Innovative Sustainable Energy Solutions in Smart Cities

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1 ABSTRACT

Rapid urbanization poses multiple environmental and social risks. More than half of the world's population lives in cities today, and cities account for two-thirds of global energy demand and around seventy percent of global CO2 emissions. Energy management in urban agglomerations becomes a strategic factor in the process of decarbonization of global economy. Digitization offers some revolutionary solutions for sustainable energy transition and enhancing energy efficiency. The most important concepts are Smart City, Smart Grid and Smart House. The general objective of the present research is to verify if new technologies, promoted by digitization, could remedy the negative impact of urbanization on the environment and to estimate how significant their contribution could be.

Keywords: smart city, smart grid, digitization, energy efficiency, smart house, sustainable energy transition

2 CHALLENGES AND OPPORTUNITIES OF URBANIZATION

2.1 Demographic and economic trends

The process of urbanization has significantly accelerated in recent years. Over a period of just 118 years the speed of urbanization has quadrupled.The last jump, from 13 percent of urban population in 1900 to 55 percent in 2018, owes something to science and technology. The world's population has been experiencing rapid urbanization since 1950. By 2050, 101 countries should have more than 80percent of the urban population, which is opposite to the overall distribution of rural-urban populations in the mid-20th century (UN DESA, 2018).

Apart from a high speed, the process of urbanization has obtained some new features not to be underestimated. First of all, when it comes to the phenomenon of urbanization, it no longer refers to megacities with more than 10 million inhabitants. Inspite of being financial and cultural centers, megacities do not more represent the majority of the urban population and are not the fastest growing urban centers. Small and medium - sized cities currently account for about 58 percent of the world's urban population and are growing at faster rates (UN DESA 2018). In such a context it becomes appropriate to talk about crucial role of urban agglomerations in sustainable development of rural neighbourhoods, especially in the countries where the percentage of rural population remains high. The second significant feature of modern urbanization is that it is not more closely linked to the industrialization process and economic growth and sometimes is rather associated with unbearable and health-damaging living conditions. The reason for this is that most of rapidly urbanizing countries belong to the middle-high income countries, like Brasil, China, Iran or Mexico, or even low-income countries, like Nigeria or The Democratic Republic of Congo. More than 90 percent of future urban population growth is expected to be in low- and middle-income countries (UN-Habitat, 2016). Many of the small and medium-sized cities do not have the technical capacity to conduct such an important urban development process and suffer from unintended difficulties (e.g.: climate change) without being able to take preventive measures, thus impeding their planning capacity. As a result, the ability of urban governments to protect both natural resources and the rights of their citizens is severely limited. Such areas carry significant risks, but they also represent the greatest opportunities for future greenhouse gas emission reductions, because their form and urban infrastructure have not been already established.

2.2 Environmental issues and international urban cooperation

Elaboration of a new urban model to implement in rapidly growing cities all over the world becomes a crucial factor in a fight against climate change. The scale of contemporary urbanization is now so large that it affects global resource flows and global cycles. Urbanization affects the entire planet, not just urban areas. Through networks of exchanges, migration and infrastructure, cities are influencing the natural environment far beyond their surface. The damage caused by uncontrolled urbanisation increases proportionally in the context of media- and low-income countries, where environmental standarts are insufficient. Rapid urbanization is leading to sustainability problems linked to segregation and rising social tensions, congestion, air pollution, waste, and the high consumption of energy and materials, often inefficient. According to the most recent report on the use of renewable energy in the city, produced in 2019 by the International Association for the Development and Promotion of the Use of Renewable Sources, cities account for 65 percent of total global energy demand and 75 percent of global CO2 emissions (REN21, 2019). Such a significant carboon footprint of the cities is caused by a strong dependence of urban economies on energy sector, which over the past 10 years has remained the largest contributor to emissions over any other sector (IPCC 2014). In the nearest future global energy consumption is destined to grow. Most of this growth is expected to come from non - OECD countries, and especially from the countries where energy demand is driven by strong economic growth, in particular in Asia. Emerging economies' cities with a population growth of more than 2 percent per year, for example, are expected to account for 70 percent of global growth in energy consumption by 2030 (IRENA 2019). At this point, implementation of innovative sustainable energy tecnologies in urban areas could become a key to decarbonising the global economy.

Such a point of view is commonly shared by the international cooperation bodies. Thus, even in one of the first declarations of the UN on sustainable development "The Future We Want" (A/RES/66/288) in the point 128 the need for energy efficiency measures in urban planning was highlighted (UN Rio +20, 2012). Eventually a significant role in the urban energy transition was occupied by the innovative technologies. Thus, in the New Urban Agenda, signed during the United Nations Conference on Housing and Sustainable Urban Development - Habitat III in 2016, smart grids, district energy systems and community energy plans are seen as the key tecnologies to successful adoption of sustainable renewable energy in end-use sectors[1] and for improvement of synergies between renewable energy and energy efficiency (UN-Habitat, 2016). On the non-governmental level two key international organizations dedicated to sustainable urban development are to be mentioned: C40 and Global Covenant of Mayors. The C40 is a network of megacities around the world, committed to tackling climate change. C40 enables cities to collaborate effectively, share knowledge and promote meaningful, measurable and sustainable actions on climate change. According to the 2017 annual C40 report, cities have the potential to contribute to more than 40 percent of the emission reductions needed to fulfill the Paris deal's highest ambitions and avoid climate change (C40, 2017). The C40 Cities Finance Facility provides intensive technical assistance to project preparation for C40 cities in developing countries. The promotion of the use of renewable energies is considered as one of the priority activities of C40. In 2017, the Clean Energy Network was established by the C40 to support the efforts of member cities to plan and implement initiatives in order to increase the supply of low-carbon energy. Member cities have shown an interest in starting to use a wide range of renewable energy sources on and off site to provide energy for residential, commercial and municipal buildings. Another important C40 project is the "C40 Cities Bloomberg Philanthropies Awards". The awards are granted annually in five categories, including Cities4Energy, dedicated to the application of energy efficiency technologies and the use of renewable energy in the cities of the United States and the world (City4Energy US and City4Energy Global) . The awards provide global recognition for cities that are demonstrating the leadership in the fight against climate change by implementing high tecnologies.

The Global Covenant of Mayors for Climate and Energy (GCoM) is the largest global coalition of cities and local governments committed voluntarily to actively combating climate change and moving towards a low-carbon, climate-resilient economy. Established in 2016, it is aimed to adress three key issues: climate change mitigation, adaptation to the adverse effects of climate change and universal access to safe, clean and affordable energy. The three GCoM initiatives address the vital need for research, innovation, technical assistance and intelligence in urban areas to push the signatory cities to contribute to a global climate solution. These initiatives, Innovate4Cities, Data4Cities, and Invest4Cities, focus on developing the next generation of knowledge, data, tools, and technical support, through which local politicians can address the challenges of sustainability (GCoM, 2018).

3 ENERGY MANAGEMENT IN SMART CITIES

3.1 The concept of Smart City

Even if having a noticeable carbon footprint, cities, at the same time, are the centres of technological innovation and scientific research. Strengthening links between cities and education institutions have led to rapid technological progress in urban areas. So the phenomenon of digitization has arisen, characterized by

[1] Residential, commercial and industrial buildings, industry, transport, waste and sanitation

some scientists as the fourth industrial revolution because of the amount of changes that it's bringing. One of the most significant ones is those of Smart Cities. Being launched as an experimental project realised by IT industry giants Cisco and IBM, it became, in 2020, a rather social phenomenon, shared in real time by users of different digital services. Many cities claim to be smart. The phenomenon of smart cities was formed by several technical concepts. Among them are: Information and Communication Technologies (ICT), Smart Grid technologies, the Internet of Things (IoT), and the technologies that are encouraged to increase energy efficiency in buildings, combined under the category of Smart House. The main feature which distinguishes a smart city from a traditional model of urban agglomeration is a presence of an additional digital layer over the urban infrastructure. This digital layer provides an interconnectivity and a big range of new services, delivered through multiple apps.

The first generation of Smart Cities is represented by the cities built from zero by the giants of the Industry 4.0, such as IBM and Cisco. Smart Cities have been projected as technological and efficient cities, designed to attract innovators and become the centres of technological progress. Technology solutions for the first-generation smart cities were imposed by IT multinationals Cisco and IBM and were designed mostly as commercial products. The general concept of Smart Cities is hiding behind the two first large-scale smart city projects: Maasdar City (UAE) and in Songdo (South Korea). The main difference which Both first-generation smart cities were developed near international airports and modern megacities with a common incentive not only to promote an innovative urban infrastructure model, but also to attract the "smart" citizens from different countries around the world. The second objective, despite significant investments, has not been achieved. The possible reasons are in the exclusion of the social factor from urban development strategies and in high costs of living. Despite these social disadvantages, the first generation of smart cities models have demonstrated the successful implementation of innovative solutions in the framework of a sustainable energy in urban areas.

A rapid spread of smart cities has provoked a huge debate in the academic world. While in the early 21st century the concept was precepted as "the rationalization of the city through technologies" (Graham, Marvin, 2001), over the years the concept became increasingly focused on improving the quality of daily life of the citizens, exploiting the benefits of ICTs and the capabilities of sensors built into urban infrastructure to optimize the management of electricity, transport, and other logistical operations (Chen 2001, Pardo 2011). In the coming years, science begins to talk about human capital as a significant factor in smart cities (Caragliu 2012), making the concept increasingly focused on well-being of the citizens (March 2016, McKinsey Institute 2018) and the environmental aspect of smart cities (Zygiaris 2013). Such an overview corresponds to the second generation of smart cities.

Unlikely to the first-generation, the implementation of projects in the smart cities 2.0 is conducted by local authorities, with a steady increase in the participation of citizens, who represent the main target group for the implementation of services. Adoptation of innovative technologies in the context of already existing infrastructures is a key characteristic of a new generation of smart cities. So very often it appears in practice in the framework of urban requalification programmes and individual Smart Home buildings. main factor making smart cities a key solution for global sustainable development is the implementation of innovative solutions for sustainable energy, among which Smart Grid and Smart Building are the most important.

3.2 Smart Grid and renewable energy manageent

Traditionally, the energy was centrally produced by large power plants, and was then transmitted to cities and then distributed to different consumers, such as: households, companies or service providers. This corresponds to a linear progression from centralized production to decentralized distribution. The main problem with these systems is their inflexibility and rigidity, which create difficulties in accommodating the highest levels of energy produced from multiple sources. Traditional centralized systems of electricity distribution do not allow the small quantities of energy to be counted. Such respectively small quantities often are lost due to unefficiency of the system of electricity ditribution. However, this landscape is changing rapidly at all stages of its supply chain: the production process is shifting from centralized to decentralized generation. Smart grid offers an effective solution for a decentralized energy distribution in urban areas by implementation of ICT and IoT tecnologies. In contrast to centralized systems, Smart Grid tecnology allows a complete inclusion of all electricity producers, independently from the amount of energy produced. All the quantities of energy distributed within a Smart Grid together form a unique network where

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all producers interact with each other. Communication between the producer and the consumer of energy becomes bilateral. Thanks to the Smart Grid technology, the energy generated in individual households can also be restored to the network. In such a framework consumer transformes into a so-called “prosumer” of electricity.[2]

A Smart Grid technology opens up great prospects for the introduction of renewable energy sources in the modern urban energy infrastructures, reducing costs for consumers and making renewable sources for energy production more competitive (Mommoh, 2012). This technology adresses both two main obstacles for a widespread of renewable energy transition. First of all, since renewable energy is nature-based, it results impossible to maintain a constant electrical voltage all the time, as it occurs in case of traditional power plants. The amount of energy produced depends on weather and climate conditions. Due to this factor it becomes impossible to maintain a constant voltage in the electrical network, which is a necessary condition for the correct operation of most electrical appliances. Smart Grid, being a flexible system, offers an effective solution to this problem, providing the use of energy from different sources at the same time in order to maintain a constant electrical voltage. The second obstacle for renewable energy widespread comes from the first one. Such inconsistency in power generation causes the need for powerful batteries, which costs often exceed the cost of the power plant itself. A high cost of storage batteries often hinders the acquisition of solar panels by individual households. Energy storage plays an important role in the process of energy production from renewable sources. It is important both for load leveling and uninterrupted power supply. Powerful storage options are particularly important when variable sources are used in isolated and autonomous power supply systems. An extremely high cost of powerful batteries is one of the main obstacles to massive distribution of renewable energy power plants. Smart grid tecnology enables its’ users to emit in the grid the unconsumed amount of electricity and to get it back from the grid with significant price benefits in case of need. Such a function of smart grid removes the necessity for a pricey powerful battery. The most practical example of this configuration is represented by the wind energy production.

Wind energy is one of the most widespread renewable sources. Turbines produce electricity at affordable cost without additional infrastructure investments. Compared to photovoltaic, wind is the most economically competitive renewable source. The greatest disadvantage of wind energy is instability in the amount of energy produced. This requires the use of powerful extremely expensive batteries to accumulate all the energy produced and maintain the same level of distribution over time. Smart Grid, by providing the efficient distribution of electricity from all renewable energy sources, can compensate for the instability of wind farms. As wind energy itself has a very low cost of production, the prices for consumers in such case will are falling significantly. Implementation of smart grid tecnology for micro-hydropower energy production demonstrates the same extremely positive effect. Hydroelectric power is the world's largest and one of the most affordable renewable energy sources. The maintenance costs are low and allow micro-hydropower plants to be installed in individual households. Small hydroelectric generators work at variable speed due to changes in water flows. In the event of a decrease in the amount of energy produced by turbines, the Smart Grid makes it possible to remedy the amount of energy missing, using energy from other sources. Another example where the Smart Grid is bringing about significant change is Photovoltaic. Within urban areas, the installation of solar panels on the roofs of the buildings is becomming a common practice. Under urban conditions, it is difficult to install a large photovoltaic plant because of the lack of space. So these are quite small amounts of energy produced on single solar panel. The smart grid tecnology, which offers high possibilities for the distribution of electricity within cities, makes it possible to achieve a maximum profit from each panel, bringing all producers together in a common grid. This allows, for example, individual homes to restore the energy produced by their solar panels to the grid, thereby generating costs. For biomass energy, Smart Grid offers opportunities to enter the urban energy market. The potential of individual biomass power plants is not sufficient to make them economically competitive to participate in electricity distribution in urban areas. The Smart Grid allows a full inclusion of biogas energy in the energy circuit in urban areas, rendering it competitive and convenient. Smart Grid technology opens up unprecedented possibilities for consumers to directly control and manage their own individual consumption patterns, in turn of providing strong incentives for efficient energy use when combined with time-dependent electricity prices. According to the European Commission, Smart Grids will push the development of the future decarbonized electricity system (EC, 2011). The first large-scale smart grid project in the world was launced by Italian multinational

[2] With the possibility to emit electric energy in the grid consumers can at the same time be also producers of energy

energy company Enel Spa. one of the first in the world has introduced a smart grid tecnology to its' clients in 2005 (Torriti, 2020). Since then, numerous italian households have installed solar panels on the rooftops being attracted by a flexible system of energy acquisition and emission back in grid,which permits quickly pay back the cost of the panels. However, the best profit from the smart grid implementation can be obtained only if applied together with the adaptation of the energy efficiency measures.

3.3 Energy efficiency and Smart Home

The decarbonization of energy infrastructure takes place in two important ways: decentralized energy distribution and energy efficiency technologies. The increase in demand for electricity and the need to introduce the quantity of energy produced from renewable sources into urban infrastructures makes energy efficiency technologies increasingly important. In the context of urban areas, this is primarily about heating and cooling systems. According to data produced by the European Commission, heating and cooling systems together account for 50 percent of EU energy demand and a large part of it is wasted. Although the heating and cooling sector is shifting to low-carbon, clean energy, more then 50 percents of the fuel used is still coming from fossil fuels (World Energy Council, 2019). Optimization of heating and cooling systems in buildings could contribute to a significant reduction in energy demand and the transition to sustainable energy infrastructure.

The concept of "Smart Building" is very close to the concept of smart cities. The Organization for Economic Cooperation and Development defines the Smart Building as a building based on a set of technologies that improve the energy efficiency of the building and increase the level of user comfort (OECD, 2010). Smart Buildings are closely linked to smart grids. This technology includes new and energy efficient building materials and information and communication technologies. Innovative solutions in building construction may include the designation of various thermal insulation technologies. One of the most common solutions of today are different external panels of thermal insulation, which can be placed above existing buildings, making buildings more energy-efficient at a low price. One of multiple examples of "New Generation" of energy-efficient building materials is a glass pane that is able to estimate and manage the amount of daylight that can enter the room. The building that owns these technologies already exists: it is The New York Times Building, designed by Renzo Piano, a famous Italian architect. The building has a continuous facade that acts as a sunscreen and changes colour during the day. The building is equipped with additional ICT-based shadow control systems. The shading system detects the position of the sun and relies on a network of sensors to automatically actuate the tent lift and down. The cheapest version of this technology is the high-reflectance and durable outside coatings applicable to roofs and walls of buildings. These coatings reflect solar radiation in both the visible and the infrared parts of the spectrum. Applied on roofs and walls, reflection of solar energy reduces the temperature of the roof and walls and therefore also reduces the heating of spaces under the roof and inside walls. Coatings of this kind, applied in the warmest climate regions, can save up to 15 percent of the energy consumption of air conditioning. The costs of this technology are affordable.

While innovative materials make it possible to optimize the heating and cooling systems of buildings from the outside, information and communication technologies (ICTs and IoT) optimize energy consumption inside the buildings. ICTs can be integrated into building management systems that control heating, lighting, ventilation and water circulation. Observation of the internal environment is carried out by the numerous installed sensors. The results of development and adoption of innovative technologies that contribute to further improvements in the energy efficiency of buildings in Europe and USA can be seen even now: between 2020-2040 the total energy demand in residential sector in these regions is expected to decrease without making any damage to the economy (World Energy Council, 2019), unlike in the rest of the world, where rapidly growing energy demand could put under threat natural balance of the planet.

4 CONCLUSION

Global urbanization poses multiple challenges for global leaders and local authorities all over the world. Among them rapid growth of urban populations in the abcence of necessary economic growth and environmental impact of the cities. Urban agglomerations are responsible for the majority of CO2 emissions into the atmosphere. The growth of the urban population leads to an increase in demand for electricity, while the energy production sector is responsible for the major part of emissions. Emissions from cities are very

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often the result of inefficient urban infrastructures and insufficient interaction between different sectors of an urban systems. With the prevalence in the global proportion of cities with a population of less than 500 000 people, one can speak of a constant transformation of the rural population into the urban one. It is important to emphasize that emerging countries, in recent years, are facing rapid and often uncontrolled urbanization, and governments in these countries very often lack the instruments and fundings needed to implement effective urban infrastructure management. At the same time high-income countries have already succeed in reducing emissions through implmentation of new tecnologies, such as smart grid or smart house. According to the latest data provided by the International Energy Agency, an effective implementation of energy efficiency tecnologies together with the expanding role of renewable sources resulted in a sharp decline in CO2 emissions from the power sector in advanced economies. At the first time since 2016 global energy-related CO2 emissions have flattened in 2019 at around 33 gigatonnes (Gt), following two years of increases. (IEA 2020). Such a successful model should be introduced and possibly implemented in rapidly urbanizing countries in order to prevent a distructive environmental impact of an uncontrolled urbanization in asian and african countries. This transition of a highly-effective model of urban infrastructures from high-income countries to media- and low- income ones should be realized on the basis of multiple global knowledge-exchange platforms, dedicated to sustainable urban development, such as UN-Habitat, C40 and Global Covenant of Mayors. Innovative solutions for urban energy infrastructures provided by digitization contribute to acceleration of sustainable energy transition, significantly reducing costs of power generation from renewable sources in the cases of all types of sustainable energy sources. Application of the Smart City and Smart Grid concepts in cities could help to reduce the negative impact of urbanization on the environment. Technological development should lead to a decrease in the cost of technologies, significantly accelerating the clean energy transition process. Such an approach opens up great prospects for international cooperation in the area of urban development and sustainable energy transition. A vital role of innovation and research in the process of reducing emissions from urban areas schould not be underestimated. Therefore, scientific research has a significant role in the implementation of sustainable development projects. International scientific cooperation is crucial as far as it enables the development of innovative urban energy system solutions that base on a common experience.

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