehicles on public roads. With the largest autonomous vehicle market globally, China has made significant strides in this technology. During the COVID-19 pandemic, the country even utilized automated vehicles to ensure the safe delivery of essential supplies, minimizing the risk of contagion. Beijing has embraced connected car technologies, including embedded sensors and cameras, to effectively monitor traffic and road conditions. Leveraging big data analysis and artificial intelligence, the city has implemented intelligent transportation management systems to facilitate efficient and seamless movement within its infrastructure.

continue table 24

City	Characteristic of Intelligent Transport System
Berlin	In 2015, Berlin embraced a smart city strategy and has since made significant advancements. One of its recent endeavors in the realm of mobility involves the implementation of in-ground sensors at roadway intersections. This innovative vehicle detection system utilizes wireless technology to gather traffic data, enabling intelligent traffic management. Berlin is also actively working towards expanding the adoption of electric vehicles (EVs). To achieve this, the city has introduced BeMobility, a program aimed at deploying e-carsharing services, EV fleets, and augmenting the number of charging stations throughout the city. The program has been allocated a substantial budget of over €9 billion to support these initiatives.
Seoul	Seoul has been an early adopter of smart mobility, implementing it as far back as 2003. Through the implementation of an advanced intelligent transportation system, bus management system, and GPS technology, the city witnessed a substantial increase in mass transit ridership from 30% to 70%. This achievement has positioned Seoul as a global leader in the field of smart mobility. In 2010, the city took a further step by establishing the World Smart Sustainable Cities Organization, aimed at supporting sustainable development and exporting transportation solutions to other regions.
Seoul	To address urban challenges, the metropolitan government of Seoul has made significant investments in technology, particularly in the areas of data collection, storage, processing, and utilization. The city's intelligent transportation system relies on sensors placed throughout the urban landscape to gather data, enabling the anticipation and prevention of traffic congestion. Moreover, the system has the capability to alert citizens about issues and provide real-time advice on alternative routes. Continuing its commitment to innovation, Seoul is currently investing in the development of 5G infrastructure and connected vehicles. The city plans to equip buses and taxis with 5G advanced driver assistance systems, leveraging vehicle-to-everything (V2X) technologies. Seoul aims to be the first city to employ 5G innovations within its public transportation network, further enhancing the efficiency and effectiveness of its mobility solutions.
Barcelona	Barcelona has emerged as a frontrunner in the realm of smart mobility, with its supercomputing center taking the lead in developing the innovative CLASS program. This program is dedicated to creating cutting-edge software that facilitates the analysis of real-time data from various sources, including smart cities, connected cars,

continue table 24

City	Characteristic of Intelligent Transport System
Barcelona	and autonomous vehicles. While Barcelona already operates an intelligent traffic management system that relies on sensors embedded in the road and infrastructure, the city has future plans to leverage vehicle-to-everything (V2X) technologies. To establish itself as a hub for V2X advancements, Barcelona is making significant investments in 5G infrastructure and a Living Lab, which serves as a prominent center for the research and development of connected and autonomous vehicles. The remarkable strides achieved by the CLASS program in advanced data analytics, combined with the progress in connected vehicles and 5G infrastructure, contribute to Barcelona's position as a leader in urban mobility.

Source: J.J. Asiag: 8 Smart Cities Lead the Way in Advanced Intelligent Transportation Systems, 2021, https://otonomo.io/blog/smart-cities-intelligent-transportation-systems/ [accessed on 20.06.2023].

Traffic management plays aa important role in a smart city by leveraging advanced technologies and data-driven solutions to optimize the flow of traffic and improve transportation efficiency. Through the use of various tools and strategies, traffic management systems aim to reduce congestion, enhance safety, and promote a smoother movement of vehicles and pedestrians throughout the city. One of the key aspects of traffic management in a smart city is the implementation of real-time monitoring systems. These systems utilize sensors, cameras, and other data collection devices to gather information on traffic conditions, including traffic volume, speed, and congestion levels. By continuously monitoring traffic patterns, authorities can gain insights into traffic flows and identify areas of congestion or potential bottlenecks[136].

With the help of advanced data analytics, traffic management systems can process and analyse the collected data in real-time. This enables traffic managers to make informed decisions and take proactive measures to mitigate congestion and improve traffic flow. For example, based on the analysis of real-time traffic data, traffic signal timings can be adjusted dynamically to optimize the movement of vehicles and reduce delays[137]. Smart traffic management also involves the use of intelligent transportation systems (ITS) and communication technologies. These systems facilitate the exchange

[136] A.A. Alhaj, N.I. Zanoon, A. Alrabea, M. Abu-Faraj, B.J.A. Ali: Improving the Smart Cities Traffic Management Systems using VANETs and IoT Features, Journal of Statistics Applications and Probability, Vol. 12, No. 2, 2023, pp. 405–414.

[137] O. Lindov, A. Omerhodžić: Implementation of Smart Road Technologies in the Function of Road Traffic Safety Management, Lecture Notes in Networks and Systems, Vol. 687, 2023, pp. 621–627.

of information between vehicles, traffic management centers, and infrastructure, creating a connected environment. Through vehicle-to-infrastructure (V2I) and vehicle--to-vehicle (V2V) communication, real-time traffic updates, alerts, and diversions can be shared with drivers, enabling them to make informed decisions and choose the most efficient routes[138].

Furthermore, traffic management systems incorporate predictive modeling and forecasting techniques to anticipate traffic patterns and plan ahead. By analysing historical data and considering factors such as weather conditions, events, and public holidays, traffic managers can predict congestion hotspots and implement proactive measures to mitigate potential traffic issues. This may include adjusting signal timings, deploying additional resources, or providing alternative routes in advance. Smart traffic management also encompasses the integration of other transportation modes, such as public transit and cycling, into the overall traffic management strategy. By promoting multimodal transportation options, authorities aim to reduce private vehicle usage and alleviate congestion. This may involve implementing intelligent public transportation systems, including real-time passenger information, smart ticketing, and integrated transit services, to encourage the use of public transport and improve its efficiency[139].

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Chapter 5

ENERGY SHARING AND PEER-TO-PEER TRADING IN SMART ENERGY SYSTEMS

5.1. Energy Communities and Local Energy Markets

Smart energy is energy generated from sustainable energy resources and distributed using devices and methods for increasing energy efficiency. Smart energy is a very important component of sustainable development. All proactive companies are doing their share in generating, using and promoting smart energy. For many companies smart energy is their top priority. Investing in smart energy systems is very beneficial and profitable to the energy producers, customers and the environment. Smart energy is being generated from sources which will never be depleted. Renewable energy sources will keep the energy affordable or even drive down the cost as more advanced technologies develop. There are many renewable resources already being used to generate smart energy. Those renewable energy resources are solar, wind, geothermal, ocean energy, biomass, etc. As technology develops the list of renewable resources to generate smart energy gets longer. There is unlimited potential for using renewable energy sources. Solar, wind and geothermal energy are the fastest growing forms of renewable energy. The main threat to the development of smart energy is the outdated grid infrastructure. The current energy distribution grid is not designed to handle smart energy distribution[140].

The government and energy companies need to work together on designing and building a new grid infrastructure to distribute smart energy. The present grid is still handling the distribution of smart energy, but this will not be the case for much longer. The rapidly increasing number of smart energy systems will overload the grid. Rebuilding the energy distribution grid will be a slow and expensive project. Financial

[140] Smart Energy. Definition from: https://smartenergyusa.com/what-is-smart-energy/ [date of access 17.08.2023].

support from the government for this project will be needed. Updating the energy grid needs to be coordinated with the demand for smart energy. There are three main benefits from using smart energy:

1. Creating independence from traditional non-renewable sources.
2. Reducing emissions from greenhouse gases causing global warming and harming the environment.
3. Using a diverse power supply.

Smart energy is one step towards an ecofriendly future. *Smart meters* are essential devices in monitoring home energy use. Smart meters send hourly reports electronically to the energy supplier related to household energy use. Some meters submit the household energy use every fifteen minutes. Smart meters also notify the utility company if there is a power outage in the area. They can also dispatch a crew to resolve the situation and restore power. Smart meters provide detailed energy use information to the energy user. This normally leads to the development of an energy saving plan and lowing the consumption of energy. Some utility companies have an online program which allow the individual energy customer to track their energy consumption data. Smart meters are constantly gaining popularity. The present energy grid infrastructure is not always compatible with smart meters. The existing grid infrastructure is the main factor slowing down the installation and use of smart meters.

Energy Communities in United States

In the United States the Inflation Reduction Act (IRA) offers a tax credit to smart energy projects located within energy communities. All clean energy projects located within energy communities are entitled to a 10% additional financial incentive. Three types of areas can be considered as an energy community under the Inflation Reduction Act[141].

Brownfields: A brownfield is a relatively small parcel of land contaminated by pollutants and in needs of cleanup and redevelopment. Those locations may be suitable for development of community solar power generation or a power storage system. Brownfields are scattered around the United States with twenty-five thousand potential sites identified for the generation of smart renewable energy (usually solar or wind)[142].

[141] What is energy community: https://www.resources.org/common-resources/what-is-an-energy-community/ [date of access 17.08.2023].
[142] https://energycomunities.gov/background/ [date of access 17.08.2023].

Coal Communities: Coal communities are considered areas where one of these conditions takes place. Coal fired power plant existed and was closed after 2010.

- Coal mine existed and closed after 2000.

There are hundreds of areas in the United States where either a coal power plant or coalmine was closed within the described timeframe. A smart energy project in those areas is eligible for financial incentives increased by an additional 10% as an energy community incentive[143].

Fossil Fuel Employment: Areas that meet one of the following conditions are eligible for *energy community* designation.

- 17% of the total employment is in the field of extraction, processing, transport or storage or coal, oil or natural gas.
- 25% of the total tax revenue is from extraction, processing, transport or storage of coal, oil or natural gas.

In addition to meeting one of these two conditions unemployment needs to be above the national average in the previous year. Any area in the United States meeting the jobs and tax revenue criteria is entitled to be designated as an *energy community* and receive an additional 10% financial incentive to develop a smart energy project[144].

The purpose of the Inflation Reduction Act (2022) was to promote and stimulate clean energy innovations. According to the criteria for an energy community approximately 42% – 50% of land in the United States qualifies for extra incentives for generating, storing and distributing clean energy.

Energy Communities in the European Union

The European Parliament is presently providing funding for identifying the best practices for the development of energy efficient communities across the European Union (EU). Three agencies were identified to coordinate the activities[145].

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[143] What is an energy community alternative approaches for geographically targeted energy policy. Available online: https://www.rff.org/publications/reports/what-is-an-energy-community-alternative-approacches-for-geographically-targeted-energy-policy/ [date of access 17.08.2023].

[144] Revitalizing Energy Communities: Two-Year Report to the President (2023). *Interagency Working Group on Coal & Power Plant Communities & Economic Revitalization (in cooperation with the U.S. Department of Energy's National Energy Technology Laboratory.*

[145] Markets and consumers. Energy communities.EC, Brussel Available online: https://energy.ec.europa.eu/topics/markets-and-consumers.energy-communities_eu [date of access 17.08.2023].

1. Energy Community Repository (ECR)

The objective of this agency is to assist local residents to establish a citizen energy community or a renewable energy community in urban areas. An energy community repository is providing technical support and administrative advice. It also conducts an impact assessment and dissemination of best practices. ECR works with the local authority, businesses and citizens. Energy communities are promoting generation and distribution of smart energy. ECR is focusing on the countries and areas which do not have strong traditions in establishing energy communities.

2. Rural Energy Community Advisory Hub

This agency was established in June 2022 for the purpose of helping in setting up citizen energy communities or renewable energy communities in rural areas. The objectives of the Rural Energy Community Advisory Hub are as follows:

- Identification of best practices in implementing rural energy projects.
- Providing technical and legal assistance to rural energy projects.
- Creating networking opportunities to rural energy projects.

The Rural Energy Community Advisory Hub contributes to the dissemination of know-how and best practices.

3. Citizen-led Renovation

This agency provides support for citizens led activities to create and empower energy communities. Citizen led renovations are assisting in energy-saving building renovation projects. It provides financial, legal and technical support to deliver energy saving renovations to existing buildings.

These three initiatives empower energy communities and local residents to produce, consume and sell clean renewable energy. The initiatives also promote energy efficiency in the household and contribute to the goals of sustainable development.

Local Energy Markets

A local energy market is a community of residential prosumers (sellers) and customers (buyers) trading locally generated electricity within the community. All the members of the community need to have access to the local market platform where the prices for energy trading are being posted. The local energy market allows all the members of the community to trade energy with each other. Buyers can purchase electric energy at a price lower than the grid tariff rate of the energy retailer. Sellers offer the energy at a higher price than the feed-in tariff paid by the retailer. A local energy market encourages the local generation of electric energy[146]. This can lower or even eliminate the need for transporting electricity long distances from a centrally located power plant. The local energy market eliminates the need for an electricity retailer (middleman). There is some cost for the trading network operators. This cost, however, is relatively low. Another benefit of a local energy market is lower grid congestion because of local proximity trading. Local electricity producers with a battery energy storage system can sell the energy at a higher rate during the time of greater demand. This reduces their energy bills and shortens the payback time for the batteries[147]. The goal of a local energy market is to balance generation and demand within real time[148]. A local energy market requires flexibility to achieve a high level of self-sufficiency. A local energy market is a locally balanced decentralized energy distribution network[149].

5.2. Benefits and Challenges in Energy Sharing

Peer-to-peer energy trading is a process of buying and selling energy between grid--connected parties. This is a growing trend in trading solar energy. The access to solar energy can be traded using a secure platform. The seller and the buyer of the energy have the choice in selecting from whom they buy the energy and to whom they sell the energy. Solar energy can be sold back to the grid. However, the power company is paying a much lower rate than the market energy price. Peer-to-peer trading can be beneficial for the seller and the buyer[150]. The seller is being paid a higher rate than the power company is willing to pay. The buyer is getting the energy cheaper than

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[146] Local energy market: https://shop.elsevier.com/books/local-electricity-markets/pinto/987-0-12-820074-2.
[147] https://energyinformatics.springeropen.com/articles/10.1186/s42162-018-0017-3 [date of access 17.08.2023].
[148] https://www.powerledger.io/platform-features/local-energy-market [date of access 17.08.2023].
[149] https://ieeexplore.ieee.org/document/7393823 [date of access 17.08.2023].
EC (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources. European Commission, Brussels (Belgium). https://eu-lex.europa.eu/legal-content/EN/TXT/PDF/?url=CELEX:32018L2001&from=EN [date of access 17.08.2023];
EC (2015). Study on the Effective Integration of Distributed Energy Resources for Providing Flexibility to the Electricity System: Final Report to the European Commission. Ecofys, Tractebel, Sweco, Brussels (Belgium); E. Mengelkamp, J. Garttner, K. Rock, S. Kessler, L. Orsini, C. Weinhardt: Designing Microgrid Energy Markets: A Case Study – The Brooklyn Microgrid. Applied Energy, 210, 2018, pp. 870–880; www.sciencedirect.com/ science/article/pii/S030626191730805X.
[150] IRENA (2019). Innovation Landscape Brief: Renewable Mini-Grids. International Renewable Energy Agency, Abu Dhabi. www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Renewable_mini-grids_2019.pdf [date of access 17.08.2023].

the power company is charging. Smart solar energy producers are looking for flexibility and control to whom they want to sell the power. Trading energy can take place by using different platforms. One of the popular platforms is Blockchain. The energy trading platforms use data-based technology that processes and stores information such as energy transactions. Energy is being distributed through microgrids. Users of the peer--to-peer trading generating and selling energy are being called prosumers while individuals buying the energy are being called customers. Some of the energy buyers do not have their own solar panels, but they are purchasing solar energy through peer-to--peer trading. The first peer-to-peer trading on record occurred in Brooklyn, New York USA[151].

Peer-to-peer energy trading is presently being tested in many places (e.g., London, UK; Medellin, Columbia and many others). In Medellin residents in disadvantaged and poor areas are selling the energy to residents in more prosperous areas. The international collaboration in implementing peer-to-peer trading is essential. The exchange of information is needed to identify the best practices in creating regulations as well as the development of effective technologies. Studying the experimental projects in Australia, Belgium, Ireland, Italy, Netherlands, Switzerland, United Kingdom and the United States, an international comparative analysis is being performed[152]. Based on the comparative analysis, a *Readiness Index* is formulated and used to assess a region's readiness for peer-to-peer trading. The International Renewable Energy Agency (IRENA) is an international organization which promotes cooperation in the implementation of sustainable and renewable forms of energy including solar, ocean, hydro-energy, biomass energy, geothermal, wind energy, etc. The purpose of IRENA is to promote energy security and simultaneously promote low carbon sustainable development. IRENA provides support to individual countries in promoting energy sustainability. IRENA can be an international platform for the development of the technology and government policies. It is also a center of excellence in sustainable development[153].

Peer-to-peer trading is slowly gaining popularity and many companies are establishing an environment for peer-to-peer trading. A number of companies have been

[151] N. Good, K.A. Ellis, P. Mancarella: Review and Classification of Barriers and Enablers of Demand Response in the Smart Grid. Renewable and Sustainable Energy Reviews, January 2017, pp. 57–72. Available online: www.sciencedirect.com/science/article/abs/pii/S1364032117300436 [date of access 17.08.2023].
[152] Arena (2017). Peer-to-Peer Distributed Ledger Technology. Australian Renewable Energy Agency, Canberra. https://arena.gov.au/au/assets/2017/10/Final-Report-MHC-AGL-IBM-P2P-DLT.pdf [date of access 17.08.2023].
[153] Auroaenergy (2020). What Makes Up the Cost of Your Electricity Bill? www.auroraenergy.com.au/what-makes-cost-your-electricity-bi-pie-graphy [date of access 17.08.2023].

established in Australia, Bangladesh, Columbia, Germany, Japan, Malaysia, Netherlands, United Kingdom and the United States as well as other countries. Listed below are different companies highlighting peer-to-peer trading. Those companies are as follows:

- **LO3:** This company uses the platform called Energy. The company is presently operating in South Australia.
- **Sonnen Flat:** This company uses the platform Sonnen Flat. To participate the customers need to have Sonnen Flat batteries to store energy.
- **Grid+:** This company operates in Texas and focuses on peer-to-peer trading.
- **Suncontract:** This company has operated in Slovenia since 2018. The company is using Blockchain as an energy trading platform. This company is supported by the European Union (EU).
- **Eemnes Energie:** This company operates in Europe. It is a Belgium company. The company is planning to coordinate peer-to-peer trading on a larger scale.
- **Power Ledger:** This company is an Australia company using the Blockchain platform. The company has projects in Australia, United States, Italy and Thailand.
- **ConsenSys:** This company operates in New York and uses the Blockchain platform for peer-to-peer trading.

Peer-to-peer electricity trading empowers prosumers and customers (sellers and buyers). It allows for the efficient use of electricity generated from renewable sources. It allows for flexibility in deployment of renewable energy to the grid. Peer-to--peer trading also allows for better congestion management[154].

Peer-to-peer trading became an online marketplace where prosumers and customers can trade electricity on agreed prices usually attractive to both parties.

Peer-to-Peer Trading Platforms

There are many peer-to-peer trading community platforms. Those platforms are already being tested[155]. They are as follows:

- **Brooklyn Microgrid (United States)**

  Members of the community can buy and sell energy from and to each other. This is a Blockchain-based platform.

[154] IRENA (2019). Innovation Landscape for a Renewable-Powered Future: Solution to Integrate Variable Renewables. International Renewable Energy Agency, Abu Dhabi. www.irena.org/-www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Landscape_2019_report.pdf [date of access 17.08.2023].

[155] IRENA (2019). Innovation Landscape Brief: Blockchain. *International Renewable Energy Agency,* Abu Dhabi. Available online: www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Landscape_Blockchain_2019.pdf [date of access 17.08.2023].

- **Centric pic (United Kingdom)**

  Energy producers can use the platform to sell the surplus energy to the grid or to the local energy market. This platform is also Blockchain-based. The platform is matching the flexible demand, generation and storage. This platform is rewarding customers flexible in their energy use.
- **Lumenaza (Germany)**

  This platform allows energy sharing either with the local community, regional or national market. It matches the demand with energy supply and storage. The billing process and observations of energy flow are very transparent.
- **Picio (United Kingdom)**

  This platform matches prosumers and customers based on their performance and location every thirty minutes. It provides contracts, metering data as well as administrates the billing. It matches energy demand with generation and storage. Prosumers and customers can see the data from whom they are buying energy and to whom they are selling energy.
- **SOLshare (Bangladesh):** This platform installs small minigrids. Customers with solar panels on their homes can share the power with the rest of the community. By providing a minigrid the entire community has access to electric power.
- **Sonnen Community (Germany):** The platform requires prosumers to have a Sonnen battery for energy storage. Energy is being shared with others in the community who do not have energy-storage capacity. The stored energy is being sold to customers during peak demand. Energy, therefore, is being sold at an attractive price of 23 Euro/kWh. There is a monthly usage fee for the platform of 20 Euro.
- **Transactive Energy Initiative (Columbia):** The platform has been accepted by Columbian policymakers. Presently the platform is recommended for use on a commercial scale.
- **Vandebron (Netherlands):** The platform allows prosumers to set the price for electric energy. The customers can buy the power directly from the prosumers. The platform provides prosumers with forecasts of the electricity generation as well as forecasts of the customer demand. There is a monthly usage fee for the platform of $12 (USD).

Advantages of Peer-to-Peer Trading

The benefits of peer-to-peer trading are as follows[156]:

1. Households without solar panels can purchase renewable energy from neighbors at a reasonable price.
2. Households with an excess of solar energy can sell the energy for a much better price than feed-in tariff from the retailer.
3. Energy does not have to be transported from a centrally located powerplant. Approximately 40% of energy cost covers the maintenance of the poles and wires needed to bring the energy from the powerplant to the customers.
4. Energy generation can take place on the site of the solar panels or wind turbines.
5. Customers have a choice from whom they will buy energy.
6. Electricity retailer (middleman) is being eliminated.
   - Using an energy trading platform like Blockchain, the transactions are public and fully transparent.
   - Peer-to-peer trading provides high flexibility in renewable energy deployment.
   - Peer-to-peer trading provides better balance and congestion management.
   - Peer-to-peer trading lowers the utility bill for the customers.
   - (New York based peer-to-peer trading lowered utility bills by 10%.)

Shortcomings and Threats in Peer-to-Peer Trading

The shortcomings and threats in peer-to-peer trading are as follows:

1. Peer-to-peer trading needs advanced metering infrastructure (Smart Meters). Most of the existing meters need to be replaced by Smart Meters.
2. There needs to be a change in regulations allowing customers to have several energy suppliers simultaneously (Multiple-suppliers model).
3. There needs to be the development of a procedure allowing energy suppliers with storage capacity to sell the energy stored in the battery.
4. There needs to be a recognition of energy suppliers in the community as legitimate energy producers equal to the utility company.
5. There is a need to eliminate the social and environmental taxes from the utility bills.

[156] IRENA (2019). Innovation Landscape Brief: Aggregators. International Renewable Energy Agency, Abu Dhabi. www.irena.org/-/media/Files/IRENA/ Agency/Publication/ 2019/Feb/ IRENA_Innovation_ Aggregators__2019.pdf [date of access 17.08.2023].
IRENA (2019). Innovation Landscape Brief: Internet of Things. International Renewable Energy Agency, Abu Dhabi. www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Internet_of_Things_ 2019.pdf [date of access 17.08.2023].

Benefits of Peer-to-Peer Energy Trading in Protecting the Environment

The environmental benefits of peer-to-peer trading are as follows[157]:

1. Peer-to-peer energy trading allows for better distribution of renewable energy.
2. Peer-to-peer energy trading reduces the distribution cost of energy. Renewable energy is being sent on shorter distances rather than longer distances from powerplants to customers.
3. Peer-to-peer energy trading is a new business model which did not exist previously. It creates a social network and better understanding of the energy market.

Many communities are expressing an interest in implementing peer-to-peer energy sharing. There are, however, significant implementation requirements which have to be met. Those requirements can be divided into four categories[158].

1. Technical Requirements

a) Hardware requirements:
- Smart meters monitoring real-time power production
- Smart grid (mini or micro)
- Communication network to handle monitoring

b) Software
- Platform for peer-to-peer energy trading
- Power supply and demand analysis
- Algorithm for automated execution of peer-to-peer trading transactions

c) Communication
- Protocol for communication and coordination between systems (Market, network, platform, customers, prosumers, operators, etc.)

2. Policies Needed

- There is a need for policies and regulations allowing for decentralization of energy distribution systems for the purpose of better utilization of the existing grid infrastructure.

[157] IRENA (2019). Innovation Landscape Brief: Artificial Intelligence and Big Data. *International Renewable Energy Agency,* Abu Dhabi; www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_AI_Big_Data_2019.pdf [date of access 17.08.2023].

[158] Y. Liu, L.Wu, J. Li: Peer-to-Peer (P2P) Electricity Trading in Distribution Systems of the Future. *The Electricity Journal,* 32(4), 2019, pp. 2-6. Available online: www/sciencedirect.com/science/article/pii/S1040619019300284 [date of access 17.08.2023]; E. An, Q. Sun, J. Hu, R. Wang: A Differential Game Approach to Distributed Energy Trading for Energy Internet. *2020 IEEE 4th Conference on Energy Internet and Energy System Integration (E12),* Wuhan (China), 2020, pp. 3608–3613; M. Badra, R. Borghol: Privacy-Preserving and Efficient Aggregation for Smart- Grid Based on Blockchain. *11th IFIP International Conference on New Technologies, Mobility and Security (NTMS).* Paris, France: IEEE, 2021.

- There needs to be government support for testing peer-to-peer energy trading and distributing the results.
- There needs to be government and community support to incorporate peer-to--peer trading on a larger commercial scale.

3. Regulatory Requirements
- Regulations need to be established related to data collection from the perspective of cybersecurity and privacy.
- Clearly define the rights and responsibilities of stakeholders involved in peer-to--peer trading.
- Clearly defined rules for operating peer-to-peer energy trading.
- Clearly defined technical criteria for peer-to-peer energy trading.
- Clearly stated charges to the customers.

4. Stakeholders' Roles and Responsibilities
- Engage in peer-to-peer energy trading.
- Provide services to the peer-to-peer energy trading system.
- Select or develop a platform for peer-to-peer energy trading.
- Ensure safety and security of the selected trading platform.

Different ongoing innovations related to peer-to-peer energy trading creates synergies in the development of better and more effective actual solutions. The innovations affecting peer-to-peer energy trading can be divided into four categories[159].

1. Enabling Technologies

i) Partially independent micro-grids
ii) Fully independent micro-grids
iii) Super grids
iv) Internet of Things and Artificial Intelligence
v) Electric vehicle smart charging
vi) Renewable power to hydrogen
vii) Renewable power to heat
viii) Behind the meter batteries
ix) Large-scale utility batteries

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[159] M.N. Bhuiyan, M.M. Rahman, M.M. Billah D. Saha: Internet of Things (IoT): A Review of Its Enabling Technologies in Healthcare Applications, Standards Protocols, Security and Market Opportunities. *IEEE Internet of Things Journal,* 8, 2021, pp. 10474–10498, DOI:10.1109/JIOT.2021.3062630; A. Bloess, W.P. Schill, A. Zerrahn: Power-to-Heat for Renewable Energy Integration: A Review of Technologies, Modeling Approaches and Flexibility Potentials. *Applied Energy,* 212, 2018, pp. 1611–1626, DOI:10.1109/ACCESS.2017.12.073; Agora Energiewende: The Role of Power-to-Heat in Renewable Energy Integration. *Agora Energiewende: Smart Energy for Europe Platform (SEFEP),* Berlin (Germany) 2014.

2. **Business Models**
   i) Community Ownership Models
   ii) Aggregators
   iii) Peer-to-Peer Electricity
   iv) Pay-as-You-Go Model
3. **Market Models**
   i) Regional Markets
   ii) Time-of-Use Tariffs
   iii) Market Integration of Distributed Energy Resources
   iv) Net-Billing Systems
4. **System Operations**
   i) Role of Distribution System Operators
   ii) Cooperation between Transmission and Distribution System Operators
   iii) Advanced Forecasting of Renewable Power Generation
   iv) Virtual Power Lines
   v) Dynamic Line Rating

The dynamic landscape of peer-to-peer energy trading is a testament to the relentless innovation that drives the energy sector forward. As we examine the various ongoing developments in this realm, it becomes evident that the synergy created by these innovations is not only fostering progress but also shaping the future of energy distribution and consumption.

5.3. Behavioural Changes and Public Awareness of Smart Energy

Sustainability cannot be accomplished by government policies and regulations. Sustainability needs everyone's participation and adjustment in their lifestyles. Behavioural psychology and economics need to develop an approach leading to a decrease in energy consumption. Reducing energy consumption decreases energy bills as well as contributing to sustainability goals[160]. Behavioural changes can significantly reduce carbon dioxide emissions. Behavioural changes can be implemented much faster than changes in infrastructure. Changing the existing infrastructure is a much slower process and can take decades to implement. The immediate savings on energy bills can be

[160] C. Wilson, H. Dowlatabadi: Models of Decision-Making and Residential Energy Use, Annual Review of Environment and Resources, 32, 2007, pp.169–203.

a convincing factor to all of us. Government agencies need to cooperate with the commercial sector to create financial incentives towards promoting efficient heating, air conditioning, transportation, etc. Energy-efficient highly-insulated commercial and residential buildings contribute significantly towards reducing energy consumption. In the United States there is a plan for the next thirty years (2020–2050). The goal is to reduce energy consumption by 40% to 60% when compared with the present consumption[161].

The plan to reduce energy consumption by 2050 focuses on the following:

- using computers to monitor and control energy consumption,
- improving the energy efficiency of computers, televisions, freight and passenger lifts etc.,
- evolving residential and commercial buildings towards *passive self-sufficient buildings* in terms of energy demand,
- improving energy consumption in production processes,
- developing electric and hybrid self-driving motor vehicles,
- modernizing existing buildings in terms of significantly reducing energy consumption,
- increasing the efficiency of electrical networks,
- reducing losses of energy transmission and distribution through the implementation of "Heat and Power" systems (local energy generation systems),
- developing new energy-efficient housing and transport systems,
- raising public awareness of the need for economical energy management,
- introducing a tax policy rewarding energy saving.

The plan until 2050 is focused on the development of an economy based on energy saving and environmental protection for future generations[162]. There are also many state initiatives and programs to reduce energy consumption. Examples of such programs in the state of Pennsylvania are as follows:

- low-interest loans (1%) from $1000 to $10,000 (USD) for installation of economical heating and air conditioning systems,
- discounts on the purchase of high-energy refrigerators, water heaters, washing machines, dryers, kitchen stoves, etc.,

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[161] M. Transue, F.A.: Comparison of Energy Efficiency Incentive Programs: Rebates and White Certificates, Utility Policy, 18(2), 2010, pp. 103–111.

[162] E. Heiskanen, M. Johnson, S. Robinson, et. al.: Low-Carbon Communities as a Context for Individual Behaviour Change, Energy Policy, 38, 2010, pp. 7586–7595.

- tax rebates on the installation of PVW systems in single-family homes or commercial buildings. In 2020, the tax rebate amounts to 26% of the investment cost (Consumer Reports).
- tax rebates for the purchase of an electric or hybrid car with a battery capacity of at least 5 kWh,
- ability to purchase electricity from various suppliers. Charges for electricity and transmission of electricity are collected separately. The customer cannot choose the company that distributes energy but has the option of choosing a company that generates electricity.

Pennsylvania low-income residents ($24,980 gross per year for one person, $33,820 for a two-person family and $42,660 for a three-person family) can benefit from free thermal insulation programs to reduce energy consumption for the home in which they live.

Data needs to be collected as to how people respond to the incentives that are given to individuals or communities related to the reduction in energy consumption. It is important to publicize and promote success stories which demonstrate that the energy savings are within our reach, and they lead directly to lowering our energy bills. The public institutions and governments have to be in the forefront of every energy-savings initiative[163]. The government needs to apply behavioural science to find effective methods for overcoming the barriers to being more energy efficient. Government initiatives need to be as effective as possible in generating motivational behavioural changes. Some of the barriers to the improvement of energy efficiency are as follows:

- The benefits of energy savings and reducing the carbon footprint are only visible over a longer period of time.
- The cost assessment for implementing energy savings initiatives (appliances, health, air conditioning, etc.) is sometimes high.

People have a tendency to discount the future[164]. Often people prefer a small reward today rather than a larger one in the future. There is a need for government policies rewarding immediately energy saving initiatives. This can be accomplished by

[163] D. Pichert, K.V. Katskopoulos: Green Defaults: Information Presentation and Pro-Environmental Behaviour. Journal of Environmental Psychology, 28, 2008, pp. 63–73.
[164] D. Fell, A. Austin, E. Kivinen, C. Wilkins: The Diffusion of Environmental Behaviours: The Role of Influential Individuals in Social Networks. *The Evidence: A Report to the Department for Environment, Food and Rural Affairs (Report 2).* London: Brook Lyndhurst/Defra, 2009.

providing substantial tax incentives for energy saving initiatives. People weigh the cost and benefits of investing time and money into becoming more energy efficient. Behaviours of individuals in different regions can vary significantly. Social, cognitive and behavioural factors are playing a role in how people respond to energy saving initiatives.

Many people express their concern about environmental changes, but only a few of them incorporate energy-efficient measures in their households. Many energy-efficient measures have been proven to be highly cost effective[165]. Often people are influenced by social norms or by observing what other individuals in their neighbourhood are doing. The government initiatives need to provide rewards to communities as well as individuals for the purpose of influencing the norms of behaviours. The existing social network can be effective in this task.

Behavioural economics have proven that individuals have a tendency to accept and follow preset default actions even if those options are not in their best interest. Effective initiatives can be changing the preset default option into a more energy-saving mode. It is important to learn how people use the energy in their homes and what are the barriers preventing them from becoming more energy efficient. There are new initiatives that allow individuals to become more energy efficient without an initial high investment. There are also renewable heat initiatives encouraging people to install renewable heating systems with either no or a small initial investment. Effective methods of lowering energy consumption are providing detailed feedback on the home energy use. In addition to that, they can be provided with information comparing their energy use to similar households[166]. In the United States many energy companies effectively use the *comparative energy consumption method* to adjust and change social norms and personal behaviours. Similar methods are also used in the United Kingdom.

It has been proven that people respond better to immediate rewards rather than long-term paybacks. Government deferring the cost of installation makes the program more appealing to individuals. Especially at the beginning, there is a need for initial encouragement to overcome the natural inertia of the human mind. Psychological research indicates the importance of social influence. People have a tendency to adapt to opinions and behaviours of others[167]. This also applies to pro-environmental behaviours. Engaging all individuals as members of the community is more effective

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[165] S. Moloney, R.E. Horne J. Fine: Transitioning to Low Carbon Communities from Behaviour Change to Systemic Change: Lessons from Australia. Energy Policy*,* 38, 2010, pp. 7614–7623.

[166] A. Kollmuss, J. Agyeman: Mind the Gap: Why Do People Act Environmentally and What Are the Barriers to Pro-Environmental Behaviour?. *Environmental Education* R*esearch,* 8(3), 2002, pp. 239–260.

[167] R. Bond, P.B. Smith: Culture and Conformity: A Meta-Analysis of Studies Using Asch's (1952b, 1956) Line Judgment Task. *Psychological Bulletin,* 119(1), 1996, pp. 111–137.

than trying to engage every individual independently as customers of energy. Engaging the entire community and making the financial incentives larger when the whole community participates has been proven to get more people to participate. People will be involved in encouraging their neighbours to participate[168]. Collaboration between organizations like a local government and reputable contractors will increase the success rate. Another factor that decreases participation in energy saving initiatives is the large amount of paperwork as well as the inconvenience of preparing the house for the work to be done[169]. There is often clean-up to be done after the work is completed. Simplifying the paperwork and reducing inconvenience is likely to increase participation. Often some incentives to the entire community (playground, fire department, schools, businesses, etc.) may also be effective in increasing participation. Because a majority of individuals select "default solutions", the entire community should be included in energy saving initiatives[170]. An effective strategy to convince homeowners to participate in energy saving initiatives is to demonstrate the correlation between energy efficiency and the market value of their property. Energy efficient homes have a much higher market value. This factor can be appealing to homeowners[171]. Some countries offer significant incentives towards installing renewable heating sources. A majority of the heating systems still use fossil fuels.

Some countries have a requirement that all homes for sale or rent need to have an energy-efficiency certificate. The certificate provides the following:

- information on home energy use,
- recommendations related to converting the home to an energy-efficient home.

Very often prospective buyers or renters view an energy consumption report before buying or renting a property. The government agencies need to work with public and private institutions as well as utility companies to demonstrate that it is possible to reduce emissions rapidly and cost effectively[172]. There are a number of initiatives on college campuses geared toward saving energy and conserving water. Those initiatives are important from the perspective of developing and promoting behavioural changes that will last for the lifetime. One of those initiatives on a large scale was taking

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[168] N. Christakis, J.: *Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives.* New York: Little, Brown & Co, 2009.

[169] L. Steg, C. Vlek: Encouraging Pro-Environmental Behaviour: An Integrative Review and Research Agenda. *Journal of Environmental Psychology,* 29, 2009, pp. 309–317.

[170] S. Bamberg: Is Residential Relocation a Good Opportunity to Change People's Travel Behavior? Results from a Theory-Driven Intervention Study. *Environment and Behavior,* 38(6), 2006, pp. 820–840.

[171] L. Laine: Room for Improvement: The Impact of EPCs on Consumer Decision-Making. London: Consumer Focus, 2011.

[172] H. Allcott: Social Norms and Energy Conservation. *Journal of Public Economics,* 95(9–10), 2011, pp. 1082–1095. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0047272711000478?via%3Dihub#preview-section-introduction [date of access 17.08.2023].

place at Kansas State University. This was done as part of a research project. There were approximately three thousand six hundred students living on the campus for a period of nine months. As part of the project, students updated the existing appliances with *Energy Star* appliances. The power consumption decreased significantly[173]. The cost of operating *Energy Star* appliances was $70,000 compared to $131,000 for the previous year. The annual saving was $61,000. Students also participated in a water conservation project leading to an annual savings of $6,600. There was also an attempt to lower the cost of doing laundry by installing and using clotheslines instead of dryers. The annual saving was $4,300 with an investment of $1,000 to install ten clothes lines on the campus. Dormitory students were also exposed to real-time visual data and energy use. This resulted in an additional saving of $5,200. During this process, students were educated in the field of sustainability. Students were searching for the availability of environmentally friendly options as an alternative to the status quo. Students also enthusiastically adopted pro-environmental behaviours such as:

- use of public transit,
- green purchasing,
- recycling.

Education appears to be an important component leading to ecological behaviour. A study indicated that teaching young children about human interaction with the environment and sustainability is very important in developing ecological values and behaviours[174]. Pro-environmental behaviour needs to be encouraged by social acceptance as well as negative environmental behaviour needs to be rejected and reversed[175].

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[173] M.A. Vicente-Molina., A. Fernandez-Sainz, J. Izagirre-Olaizola: Environmental Knowledge and Other Variables Affecting Pro-Environmental Behavior: Comparison of University Students from Emerging and Advanced Countries. *Journal of Cleaner Production,* 61, 2013, pp. 130–138.

[174] M. Spearman, A. Eckhoff: Teaching Young Learners about Sustainability. Childhood Education, 88(6), 2012, p. 354.

[175] J.E. Givens, A.K. Jorgenson: Individual Environmental Concern in World Polity: A Multilevel Analysis. *Social Science Research,* 42(6), 2012, pp.418–431.

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35. Vicente-Molina M.A., Fernandez-Sainz A., Izagirre-Olaizola J.: Environmental Knowledge and Other Variables Affecting Pro-Environmental Behavior: Comparison of University Students from Emerging and Advanced Countries. *Journal of Cleaner Production,* 61, 2013, 130–138.

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Chapter 6

TECHNOLOGIES OF THE FOUTH INDUSTRIAL REVOLUTION IN SMART CITIES

6.1. Advanced technologies and innovations in Smart Energy Systems

Ghiasi et al. (2022)[176] states that the global demand for energy in 2018 has increased by 2.3% compared to 2017. In 2011, the European Council adopted a long-term energy and climate strategy called Roadmap 2050. One of the outputs of the strategy is a support of the smart grid, symbiosis of ICT and energy, and decentralized resources.

Every entity that produces electricity and wants to supply it to other consumers have to understand how electricity distribution works both from a technical point of view (connection to the distribution network) and from a legislative point of view as were mentioned in previous chapter. Many projects in the field of smart grid in cities cannot be implemented in isolation, without a solution for correct connection to the current grid.

When managing the Smart Energy Grid, the goal is to optimize energy supply and consumption – the price of the consumed energy as low as possible and at the same time the required quality (voltage, frequency and stability of supply) should be achieved.

There exist prediction models for decision making that try to estimate the need for electricity in the near future for a given location (in our case, a city) based on several parameters. The main parameters of such models are:

- Weather forecast
- Estimated consumption
- Losses
- Prediction the production of local resources (photovoltaics, wind)

[176] Ghiasi M., Wang Z., Mehrandezh M., Jalilian S., Ghadimi,N.: Evolution of smart grids towards the Internet of energy: Concept and essential components for deep decarbonisation. IET Smart Grids, vol. 6(1), 2022, doi.org/10.1049/stg2.12095.

A recent trend in smart energy ecosystem is a decentralized energy source – electricity is produced in smaller sources directly at the point of consumption. Decentralized approach can be realized as a microgrid. The microgrid can operate as “island” (independent system) or can be connected to the central grid. A popular choice is such solution is a hybrid system with solar and wind energy.

Rossi et al (2016)[177] deals with Smart Grid data analysis. There is presentation of a successful project in assisting the industry via conducting a large anomaly-detection study on the data of one of the power distribution companies in the Czech Republic. In the study, authors move away from the concept of single events identified as anomaly to the concept of collective anomaly, that is item sets of events that may be anomalous based on their patterns of appearance. This can assist the operators of the distribution system in the transformation of their grid to a smarter grid. As the main result, it was provided to stakeholders both a visual representation of the candidate anomalies and the identification of the top-10 anomalies for a subset of Smart Meters.

A significant trend in the field of Smart energy is also the development of new types of batteries. Currently, lithium (Li-Ion) batteries are dominant (60% of the world's lithium is processed in China), but lithium is needed for their production, which affects their price – from 2017 to November 2022, lithium prices quadrupled. One of the possible new solutions are sodium (Na-Ion) batteries. Although they have a lower energy density, they are expected to have a lower price and a longer lifespan. On the other hand – the disadvantage of sodium is safety – it burns spontaneously in air. The Chinese company Great Power is developing batteries with a capacity of up to 10 MWh (energy density 150 Wh/kg; energy density of Li-Ion battery is about 300 Wh/kg now). These batteries can also be used for effective network stabilization. According to available data, lithium batteries are sold at prices still exceeding USD 100/kWh. In addition, Chinese company CATL states that sodium battery prices may drop to $40 per kWh in the future. The intensive development of sodium batteries in China is also supported by the fact that China does not have large reserves of lithium.

According to Huawei, the following technological trends will shape the development of Smart energy and photovoltaics by 2025:

- Digitalisation
- Unattended operation and service
- Proactive support of distribution networks

[177] Rossi B., Chren S., Barbora Buhnova B., Pitner T.: Anomaly Detection in Smart Grid Data: An Experience Report. In The 2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC 2016). Budapest: IEEE, 2016, pp. 2313–2318.

- Virtual power plants
- Increasing energy density
- Modular design
- Safety and reliability
- Smart upgrades using artificial intelligence

Communication via the 5G (and future 6G) network is closely related to energy consumption, which has technologically higher energy efficiency, so that although it transmits a much larger volume of data, energy consumption is lower. The 5G base stations themselves make better use of energy. Their improved design does not need a cooling device, which reduces energy consumption.

6.2. Artificial Intelligence and Machine Learning in Smart Energy

The basic benefit of artificial intelligence in Smart Energy is the ability to evaluate large volumes of data and make decisions in real time (according Siemens "Smart Energy Infrastructure Guide"[178] data from one million smart meters generate over 2900 terabytes per year). Typically, already used in electricity trading, elements of artificial intelligence are also used in so-called smart networks, which are characterized by the fact that they adapt their operation to changing conditions. According to experts, the ability of Artificial Intelligence (AI) to "predict" on the basis of data – basically just use the large computing capacity and availability of data for detailed modeling – has the greatest potential to contribute to efficiency and the overall technological transformation of the energy industry. For example, the Frauenhofer Institute[179] is investigating whether AI could help stabilize the grid by monitoring production, consumption and transmission in real time and predicting possible anomalies, outages or, on the contrary, impending surpluses in time. In a similar way, artificial intelligence could also contribute to the planning of maintenance and repairs.

The renewable energy is a powerful resource, that fit the context of climate change and fossil fuel depletion. The energy from renewables respond to the global demand for cheap and clean energy. However, renewable energy is usually characterized by less stability (variability of the wind condition or solar irradiation), which places significant

[178] https://assets.new.siemens.com/siemens/assets/api/uuid:7e07495d-f680-4f38-99d1-6afaa2c3b9d9/Siemens-Smart-Energy-Infrastructure-Guide.pdf [date of access 17.08.2023].
[179] https://www.fraunhofer.de/en/research/fraunhofer-strategic-research-fields/artificial-intelligence.html.

demands on the management of renewable energy sources. Artificial Intelligence (AI) represents tool to effectively find optimal solution. The advantages of AI deployment include possibility of performing prediction and generalization in high speed. Serban and Lytras (2020)[180] describe the new ground for future generation of smart cities services – the integration of AI with 5G networks and sensors networks. AI systems are able to change their behaviour without explicit reprogramming, relying only on experience resulted from observation, collecting and analyse large datasets. The efficiency energy management depends critically on load and renewable energy forecast. Prediction, simulation and management decisions based on deep analyse of large data sets enable AI to identify recurring, cyclical models and patterns, to detect inconsistencies in processes stages, to forecast the trends both for energy production and for energy demand, to reduce or remove the imbalances in demand and supply caused by the variation in renewable energy, to prevent power outages by optimizing the demand and supply within the smart grids, to increase energy efficiency and help the power grid optimization in a cost effective way. For machine learning techniques in energy optimization computational neural networks are used and for relocating of smart grids evolutionary algorithms are used.

Chaouachi et al. (2013)[181] presents solution of artificial neural network developed to predict 24 hour ahead photovoltaic generation and 1 hour ahead wind power generation as tool for intelligent management of a microgrid. The efficiency of the microgrid operation strongly depends on the battery scheduling process, which cannot be achieved through conventional optimization formulation

The German energy company Next Kraftwerke[182] provides, among other services, smart virtual power plants. It is essentially nothing more than the connection of photovoltaics, a battery and an autonomous decision-making system that evaluates various factors and accordingly decides whether to purchase, store or produce electricity. Its goal can be overall financial savings, but also the provision of energy for a certain time of day, for example if the owner of the power plant plans to charge an electric car or do other activities with high energy consumption.

Artificial Intelligence based tools are often seen as black-box models and this penalizes their acceptability by end-users. The lack of interpretability of AI tools is

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[180] Serban A., Lytras M.: Artificial Intelligence for Smart Renewable Energy Sector in Europe – Smart Energy Infrastructures for Next Generation Smart Cities. IEEE Access, vol. 8(2020), 2020, pp. 77364–77377.

[181] Chaouachi A., Kamel R., Andoulsi R., Nagasaka K.: Multiobjective Intelligent Energy Management for a Microgrid. IEEE Transactions on Industrial Electronics 60(4), 2013, pp. 1688–1699, DOI:10.1109/TIE.2012.2188873.

[182] https://www.next-kraftwerke.com/ [date of access 17.08.2023].

a major challenge for the wider adoption of AI in the energy sector and a fundamental requirement to better support humans in the decision-aid process. As energy systems are impacted by multiple uncertainty sources (e.g. available power of Renewable Energy Sources plants, weather and meteorological conditions, market conditions), developed AI tools should not only be performant on average situations but be able to guarantee robust solutions in the case of an extreme event. Replacing the modeling chain of several models with a single AI-based model is addressed by the project Smart4RES (Grant No 864337 supported by H2020 Program) described in Parginos et al. (2023) [183].

Another example of AI and machine learning algorithm in energy is the worldwide software company N-iX [184] developing smart forecasting (to determine the energy output in particular geographical areas), predictive analysis for renewables, failure prevention (identifying potential problems before they happen) and resource management (suppliers can balance traditional and renewable energy proportions and tune the grid for optimal use).

The Czech company SOMI[185] entered the market with a unique photovoltaic power plant system, which is the only one in the world controlled by artificial intelligence. Thanks to a smart algorithm that learns the building's energy habits, significant savings can be made. An intelligent photovoltaic power plant does not only use energy obtained from the sun. It can also smartly buy and recharge batteries from the electricity grid at the moment when the price of energy is the lowest, and conversely sell excess energy back to the grid at the time when the price on the spot market is the highest. Thanks to this solution, it is highly effective even in the winter months or at night when the sun does not shine. In addition, based on information from weather stations, it can predict the illumination of panels in a given location and thus the efficiency of photovoltaics.

Schlieger company states AI accelerates ROI in solar photovoltaic by 30% [186]. The company wants to achieve 15-minute electricity trading, for which artificial intelligence will be necessary. Schlieger's consumption prediction systems learn from anonymized data from its customers.

[183] Parginos, K., Kariniotakis, G., Bessa, R., Camal, S.: Towards a paradigm of explainable AI applied in energy meteorology. EGU General Assembly 2023 conference, Vienna, Austria, 2023, pp. 24–28, https://doi.org/10.5194/egusphere-egu23-13992 [date of access 17.08.2023].
[184] https://www.n-ix.com/artificial-intelligence-in-energy/ [date of access 17.08.2023].
[185] https://somias.cz/en/chytre-rizeni/ [date of access 17.08.2023].
[186] https://www.seznamzpravy.cz/clanek/ekonomika-firmy-ted-nabijim-zitra-prodam-umela-inteligence-pomaha-vydelavat-na-solarech-233957 [date of access 17.08.2023].

6.3. Internet of Things and Sensor Networks for Energy Efficiency

The concept of the Internet of Things (IoT) emerged around 1999 and has since become one of the dominant trends in IT/ICT. IoT networks are made up of a lot of smart devices having networking capabilities, also known as endpoints. IoT leverages various technologies including connectivity, smart sensors, automation, data processing, machine learning etc., to provide smart solutions for a wide range of applications such as smart cities, smart homes, smart factories, connected cars and more.

IoT based energy management is focused on following areas:

- Which machines and systems consume the most energy?
- When and where is the power supply disturbed or interrupted?
- When do my machines and systems consume particularly much or little energy?
- What factors cause a machine to consume more energy than usual?
- Monitor consumption in real time
- Compare consumption of individual machines

IoT technology can be part of a Smart grid as Advanced Metering Infrastructure – bidirectional communication network between smart meters and control system to collect, send and analyse energy consumption data. This solution can be considered a successor to the industrial bus M-bus (https://m-bus.com/), a European standard which was developed for remote readings of electricity meters or heat meters (communication takes place as the Master-Slave, while up to 250 stations can be connected to one serial bus. The length of the segment can be up to 1000 m at a speed of 300 baud; rather than speed, this bus is optimized for immunity to interference).

Other technologies, suitable for IoT solutions in energy management, especially for remote readings, are based on LPWAN networks (Low – Power – Wide Area Network). Modern wireless IoT networks with wide coverage are expanding significantly – for example, Sigfox, LoRaWAN or NB-IoT networks. They are very efficient from the point of view of powering the connected devices – at a reading frequency of once a day, the power supply of the built-in battery lasts up to 10 years. Secure (encrypted) communication takes place between the device and the network of public broadcasters. In this way, the data is then transferred to a central application, which can simply be operated in the cloud, and there is no need to build or install anything on site.

When analysing the use of IoT for energy efficiency control, it is also necessary to mention the energy consumption within the IoT infrastructure. Shah (2022)[187] states that 30 % of the energy in IoT devices is wasted. The processing, transmission, and receiving of data to meet the application's requirements is the primary source of energy waste in wireless network. Energy management may be the first factor taken into account for any ecosystem when developing a fully integrated IOT strategy. Reducing the transmissions of data will eventually decrease the energy wastage of these smart devices. It is known from the studies about communication unit that a huge amount of energy is expended in certain ways that does not provide any valuable additions to the application (collision, redundant data, control packet overhead…).

The previously created and established IoT concept is followed by the *Internet of Energy* (IoE) that concerns energy generation, energy distribution, and energy usage. The IoE can help reduce waste, improve generation, transmission, and storage, and help us make the most of our power systems. The goal of IoE is to create monitoring networks of sensors with the help of already established IoT technology, over which a number of smart grid applications can run. These would then enable detailed monitoring of the current state of the network, management of electricity consumption, management of distributed storage or the integration of renewable resources into the electricity network. IoE is built on standard communication protocols and led to optimize energy use and minimize costs.

What can be addressed with IoE:

- Electricity consumption monitoring (down to the hourly level)
- Unauthorized consumption of electricity (illegal connection)
- Device failure
- Appliances not switched off
- Unauthorized use (for example cryptocurrency mining)
- Better load balancing for power grids

The Predix platform from GE Digital[188] can be considered one of the first solutions from the IoE category, which supports the entire process of data analysis from cloud data storage to "edge" solutions (i.e. computational algorithms run on raw data or machine data as close as possible to the place where it was collected). The Predix platform includes advanced features based on machine learning, such as predictive maintenance or network performance optimization.

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[187] Shah S., Jadeja A., Doshi N.: An Analytical Survey of Energy Efficiency in IoT Paradigm. Procedia Computer Science vol. 210(2022), 2022, pp. 283–288.

[188] https://www.ge.com/digital/iiot-platform [date of access 17.08.2023].

Another company that came up with an IoE solution is Siemens. In 2018, it introduced Sensformer – the world's first digital transformer. Power transformers are key elements in power grid infrastructure that regulate voltage and current between different power supply units. Sensformer contains sensors that continuously monitor the most important operating parameters, such as oil level, temperature, transformer voltage or current GPS coordinates. Communication takes place via GSM or Ethernet, so no secondary IT infrastructure is needed. Each such transformer also has its digital twin, which simulates the behaviour of its physical counterpart in real time. Thanks to this, it is possible to predict and quickly react to momentary overloads without shortening the lifetime of the transformer. In 2019, Siemens came up with the Sensgear smart switchboard. The built-in sensors of this device constantly monitor external parameters, such as the weather in a given location and GPS coordinates, as well as internal parameters, such as gas density, temperature or circuit shutdown. In 2021, Siemens equipped a family of smart switchboards and transformers with edge computing. Until now, most digital solutions for substation equipment only used cloud connections, but the use of edge computing offers the possibility of connecting devices directly in the substation.

Top IoE startups according Startus Insights website:

- 2GG Smart Meters (Slovenia) – develops SMaaS (Smart Metering as a Service). A secure communication hub (concentrator) transmits the metering data to a cloud server that stores and analyses it. The startup’s system features analytics software to identify usage patterns, prevent leakage, forecast demand, optimize supply, and manage production efficiency.
- Leap (USA) – a solution to allow connected devices to help balance the grid and access wholesale markets through a single application program interface (API)
- Bandora Systems (Portugal) – offers a real-time demand-side management solution
- Convert Science (Germany) – develops digital addressable lighting interface, streaming architecture of control networks (sACN), Art-Net, and other lighting control protocols
- RESYNC (Singapore) – intelligent energy cloud solutions for smart grids and buildings

It is imperative to address security in IoE projects. Standardization of smart grid technology systems is also necessary. It should be taken into account that the deployment of IoE requires a transition to smart appliances and higher initial costs may be associated with this.

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https://www.ge.com/digital/iiot-platform [date of access 17.08.2023].

Chapter 7

INTEGRATION SMART ENERGY SYSTEMS AND SECURITY

7.1. State of art at energy distribution

In previous chapter there are focus on several topics connected with Smart city technologies and projects, e.g. Energy Management System (EMS) in smart city. If we want to analyse trends and technologies in energy management in a smart city, it is necessary to realize a fundamental thing. None of the Smart grid solutions is and cannot be completely isolated from the current existing electricity distribution system. Therefore, it is necessary to have a basic knowledge of how the electrical distribution network currently works, and what parameters each solution must meet in order to be compatible with this network.

Nowadays we have the possibility to buy electricity from different producers and we can even specify from which source (if and in what quantity we use electricity produced from renewable sources).

In Europe, however, we do not physically receive electricity directly from the producer, but the electricity travels to the place of consumption via the distribution network (grid). Each state operates an organization or company that ensures the operation of the distribution system. Distribution systems are connected between individual states into a common distribution system. The scheme of the distribution systems operating in Europe is shown in Figure 8. The basic European system is called UCTE, covering Western, Southern, Central Europe and the Balkans. This system was created in 1999 (a transformation from the previous UCPTE system. In 1995, the CENTREL system joined UCPTE, which connected Poland, the Czech Republic, Slovakia and Hungary). The Scandinavian countries operate a separate system, and Great Britain and Ireland have their own system. The post-Soviet states are connected to the Russian distribution system. In some parts of Europe, there are still insufficient interconnections between national systems (e.g. Spain via the Pyrenees or Italy). Through submarine cables, UCTE has been asynchronously connected via

DC couplers to other synchronous zones: the British Isles and Scandinavia. Ukraine was provisionally connected to the European system in 2022 as a result of the war with Russia, which allowed the stabilization of performance in the Ukrainian network.

Phase Shift Transformers (PST) are used to regulate and limit cross-border flows. The PST transformer affects the angle between the input and output voltages, which allows the flow of active power to be decreased or increased.

Since 2009, operators of European national energy distribution systems (UCTE and Great Britain) have been united in an organization ENTSO-E (European Network of Transmission System Operators for Electricity).

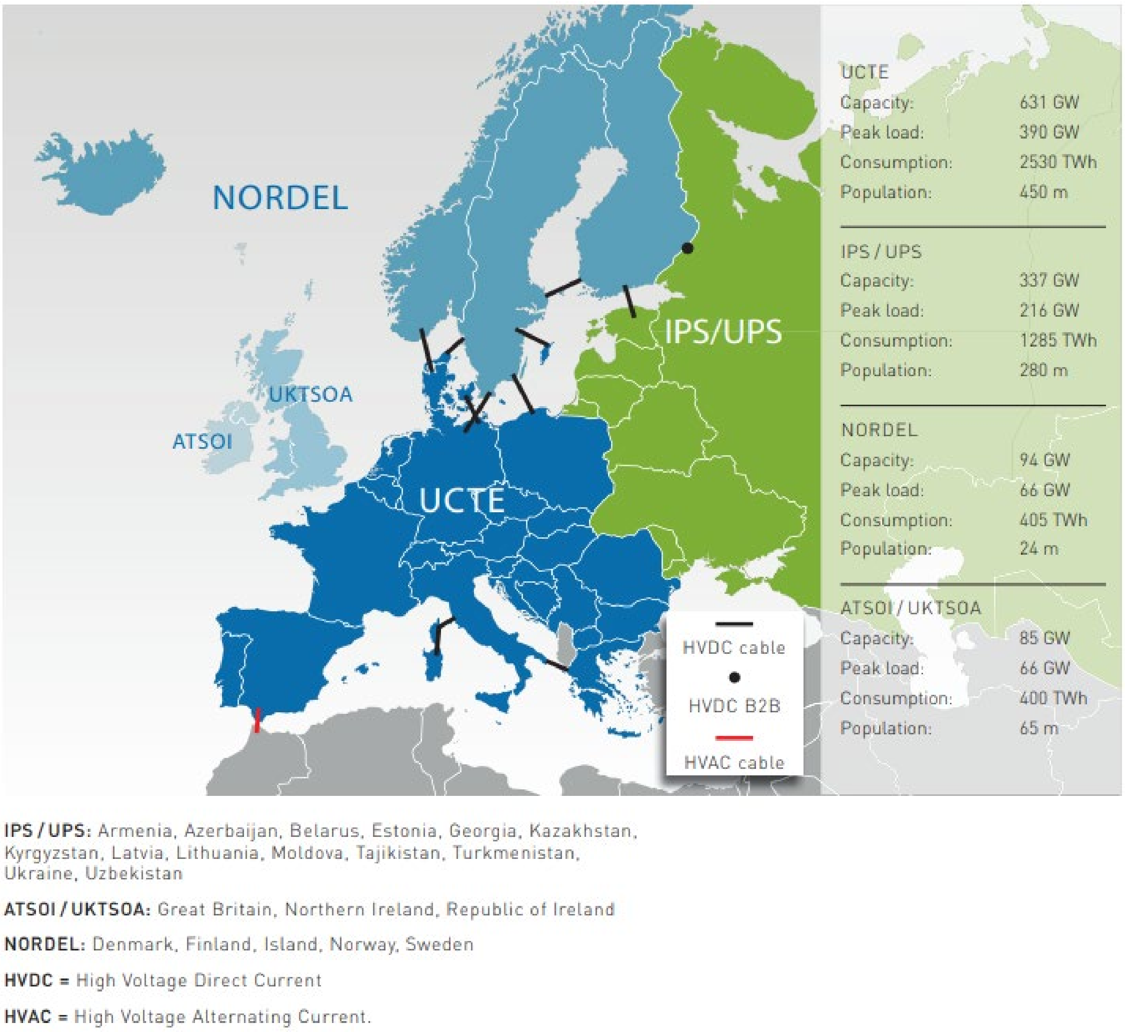

Fig. 8. Electricity distribution systems in Europe (established in 1999)
Source: The 50 Year Success Strory – Evolution of a European Interconnected Grid. Secretariat of UCTE. [online]. Available at https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/ce/110422_UCPTE-UCTE_The50yearSuccessStory.pdf [date of access 17.08.2023].

In April 2022, the European Parliament adopted a revised regulation on the Trans-European Energy Networks (TEN-E). The aim of the new rules is to modernize, decarbonise and connect the cross-border energy infrastructures of member states, helping the EU achieve its climate neutrality goals by 2050. The revised regulation also aims to continue to ensure market integration, competitiveness and security of supply. The main innovations are mandatory sustainability criteria for all projects, support for renewable energy sources, building a more connected and integrated energy infrastructure and faster deployment of smart grids.

EU Regulation 714/2009/EC requires the distribution network operator to be independent from the production and sale of electricity (independence from commodity market interest). In Central Europe, distribution network operators are listed in table 25.

Table 25

Operators of energy distribution grids in Central Europe

State	**Grid operator**	**Webpage**
Poland	PSE S.A.	https://www.pse.pl/web/pse-eng
Czech Republic	ČEPS a.s.	https://www.ceps.cz/en/homepage
Slovakia	SEPS	https://www.sepsas.sk/en/
Hungary	MVM	https://mvm.hu/en/Tevekenysegunk/AtvitelRendszerIranyitas

The main tasks provided by the transmission network operator at the state level:

- Stabilization of transmitted power (there is available as much electricity as is needed)
- Primary regulation to ensure the quality of electricity – stable frequency of 50 Hz alternating current
- Minimization of losses during the transmission of electricity over longer distances
- Power factor regulation
- Ensuring compliance with European Union legislation
- Ensuring the technical safety of the network (fault-tolerant solution, redundancy of routes…)
- Ensuring security
- Network regulation within dispatch control – for example immediate elimination of blackouts

Stabilization of transmitted power means ensuring synchronization between production and consumption. A source of electricity – a power plant – cannot produce electricity without a demand and consumption. So, the grid control consists in the application of a mathematical model that estimates future consumption according to a number of parameters and accordingly regulates the connection or disconnection of a single source from the network.

3000 MW resources are reserved for regulating the stable frequency of 50 Hz alternating current in the European distribution network. Failure of this source would cause the frequency to fluctuate to 49,8 Hz in 15 minutes [Source: interview in CEPS].

In terms of electrical power losses during transmission, the problem starts with alternating current at distances greater than 3000 km. Losses incurred during the transport of electrical energy depend on the impedance of the transmission line and on the square of the current:

$$P_z = z * I^2 \ [W]$$

Where:
Pz – power loss changing to heat [W]
z – transmission line impedance [Ω]
I – current [A]

Because of the losses very high voltage is used for transmissions on longer distances – mostly 400 kV or 220 kV in Europe, exceptionally 800 kV (Hungary or Ukraine). However, such high voltages are problematic due to the known range safety zone, for 400 kV distribution it is 20 meters, for 800 kV up to 60 meters.

The recent trend in dealing with power transmission over longer distances is the use of High Voltage Direct Current lines – HVDC. Especially China is establishing itself in this area. HVDC transmissions are also used in submarine lines. The advantages of energy transmission through direct current lines: there is no need to maintain the system in synchronous mode, smaller conductor cross-section (and therefore less weight and deflection), lower costs for insulation and masts, constant magnetic field around the conductors – less impact on living organisms, lower operating costs for large distance. On the other hand, HVDC also has its disadvantages – transformers cannot be used for supply regulation, complex and expensive semiconductor converters are needed for lines, voltage control is problematic[189].

[189] Grant J.: Review of HVDC technology, applications and future prospects. Science Direct, 2017.

EU requires maximum transparency and therefore the publication of data and documents related to the implementation of the network. This is contrary to the requirement to ensure system security.

The basic distribution network in Europe is under a voltage of 110 kV. In the transformer stations of the distribution system, the very high voltage of 110 kV is reduced to the high voltage level (35 kV or 20 kV). Topologically, these are mostly beam networks, where several high-voltage lines extend from the transformer station in all directions. In order to ensure the distribution of electricity even during non-standard conditions in the network, these main lines are still connected to each other, which ensures protection against blackouts. The last stage of the transformation of electrical energy consists of low-voltage distribution networks and is used directly to supply end-customers.

In the case of larger voltage deviations from the nominal value or a significant asymmetry of the voltage in the phases, the quality of the supplied electricity decreases. The reason of electricity decreases may be:

- voltage drop on long lines,
- the nature and range of connected devices
- the insufficient balance of single-phase consumption.

The quality of electricity is ensured at the dispatcher control level of the distribution network by regulating the mode of operation of the network.

7.2. Integration of Smart Energy with Other Smart City Components

An integral part of Smart city planning and modeling is the Smart energy management solution. There are two approaches of the smart city[190]: top-down (initiated by city institutions with a straight forward planning concept) and bottom-up (modelled by local inhabitants). Every smart city design has a different focus on what "Smart city" means and how to proceed with their specific development. Technological expansions of city infrastructure often do not simultaneously imply improvements neither regarding sustainability issues nor the reduction of energy demand or increase the quality of life. There may be the risk that a smart city development is interpreted one-sidedly from

[190] Maier S.: Smart energy systems for smart city districts: case study Reininghaus District. Energy, Sustainability and Society 6, (article number 23), 2016.

a technical-business perspective only and social and environmental requirements can be missed. The main goal of the Smart city should clearly be to increase the quality of life for its citizens through better public services and a cleaner environment.

One goal of European Union is to achieve a 40% reduction of greenhouse gas emission by 2030. Hence, the EU passed the Energy Performance of Buildings Directive 2010[191] and in the Energy Efficiency Directive 2012[192] stating that all public buildings by 2018 and all new buildings by 2020 must be nearly zero energy buildings. The laws state that smart initiatives must include more than just adding smart grid technologies or technical process automation to the existing infrastructure. The aim of Smart energy management is to increased efficiency, reduced costs, and achieve better sustainability.

The paper [193] emphasizes interdisciplinary approach for implementation of energy system as it consists of three layers – the physical (physical components and devices), the communication and the intelligence layer (management/control).

Smart energy can offer especially:

- Intelligent management of energy consumption, including energy management of urban buildings and supporting their energy-saving solutions;
- The use of renewable energy sources or the combined production of electricity and heat and their secure integration into the city's energy network;
- The use of Smart grid elements in the city's distribution system
- Intelligent management of urban services towards efficient use of energy and natural resources sources (for example, energy-saving and environmentally friendly public lighting).

The operator of a modern energy distribution system must monitor real-time operational data across the distribution network and calculate electricity service prices every few minutes at each local node in the network. Electronic distributed control systems, so-called intelligent software agents, will simultaneously solve customers' problems with managing their energy use and distributed energy sources, and at the same time they will also directly control customer devices in order to manage network operations as efficiently as possible and save customers money. Low prices can, for example, lead to the automatic charging of all available batteries in houses or cars or even to the temporary shutdown of local sources (solar panels or wind farms).

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[191] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=URISERV:en0021&from=EN&isLegissum=true [date of access 17.08.2023].

[192] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF [date of access 17.08.2023].

[193] Shah S., Jadeja A., Doshi N.: An Analytical Survey of Energy Efficiency in IoT Paradigm. Procedia Computer Science vol 210(2022), 2022, pp. 283–288.

According earth.org top smart cities in the world are Singapore, Helsinki, Zurich, Oslo and Amsterdam. These cities always involve the application of a whole range of projects, from smart transport to smart building management systems to green energy systems.

7.3. Security and safety in smart energy systems

According DataGuard website, the amount of data stolen in cyber-breaches reached over 260 terabytes in 2021 and cybercrime is forecasted to cost the world 8 trillion $ in 2023[194]. A very essential part of every Smart energy project must be a security and safety solution. Let us remind that the term "safety" means ensuring technical security, while "security" is mainly protection against unauthorized access and harmful effects of software or people attacks. The "smart" technology stack has several layers: hardware, software, communications and the cloud. The most common device in smart grid is a smart meter. The smart meter has to be always online. As a threat to the smart meter, we can mention the possibility of interception and using as access point. IoT sensors without encrypting and secure network can suffer from cross-device tracking also. The weak point of the technological solution can be the security of wireless networks and RFID (Radio Frequency Identification) devices. Smart solutions are very often built on the use of cloud services, which generates the following risks:

- Unauthorized access (brute force attack or dictionary attack)
- Insecure API (Application Programming Interface) for communicating with the cloud
- Availability (internet outage)
- Account hijacking (phishing)
- Eavesdropping of communications and data analysis

The administrator of Smart energy management should pay attention and ensure the following:

- Use core security services (preventing against physical attacks – not only by hacker themselves but also drones)
- Use cryptography (include secure boot, firmware updates and hashing techniques against spoofing)

[194] https://www.dataguard.co.uk/ [date of access 17.08.2023].

- Secure communication (add encryption protocols)
- Restrict sensors access
- Restrict data access
- Don't forget to secure gateway devices
- Access control and authentication
- Machine-to-machine (M2M) authentication at hardware level

The paper (Bekara, 2014)[195] investigates the security issues and challenges on the IoT-based Smart grid, and define the major security services that we should consider when dealing with Smart grid security. Smart grid highly integrates ICT on whole energy chain from producers to end-consumers and all devices share the capacities of computing and communication.

We must also not forget to ensure physical security, especially for equipment in an outdoor environment.

Since the energy industry falls under the so-called critical infrastructure, the minimum requirements for safety are defined legislatively by individual states. ISO 27000 certification is often required for organizations and companies that are connected to government infrastructure. A problem for meeting this requirement can be the fact that the participating state institutions themselves do not have this certification. In the Czech Republic, the definition of legislative requirements for cyber security falls under the authority of NUKIB (National Cyber and Information Security Agency; https://www.nukib.cz/en/). The Act No 181/2014 Coll. "On Cyber Security" is essential for the safety of critical infrastructure (https://www.nukib.cz/en/cyber-security/regulation-and-audit/legislation/).

In USA and Canada, after the great blackout in 1965, he North American Electric Reliability Corporation (NERC) was formed to coordinate efforts to avoid another crisis of that magnitude. NERC has developed a set of Critical Infrastructure Protection (CIP) standards many which are mandatory now. The NERC CIP is a helpful framework, but like most standards intended to apply to a broad industry, they typically lack specificity but still takes time and money to ensure compliance.

At the end of 2022, the EU has adopted important regulations to protect network and information security in "critical sectors" with the "NIS2" (Network Information Security) directive[196] which replaces the earlier NIS1 directive. The directive is based

[195] Bekara Ch.: Security Issues and Challenges for the IoT-based Smart Grid. Procedia Computer Science, vol. 34 (2014), 2014, pp. 532–537.
[196] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022L2555 [date of access 17.08.2023].

on the standard ISO 27000 that covers about 70% of NIS2 requirements. For every company at EU countries, the implementation of this directive is mandatory from October 18, 2024.

For improving cybersecurity, artificial intelligence can be used also. AI can monitor and detect security incidents or vulnerabilities. It should be taken into account that the target of a cyber-attack can be the AI itself (e.g. data poisoning for learning). There is a standard under development – ISO/IEC DTR 5469 – that defines Functional safety and AI systems (Schmittner and Shaaban, 2023)[197].

Leading-edge security technologies that have just emerged in the market are ATM systems (Automated Threat Mitigation). The operational analytics to detect anomalies uses artificial intelligence technology. The system can pore through reams of data and make nearly real-time decisions based on a security threat.

Human factor will always be a determining factor in the efficacy of security efforts. Education is also required among the nontechnical community so that users can routinely recognize threats such as phishing schemes and social engineering exploits.

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CONCLUSION

The presented book “Smart Energy System in the Smart City: Key Components” has unraveled the transformative power of intelligent energy management. From its inception, the concept of smart cities has captured the imagination of urban planners, policymakers, and technologists worldwide, seeking innovative solutions to address the challenges of urbanization and environmental sustainability. Through a comprehensive exploration of key components, this book has shed light on the critical role played by smart energy systems in shaping the cities of tomorrow.

Throughout the chapters, we have witnessed the convergence of cutting-edge technologies, data-driven insights, and citizen engagement, all working in tandem to optimize energy consumption, harness renewable resources, and improve overall energy efficiency. The integration of renewable energy sources, such as solar, wind, hydro, and geothermal, has emerged as a pivotal aspect, allowing cities to reduce their carbon footprint and move towards a cleaner energy future.

Furthermore, the book has highlighted the significance of demand response mechanisms, empowering citizens and businesses to actively participate in energy conservation. By leveraging data analytics and real-time communication, demand response not only optimizes energy usage but also fosters a culture of energy consciousness among urban dwellers.

As we explored the future energy trends and emerging technologies, it became evident that smart cities are at the forefront of innovation, constantly evolving to embrace the latest advancements in energy management. From electric mobility solutions to energy-sharing platforms and beyond, these forward-looking cities are driving the transition towards a more sustainable and interconnected energy ecosystem.

Ultimately, the success of smart energy systems in smart cities hinges on collaboration and the collective efforts of governments, businesses, communities, and individuals. By fostering partnerships and prioritizing sustainability, we can build cities that not only provide a high quality of life for their residents but also serve as models of environmental stewardship for the world.

The exploration of concepts presented in the book opens up many of possibilities for future research in the realm of smart cities and energy management. Future research could delve deeper into the application of artificial intelligence and machine learning algorithms in smart energy systems. Investigating how AI-driven predictive models can optimize energy distribution, consumption patterns, and demand response strategies would contribute to more efficient and adaptive energy grids. Also possible future research could concentrate on enhancing the integration of smart technologies within buildings to optimize energy usage. Investigating the effectiveness of smart sensors, automated controls, and building energy management systems would be crucial in maximizing energy efficiency and reducing carbon emissions in urban infrastructures.

Presented book serves as a comprehensive guide to understanding the multifaceted nature of smart energy systems and their indispensable role in building the smart cities of the future. Armed with the knowledge gained from this exploration, we are equipped to forge a path towards a greener, more sustainable, and technologically advanced urban landscape. As we embark on this journey, let us remember that our actions today will shape the world we pass on to future generations, and it is through the implementation of smart energy systems that we can lay the foundation for a brighter and more prosperous tomorrow.

WYDAWNICTWO POLITECHNIKI ŚLĄSKIEJ
ul. Akademicka 5, 44-100 Gliwice
tel. (32) 237-13-81
wydawnictwo@polsl.pl
www.wydawnictwopolitechniki.pl

UIW 48600

Sprzedaż i Marketing
tel. (32) 237-18-48
wydawnictwo_mark@polsl.pl

Ark. wyd. 13

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The book was written by international team of scientists: PhD. (hab.) Eng. Bożena Gajdzik, Professor at the Silesian University of Technology, Poland; full Professor, Ph.D. Radosław Wolniak, Silesian University of Technology, Poland, Wiesław Grebski – Emeritus Professor of Pennsylvania State University, USA; PhD., Michaline Grebski – Colorado Mesa University, PhD. Eng. Roman Danel – Institute of Technology and Business, Budějovice, Czech Republic. In this book, we will unravel the key components that underpin the successful implementation of Smart Energy Systems in the smart city context. From advanced renewable energy sources and smart grids to intelligent energy storage solutions and demand response mechanisms, each component plays a critical role in shaping the future of urban energy management. With technological advances and the strongly promoted concept of Industry 4.0, Smart Cities are developing. Digital and smart technologies are strongly entering cities. For the past few years, the term 'Smart City' has become increasingly fashionable. Smart City is becoming a word that is very capacious. The book is about cities with energy systems supported by new technologies of Industry 4.0. Such energy systems were called smart energy systems.

Keywords:

- smart city
- energy system
- energy management
- advanced technologies
- Fourth Industrial Revolution

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Wydawnictwo Politechniki Śląskiej
44-100 Gliwice, ul. Akademicka 5
tel. (32) 237-13-81
www.wydawnictwopolitechniki.pl
Dział Sprzedaży i Reklamy
tel. (32) 237-18-48
e-mail: wydawnictwo_mark@polsl.pl
http://www.polsl.pl/Jednostki/RJO2-WPS