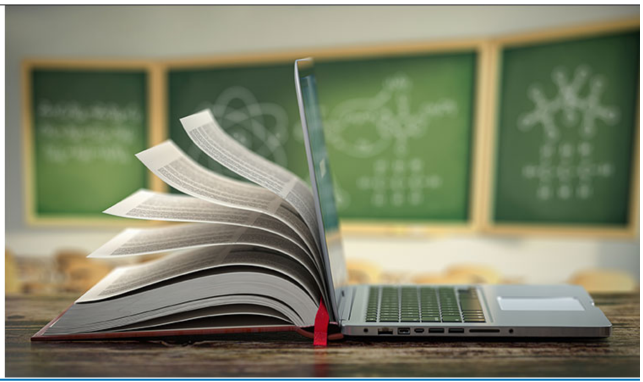
IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

The Role of the Internet of Things (IoT) in Energy Management of a Smart City

To cite this article: I Maltseva and K Tkachuk 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **972** 012018



The Role of the Internet of Things (IoT) in Energy Management of a Smart City

I Maltseva[1], K Tkachuk[2]

[1]Ural Federal University, 19 Mira street, Yekaterinburg, 620002, Russia

[2]Institute of Energy Efficient and Sustainable Design and Building, Technical University of Munich, Arcisstraße 21, 80333 Munich, Germany

E-mail: i.n.maltceva@urfu.ru

Abstract. The 2030 climate & energy framework contains three key targets for Europe: to cut greenhouse gas (GHG) emissions and increase the share of renewable energy (RE) sources and promote energy efficiency. These tasks are relevant for Russia as well. As one of the frontrunners, Germany has raised its RE share target to 65% by 2030. At the same time, global energy needs are expected to increase by 30% by 2040. In this context, energy systems should not only be planned for the current supply but also be designed for a substantial increase in energy demand. To achieve these goals and avoid an energy crisis, the general idea is to shift from centralized to decentralized energy systems. Furthermore, energy sectors are currently integrated with Information and Communication Technology (ICT) solutions, especially the Internet of Things (IoT), for efficient and sustainable energy management. The article analyses the role of IoT technology in existing and future energy systems according to three scales: flat, building and city.

1. Introduction

In modern society, one of the main tasks in the field of energy systems is the creation of sustainable energy infrastructure, which is a properly organized eco- and society-friendly technical system that not only transmits energy from producer to consumer, but also fulfils all the environmental and technical requirements. Efficiency and energy saving are particularly important in matters of global climate change and the Agenda 2030 Sustainable Development Goals. In 2014, the European Council set three key targets for the year 2030 [1]: cut at least 40 % of greenhouse gas (GHG) emissions from the year 1990 level, reach at least 27 % share for renewable energies (RE) and gain at least 27 % improvement in energy efficiency. Especially, Germany lifts its RE share target to 65% by 2030 [2].

At the same time, the energy systems should not only be planned for the current supply but also be prepared for a substantial increase in energy demand. Global energy needs are expected to increase by 30 % by 2040 [3]. Further, 70 % of global GHGs are emitted from cities occupying only 2 % of the world's land [4]. Therefore, many efforts have to be made in cities to meet our environmental goals and avoid energy crises. The solution, in this case, cannot be simple. It has to be smart, innovative and fully change the current state of energy infrastructure, which would not be able to meet the future requirements of a zero-emission society.

In this context, the Internet of Things (IoT) plays a significant role in sustainable development [5]. This technology enables sensing, monitoring and collecting real-time energy consumption both on small and large scale by using a ubiquitous computing platform [6,7]. The availability of real-time data offers several opportunities to reduce energy consumption [7]. Further, the energy sector is currently integrated with Information and Communication Technology (ICT) solutions, such as IoT, for efficient and sustainable energy management. This article investigates the role of IoT technology in existing and future energy systems according to three scales: flat, building and city level.

2. Decentralization of energy systems as a step towards smart cities

Major challenges of future energy systems and stricter requirements from policies protecting the environment and fighting global warming will force us to deal with numerous problems we already have right now or will face in the nearest future. In our research have identified four main groups of problems according to tasks that Global Agenda 2030 has formulated:

- Decrease of emissions;
- Maintenance and upgrade of existing grids and stations;
- Increase renewable energy share in the energy mix and support its attractiveness for consumers;
- Support local providers of energy, such as private photovoltaics (PV) panels, geothermal or power-to-grid (P2G) systems.

Analysing existing case studies in this sphere, we came up to the solution, that is already implemented in some countries worldwide [8,9]. The general idea that is proposed by different articles is to shift from Centralized energy systems (CES) to Decentralized energy systems (DES) [10,11]. Main advantages of DES are:

- Low to zero-carbon emissions;
- Larger RE share in the local energy mix;
- Reduced costs for transmission systems;
- Improved efficiency and lower grid loss;
- Increased reliance on distributed generation involving local small-scale providers.

Introducing DES on single house and neighbourhood level will help stabilizing the energy system of a city by providing an opportunity for every consumer to be a supplier for himself. If there is more energy than he needs he can put the energy back into the city grid and receive payment for it. In this case, DES stands head and shoulders above CES as it is basing on RE sources in almost every house connected to the grid. This can be easily done by PV panels and geothermal heat exchangers on a local level and with the help of wind turbines and small hydropower plants on a city level. The reason why we are so interested in renewables when we are speaking about CO2 emissions is the statistic of Life Cycle (LC) GHG emissions obtained by other researches. On the figures 1 and 2, we can clearly see the differences in environmental impact from different energy sources [12].

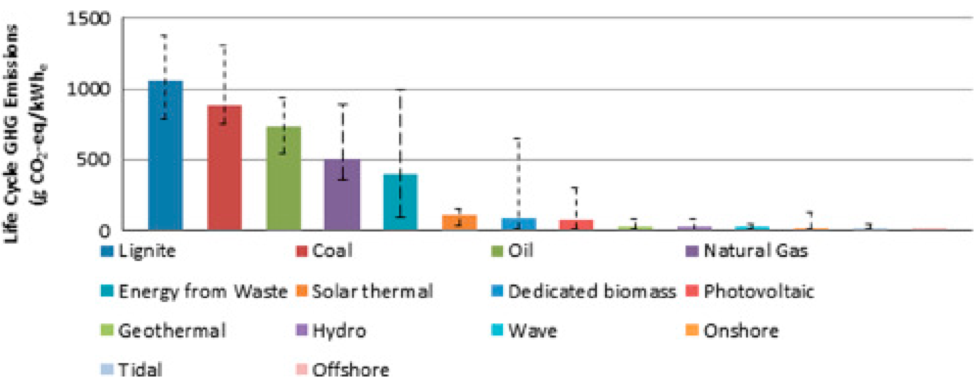


Figure 1. Maximum GHG emission levels of electricity generation methods.

IOP Conf. Series: Materials Science and Engineering **972** (2020) 012018 doi:10.1088/1757-899X/972/1/012018

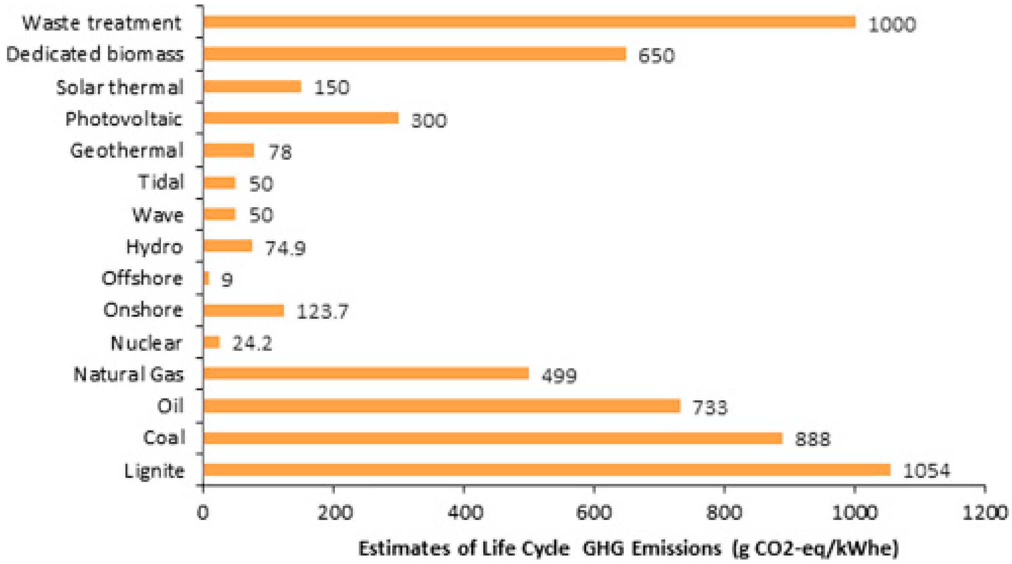


Figure 2. Life cycle GHG emission estimates of electricity generation methods.

Moreover, DES allows a multi-way flow of energy, which allows to redistribute the energy between users according to the current demand and lower the load on main energy roots as DES is built on microgrids. These grids are connecting every house locally, and through those grids it is possible to split the load on some roots and rise on the others. In other words, with DES we are creating the "energy cloud" (figure 3) across the district, neighbourhood or city, whose density depends on the energy demand and there is a lot of different roots for transmiting the needed energy to the consumer. Additionally, operating the energy without a centralized grid and flow direction allows to avoid grid losses (in reference to a centralized plant connected to extra-high voltage grids (EHV)) and save up to 15% of transition losses in energy systems [13].

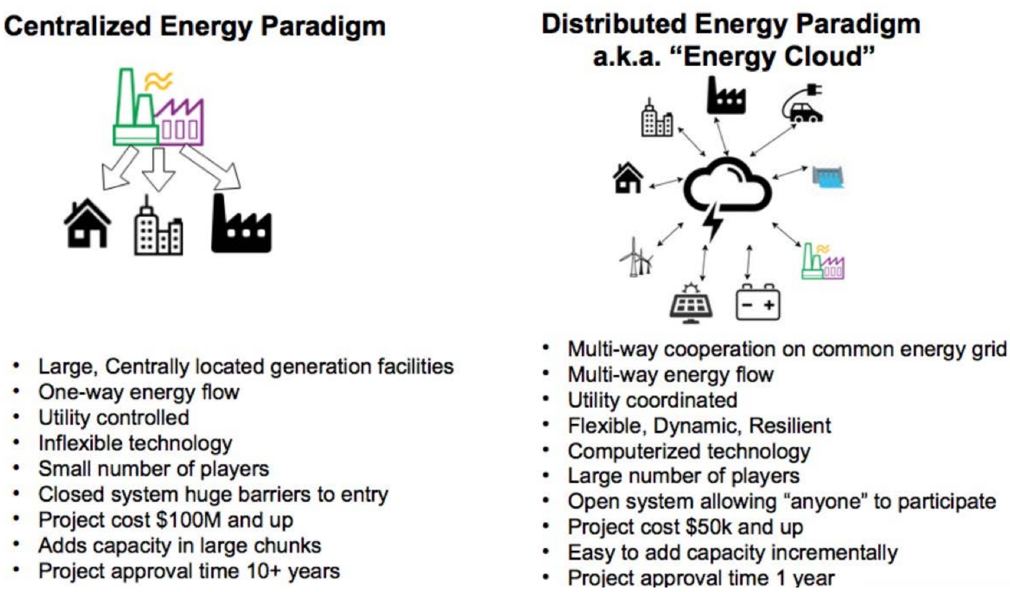


Figure 3. Visual representation of "energy cloud" (https://longtailpipe.com/2016/08/30/ti-enabling-smart-evses-by-adding-wifi-to-charging-station-reference-design/).

In addition, DES will make consumers much less dependent on one supplier of energy and even if something happens with the power plant or with grids, the system will be able to sustain itself by reallocating the energy flow for a period of time that will be needed to solve the problems.

Last but not least, public appreciation plays now a key role in the implementation of emerging technologies on a government level. In order to be accepted, technologies have to be user-friendly, be clear about what they are doing and how they can help. Their design should be appealing, which is another advantage of DES over CES since no one wants to have a big power grid in their backyard.

Considering all the advantages of DES, the authors believe that DES will be the main approach for the transition of the existing energy infrastructure to the new, sustainable and flexible infrastructure of the future.

3. Internet of Things and its part in the future of energy infrastructure

Considering the implementation of DES in the future energy systems we have to consider as well how to operate such a complex system, with big and always changing number of suppliers. The amount of data to deal with will grow exponentially, due to a multi-way flow of energy together with the appearance of new supplies in the grid system, such as private households with PV panels, ground heat exchangers, etc.

Modern technologies already have a solution to deal with Big Data and use it to control complex systems in real-time. The solution, the Internet of Things (IoT), also called the Internet of Everything or the Industrial Internet, is a new technology paradigm envisioned as a global network of machines and devices capable of interacting with each other. The IoT is recognized as one of the most important areas of future technology and is gaining vast attention from a wide range of industries [14]. In our particular case of future of energy infrastructure, IoT approach as well can and should be used as a core operator of all data, which is obtained from all controlling units and sensors from every household, connected to the grid.

3.1. IoT for Energy Management

Taking a closer look at how to implement IoT on a city scale for energy infrastructure, we need first to understand how it is working from inside. Figure 4 shows the IoT architecture in general [15].

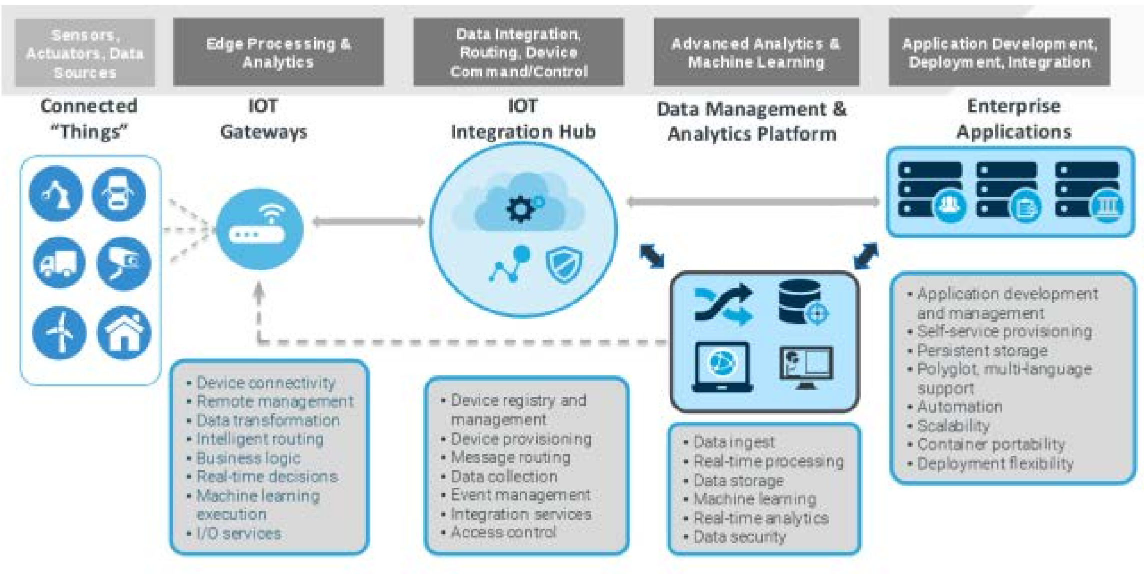


Figure 4. Visual representation of IoT system.

Within the system, there are five main elements:

- Data source – sensors, meters, etc., all that gathers data about the system;
- Control units on data source - real-time reaction on the data obtained from the data source or received response from main IoT hub;
- IoT Hub – main data server, which receives all the data from every data source, collects and provides access to it. As well responsible for registration of new data sources and their connection between each other;
- Data processing and analytics – real-time analytics of data from IoT hub, combined with machine learning. Responsible for the overall performance of the system and telling all control units how to work;
- Enterprise application – front-end part of the IoT system that is responsible application development, deployment and integration.

The same architecture is chosen for our project, only the data source will be specific for our task.

Design process of energy infrastructure always depends on the system we are working with. Detailed communication solutions and connections between the systems cannot be transferred from one implementation to another and always needs some adjustment for proper working. As well there is a considerable need in data to operate the whole system, having to be gathered from real sensors. Immediately upon obtaining the first batch of it, the system control needs to be started and its efficiency has to be improved until it reaches the expected level.

Nevertheless, the authors have done the evaluation of existing IoT technologies and equipment that are generally presented in every system and have divided them into three big groups according to the level they are working with: IoT on a flat level, IoT on a Building level and IoT on a city scale.

3.2. IoT in a Flat

IoT systems on a flat scale are mostly working with consumers. Communication between consumer and supplier can be extended under the umbrella of the mobile Internet of Things to include versatile resources, such as smartphones, smart meters and sensors (figure 5) in a flat that can be utilized for obtaining data and controlling energy efficiency. This approach assists in ensuring the awareness about the energy consumption of every person in a flat, specifying how much energy is spent by every system in a flat and how much it costs. In addition, it allows to provide real-time data how much money you have already spent for heating, cooling, etc. and let you know how much will the bills at the end of the month will change, if you change the heating or cooling in your flat. Mainly, this is done with the help of phone apps and smart meters installed in your flat, showing all these parameters on the screen in real-time.

Figure 5. Example of an in-home display and smart meter system (https://www.cse.org.uk/projects/view/1309; https://www.cse.org.uk/advice/advice-and-support/smart-meters).

Smart meters are the key operators of the IoT energy systems. Data obtained through them provides the system with better knowledge of people behaviour in the flat. This knowledge can be used in many different ways and will result in a higher quality of life and at the same time lower energy consumption. For example, predicting the person's location based on an increasing energy consumption in the kitchen as the oven is turned on, the system can automatically turn off the heating in the living rooms. That can result in savings up to 25% of the overall heating costs. Another example can be automated control of cooling systems according to people location and, in addition, automatically turning on and off the ventilation only when needed. This can as well result in substantial savings in energy consumption of a building [16].

Given the above, consumers start using the resources more responsibly and at the same time the data gathered from these smart meters will allow the supplier to produce the exact amount of energy needed by predicting the run-time loads in the system, redistribute the energy flow, produce additionally if needed and in the result cut down the amount of energy waste.

3.3. IoT in a Building

Building level is the intermediate point between the flat and a city. It is already not controlling the systems in a flat and still not controlling the overall energy flow of a city. IoT on a building scale is a data operator that gathers, analyses and transmits the information from every flat to suppliers.

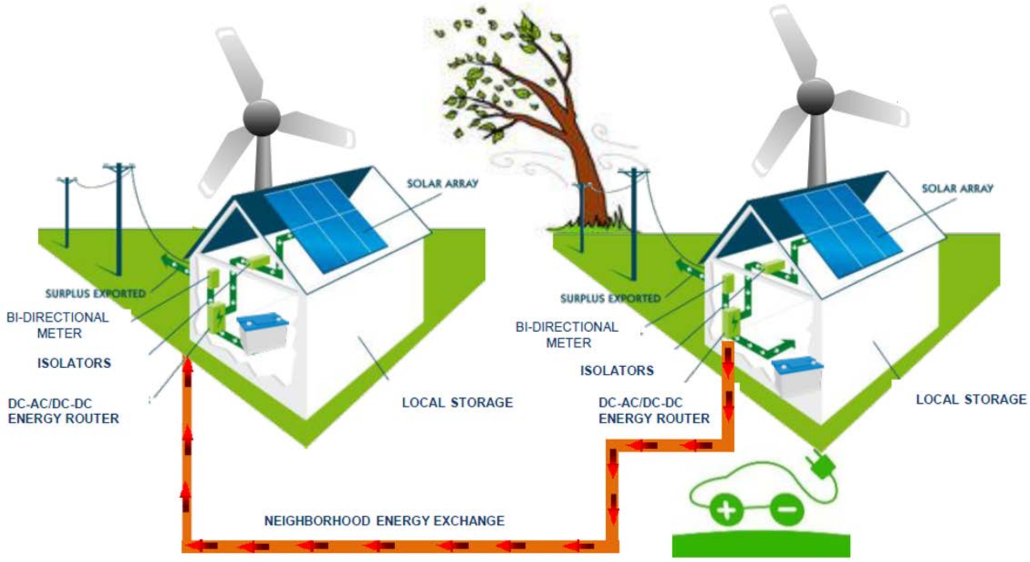


Figure 6. Building scale data operation (https://www.et.aau.dk/research-programmes/microgrids/activities/dc-next-eve-lvdc-microgrids-for-evolved-energy-communities).

The supplier receives from the building already processed data instead of the raw information output from meters. Moreover, some actions towards efficiency were already taken by the IoT processor in the building. This allows the system to perform properly even if the city scale system is not responding or there are some problems in it. Additional benefits from the IoT in the building can be obtained by installing PV panels, ground heat exchangers, air and heat recuperators and local energy storage. These solutions will make the building more self-sustained, i.e. mostly use its own energy produced by renewable sources for the dweller's needs and even put the electricity back in the grid if the production is greater than consumption right now.

3.4. IoT in a City

In order to achieve global sustainable development goals, energy systems in a city have to be intelligent. Smart Energy System solution was first introduced by Lund, Andersen, Østergaard, Mathiesen and Connolly in 2012 [17]. It is the new paradigm to combine every part of energy grids, such as Smart Electricity Grid and Smart Thermal Grid, for creating a synergy effect among them [18]. All smart systems, such as Smart Grid, Smart Street Lighting, Smart Parking, Smart Water Grid and Smart Thermal Grid, are interconnected on the city level allowing to both communicate and complement each other. Such connection opens new opportunities for creation sustainable and independent infrastructure that is strongly based on renewable sources of energy.

When it comes to operation of all these systems together IoT starts to play a decisive role. The amount of data going through the core control system cannot be operated by human. Numerous parameters, each of which can affect the efficiency of the whole system is controlled by the program based on data coming from every smart meter of every flat in a building of every neighbourhood of a city. In addition, these parameters are constantly changing independently from each other. For example, if clouds appear and PV panels do not produce much energy anymore, this does not mean that the ground heat exchangers and wind turbines will stop as well. The city energy system has to immediately react on this and either open access to energy storages to fulfil the energy demand or request the needed amount of energy directly from nearby power plant.

As a result, many technologies and smart infrastructures, such as Smart Grids, Smart Lighting, Smart Parking and vehicle-to-grid (V2G), can interact with each other to create synergies. As shown in Figure 3-5, PV panels can be used as shade structures over parking lots to charge EVs during day time [19]. EVs in turn can be used as energy storage and send electricity back to the smart grid through V2G if needed. Furthermore, a smart street lighting system based on smart grids contributes to saving energy, and drivers do not have to waste much time on streets to find parking spots, thanks to a smart parking system [20].

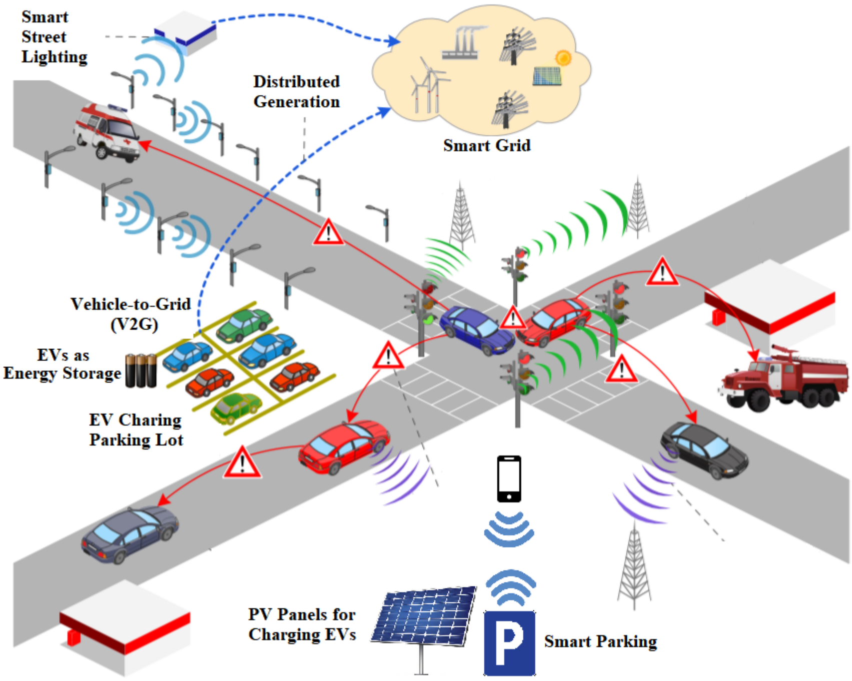


Figure 7. Smart systems and the Smart Grid in a Smart City.

Right now, we cannot fully rely on only renewable sources of energy due to their instability, but making a step towards them will give us an opportunity to tackle the problems connected with them and find the solutions sooner.

IOP Conf. Series: Materials Science and Engineering **972** (2020) 012018 doi:10.1088/1757-899X/972/1/012018

4. Conclusion

In order to meet the needs of the growing society of 21st century, energy infrastructure has to be sustainable, efficient and renewable. Reaching these goals is not easy, but there are many small steps we can do right now to reach the target in the nearest future, for example:

- Promote e-mobility;
- Install smart energy-efficient street lighting;
- Refurbish houses to reduce energy consumption, aiming towards 100 % renewable energy;
- Circulate a SmartCity app that creates intelligent links between all services.

These solutions will solve some problems on their own, but without a complex approach that includes step-by-step decentralisation of energy infrastructure, they will only remain as small steps. In order to create a sustainable eco- and society-friendly system, we have to solve both small problems and implement particular solutions. At the same time, we must think on a big scale and change our infrastructure towards fully independent local suppliers and microgrids connection between them. Coordination within the system can be done by a main IoT Hub that collects, reads and controls the system according to obtained information. Automation of these processes will lead to substantial improvement of overall energy performance of system on flat, building, neighbourhood and city scales.

In addition, Global urbanization is one of the main societal trends and all cities must be ready. Major challenges of future energy systems and stricter requirements from policies protecting the environment and fighting global warming will force us to deal with numerous problems we already have right now or will face in the nearest future.

Researches are already tackling these problems and many solutions appearing with technology development. Smart City is one of the perspective solutions, considering urbanization. But the infrastructure has to be ready for it. Such a complex solution requires long preparations before the implementation and the sooner we start them the sooner we will see the result.

In cities, everything is related to energy, thus a number of smart systems have been researched, developed and implemented to efficiently manage energy. This study attempts to investigate some of the smart energy systems, focusing on the role of IoT in these.

Moreover, overall performance of all systems has to correspond to the efficiency goals and the whole control of infrastructure has to be taken on the next level. Authors believe that IoT is the actual future of energy infrastructure. It allows to operate all the data coming from every sensor in every flat and building of the city and adjust the parameters in real-time. In addition, the system greatly benefits from the amount of available data since analysing it the control of the whole system will be very precise and even more efficient than operated by a human

Reference

[1] European Council 23/24 October 2014 Conclusions
[2] CDU, CSU and SPD 2018 Ergebnisse der Sondierungsgespräche von CDU, CSU und SPD: Finale Fassung
[3] IEA 2017 World Energy Outlook 2017
[4] UN 2011 Global Report on Human Settlement 2011
[5] IERC 2012 The Internet of Things 2012: New Horizons ISBN 978-0-9553707-9-3 ed Smith I G
[6] Al-Ali A R 2016 Internet of Things Role in the Renewable Energy Resources *Energy Procedia* **100** 34–38
[7] Shrouf F and Miragliotta G 2015 Energy management based on Internet of Things: practices and framework for adoption in production management *Journal of Cleaner Production* **100** 235–246
[8] Mahapatra S and Dasappa S 2012 Rural electrification: Optimising the choice between decentralised renewable energy sources and grid extension *Energy for Sustainable Development* **16** 146–154

[9] Williams J 2010 The deployment of decentralised energy systems as part of the housing growth programme in the UK *Energy Policy* **38** 7604–7613
[10] IPCC 2007 Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
[11] Mathews J A 2013 The renewable energies technology surge: A new techno-economic paradigm in the making? *Futures* **46** 10–22
[12] Amponsah, N Y, Troldborg M, Kington B, Aalders I and Hough R L 2014 Greenhouse gas emissions from renewable energy sources: A review of lifecycle considerations *Renewable and Sustainable Energy Reviews* **39** 461–475
[13] Hu J, Harmsen R, and Crijns-Graus W 2017 Developing a Method to Account for Avoided Grid Losses from Decentralized Generation: the EU Case *Energy Procedia* **141** 604–610
[14] Lee I and Lee K 2015 The Internet of Things (IoT): Applications, investments, and challenges for enterprises *Business Horizons* **58** 431–440
[15] Patrick Goemaere and Rajat Ghai 2018 Edge Compute and Software Life-Cycle Management SCTE•ISBE and NCTA page 13
[16] Lachhab F, Bakhouya M, Ouladsine R and Essaaidi M 2018 Towards an Intelligent Approach for Ventilation Systems Control using IoT and Big Data Technologies *Procedia Computer Science* **130** 926–931
[17] Lund Henrik, Andersen A N, Østergaard Poul, Mathiesen Brian and Connolly David 2012 From electricity smart grids to smart energy systems – A market operation based approach and understanding *Energy* **42** 96–102
[18] Mathiesen B V, Lund H, Connolly D, Østergaard P A and Möller B 2013 The design of Smart Energy Systems for 100% renewable energy and transport solutions. Book of Abstracts: 8th Conference on Sustainable Development of Energy, Water and Environment Systems
[19] Birnie D P 2009 Solar-to-vehicle (S2V) systems for powering commuters of the future. *Journal of Power Sources* **186** 539–542
[20] Turner S and Uludag S 2016 Toward Smart Cities via the Smart Grid and Intelligent Transportation Systems 117–166.