66% of the total primary energy consumption falls on cities that try to deal with this tendency by becoming more ‘green’ and ‘smart’ to avoid increasing pollution and greenhouse gas emissions. Thanks to microgrids and cooperating technologies, a new vision of energy consumer was introduced. A ‘prosumer’ is able not only to manage the demand in an aware manner but also to produce and sell energy. The aim of this paper is to present core microgrids technologies that can nowadays help customers to become ‘prosumers’ in urban areas.

**Keywords:** microgrids, smart grids, demand response, prosumers

**Introduction**

Nowadays, nearly half of the world’s population live in cities, consuming about two-thirds of the total primary energy. What is more, these numbers are constantly increasing. More residents mean a higher demand and that implies a necessity for a higher supply. Unfortunately, fossil fuels are still the most significant and common source of energy. Meeting the growing demand with existing energy production methods will have an impact on the rise of further atmospheric pollution.

What is more, an urban energy infrastructure will consequently need to be adopted and upgraded to meet a rising energy consumption and demand for energy services. As a consequence, cities face this new situation and deal with it by becoming more ‘green’ and ‘smart’. Local governments have started to elaborate policies including the popularization of new technologies among which the most important are: local smart grids (microgrids), smart buildings, smart metering, renewable energy resources, electric vehicle infrastructure or services such as demand response and net metering. As implemented, they can improve energy efficiency and the quality of service as well as balance the local energy supply and demand. In the next parts of this paper, these technologies will be presented to illustrate the emerging methods of energy management in urban areas that are possible thanks to ICT.

The structure of the paper is organized as follows. Microgrids, smart buildings, and smart metering will be described in second section. Renewable energy resources are the topic of the third section. Next, electric vehicles and loading infrastructures will be presented. The fifth section is dedicated to services: demand response and net metering. The sixth is about a new concept, namely the Internet of Things, which can be successfully adapted for smartgrids. The closure of the paper consists of conclusions and further discussion. The review of technologies for prosumers’ society creation is presented in the figure below.
Fig. 1. Smart grid technologies in prosumers society creation

Source: own evaluation.

Shortcuts used
AMI – Advanced Metering Infrastructure
EV – Electric Vehicles
BMS – Building Management System
DR – Demand Response
HRV – Heat Recovery Ventilation
ICT – Information Communication Technologies
RES – Renewable Energy Resources
V2G – Vehicle-to-Grid
IoT – Internet of Things
1. Microgrids in urban areas

In many cities, electrical grids were built decades ago and it is often necessary to make new investments. It is a good opportunity to consider building a smart grid instead of modifying an existing one. Local microgrids are characterized by distributed and dispersed topology as well as ICT systems and numerous sensors that take effect in self-monitoring, self-healing, remote monitoring and a pervasive control system. For citizens, microgrids mean an availability of possessing complete price information in real-time and new possibilities of making choices in their energy consumption profile. Thanks to microgrids, it is possible to make a grid more stable and efficient [1] [2] [3].

Energy consumers used to pay bills due to data read from their meters. In many cities, traditional meters have remained unchanged for decades and often keep customers from becoming an active energy consumer or changing energy supplier. In a conventional system, energy was produced in several major sources and delivered to customers via high voltage, long distance transmission lines. Even if a consumer could choose a price tariff, his or her role has remained passive. In this situation, growing energy demand can only be satisfied with a growth of power supply. This is not an optimal solution but, thanks to changing customer’s behaviour profiles, it is possible to reduce demand. With the intrusion of smart meters this idea may become achievable. Smart metering enables one to record real-time energy consumption and provides two-way communication (operator-consumer and consumer-operator). What is more, the customer may be informed about actual, variable energy prices. This type of meter is gaining popularity as it becomes available at more acceptable prices. The smart metering system is a complex and integrated ICT system. Its implementation requires the installation of smart meters in customers’ households, a central database, an ICT infrastructure and managing system.

An example of such implementation is AMI. It includes meters, hubs, communications modules plus software and allows real-time, two-way communication. With this model of communication, a significant growth of exchanged data emerges. This indicates the need for an ICT managing system, as collected data may be valuable not only for utilities, but also for consumers, suppliers or local microgrid operators.

The smart metering systems allows consumers, suppliers, utility and service providers to gather data captured and distributed by AMI [4]. A customer is gaining access to new kinds of information about the current and forecasted prices as well as an energy usage profile. It encourages the consumer to change his/her current electricity demand patterns, reduce power bills and use energy in a more conscious, responsible and educated manner: in other words, to make a change from a passive to an active attitude.

Cities frequently have to deal with buildings that consume large amounts of energy. Due to the European Union Directive on the Energy Performance of Buildings 1, more than 40% of energy consumption in Europe is because of heating and lighting operations in buildings. One of the ways of reducing these numbers is to introduce passive, smart buildings into urban areas [5]. Usage of local RES, proper exposure, suitable materials, thermal mass, adequate ventilation and insulation can lead to significant energy savings. Features of creating a passive, smart building are: exposure towards the equator, compact shape, superinsulation, right fenestration, air tightness and an ICT support – BMS. Reduced energy demand for heating can be attained by: smart design, increased

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1 EPBD 2002/91/EC.
thermal insulation, air tightening the building envelope, installing high performance windows, incorporating an HRV and BMS optimizing energy usage. However, it is difficult for cities to modernise all existing buildings; some investment in retrofitting can be taken and new buildings should be designed in a smart, passive manner [6].

Smart buildings may play a relevant role in local microgrids. With some micro RES installed, they will not only consume energy but produce it as well. This will lead to changes in customer’s energy usage profiles and the creation of a ‘prosumers’ society.

Due to the European Commission Report [7], it is obvious that if smart, green buildings are to become commonplace that this can only happen with ICT-aided solutions. BMS systems are already present in existing buildings. Their basic functions are limited to: light control, monitoring and security systems. But getting ‘smart’ means more advanced features that also include communication with local microgrids, smart meters, household appliances, optimization of energy consumption, usage of EV and V2G.

Building urban housing developments made of smart, passive buildings inside municipally boundaries can be an essential factor for cities in getting ‘smart’. In addition, existing buildings may have been adopted by installing micro RES and improving insulation.

Energy-independent buildings, together with other dispersed RES, energy storage systems and smart metering will allow the full benefits of municipal microgrids and support citizens to become more energy-aware, responsible in energy usage, and teach them how to benefit from new opportunities.

2. RES in micro scale

Wind, biomass, geothermal, ocean, solar energy, hydropower – all RES can be integrated into the electrical grid from the national to a local scale. Hitherto, integration of wind or solar power plants, due to their vulnerability, may be more difficult without storage devices. An urban architecture suspends the development of big power plants, but it is possible to implement these in microscale based on RES: small wind turbines on roofs, photovoltaic cells, biomass power plants, etc. Larger installations may be put close to the city’s boundaries [8]. RES are available, mature and ready to use. What is more, switching from fossil fuels to local RES reduces greenhouse gas emissions and supply climate protection. That means also supporting sustainable development – an idea that is getting more and more popular in cities and towns all around the world. That is why local governments have started to become involved in RES intrusion and dissemination.

Popularization of RES power plants also demands flexible methods of short-term load and demand forecasting. Proper operation of these resources in microgrids requires support from ICT technologies due to its dispersed localization, and often, variable supply. The introduction of ‘green’ power plants should be aided by solutions presented in previous sections: smart metering, buildings and grids [9].

Putting RES into a smart grid can influence its stability because these resources distinguish itself with high variability. For example: during a sunny, windy day micro turbines and PV systems installed on roofs may produce more energy than during a windless, cloudy one. These variations of supply may be limited by the intrusion of local storage devices (or in micro-scale by V2G technology). Energy storage devices can advance the whole performance of a local smart grid since they stabilize and allow distributed RES to work at a constant and stable output, in the face of possible
fluctuations, offer the ride-through capability during dynamic variations of RES and enable them to flawlessly operate as a dispatchable unit.

With the gradual dissemination of distributed RES it will become more and more common that small, single households have some micro power plants installed. This is a crucial step for ‘prosumers’ society creation.

An urban community of prosumers would allow for a decrease in energy demand due to the optimization of energy usage patterns. Decentralisation of the energy generation can also lower the costs of building new large power plants in order to meet the growing demand and need. Besides, it can improve grid reliability, stability and quality of services. Nevertheless, it is important to outline the need for cooperation between RES power plants and ICT to lower the possible negative influence on grid stability caused by changing weather conditions.

3. ‘Green’, individual, urban transport

EVs are often perceived as an essential part of the future car fleet as a result of reductions in greenhouse gas production. Due to the fact that transportation is a considerable contributor to CO$_2$ emission, fossil fuel vehicles are considered to be one of the major obstacles to sustainable development [10] [11].

Even though all benefits that are seen in EV popularization (such as a diminution in fuel consumption and CO$_2$ production or increase in system stability), some technical features need to be solved first. Among them, the following can be listed:

- EV’s influence on power system and increase in energy demand due to battery loading,
- lack of sufficient charging infrastructure,
- insufficient amount of ‘green’ energy from RES needed for battery loading. This aspect is important because charging EVs with energy from fossil fuels has almost the same ecological impact as driving traditional vehicles.

Building a charging infrastructure demands investments that are necessary if EVs are going to become widespread. The other aspects may be solved by microgrid implementation and its services, mainly DR. Cooperation between EVs and local smart grids result in a new feature – V2G. This idea is expected to be one of the core technologies for smart grids integrating RES. It is a promising solution for creating energy reserves in smart cities. The availability of capacity is predicted to be very high due to the fact that EVs are parked usually for 92% of the day. Nevertheless, it is crucial to aggregate the capacities of many electric vehicle batteries because the capacity of a simple vehicle is very small. That is why an ICT aggregating control system should be implemented in an urban microgrid area.

V2G allows one to charge or discharge the EV’s battery in a controlled manner. During peak periods, batteries can be discharged up to the selected level to the supply grid. When the supply exceeds demand, V2G operates backwards: surpluses of energy are used for battery charging.

EVs may be considered as one of the most promising solutions for the decarbonization of urban, individual transport. Yet, to make it possible, cooperation with local microgrids needs to be established and a proper infrastructure built.
4. Microgrid services for prosumers

Smart cities deployment means an intrusion of new services as well as technologies that were presented in previous sections. The intrusion of smart meters and ICT systems makes new services possible, i.e. DR and net metering that will be presented in the following section.

Information collected from smart metering systems is distributed by the system to provide DR. Participating customers respond to changes in energy load by demand reductions in return for incentives, usually financial [12].

DR leads to balancing supply and demand. Because it is achieved thanks to reductions in demand level, no huge investments in additional power plants are necessary. DR participants may reduce demand by postponing some energy consumption from peak-hours to peak-off periods [13]. Yet, further reductions are made thanks to gaining awareness and knowledge about energy saving methods (i.e. buying energy-saving household devices or running appliances in ‘eco’ mode).

A load curve shows how much energy a customer consumes during a day. Typically, there are two peaks: antemeridian (08:00–12:00) and postmeridian (16:00–20:00) when energy supply is often insufficient. DR enables one to reduce an energy demand by shifting it in time for hours with energy surplus. Thanks to DR, the 24-hour load curve is getting flatter and peaks are shaved.

There are several types of DR. In price-based programs, the customer is signing a contract with an energy supplier for a chosen price tariff. Prices might vary during a day, week or season or may change in a real-time. During peak-periods, the customer is allowed to use energy but usually has to pay more. Among price-based DR programs, the following may be distinguished:

- Time-of-Use Pricing with minimum two price rates: during and off-peak periods. The process can also vary according to the season or holidays. Tariffs are usually defined for a long period of time and that is why Time-of-Use Pricing cannot respond to an actual energy demand in a detailed manner;
- Critical Peak Pricing with established price tariffs. Yet, during peak-periods on selected days there is a high, critical peak price set;
- Real-Time Pricing in which prices can change dynamically, with an hour- or a daytime anticipation.

The second group are incentive-based DR where the customer receives information about the necessity for a demand reduction during a particular period of time. An agreement for that reduction signifies getting an incentive and a rejection of demand reductions leads to charging a penalty. In some of these programs, the customer may be paid for allowing an energy supplier to manage demand remotely during peak-periods. Among the most popular incentive-based DR there are:

- Direct Load Control, in which loads may be remotely switched off and the customer receives benefits;
-Interruptible/Curtailable Rates, where the supplier may cut off all or part of a customer’s energy supply in a given period of time. Also, a customer can make reductions when asked. Though, if he/she refuses, a financial penalty will be charged.
- Emergency DR. Customer reduces load voluntary instead for incentives but is not obligated to make any reductions on request. In this group of DR, it is difficult to forecast possible energy savings;
Capacity market Programs. Reduction is propounded by a supplier. Customers may notify their participation instead of benefits. Yet, if they commit themselves to a decreased demand and then refuse, a financial penalty will be charged;

Ancillary Service Market Programs. Consumers are declaring their readiness to make a reduction in energy consumption for an actual market price. If their offers are accepted by an energy supplier, they are counted as a power reserve that can be used in peak-period or during grid instability;

Demand Bidding Programs often dedicated to commercial and big energy consumers. Customers declare a possible reduction that can be used for a given price. If an energy supplier agrees, the customer is obligated to make the stated reductions.

Implementation and dissemination of DR requires solving some challenges: standardization, customers with very variable energy usage patterns, a sudden growth of a demand after a reduction period, forecasting energy demand with reference to changing weather conditions, valuation of a base customer’s energy usage pattern used for calculating reductions made and financial incentives earned.

DR deployment can be supported by local, urban microgrids with smart meters installed. Smart grids can aggregate benefits for all residents in a given city area where such a grid is implemented. As it was mentioned in previous sections, the prosumer is able to produce energy. That connects the possibility of selling surpluses to a grid as well. That process can be intricate for a customer. One of the solutions that can encourage prosumers to actively participate in the energy market is net metering.

Net metering is dedicated for single energy consumers such as private households that have installed micro-RES-like photovoltaic cells, wind turbines, small fuel cells or possesses an EV. Its batteries can be charged during off–peak period and store energy. Later, during peak-periods it can be sold to a grid or more likely – could function as a reserve or other ancillary services.

Net metering is about giving prosumers financial benefits thanks to reductions in energy charges. The prosumer may produce, buy or sell surpluses at any time [14]. This is intended to stimulate RES dissemination in households, making a local community more ‘energy active’ – that means a community of prosumers instead of passive energy consumers.

To make net metering more convenient, smart meters need to run in two opposite ways: one during energy buying and the second one during energy selling. The amount of energy bought minus the amount of energy sold gives a ‘net’ amount of energy that the customer will be charged for [15].

Implementing net metering in smart cities may be significant for microgrids, RES and prosumers’ popularization. Nevertheless, there are some aspects that have to be solved: support and promotion of only some chosen types of RES may have a negative impact on a grid; an accurate specification of possible participants of net metering has to be made; a designation of any additional charges for the customer’s participation in a program; defining an infrastructure considering the rules of settlement, aggregation of data, possible limits of energy sold, etc.

Combining microgrids with RES and net metering can be a good solution for gaining local stability and effectiveness of an energy supply or even, in particular cases, local energy independence.
5. Internet of Things for data management in smartgrids

One of the main features of a smart grid is two-way communication between the power system operator and the final energy consumer. From each household, a lot of different data can be transferred, i.e. the level of energy usage (including participation of smart loads), possible breakdowns, amount of energy produced in a household (if some micro-RES installations are present), data from demand response programs.

In comparison to a traditional, centralized power system, two-way communication is a major change. Up to now, only energy usage data was periodically read from an energy-meter. With a smart grid, thanks to intelligent meters and information management systems that can be installed in households, a large amount of collected data grows significantly. Unfortunately, this growth can be an opportunity as well as one of the possible technical barriers to smart grid deployment. This is because the existing infrastructure usually is not prepared for such broad communication. This builds a gap for some new solutions that can be introduced into smart grids. One of them can be the Internet of Things (IoT).

In the IoT, the concept is distinctively addressable: various physical objects are connected to the Internet. They can identify themselves to other devices based upon the TCP/IP stack [16]. Distinguishable, independent, autonomous, adaptive, reactive and self-configurable objects interact and cooperate constantly with each other to ensure ubiquitous communication via the Internet [17, 18, 19, 20, 21]. In IoT data management, devices become context-aware, organize themselves, transfer information and respond to varying, dynamic circumstances.

In smart grid data management, IoT can be implemented for tracking behaviors in electrical vehicles. Data collected from these vehicles can be further used for building user-driven patterns. These patterns are later used by the system operator for forecasting energy demand or for planning charging infrastructure development as it points toward places where the density of EVs is high.

The next point of implementing IoT is enhanced situation awareness that might be gained by having sensors deployed in smart buildings or in renewable energy power plants. In smart buildings, numerous loads can be managed automatically by scheduling their usage due to, i.e. energy prices and inhabitants’ routine, habits. For typical energy consumers, the idea of energy efficiency is quite well known but subsidiary to their desire for comfort and convenience [22]. That is a point in which IoT may be useful, as numerous features could be executed remotely, reflecting the consumer’s preferences.

In RES power plants (either big or small, dispersed ones), IoT sensor devices may report changing weather conditions that are crucial for load forecasts. What is more, thanks to IoT, these power plants may be remotely switched off or on.

Some IoT sensors can be implemented in smart buildings for monitoring household parameters. Temperature, insulation, CO₂ level or humidity can be improved if needed by turning on/off air-conditioning, heating, ventilation or curtain windows with automated window shades, thanks to IoT management devices.

IoT can enable more dynamic energy pricing due to real-time collected data and smart meters installed in households. This can improve DR program performance and gain benefits for the power system operator thanks to a better balancing of demand and load.
As a last feature, IoT can furthermore advance the quality of the smart grid’s self-healing. This is because IoT can detect random conditions or breakdowns and respond swiftly. As an effect, the smart grid may switch from a wide grid to an islanded mode and operate in it until the system is again stable.

6. Conclusions and further discussion

Cities have to face new challenges thanks to growing energy demand. The traditional, conventional energy supply system based on fossil fuels is becoming inefficient due to increasing urban population. What is more, it has high environmental, social and health costs.

Today’s efforts in creating benefits for citizens should aid one to provide an acceptable sustainable legacy for future generations. Sustainable city development is becoming present in cities all around the world and sustainable energy, based on local Renewable Energy Resources, can be an important issue of that development.

A combination of RES implementation, urban microgrid deployment, electric vehicles and storage systems popularisation and common usage of Demand Response and Net Metering programmes may have a major influence in going towards smart, green cities of the future.

All new solutions brought by microgrids can help customers to become more aware of energy consumption. But what is more, they are gaining the possibilities of producing energy in households. This is a huge change from a passive to an active role in the power system and energy market. To illustrate these new opportunities, main technologies that can help prosumers were presented in the paper. Although all of them tend to be quite mature and ready to use, there are still some aspects that can be discussed.

One of the most important of these is the ethical aspect of microgrid intrusion. Data gathered by ICT systems in such grids may affect customer’s privacy and be used for theft or to make their lives unbearable [23]. Participation in DR or possessing a smart meter implicates sending data about daily habits, held devices or absences, i.e. during holidays. Similarly, the use of EV can lead to unpleasant implications such as theft of data about typical routes and visited places.

Implementation of smart grids and meters means new investments and this results in costs that have to be incurred. Consequently, energy prices may grow higher. Some consumers will probably also not understand or need new services. These two reasons may lead to excessive reductions in energy usage ‘just in case’ to avoid higher bills. As an effect, the scale of so-called energy poverty may arise. All these aspects need to be taken into consideration and may be a subject of further discussion about prosumers-aiding technologies.
Bibliography


Streszczenie

Streszczenie. 66% całkowitej konsumpcji energii przypada na miasta, które starają się radzić z tym trendem oraz unikać wzrastającego poziomu zanieczyszczenia oraz emisji gazów cieplarnianych poprzez stawianie się bardziej „zielonymi” i „inteligentnymi”. Dzięki mikrosieciom i technologiom z nimi współpracującymi pojawił się nowa wizja konsumenta energii. „Prosument” jest zdolny nie tylko do zarządzania swoim popytem w sposób świadomy, lecz także do produkcji i sprzedaży energii elektrycznej. Celem niniejszego artykułu jest zaprezentowanie kluczowych technologii mikrosieci wspomagających kształtowanie się społeczeństwa prosumentów na obszarach zurbanizowanych.

Słowa kluczowe: mikrosieci, sieci inteligentne, zarządzanie stroną popytową, prosumenti