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The Role of Green Internet of Things (G-IoT) and Big Data in Making Cities Smarter, Safer and More Sustainable

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Abstract: The world population growth and increased demands for limited goods consequently imply the necessity for more efficient use of materials and resources. As the novel advances in Information and Communication Technology (ICT) have totally revolutionized the numerous areas, their utilization at the same time possesses a negative influence on the human health and the environment. For that reason, the society is going toward the greener future where the usage of raw and non-renewable materials and resources will be reduced while energy consumption and pollution will be decreased. As ICT can be considered as a tool for addressing environmental problems, Green Internet of Things (G-IoT) takes one of the most important roles on the way to create a green and sustainable place for living. Big data analysis is essential in achieving valuable insights from voluminous and various G-IoT generated data. The obtained knowledge enables easier decision-making, forecasting and other activities regarding smart city services, and in return contributes to a continuous improvement of G-IoT technologies. Hence, even the vision of smart and sustainable cities has already become a reality, the G-IoT approaches and insights achieved from Big data analysis will make cities significantly smarter, safer and more sustainable. This paper tries to summarize the role of novel technology advancements and Big data' achievements in the process of creating cities where the quality of life will be enhanced alongside reduced pollution and more efficient utilization of goods. It has been shown that G-IoT and Big data operating symbiotically successfully contribute to the fruition of smart and sustainable city vision.

Keywords: G-IoT, Big data, Green, Sustainable, Smart, City

1. INTRODUCTION

According to the United Nations (UN) predictions [1], the world population will reach nearly to 10 billion by 2050 compared to present 7.5 billion. This significant human population growth can be viewed as the outcome of improved living conditions and achievements in modern medicine. Nowadays, there are 21 megacities (10+ million citizens), while around 1 million people move to cities every day [2]. It is anticipated that by 2050, nearly 70% of the world population will live in cities as a consequence of increased levels of urbanization and accelerating migration [3]. This fact will increase demands on resources and infrastructure (Fig. 1) what implies the necessity of making cities, and the world in general, smarter, safer and more sustainable.

The intelligent and green city is a vision that has already become a reality (Fig. 2) [4]. Substantial advances in Information and Communication Technology (ICT) contribute to the improved quality of life, reduced consumption of energy and limited goods and decreased hazardous emissions and pollutions.

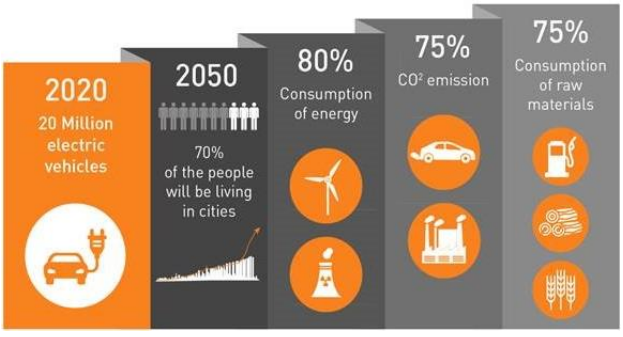

Figure 1. The increasing relevance of cities [3]

Since its appearance, the Internet of Things (IoT), based on billions of embedded sensors and smart things that enable the connection of anyone, anywhere, anyhow and anytime, plays a central role in revolutionizing numerous sectors (e.g., healthcare, transport, industry, education, agriculture, forestry and aquaculture, tourism, waste management, etc.) consequently leading to the smarter, greener and more efficient world. Despite the tremendous benefits ICT and IoT offer, increasing number of smart devices used every day in novel technology approaches,

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contributes to increased energy and resource consumption and associated e-waste and hazardous emissions generation. Moving towards a greener future, where energy, limited materials and resources will be more efficiently used alongside decreased pollutions, promise to make smarter and greener place for living. Green ICTs, particularly Green Internet of Things (G-IoT) has a key role in the realization of the smart and sustainable cities.

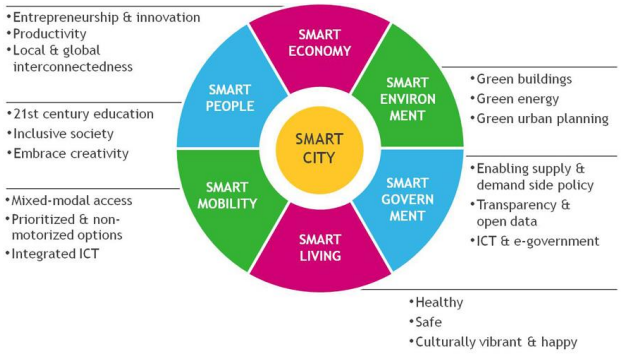

Figure 2. The Smart City [4]

The constant rise of used smart things/devices that generate a massive amount of data implies that the success of G-IoT depends on Big data. In addition to volume, Big data are characterized by velocity, variety, and veracity. However, the collected data alone doesn't serve much. That is where Big data analytics come in. Implementation of Big data analytics enables achieving useful insights on which basis adequate decision can be made and actions performed. Therefore, Big data analytics contributes significantly to understanding a large amount of information and assists in life changing improvements by making cities smarter, safer and greener. On the other side, analysis of a large amount of data helps to constantly improve G-IoT according to new demands. Evidently, G-IoT and Big data together work well and provide continuous improvement of living environment conditions.

This paper tries to assist in understanding the symbiotic relationship between G-IoT and Big data through the analysis of their roles and contributions in creating an intelligent and sustainable city by reducing pollutions, decreasing energy demands, and efficient resources utilization. Hence, this paper is structured as follows. Section 2 demonstrates the foundation of G-IoT concepts and its role in the realization of an intelligent and sustainable city. Established on the G-IoT generated data, Section 3 analyzes the approaches for dealing with voluminous nature of diverse and in real-time generated data. Big data analytics and its significance in enhancing living conditions are highlighted in this section. Lastly, Section 4 contains concluding remarks.

2. GREEN INTERNET OF THINGS (G-IOT) AND ITS ROLE IN CREATING SMART AND SUSTAINABLE CITIES

Keeping in mind the impact of people's everyday activities on the environment and the human health, the creation of a sustainable place for a living requires the engagement of all stakeholders, governments, and companies, as well as individuals, to successfully deal with challenges such as climate change, the depletion of natural resources and disappearing biodiversity. The evolution of G-IoT vision is the result of efforts to improve the quality of life through environmental protection and sustainability using technology advancements (Fig. 3) [5].

The creation of a system of systems by connecting billions of devices, vehicles and infrastructure everywhere in a city, enable stakeholders to reduce carbon emission, decrease energy and water consumption, increase safety efficiency, and human well-being [2].

G-IoT consists of two aspects [6]:

- Design and production of green computing devices, networking architectures and communications protocols with optimized power consumption and maximized bandwidth utilization.
- The utilization and disposal of green devices and technologies to reduce carbon emissions and pollutions and enhance the energy efficiency.

The G-IoT architecture consists of next buildings elements [7, 8]:

- Sensing nodes,
- Fog/Edge nodes as local embedded processing nodes,
- Cloud-based embedded processing nodes,
- Software to automate tasks and enable new classes of services,
- Security implemented across the signal path.

Therefore, the realization of G-IoT vision considers the inclusion of top green ICTs such as Wireless Sensor Networks (WSN), cellular networks, Radio-Frequency Identification (RFID), energy harvesting devices and communications, machine-to-machine communications (M2M), cognitive radio, Cloud/Fog/Edge computing, Big data analytics, as well as nanotechnologies, and biometrics in recent time (Fig. 4).

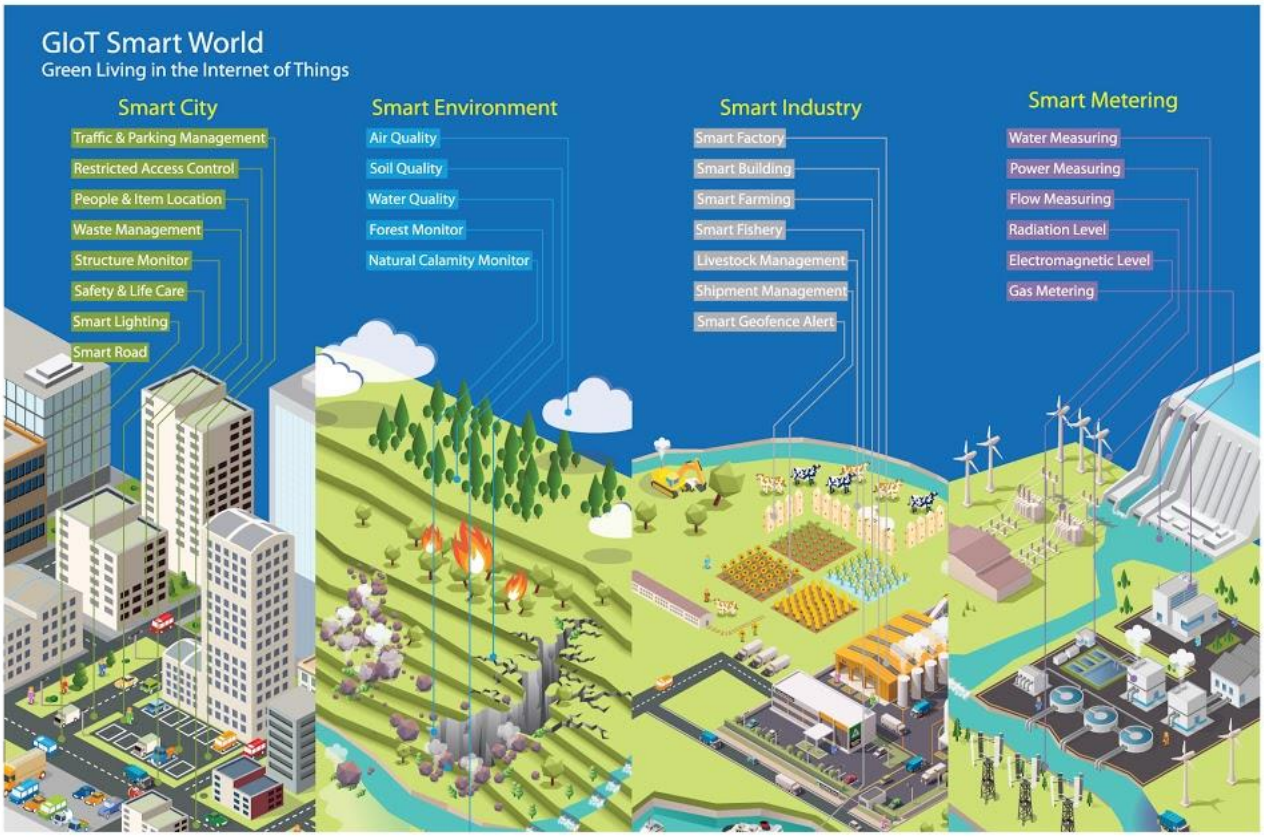

Figure 3. G-IoT smart world vision [5]

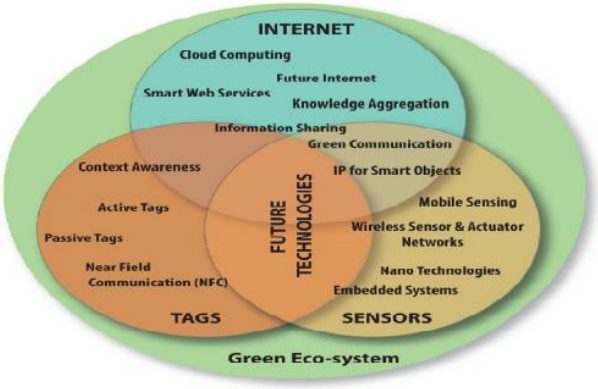

Figure 4. G-IoT enablers [6]

WSN and RFID are two complementary technologies that enable the identification of every object in IoT, their connection, collaboration, and cooperation. Hence the IoT will become G-IoT only if significant achievements are being accomplished in the processes of making WSN and RFID greener.

WSN, as a group of spatially distributed sensing devices able to monitor and record a variety of conditions, is an invaluable resource for realizing the IoT vision. The novel designs and materials used for the production of WSN building elements as well as improving the energy efficiency of WSN devices and during the realization of signal processing and networking protocols makes WSN greener than ever before. Secure, reliable, energy-efficient and cost-effective WSNs are essential for the realization of G-IoT.

RFID, as a low-cost and flexible technology used in numerous applications to identify and track people or objects in real-time, is one of the fastest growing wireless technologies nowadays [9]. Thanks to its features and potentials, RFID is more than desirable in IoT. However, as any other ICT, RFID also has a negative influence on the environment. In order to reduce or eliminate the RFID harmful effects on the environment, novel materials, alternative processes and approaches for manufacturing biodegradable RFID systems are being explored constantly [10]. In other words, the research community increased interest and significant investments are focused on the investigation of novel, cheaper and energy-efficient tags design using new materials (e.g., conductive adhesive, plastics, textile fabric) and approaches (e.g., chipless RFID tags, passive wireless RFID sensors) [9].

Alongside green WSN and RFID technologies, the achievement of G-IoT vision requires more energy and cost efficient, reliable and secure M2M communications, and information networking architectures [11]. M2M communications, defined as the communication among two or more things/devices without human intervention, is a fundamental part of the IoT [12]. As the main objective of green communication technology is reduction of energy consumption and CO_2 transmission in communication and networking devices, the large amount of attention and considerable research has been devoted to the evolving communications architectures, green wireless communication, energy efficient routing, relay selection strategies for green communication, energy efficient packet forwarding, and networking games [8].

As the G-IoT is established on green design, green communication, green processing, green utilization and green disposal, the following tasks are required to be performed in order to realize the vision of G-IoT [8, 13-15]:

- Implementing eco-friendly design and the applying bio-products in manufacturing processes of G-IoT components;
- Cutting down energy usage and operational costs through designing and producing energy-efficient G-IoT components, shutting down G-IoT equipment whenever possible, implementing sleep scheduling algorithms, increasing the efficiency of data center cooling and power supply, etc.;
- Using renewable green power sources such as solar, wind, water, oxygen, geothermal, biogas sources.
- Sending data only when is needed/required;
- Minimizing the length of the data path and the length of the wireless data path;
- Adjusting processing for communications (e.g., data fusion, compressive sensing);
- Implementing advanced communication techniques (e.g., MIMO (multiple-input-multiple-output) or cognitive radio utilization);
- The inclusion of security issues in the sensing infrastructure, communication network, application level and in overall G-IoT architecture.

The results of the accomplished aforementioned tasks are design, manufacturing, development, utilization, and disposal of associated G-IoT components in environmentally and economically responsible way. Hence, the G-IoT, compared to the IoT, is more energy efficient, reduces the amount of waste and greenhouse gas emissions and has insignificant or no impact on the human health and the environment.

The examples of how G-IoT solutions can contribute to the realization of the smart, safe and green city can be summarized as follows:

- On the way to a smart, green and strong sustainable world, the energy sector is of crucial interest. Traditional ways for electric generation are based on fossil fuel consumption, causing increased carbon emissions, global warming and climate change [16]. For this reason, it is essential to make the energy sector more environmentally friendly and sustainable. The innovative technology solutions, G-IoT solutions particularly, are able to realize more efficient distribution and utilization of energy [2], leading to improved balance between energy demand and supply. This can be achieved by using energy network integrated with a large network of smart appliances, smart meters, actuators and sensors etc, which automatically monitor energy flows and adjust it to change [17]. This paradigm is known under the term Smart Grid (SG). As the continuous growth of smart devices used in SG leads to increased energy consumption and carbon emissions, it is mandatory to implement green communication, green computing technologies and green power resources in SG, which results in the creation of new vision - the Green SG (G-SG). The G-SG is an autonomous and self-healing system, secure, highly reliable and of high quality, uses assets in optimal ways, it is cost-effective and takes care of environmental protection [18, 19]. As such, G-SG allows variable and decentralized energy generation, storage and distribution, and facilitates the incorporation of distributed and renewable energy sources (e.g., wind, solar, hydro, wave, geothermal) [20]. Since it is anticipated that the G-IoT will significantly contribute in achieving the European Union's goals until 2020 (reduced carbon emissions by 20%, energy consumption savings by 20 % and increasing the share of renewable resources to 20%) [21], the future generation of SG will be completely automated and G-IoT-based indubitably.
- Smart water management, as another key building block of the smart cities, consists of integrated ICT products, solutions, and systems in areas of managing water flow, distribution and pressure [22]. G-IoT vision has potential to achieve significant water savings in building sectors and thus improves the sustainable water management. With the help of smart metering devices, real-time and remote monitoring of water consumption and

problem diagnose, G-IoT is capable of optimizing all aspects of cities water management system.

- The foundation of G-IoT solutions in smart buildings is the integration of all devices (such as smart meters for electricity, gas and water consumption monitoring, HVAC (Heating, Ventilating, and Air Conditioning), home automation gateway, home smart appliances, audio and video, lighting, etc.) as well as the connection of smart building with people, another buildings, technology, smart girds, and the environment [23]. In addition, the G-IoT plays a significant role in improving the complete building life cycle, from urban planning and design, construction and operation, to maintenance and removal. In this way the realization of green buildings, as sustainable structures with significantly increased energy and water efficiency, alongside reduced buildings' carbon footprint is being closer to the reality than ever before. According to [24], green buildings, Leadership in Energy and Environmental Design (LEED) certifications, and net-zero energy buildings (buildings that reduce the utilization of non-renewable energy by producing enough renewable energy to meet its own energy consumption requirements [25]) will become increasingly widespread. Without any doubt, the G-IoT will significantly contributes to it by making buildings smarter and more efficient in term of energy and resource usage, making them secure, safer, more sustainable, and user and environmentally friendly [26, 27].

- As more people live in the city, more waste is being generated on a daily basis what represents a huge challenge in the realization of smart and green cities. It is anticipated that the global waste volume will increase 50% over next few years [28] and it will reach 2.3 billion tons by the end of 2025 [29]. Regardless of the waste type (solid, liquid, chemical, hazardous and toxic, organic, recyclable) and their source (e.g., residential and commercial buildings, houses, transport and streets, hospitals, industry, construction) the smart waste management is a precondition towards the fruition of the smart, green and sustainable city vision. Therefore, a rising interest in realizing successfully waste management is present. Numerous companies around the world are installing IoT-based systems for more effective waste management (e.g., Enevo, Compology, Bigbelly, Sutera, etc.) [30]. The waste management solution based on the G-IoT stands for the appliance of novel technologies or practices in cutting down or removing waste and pollutions, as well as collecting and reusing or recycling waste, converting it into valuable resources. Connected waste management at the city level contributes to significant cost-savings and decreased CO_2 emissions [2].

- Considering the speed of urbanization and the dimensions of cities, urban surveillance is an essential part of smart city vision. Efficient smart city surveillance is of crucial interest in numerous critical and dynamic data-driven tasks [31]. The transport sector, as one of the most significant parts of a smart city, demands the adequate level of monitoring and surveillance. In addition, having in mind that transport sector is responsible for about 25% of global CO_2 emissions implies the necessity for making this sector smarter and greener as much as possible. G-IoT holds the potential to significantly contribute to the reduction of energy consumption and associated emissions and pollutions in the transport sector. Avoiding or reducing trips, moving towards more environmentally efficient transport modes and improving vehicle and fuel technology are three main interlinked principles that must be fulfilled in order to realize a smart and sustainable transport [8]. The realization of Internet of Vehicle (IoV) vision, where various types of vehicles are being connected, delivers better services alongside improved safety and efficiency. For instance, connected emergency vehicles enable responders to reach emergency scenes more quickly and help to citizens faster. Car-sharing and ride-sharing services help reduction of traffic congestion, transport associated emissions and resources as well as significant time and cost savings. Connected streetlights enable the remote adjustments of lighting, that alongside reduced energy consumption and associated costs, make streets and the city safer. Video surveillance system also contributes to the safety of cities by monitoring vehicle and pedestrian traffic and helps crime determination [2]. Hence, G-IoT supported monitoring of traffic jams, optimization of the flow of goods and route planning are examples how it is possible to minimize transport systems' negative influence on the environment alongside reduced dependence on fossil fuels and energy [20].

The examples above are by no means exhaustive and they have been shown for illustrating the G-IoT potentials to make significant improvements in energy efficiency, reduced resource consumption, costs-saving and decreased negative impact on the environment, thus leading the vision of smart, safe, secure and sustainable city to fruition. Smart buildings, smart infrastructure, and smart services prove that the G-IoT is an appropriate tool for strengthening economic and environmental sustainability.

3. BIG DATA CONTRIBUTION IN MAKING CITIES SMARTER AND SUSTAINABLE

Since the IoT and G-IoT are all about collecting and using data, their success depends on Big data. For that reason, it is necessary to understand the relationship between G-IoT and Big data and their common work to perform analysis, gain numerous and insightful results and do the adequate actions. The ten successfully examples of IoT and Big data symbiosis are presented in [32]. All these examples show the power of G-IoT and Big data analytics relation. However, massive volumes and fast generated data from various and numerous devices (e.g., smartphones, computers, sensors, cameras, RFID tags, GPS, etc.) must be processed in order to obtain certain knowledge and perform appropriate activities. Hence, effective analysis and utilization of a large amount of variety of data (structured and unstructured), that arrives at real-time speed and can be of uncertain provenance (veracity) are mandatory in the process of obtaining valuable insights. Processing such information generated in smart city vision is not possible using traditional SQL-queried relational database management systems (RDBMSs). The utilization of Hadoop distributed data processing system and non-relational databases (NoSQL databases) enables achieving important insights from data collected [33-35].

The G-IoT and Cloud computing service enable the storing, processing and mining data in an efficient manner. In other words, the Cloud computing successfully deals with the massive volume of urban dynamic data enabling their analysis with powerful computing tools [31]. Furthermore, moving certain application processes or services to the edge of the network, lead to reduced amount of data that has to be processed, analyzed and stored. This approach refers to Fog computing [36] and significantly enhance data storing, processing and analysis in the applications that require real-time data storage and processing, such as the smart city. The combination of G-IoT and all the developing ICTs facilitates the collection of smart city data, its delivering and analysis in order to perform adequate actions for city's service improvements, urban planning, and governance.

There are various soft computing techniques that can be applied in order to gain important insights from the collected data and make smart decisions (Fig. 5) [37]. Well-known data mining and machine learning techniques, such as clustering, classification, frequent pattern mining, outlier detection, fuzzy logic or neural networks as well as novel algorithms and visualization techniques are being applied regarding of the problem domain, compatibility of the data set, and desired outcome [38, 39].

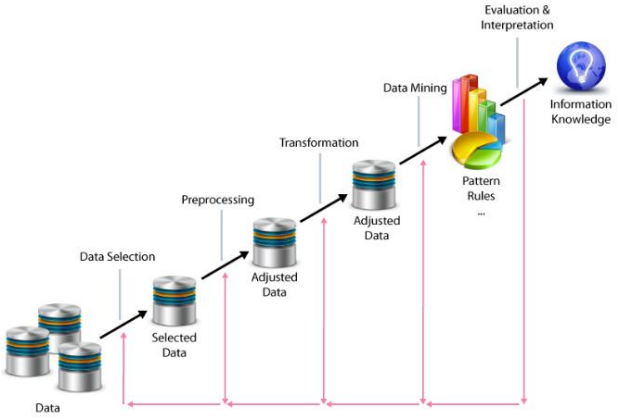

Figure 5. The extraction of knowledge [37]

The contribution of G-IoT and Big data analytics in the realization of smart and green city vision and enhancing different smart city services can be summarized into:

- The technology progress has facilitate the utilization of smart meters that enable on-line measuring of various resources consumption, such as electric, heat, gas, and water. In this way, the smart meters generate data necessary for successfully resource management. In other words, Big data analytics applied to data gathered from smart devices, sensors, and smart meters, enable consumption prediction, outages reductions, and assets monitoring. G-IoT components together with Cloud/Fog/Edge-based automated management system hold the potential to significantly improve efficiency in energy and water consumption. Based on Big data analytics and visualizations, adequate predictions and preventing actions as well as other intelligent decisions can be made in sustainable resource management [40]. Therefore, the analysis of data generated by all electrical devices and other smart devices used in the vision of smart and green building enables achieving better insight in the usage of energy and other resources and leads to enhanced monitoring, controlling and alerting actions. For example, it is expected that the smart grids in the future will be composed of micro-power system networks, linked to each other via the Cloud, and capable to monitor, run or disconnect themselves and heal based on the data collected with smart metering devices [20, 26]. In addition, using innovative building management systems and building automation systems, the consumption of energy in building sector can be reduced by 30-80% [25].
- The waste management system based on the G-IoT possesses the power to collect the data from multiple sensors and information system that

contain information about the container filling level, garbage truck location, and traffic congestion. The collected data is being transmitted to the Cloud so that waste management companies can do analysis, predicting and optimization actions [41, 42]. For instance, the optimization of container collection times can be achieved based on the sensor data that contains information about waste level. The container can inform of waste level or last collection, and based on those data they are being marked for collection. Garbage truck only collects full or overdue containers what at the same time leads to the optimization of garbage truck routes. In this way, the G-IoT significantly contributes to more improved, sustainable and cost-efficient waste management bringing benefits to both, directly and indirectly parties involved in trash disposal.

- Smart city surveillance systems are essential for fighting crime and public security. Alongside public places monitoring, these systems facilitate detection of any violent act and the people involved, enable tracking people and objects, as well as alarming in case of any event of interest happens [43]. Also, the utilization of smart sensors, cameras, location-based applications and intelligent infrastructures significantly contributes to improving transport sector, making it secure and sustainable. Traffic control and optimization can be successfully enhanced with the help of G-IoT. The connection of vehicles, roads, lights and control systems, create massive amounts of data at high speed. Gathering and analyzing real-time information on traffic conditions make traffic, driving and parking more efficient [44, 45]. For example, the G-IoT solutions based on data collected and processed are able to recommend the best route and optimal driving speed to avoid congestion, or to help drivers get the closest available parking place in a busy area [2]. The citizens via their smartphones and mobile devices can always have the real-time information on public transportation and its availability. Additionally, street lights can be adjusted according to the presence of the people in a particular area, contributing in such way to safety and reduced energy consumption at the same time [46].

The list above presents only a few among numerous benefits Big data analytics and the G-IoT together offers in the realization of smart city vision. Therefore, G-IoT and Big data can't be looked separately; they are linked inherently to one another. Only in this way it is possible to derive valuable insights and made intelligent and on-time decisions for improving the quality of life through enhanced smart city infrastructure and services.

4. THE EVALUATION OF CITY'S SUSTAINABILITY

Based on aforementioned, the challenges for making cities smarter and greener include cost, efficiency, sustainability, communication, safety, and security [23]. In order to overcome the consequences of increased urbanization, like overexploitation of resources, deficiency of services, and waste and emissions expansion, it is mandatory to achieve goals of city's sustainability (economic, social, and environmental sustainability) [47]. The city's economic sustainability depends on the provision of more efficient and better-integrated services and infrastructures and on new financial models. Consequently, improved quality of life will contribute to city's attractiveness for people, business, and capital. In addition, an innovative technology and infrastructure integration assists to the reduction of city's negative influence on the environment and lead to the environmental sustainability [48].

In order to measure the sustainability of smart cities, it is necessary to take into account the quality of environmental assets, efficient use of resources, climate change risks, and maximized economic and social co-benefits [49]. The measurement includes the assessment of approximately 30 quantitative and qualitative indicators together across the following categories [50, 51]: energy, CO_2 emissions, buildings, land use, transport, water and sanitation, waste management, air quality and environmental governance (Fig. 6).

The results of the comparative analysis can be found in various reports [49-53]. According to [53], the overall sustainable cities index ranking in 2016 is shown in Fig. 7. As the assessment of cities' sustainability and the indicative ranking is performed using around 30 different indicators, it is evident that enormous amount of variety of data generated at real-time had been processed. Hence, the presented ranking is based on the knowledge obtained by applying Big data analytics on the aggregated data. Since the results consider cities' care for people, planet, and profit (social, environmental, and economic sustainability), the G-IoT, even it is still nascent in its nature, holds enormous potential to significantly improve smart cities applications and services. In other words, it is expected that the explosion of G-IoT and Big data and their symbiosis will very soon show its power in improving the quality of life creating the smart, secure, safe, and sustainable places to live.

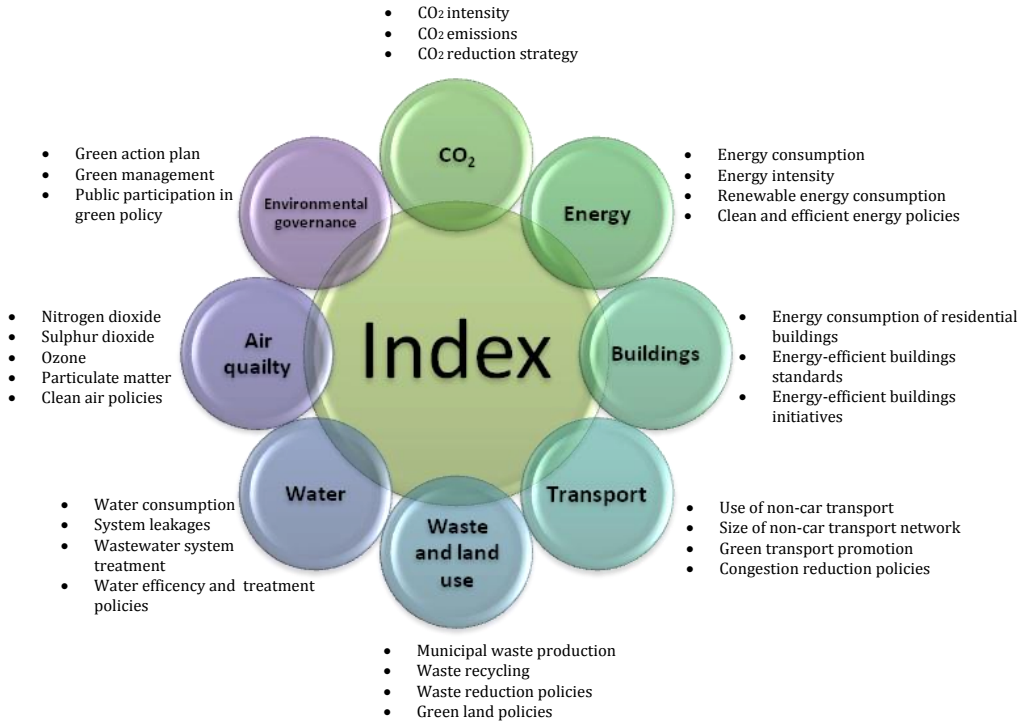

Figure 6. Green City indicators

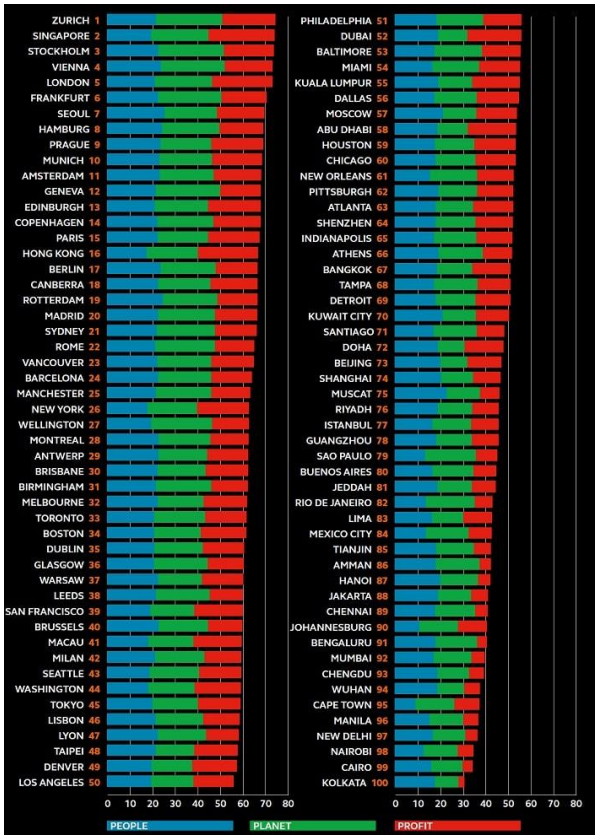

Figure 7. Overall sustainability city index rankings [53]

5. CONCLUDING REMARKS

Since human existence, the tendency to have a safe, good and sustainable place to live hasn't changed. With the technology advancements, the vision of smart, safe and green living spaces is becoming the reality. A rising number of people and their mitigation to urban places imply the increasing consumption of a number of limited resources and goods, alongside waste and hazardous emissions expansion. As the innovative technology significantly contributes to the fruition of smart and sustainable city vision, at the same time it has quite often the negative impact on the environment and consequently on the human. In order to deal with these serious challenges, it is necessary to perform certain actions which will, in general, reduce the negative impact on the environment and human well-being. Moving towards green technologies, especially G-IoT, appears as the adequate solution. Designing, producing, using and disposing of products and devices in a green manner (without negative influence on the human health and the environment) makes G-IoT the technical backbone of the smart world and the technology of the future. The inclusion of the G-IoT devices and services in the realization of smart city vision leads to the creation of volume and variety of data generated on an everyday basis. In order to obtain valuable insights from data collected, there is a need to process and analyze it. Gaining knowledge about people's lives, work and thoughts open a whole world of potential improvements in operating and managing cities. Therefore, G-IoT and Big

data can only together contribute to the significant enhancement in quality of life, making the world a better, safer and more sustainable place to live.

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