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Contents

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ESCO FINANCING MODEL AS A MEAN OF ENERGY EFFICIENCY IMPROVEMENT WITHIN PUBLIC SECTOR

Abstract
Paper presents the possibilities of investments financing scheme within energy efficiency using ESCO financing model, in the context of obligations related with Directive 2006/32/EC. The purpose of this paper is to analyze ESCO model as a part of public-private partnership (PPP). Article discusses benefits and potential risks associated with ESCO model investments. Cited are also good practices.

Keywords
ESCO, energy efficiency, Directive 2006/32/EC, public-private partnerships, energy savings

Introduction

Issues related to the economy, energy, resources and the environment are nowadays combined with one another. A low carbon economy is in line with issues related to the concept of sustainable development. Sustainable development has been defined in many ways, but the most frequently quoted definition can be found in *Our Common Future*, also known as the Brundtland Report:
"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." [1]

21st century has brought a number of global challenges, which impact on regional and local level is and will be still increasing. Continuing the functioning of economies, in line with model of exponential growth - developed in the last century, can lead to instability of global economy. The answer to these challenges is the concept of low-carbon and resource-efficient economy, developed by the European Union.

A low carbon economy is a human activity that brings profit to investors and domestic economic growth, while minimizing the negative impact on the environment. This growth – here understood as an aspect of sustainable development - should be implemented by the most effective use of available resources, while ensuring minimization of negative environmental impact. The European Union defines 'low-carbon economy' through the target, agreed at international level, in the form of maintaining atmospheric warming below 2°C, as a contribution to the sustainable development of the EU member states. To achieve this goal, greenhouse gas emissions must be reduced by 80-95% till 2050, compared to 1990, which means that there is a need to reduce current emissions by 40% till 2030. [2] Reducing emissions is not only a huge social benefit - after all less amount and intensity of weather extremes is less human tragedies, incidentally cleaner air is billions saved on health care - but also tangible economic benefits: increased employment, innovation and improvement of the competitiveness of the EU within the global market. Suffice it to say that the market for low-carbon products and services is estimated at more than $ 3 trillion. At the same time among the five countries with the highest number of patents for "clean" technologies, there is only one from EU member area.

The main objective of the strategy for smart, sustainable and inclusive growth, "Europe 2020", adopted by the European Council in June 2010, is the reduction by EU Member States, primary energy consumption by the year 2020 by 20% in comparison with consumption from 2010. Extremely highlighted, except the shift from fossil fuels to renewable energy sources, is the aim to increase the efficiency of energy use, reduce energy demand and attempt to decouple it from economic growth. [3].
Given that buildings absorb about 40% of final energy, significant savings in this field can bring investment in energy efficiency of buildings. In the opinion of the European Commission (EC), the widespread use of energy

efficient equipment and technologies, combined with the use of renewable energy is a cost-effective way of strengthening the security of energy supply. Despite significant progress in reducing the energy use, recent EC research suggests that without further action, EU will be able to achieve its energy efficiency target only half. The Commission paid attention to the fact that public-private partnership is one way aiming at increasing energy efficiency. [4]

In October 2014, the provisions related to the new climate and energy package – 2030, were adopted. The European Commission proposed two main objectives: the reduction of greenhouse gas emissions by 40% compared to 1990 and increase the share of renewables to 27% of the total electricity consumption. It also established 27% improvement in energy efficiency, but adopted as an indicative target, not a binding one. Reducing greenhouse gas emissions in 2030, has already been identified as a target for the implementation within the document Energy Roadmap 2050. It is not a document formally adopted, but sets the direction of EU action [5].

Over the last 10 years Poland has made a huge progress within energy efficiency issues. According to the Ministry of Economy the energy intensity of GDP fell by 1/3 [6]. Still, the energy efficiency of the Polish economy is about three times lower than in most developed European countries and about two times lower than the average efficiency in the EU. Additionally, primary energy consumption in Poland, related to population, is almost 40% higher than in the EU-15. This dependence indicates the great potential for energy savings in Poland, characteristic for intensive growing economy [6].

The huge potential for energy savings lies in the resources of municipal economy. In particular, these resources should be attributed to public buildings and public lighting. According to the authors of the report, McKinsey & Company, eight of the eleven most important methods of reducing CO_2 emissions is attributable to the building sector. These include the most basic one that improve the tightness of buildings, insulation of attics and spaces in walls, to more advanced one, designed to equip existing buildings with installations, leading them to the low-energy consumption standards or even passive one. The authors estimate that full implementation of the above parameters will reduce energy consumption for heating/air conditioning systems to ~30 kWh per m^2 per year, which will translate into a reduction in emissions by ~15MtCO_2e to the year 2030 [7]. In most cases, the reduction of energy consumption in the public sphere, and hence its cost, is associated with high investment. These expenditures will be difficult to bear by the local government units (LGU) in Poland, because they are in difficult financial condition. Debt of local government units in 2014 amounted to PLN 72.1 billion. Nationally, their debt is just over 37% of their income [8]. On the other hand, there is a marked increase within investment spent in the sector of local government units - 19.2% y / y in 2014. against (-2.6%) y / y in 2013.

Given the limits of permissible debt of local government units, their income and planned level of service and repayment obligations, the ability of credit investments related to energy efficiency is unrealistic. Particularly important in this situation is to create appropriate institutional and regulatory tools, which will enable the implementation of investments aimed at energy efficiency of local government. The European Commission puts the emphasis on the ESCOs. According to Directive 2006/32/EC of 5th April 2006 on energy end-use efficiency and energy services, ESCO is entity that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria of energy service companies, or provide other energy efficiency improvement measures in the plant or in the premises of a user [9]. These services, however, are rendered in an innovative way. The company ESCO dedicates its financial resources for the implementation for the customer, i.e. energy consumer, modernization project. All the costs spent on investment by ESCO (including salary) is recovered by payments spread over time, which source are savings related to the implementation of measures to increase energy efficiency.

These services, however, are provided in a different way from the traditional form. Company ESCO commits its financial resources to carry out the client undertaking modernization and recover outlays (including remuneration) by payments spread over time. Payments made by the customer come from the generated savings in energy costs. [6]. This model is often called ‘financing by a third party’. In the case of the budget deficit and growing public debt savings can bring real benefits to public finances and taxpayers, leading to a reduction in expenditure. ESCO model supports significantly the implementation of obligations of the state in terms of energy efficiency, taking advantage of the private capital. In general, ESCOs act as project developers

for a comprehensive range of energy conservation measures and assume the technical and performance risks associated with a project. When an ESCO implements a project, the company's compensation is directly linked to the actual energy cost savings.

Why ESCO model?

ESCO model first appeared in the US in the seventies of the twentieth century. In the United States, this model suffered with the rest of the world's biggest successes. The emergence of ESCOs was related to the global energy crisis. Due to the enormous increase in energy prices, entrepreneurs were wondering how they can reduce their energy consumption. The first company, which proposed solution was a company from Texas - Time Energy. They introduced a device, which automatized turning on and off lights and other appliances, which aim was to help generating significant savings in energy costs (for large-scale production). However, the market did not accept this offer promising. Customers doubted that the cost savings that they will make by purchasing the device, actually materialize and will have a significant impact on reducing energy bills. Time Energy Company, however, did not give up and decided to meet the expectations of potential customers. They offered the device and its installation without incurring upfront costs, and wished only a percentage of the savings that the device generated within company. With this move the company achieved higher sales and a higher return on capital, as the savings proved to be very large [10].

A significant part of the investments related to energy efficiency is associated with high economic attractiveness, both for the potential recipient of the ESCOs, as well as for the companies providing the service. Due to the fact of quite a large diversity of potential investment prospects and the multiplicity of concepts and methods of their implementation (depending on customer requirements), one should think carefully about the concept most appropriate for use in a particular case. ESCO method must not only relate to the financing of investments. This model is often characterized also by managing the investment during its operation (the duration of the PPP contract). This is primarily for further energy efficiency optimization. Another essential advantage of the method is to ensure that ESCO achieve energy and cost savings.

Customers of ESCOs can be either public sector, commercial or households (to a lesser extent). Each sector has different characteristics and has a different development potential. The aim of this article it to explain the issues related to the ESCO model, applicable primarily in the public sector. The reason for this is that within this sector lies a very large potential for energy efficiency, which however, still remains untapped. In the public sector we are dealing mainly with two types of investments. The first type are investments related to modernization of public lighting. They are characterized by relatively short periods of return and are relatively easy to perform and contracting. They are the most popular ESCO investments type among local governments [11]. The second type of investments are the modernization of the energy utilities. These projects are more complex and require more thorough preparation and knowledge, both from the potential customer and ESCO. Above all, these projects are characterized by long periods of recovery, which is connected with the necessity of signing a PPP contract for more than 10 or even 15 or 20 years. A promising prospect for the ESCO market in Poland is, in that case, grouping of tenders for the purchase of electricity (increasingly used by the public sector) and investments in improving energy efficiency.

The tendering and types of ESCO contracts

The investment in ESCO model each time is associated with signing the relevant agreement between the parties - the client and Energy Service Company (ESCO). Until then it is necessary to make preparations, which should include (in the case of a public entity) [12]:

- inventory of existing equipment and costs analysis associated with its operation
- estimation of energy consumption and its costs
- preparation the specification of contract basic terms and conditions and proposals for tender conditions

At each of these stages, both during the inventory, estimation of energy consumption and preparation of tender documents, it is highly recommended to consult with qualified specialists in data fields (respectively: economists, engineers, auditors, lawyers) to adequately determine the current status and the savings that are possible to generate. This is the starting point for the proper preparation of tender and related documents. Then it is recommended to consult on possible technology and the scope of their implementation, and to

conduct a preliminary analysis costs of reaching them. Only after such a procedure can a potential local government unit, prepare for tender announcement. Due to the fact that the potential investment is cost intensive, and the agreement signed with ESCO, which wins the tender, long-term (10, 15 years or more), it is recommended that qualified companies/experienced individuals should supervise the legal proceedings and agreements in the field of PPP (public private partnership).
The agreement, which is signed between the public partner (in our case), and the ESCO company is called the energy performance contracting (EPC).

Within ESCO model one can distinguish between five basic types of agreements (contracts):

First, The contract supply of electricity/heat *(*delivery contracting*).* In this model, ESCO is committed to both energy supply (electricity/heat), as well as infrastructure investments in equipment in order to contribute to increase energy efficiency. This service usually includes the maintenance service of systems. In this case, the settlement between the ESCO and the customer is based on payment which covers 2 factors:

- the fixed component (which includes the cost of repayment of the investment and other fixed costs)
- the fee for a variable amount of energy delivered

The diagram below shows the main assumptions of described concept.

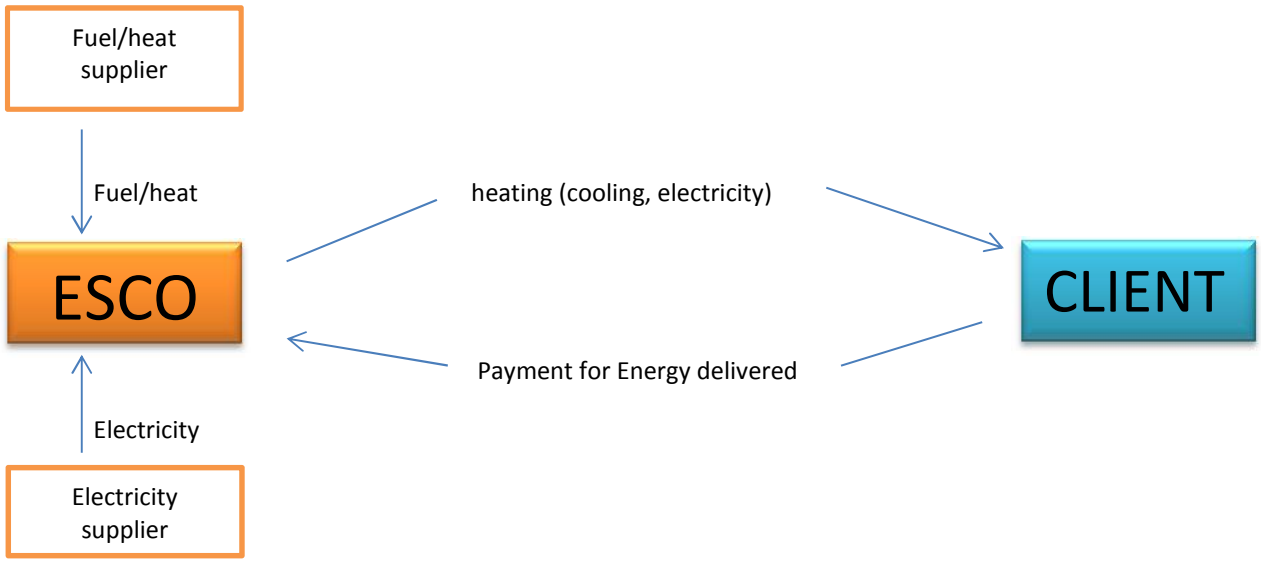

Fig. 1. Diagram of the investment on the basis of delivery contracting
Source: Author's

Second, Guaranteed Savings Agreement. Within this agreement, concluded between the customer and the ESCO, technical and financial conditions and the method of measurement of energy savings, as well as the warranty of savings are covered. In the agreement, the emphasis is on reducing the demand for energy (improving energy efficiency). Remuneration of ESCO is based on savings achieved. Within the duration of the contract, cost payback for ESCO includes savings achieved increased by financial costs. One can also encounter contracts where cost savings are to cover management costs, plus financial costs. This type of contract is particularly advantageous from the point of view of a potential customer. It provides guarantees on a certain level of "energy performance", parallel with the transfer of risk to ESCO. Obtaining adequate energy yield guarantees the repayment of the investment costs. This agreement precisely defines the rules of settlement between the ESCO and the owner of the object. The diagram below shows the main assumptions of described concept.

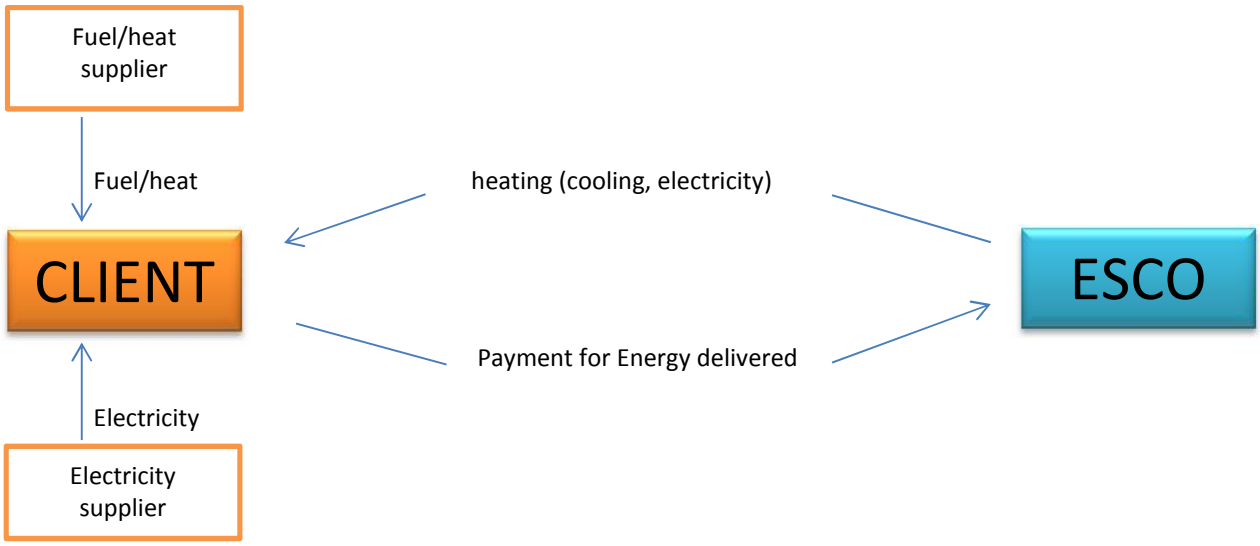

Fig. 2. Diagram of the investment on the basis of energy performance contracting
Source: Author's

Third, Shared Savings Agreement. These are contracts in which the ESCO assumes the risk related to energy saving and the financing is the responsibility of the customer.

Fourth, First Out Contracts Agreement. These agreements provide the total assignment of savings on ESCO for a specified period of time (First Out Contracts), in which all the savings on energy costs are used to pay interest and amortization of debt until full repayment.

Fifth, *Chauffage* Agreement [13]. Agreements on energy management, under which the ESCO is paid for the provision of energy services, e.g. the so-called *Chauffage* Agreement in terms of heating or lighting of given space. Within the *chauffage* contract type, ESCO guarantees that energy costs borne by the public partner will be reduced by a certain percentage. During the period of the contract, the ESCO assumes responsibility for paying the owner's bill for the use of media, and the owner agrees to pay the ESCO certain percentage of the historical cost of energy. ESCO usually uses discounts of around 15%. Periods of the contracts vary between 7 and 10 years, and the ESCO is supposed to receive payments to recover costs of investment and pay the bills of the owner for the use of the media. ESCO generates a return through the provision of sufficient savings to compensate for the discount given to the customer. Within the *chauffage* contract type, performer - ESCO becomes the owner of the power processing system located on the premises belonging to the customer. Cooling and hot water supply are considered to be flows of processed energy (e.g. Electricity can be used in the cooling system and the boiler fuel can be used for heating water). After signing the contract, the contractor uses and maintains the installations belonging to the client, it pays the bills for the energy consumed by the power processing system and makes investments in premises to increase their efficiency. Within the term of contract validation, the contractor sells the "processed" energy, giving the customer a predetermined "discount", obeying the previously agreed minimum level of quality of "processed" energy supply. The diagram below shows the main assumptions of described concept.

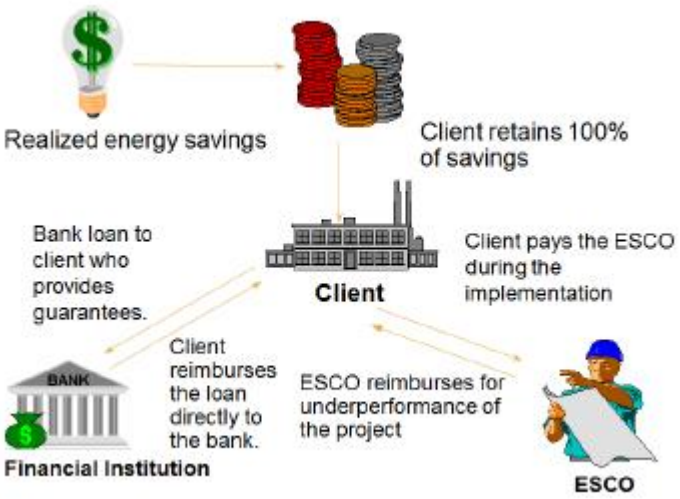

Fig. 3. Diagram of the investment on the basis of *chauffage* agreement
Source: [14]

The above described agreements may be concluded in different variants. If the customer expects rapid obligations repayment to the ESCO, and then self-management of infrastructure, he can allocate for this purpose all the cost savings achieved as a result of modernization. The customer may, however, wish from the beginning to participate in cost savings. In this case, the repayment period will be extended accordingly. These aspects, in detail, should be governed by public-partnership agreement. There are also situations in which a client from the beginning of the contract recovers part of the guaranteed energy cost savings (e.g. 30%) and participation (e.g. 50%) part of the larger savings guaranteed (if any). This situation is shown in the following figure.

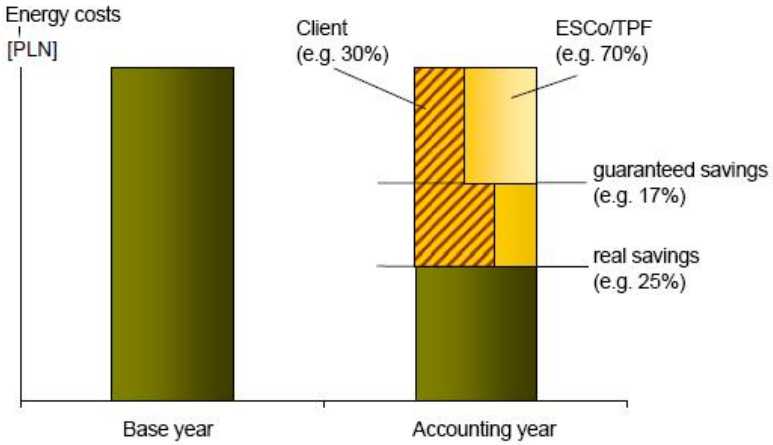

Fig. 4. Distribution of the savings associated with the increase in energy efficiency
Source: [15]

Barriers for ESCO market development within the public sector in Poland

In accordance with art. 6 Directive 2006/32/EC on end-use of energy and energy services, member states should ensure that "there are sufficient incentives, equal competition and level playing fields for market actors other than energy distributors, distribution system operators and retail energy sales companies, such as ESCOs, installers, energy advisors and energy consultants, to independently offer and implement the energy services, energy audits and energy efficiency improvement measures…" [16]. The quoted provision in the Directive means that each Member State should create the right conditions and, above all, incentives for the development of the energy services market (including ESCOs) in Poland.

Currently any system for permanent monitoring and obtaining precise statistical data on the ESCO market in Poland does not exist. With high probability it can be found that monitoring process is carried out by leading companies that are present on the Polish market and provide the above mentioned services. According to estimates cited by the Institute of Environmental Economics, turnover in this market in the year 2011 in Poland

was closing with the minimum value PLN 40 million, while the top was estimated on PLN 100 million. The report's authors agreed that the value of PLN 40 million is probably an underestimate therefore it should be assumed value of PLN 100 million, as the real defining the upper limits of the size of the market in 2011 [11].

The following table presents the assessment of the implementation of the European Directive 2006/32/EC in the context of the development of the ESCO market in Poland.

Table 1: The evaluation of the implementation of recommendations resulting from the Directive 2006/32/EC, in the context of the development of the ESCO market in Poland

Provisions of Directive 2006/32/EC in the context of development of the ESCO market	**The level of recommendation implementation in Poland**
Creating a fund and appropriate programs directed to support and promote the development of energy services market (including the creation of new start-ups)	Insufficient
Exchange of information and best practice among other member states	Insufficient
Ensuring the availability of high quality energy audits	Insufficient
Stimulating investment agreements in the formula of "third party financing" - TPF	Insufficient
Providing access to skills acquisition systems, accreditation and certification schemes for providers of energy services, energy audits and energy efficiency improvement measures	Insufficient
Providing space on the market and fair competition for market actors (except for energy distributors, distribution system operators), for example ESCOs, so that they can offer energy services, audits and measures to improve energy efficiency	Insufficient
Elimination of instruments (national legislation), that unnecessarily or disproportionately inhibit or restrict the use of financial instruments for energy savings in the market for energy services or other energy efficiency improvement measures	Insufficient

Source: Author's, on the basis of the Directive 2006/32/EC … [16]

From the above table it can be inferred that in Poland the ESCO sector does not develop in accordance with the provisions of the aforementioned directive. The main barriers to ESCO market development in Poland are [11] [17]:

- Lack of legislation - concerns of the officials, related to the legality of the use of this formula. Projects implemented in the formula of PPP are very often checked and reviewed by institutions such as: RIO, NIK, OPP, ABW, CBA, CBS. In 2014, 41% of the units carrying out projects in PPP formula, were subject to one of these institutions [18]
- Unacquaintance of ESCO mechanism - in the opinion of representatives of ESCO, contracts formula with guaranteed savings is very poorly recognized among the public administration
- ownership issues - applies to lighting. In a large part of the country, owners of lighting systems are distribution network operators (OSD). At the same time they sell energy and conserve installations. Therefore, replacement of lighting (LED), and thus - reducing the bills of customer, is for them quite inconvenient
- Competition from grants - most of the available grants excluded the possibility of co-financing from ESCO model
- Lack of ESCO mechanism understanding by public sector
- The issue of "energy effect ownership" - it often happens that generated savings do not remain in the budget of the unit, but it causes that in subsequent years the amount allocated for energy are reduced

Recommendations for the development of the ESCO model in Poland [17] [19]:

- Striving for maximum simplification and transparency of legislation
- Definitely more activities should be taken by the government administration in popularizing knowledge about the ESCO model
- Clarification of issues related to the impact of the obligations arising from PPP contracts on national debt level
- Reclassification of remuneration for the private partner to - respectively - categories of current expenditures and property (for public entities)
- Creation and implementation the standards related to the organization of the process of project preparation and chart the desired "access track" (scenario, necessary next steps of procedure) or the necessary provisions of the agreement. In many countries, standards developed by the public authorities are mandatory
- Establishment of an intersectional ESCO panel - the development of institutional, legal, administrative solutions, facilitating the functioning of this sector
- Allowing co-financing ESCO energy efficiency projects funded with grant money form EU
- Establishment of a Strategic Coordination Center within the PPP formula for public sector (including ESCO)
- Creation within the Ministry of Economy organizational unit, responsible for the implementation of PPP in Poland (including the department responsible for ESCO services sector). Unit shall perform the functions of: programming, coordination, monitoring, analysis, legislative
- Introduction of the provisions promoting ESCO services in the regulations to the Public Finance Act
- Creation of a National Contact Point for ESCO, as an institution providing know-how of both - ESCO and beneficiaries of investments in improving energy efficiency. The activities of the Contact Point should include, among others, support for public finance sector units, local government units, which intend to save energy in the ESCO formula
- Development by the government framework agreements for ESCO contracts and contracts for energy efficiency (Energy Performance Contracts), related instructions and materials procurement. Such agreements would significantly facilitate the use of ESCO contracting by the public finance sector entities, showing ESCO contract model in the meaning of a public institution, enabling the use of incentives and privileges.

Adoption of a national campaign for energy efficiency. Such campaign is necessary to effectively stimulate actions on energy efficiency in society. It is necessary to allocate budget funds for campaigns. A national campaign should also include information about the ESCO Contact Point.

Good practice in the field of energy services in Poland

Energy services provision history in Poland has its roots back in the 90's. It is related to the democratic changes that enabled companies and public institutions to establish international contacts with entities that have successfully implemented the ESCO model in other countries in Europe and in the United States. The first completed projects were small in size and have a rather demonstrative character. As one of the pioneers of the market in the early 90s was considered the Municipal Heat Supply Company from Krakow. It was involved in two international projects. The first - carried out under the supervision of the World Bank - concerned the modernization and replacement of a thermal system. The second - implemented jointly with the Department of Energy of the United States - Energy Efficiency Program and Clean Fossil Fuels for Krakow. Then, the first commercial company - ECOGY Sp. z. o.o. aimed at modernization of coal-fired boilers, based on the fundamentals of the model ESCO. The founders of the company was Japanese – American – Polish consortium.
The end of the 90's is associated with entering in to the polish market of large international players specialized in the ESCO model, who decided to open their branches in Poland. Companies as: Dalkia, MVV, Landis & Gyr (later in the group Siemens), Ineoineo or Auxima Services should be mentioned [20].

Table 2: Thermomodernization of public buildings in Radzionków municipality

Thermomodernization of public buildings in Radzionków municipality		
Main targets	**Modernization scope**	**Results**
▪ savings on the expenditure incurred for heat and electricity ▪ maintenance the premises for 10 years - from 2010 to 2020 ▪ reduction of CO2 emissions ▪ upgrade the standard of premises	▪ thermo-modernization of central heating and heat sources ▪ modernization of the lighting sources ▪ implementation of a system thermal management and lighting	▪ replacement of 762 pieces of windows ▪ modernization of 3 boilers ▪ exchange 1 179 lighting points ▪ improving the aesthetics of the city ▪ positive impact on the environment - the expected reduction in CO2 emissions by 2020 - 4 550 tons ▪ thermal energy savings - 54% ▪ electricity savings – 40%

Source: [21]

The thermomodernization investment in Radzionków municipality can be recognized as one of the best examples of public-private partnership in Poland. Private partner of municipality was a company - Siemens sp. z. o.o. The main task of the private partner within the project was to create, finance and manage thermal energy services. Company also gave a full guarantee that the established economic effect will be achieved. The agreement covers a period of 10 years - from 2010 to 2020. During this period, the Contractor has to maintain investment in working order to ensure the level of guaranteed savings of thermal energy and electricity. Siemens took it upon themselves to maintain the facilities in proper technical and aesthetic condition, in full scope of design and material realization of the investment. The amount of estimated savings thanks to the modernization equals PLN 3 417 000,00. Annual maintenance costs of modernized buildings is 79 570 PLN/ year.

Table 3: Comprehensive thermomodernization of public buildings in Karczew municipality in the formula of public-private partnership

Comprehensive thermomodernization of public buildings in Karczew municipality in the formula of public-private partnership		
Main targets	**Modernization scope**	**Results**
▪ reduce the cost of heat and electricity in buildings ▪ maintenance and management of heat sources to the extent necessary to maintain the specified environmental effects throughout the duration of the PPP contract ▪ preservation of the ecological effect	▪ thermo-modernization of central heating and heat sources ▪ thermomodernization and maintenance of public buildings (maintenance, repair, overhaul) ▪ modernization of the electrical installation ▪ implementation of thermal management and lighting system	▪ projected savings of thermal energy - 56% ▪ projected savings of electricity - 21% ▪ Improving the functioning and the aesthetics of public buildings

Source: Elaboration based on presentation given at the conference: "Comprehensive thermal utilities in the Karczew municipality in the form of a public-private partnership, involving the National Fund for Environmental Protection and Water Management grants"

Karczew municipality received a funding from the National Fund for Environmental Protection and Water Management (NFOŚiGW) in the form of grant for thermomodernization of buildings within the Green

Investment Scheme (GIS). Two contracts(agreements) for subsidies were signed. The total value of subsidies amounted to PLN 1 434 180,00. The first agreement was implemented in the form of grant - except for the PPP formula. It concerned the thermomodernization of Municipal Office in Karczew. The second one concerned the thermomodernization of six educational buildings in the municipality of Karczew and it was implemented within PPP formula. On the 2nd of January, 2013, the municipality Karczew signed the first agreement in Mazovia, regulated under public-private partnership. Private partner, as in the case considered above was the company Siemens sp. z o.o. The value of contracts under the PPP is PLN 10 489 341.00. Modernization formula, which was chosen by Karczew municipality is particularly interesting not only because of the PPP, but also because it is combined with the grant from the National Fund.

Summary

Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the European Union. Energy efficiency in buildings is key to achieve EU objectives, namely reducing greenhouse gas emissions by 80-95% by 2050 (relative to 1990 years). However, for this to happen the energy services market in Europe should be strengthened. Legal uncertainty, lack of knowledge and awareness of environmental attitudes are the biggest barriers for further development of the ESCO market, including in Poland.

The European Court of Auditors draws attention to the mismanagement of money spent at national level, related to the efforts to increase energy efficiency. According to the Court the money in individual member states have been spent improperly, because it does not provide a return on investment in the form of future energy savings. According to the former President of the European ESCO Association, Stéphane Le Gentil, energy efficiency was clearly secondary. If used EPC contracts, the situation would be quite different, as within the EPC system, energy saving is guaranteed, because it is the basis for the reimbursement of investment costs for ESCOs. [22]

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MICROBIAL FUEL CELLS – MINIREVIEW OF TECHNOLOGY AND APPLICATION

Abstract
Nowadays it can be seen that interest in renewable energy is growing up significantly. Among others we can observe huge development of fuel cells. These devices are used mostly for power production but it is not their only application. There are lots of different types of fuel cells. One of the lasts inventions are microbial fuel cells (MFC), which are based on use of microorganisms. There are lots of research focusing on constructions and application of MFC in different ways.

Keywords
Microbial fuel cell, microorganisms, wastewater, membranes, electrodes

Introduction

Fuel cells are electrochemical devices that produce useful energy in the form of electricity as a result of a chemical reaction of hydrogen with oxygen. By-product of this process is water. In microbial fuel cells transformation of organic matter to electricity occurs with the participation of isolated and purified enzymes (most commonly used dehydrogenase and oxidase) or microorganisms cultures. Direct application of microorganisms in the microbial fuel cells eliminates the need for isolation and purification of enzymes, which is often difficult and expensive. Additionally it provides the natural environment for biological processes - the cell. But also leads to the necessity for ensuring adequate living conditions for microorganisms [1]. It also should be mentioned that there are two main types of microbial electrochemical technologies (MET) - microbial fuel cells (MFC) and microbial electrolysis cells (MEC). Microbial electrolysis cells partially reverse the process to generate chemical products like hydrogen or methane from organic material by applying an electric current while microbial fuel cells produce electric current from the bio-decomposition of organic compounds.

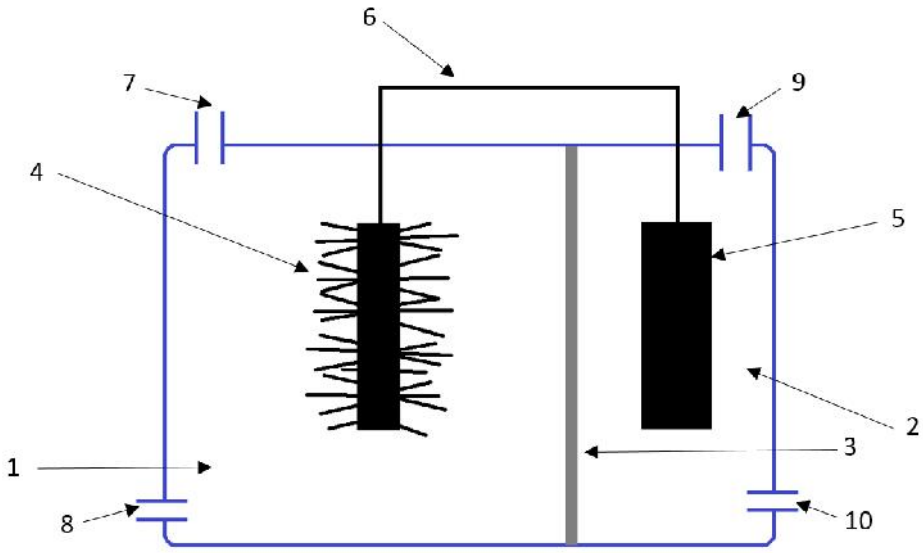

Fig 1. Scheme of typical two-chambered MFC. 1 – anodic chamber, 2 – cathodic chamber, 3 – membrane (PEM), 4 – anode, 5 – cathode, 6 –electric current , 7 – feed input, 8 – feed output, 9 – oxygen input, 10 – cathodic chamber output
Source: Author's

Typical microbial fuel cell consists of anode and cathode chambers separated by an ion-selective membrane permeable for ions. Usually membrane is permeable for protons. Then it is called as proton exchange

membrane (PEM). Another popular type of MFC is one-chambered MFC, where cathode come into directly contact with surrounding atmosphere.

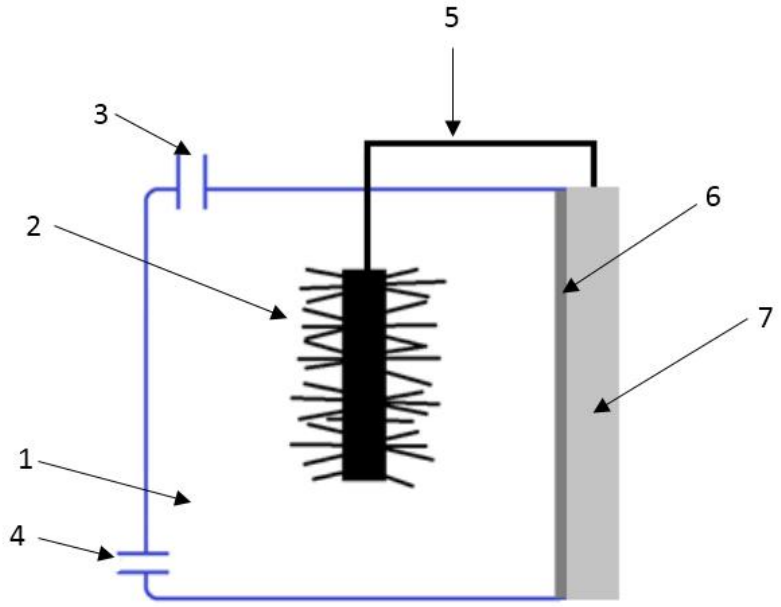

Fig 2. Scheme of one-chambered MFC. 1 – anodic chamber, 2 – anode, 3 – feed input, 4 – feed output, 5 -electric current, 6 -membrane (PEM), 7 – cathode
Source: Author's

Operating principle of the simplest MFC is based on the conversion of chemical energy contained in organic compounds directly into electricity. It is possible because of oxidation of organic matter by microorganisms (which act as specific biocatalysts) contained in the anode chamber and transfer of electrons to the nearby electrode. Simultaneously the release of protons into solution takes place. This process is performed under anaerobic conditions. Then released electrons move toward the cathode through an external electrical circuit which in presence of the potential difference between the anode and the cathode produces electricity. At the same time protons generated on the anode migrate through the semi permeable membrane to the aerobic cathode chamber. At the cathode chemical or microbial reduction occurs in which protons in conjunction with electrons and oxygen are forming water [2].

Performance of MFC and parameters affecting on its efficiency

Efficiency of microbial fuel cells is a key issue in the context of their use as competitive technology to produce renewable energy. Therefore, the main challenge to researchers is to create such cell which would generate a large amount of power when fed by industrial or domestic waste. In most cases electricity produced by the MFC is given in the mV or mA (sometimes per square meter of fuel cell anode surface area). While productivity of cells is characterized by various parameters such as: *Coulombic efficiency (CE)* specified by number of transported electrons in relation to the number of electrons theoretically generated by the substrate or of substrate bioconversion rate. Specified biological parameters are also frequently used which is for example chemical oxygen demand (COD) which depends both on the amount of bacterial cells and the kinetics of the processes performed by bacteria or organic biomass availability in provided feed. *Coulombic efficiency* of MFC designed for laboratory needs fed by clean substrate is even 80-99%, but this parameter for cells fed by heterogeneous substrate, e.g. wastewater from industry is even four times lower [12]. It is known that in order to get the maximum theoretical energy in the cell supplied substrate must be completely oxidized to CO_2 simultaneous with efficient transport of electrons to the electrode. Considering this first requirement and heterogeneous composition of the waste delivered to MFC obtaining high efficiency of cell seems to be very difficult. Regarding values of removed COD achieved in MFC, they oscillate between 40 and 60% in the case of heterogeneous substrate, in turn MFC fed with pure glucose gives removed COD on level of 90% [11, 13].

Despite considerable efforts an electrical voltage in an amount corresponding to the theoretical maximum efficiency of work of a single cell, which is 1,14V has not been received yet. So far, a single cell is able to

generate only from 0.3 to 0.7 V [7, 14]. Therefore, lots of researchers are still working on improving performance of MFC technology. The objective of this is creation of such a cell, which produces the highest amount of energy with the contribution of external energy as low as possible [15].

There are many biological, physical and chemical parameters that influence the productivity of MFC. The parameters concern the mass transfer within the biofilm, the oxidation of substrate that is carried out by microorganisms, the electron transfer and the reduction reaction occurring at the cathode. However, the transfer of electrons issue as well as biological activity of microorganisms are the most frequently discussed and studied problems [16]. The amount of power generated by the MFC is primarily determined by the type and density of cells co-creating a consortium of bio-anode [17]. In contrast the rate of bioconversion process carried out by microorganisms depends on the temperature and pH conditions in the MFC. Among the advantages of the MFC functioning in the low temperatures (20-30 °C) is seen as very valuable compared with other methods of bioconversion, but these very low temperatures are sometimes regarded as a limiting factor [12].

An important parameter is also the pH of the solution which is particularly significant in the case of direct contact of bio-anode with supplied substrate. When wastewater is the feedstock it is very difficult to ensure constant pH range, optimal for the growth of microorganisms. On the other hand the oxidation of the organic substances present in the supplied feedstock produces protons, which in theory are transported to the cathode chamber. However, it is noted that this transportation may be difficult, and leads to acidification of the solution in anode chamber [16], what in turn reduces the biological activity of microorganisms and results in decreasing the amount of energy generated in the MFC. Another very important factor which influences the MFC performance is quality of the substrate. Theoretically the more reduced compound is used as the substrate the greater power can be obtained. It is confirmed by the fact, that much lower amount of electricity is produced by MFC supplied with liquid waste than by MFC supplied with pure substrates as glucose. It turns out that the amount of energy generated by the MFC increases with increasing of biodegradable fraction of wastewater. Amount of generated power in MFC also depends strongly on the concentration of oxygen in the cathode chamber and reduction reaction occurring at the cathode may be a limiting factor in its performance. Slight contact between the source of oxygen and the electrode could reduce efficiency of the process [15]. On the other hand admission of oxygen to the anode chamber may cause loss of productivity due to anaerobic metabolism of electrochemically active microorganisms. Therefore, to ensure high rate of reaction on the anode the possible leak of oxygen from cathode chamber must be prevented. An important parameter is also the kinetics of the reduction reaction which can be controlled by the addition of catalysts [12]. The use of MFC in industrial scale is limited by internal resistance of the MFC. Modifications of basic design seems to be necessary to overcome this problem.

Concerning fuel in MFC almost every biodegradable source of organic matter from pure compounds (e.g. acetate, glucose, cysteine, ethanol) to mixtures of organic compounds (e.g. wastewater, animal farm leachate, liquid waste from agricultural and industrial sectors) can be used for production of energy in MFC [3]. It happens due to ability of microorganisms to use different sources of organic matter. By that MFC seems to be the ideal technology for the production of energy from biomass.

Microorganism

The main sources of organisms in the MFC are usually sediments, soil and wastewater rich in bacteria [4,5]. Inoculum from previously activated sludge from wastewater treatment processes or from another previously operated MFC are often used [6,7]. Because of using various kinds of inoculum in the anode chamber representatives of various species of microorganisms could be found in the biofilm. Apart from many unidentified microorganisms there are bacteria belonging to the class: *Alfaproteobacteria, Betaproteobacteria, Gammaproteobacteria, Deltaproteobacteria, Clostridia, Bacteroidetes, Flavobacteria, Sphingobacteria, Deferribacteres, Spirochaetes, Planctomycetes, Nitrospirales* but also fungi, for example *Saccharomyces* and *Pichia* genus [8,9,10]. So far the highest value of the power generated by MFC is achieved with use of multi-species bioanode where microorganisms grow as a biofilm [11]. Mixed culture or microbial consortia seem to be more durable and efficient than single strains. Additionally their isolation from natural sources is much easier. The use of pure cultures have also some technical limitations, mainly due to necessity to ensure sterile conditions and according to this high cost of the process [6]. There are few species of microorganisms characterized below, which are used in MFC as pure cultures with satisfactory performance [42].

Shewanella species - Shewenella is a marine bacteria, which produces trimethylamines, from *Shewanellaceae* family. This bacteria is regular component of the surface flora of fish. Shewanella is implicated in fish spoilage and therefore is associated with the odour of rotting fish. Frequently used strain is fast-growing *Shewenella putrefaciens*. In solid and liquid media, this strain is often recognizable by its bright pink color.

Pseudomonas species - *Pseudomonas* is aerobic, Gram-negative genus of gammaproteobacteria from *Pseudomonadaceae* family. This genus demonstrates a wide range of metabolic diversity and by that can colonize a wide range of niches. *Pseudomonas aeruginosa* produces chemical mediators such as pyocyanin and related compounds which can shuttle electrons to an electrode and produce electricity in MFC without using exogenous mediators. [biocatalyst in MFC]

Geobacter species - *Geobacter* are anaerobic respiration bacterial species, from phylum proteobacteria, which can be useful in bioremediation. This species have been found in soils and aquatic sediment. It has got ability to oxidize organic compounds and metals (including iron, radioactive metals, petroleum compounds) into carbon dioxide while using iron oxide or other available metals as electron acceptor. *Geobacter* is also able to respire upon a graphite electrode.

Modification and optimization of typical MFC

Two-chamber cell was the first, simplest model of microbial fuel cell. However, MFC can be constructed also in other configurations. Modifications of basic model were started due to economic and technical aspects, to reduce the costs and increase MFC performance. For example single-chamber cell was designed, in which cathode chamber was removed and the cathode was in constant and direct contact with air. This structure was tested in order to ensure easier and cheaper access of oxygen to the cathode - in two-chambered MFC there is necessity of constant aeration of the solution in the cathode chamber, which provides to increasing in the costs of MFC performance. Many attempts is carried out to optimize the process in different ways such as: searching for a better and cheaper materials forming the ion-selective membrane, optimization of mass transfer in the MFC or designing a new cathode. New solutions lead not only to decrease the cost of production of MFC but also simplify the design and increase the efficiency of their work. Problematic attempts of up-scaling of those devices led designers to create complex systems combining several MFC in various configurations which offer opportunities for the use of microbial fuel cells on a large scale.

To obtain a greater amount of energy modifications of the electrodes were repeatedly attempted. Among others the size and shape of anode were changed and the best effects were obtained using the electrode with the shape of brush that providing increase in the porosity and making surface accessible for electrochemically active organisms [17]. As it was already mentioned the increasing of the anode surface allows bacterial growth in the form of biofilms which leads to higher production of energy by MFC [27]. Recent studies indicate that such improvement can increase fuel cells efficiency up to 150% [28].

Application of variety of materials was also tested in order to build the fuel cells that would be not only cheaper but also biocompatible and chemically stable. Not all of them characterise with such a good electric conductivity as metals, but using for example graphite in combination with nanoparticles of gold resulting in an up to 20-fold increase in voltage in the cell compared to the homogeneous electrode [17]. The expected results can also be supplemented with redox mediators on the electrode or medium. Unfortunately this method has restrictions on application: these substances in fact must be regularly added to the bioreactor or subjected to recycling. Exogenous redox mediators are very expensive and therefore beyond the study of small size MFC in the laboratory wider studies in this direction do not seem to be forward-looking.

Immersing the cathode in water rich in dissolved oxygen can be replaced by the constant exposure to air which is a passive oxygenation of this electrode (cathode-air) or by using a cathode connected to the semi-permeable membrane. In addition, those already mentioned catalysts are used in order to streamline the functioning. An example would be platinum, which increases the contact of oxygen with a cathode, what effectively reduces overpotential that appears on an electrode and as a result contributes to increase the voltage generated by the MFC [29]. However, the use of platinum significantly increases the cost of the project, and this metal turned out to be also sensitive to sulphides diffusing from the anode compartment by proton exchange membrane (PEM) [13].That is why lower-cost catalysts other than platinum, such as ferric cyanide [30] and potassium

permanganate [31], potassium dichromate or manganese oxide are sought [7]. On the other hand the use of ferrocyanide as electron acceptor enabled further improvement of the functioning of the MFC, but this compound due to its toxicity is not a good contender for use on a large scale. So the alternative seems to be the use of metal oxides integrated with carbon or special materials such as fullerenes, as a material for the cathode structure which improves electrode contact with oxygen [32]. Tsai et al. (2009) in turn used carbon cathode with addition of carbon nanotubes instead of platinum catalyst in MFC powered with sewage. In these research an increase of voltage, power and coulombic efficiency generated by MFC was observed. Additionally resignation from catalyst enabled to reduce project costs [13]. Microbial fuel cells require stable pH in both anode and cathode chambers. To maintain the suitable conditions different anolythe and catholyte solutions are used [35]. The most commonly buffer applied in cathode compartment is phosphate. However, its utilization may occur too expensive and undesired due to depletion of phosphorus in a global scale. Therefore, recent attention is focused on application of other catholyte solutions as a replacement for phosphate. The studies performed in laboratory scale show the great potential of saline solutions applied for two-chamber MFC [36,37], or its mixtures with phosphate buffer [38]. New catholytes (i.e. sodium percarbonate) are also applied as an alternative electron acceptors [39].

Another promising approach is the use of biocathode, which has certain advantages over conventional abiotic cathodes. Besides lower costs of construction and operating, additional benefits are being achieved related to production of useful products by microorganisms growing on the surface, and the removal of unnecessary compounds from the cathode compartment [7]. Last development in the MFC design is maintaining anaerobic conditions in the cathode compartment. That allows to use other electrons acceptors like i.e. nitrate. Such modifications are successfully used for denitrification of wastewater in laboratory scale [40]. What is also very important, application of anaerobic conditions decrease the costs of MFC technologies [41].

Membrane is one of most important part of a MFC. It has to enable proton exchange but also separate the aerobic cathodic chamber from the anaerobic anodic compartment. As a result of this, main purposes of the membrane are [24]:

- to reduce the substrate flow from the anode to cathode chamber;
- to avoid the back-diffusion of the electron acceptor;
- to perform as a barrier to the transfer of other ions between the chambers;
- to increase the Coulombic efficiency (CE) by reducing the flow of the oxygen to the solution in the anode chamber;
- to ensure an efficient operation during a long time.

There are lots of membrane types used in microbial fuel cells. Most frequently used are characterized below.

Cation exchange membranes

Cation exchange membranes (CEM) are favoured to MFC's separators because they conduct protons direct from anode chamber, where protons are generated, to cathode chamber. Main types of CEM are: Nafion, Hyflon, Zirfon and Ultrex CMI 7000 [42]. Nafion is the most popular CEM. It is a synthetic, sulfonated copolymer of tetrafluoroethylene and ethanesulfonyl fluoride produced by DuPont. It has a good proton conductivity. There are two types of Nafion – thinner Nafion 112 and thicker Nafion 117. Nafion 112 membranes have higher maximum voltage, current and power densities because of lower resistance, but they also have higher permeability of oxygen which leads to deterioration of MFC's performance.

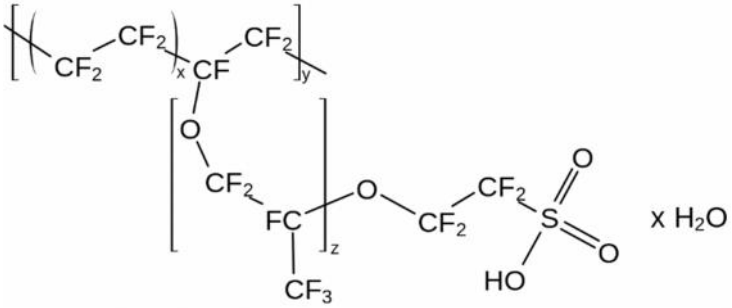

Fig 3. Nafion structure

Source: [34]

Hylfon is a membrane consisting of perfluorosulfonylfluoridevinyl ether. Zirfon is an ultrafiltration composite membrane that consists of an asymmetric polysulfone membrane structure and inorganic filter particles of ZrO_2. Main disadvantages of CEMs are pH difference between the anode chamber, where proton accumulation takes place, and the cathode chamber, oxygen diffusion from the cathode chamber to the anode chamber, where anaerobic conditions must be kept, loss of substrate and biofouling.

Anion exchange membranes

AEM (anion exchange membrane) is acting as proton carriers and facilitate proton transfer by conducting hydroxide (or carbonate) anions from the cathode chamber to the anode chamber. This transfer mechanism reduces pH difference, because it helps to avoid proton accumulation in the anode chamber. That makes MFC performance with AEM better than with Nafion membrane. But AEM also favours substrate crossover, which promote microbial growth in the cathode chamber and reduce MFC performance by that. This is major drawback of AEM. Most popular and most commonly used AEMs are Ultrex AMI-7001 and fumasep FAB [42].

Porous membranes

This type of membranes is used mainly because of their low cost. Glass wool is more cost effective for wastewater treatment and power generation instead of expensive PEMs. Microfiltration membranes have been used to decolorize azo dyes. [42] Main problem with porous membranes is that porous structure favours crossover of oxygen, substrates and other bigger molecules. Crossover rate is higher than in dense membrane, but lower than in membraneless MFC. Good property of this type of membrane is low membrane internal resistance. But biofilm is quickly forming on the surface of membrane, which increases its resistance. That makes porous membranes simply useless in long-term working MFC.

Membraneless MFC

The presence of membrane causes problems such as limited proton transfer, biofouling and high costs of the conventional and well-known membranes. There is a possibility to avoid it by removing the membrane from the MFC. There are some research which show that membraneless MFC has lower cell internal resistance and high proton transfer rate. But it is directly connected with high oxygen diffusion in the vicinity of anode, what causes the drastically drop of CE of the MFCs by about 20% [42]. Moreover, this type of MFC leads to form biofilms on cathode surfaces which limits oxygen diffusion to the cathode and by that reduces MFC efficiency. There are many advantages of membraneless technology like no membrane biofouling issues, zero membrane internal resistance and lower MFC operational costs. However, membraneless technology is inadvisable for long term MFC performance because of its high oxygen and substrate crossover rate which could result in significant decrease of MFC efficiency.

There are also some studies about alternative membranes such as:

- low cost agar membrane [24];
- polymer inclusion based on ionic liquids;
- composite materials (e.g. metal-polymer, metal-carbon).

The review of the problems posed by current membrane separators affecting MFC performance leads to identifying following main challenges to overcome in order to design very well performing MFC:

- low membrane resistance (improving proton transfer from anodic chamber to cathodic chamber);
- non-porous or dense membranes (preventing oxygen diffusion from the cathode chamber to the anodic chamber and substrate crossover in the opposite direction);
- high biofouling resistance (allowing MFC to be operated longer without serious drops in performance);
- cheaper membrane material (reducing MFC's cost).

Present and potential ways for application of MFC

Ways of industrial application of microbial electrochemical technologies (MET) depend of the type of the device. Below some of the possible applications of MET are shortly described.

On the beginning of MFC development, about over twenty years ago, there was speculation about application of this devices for power small vehicles or boats without having to charge the batteries, as a small power generators to use in areas without access to electricity or as additional equipment in small wastewater treatment plant in sugar factories or dairies [18]. Currently proposed application of microbial fuel cells are much wider: besides utilization of industrial waste MFC could be used for recovery of important biogens such as phosphorus from wastewaters, desalination of sea water [43,44], hydrogen production (MEC), bioremediation of soils, power portable electrical devices and telemetry stations or function as biosensors.

Such applications like power source for portable electrical equipment in the areas without access to the grid or traditional power generators are much more interesting than the originally proposed target of MFC. What is more in some cases this is no longer just a theory. Today there are studies and research in pilot scale in this area and some of them have already found their application in practice. The most spectacular examples are projects of autonomous mini-robots. One of the most interesting is "slugbot" - robot producing electricity from biomass which are the slugs, common pests of English fields. Produced energy robot used to move and capture another pest in the field [2].

The ability of microorganisms functioning in MFC to degrade a wide spectrum of environmental pollution can be even more valuable than the production of energy, especially in systems that allow for using of technology to treat the wastewater in situ [19]. It is known that the species of the genus *Geobacter* are able to degrading components of crude oil and leachate from landfills present in groundwater. The oxidation of these pollutants is associated with reduction of iron (III). Both oxidation and reduction can be improved by addition of mediators or chelators of Fe (III), so the addition of them to the reaction environment could enable utilization of these refuse. It has been proven that pure cultures of *Geobacter metallireducens* oxidize benzene and toluene using the electrode as a final electron acceptor [20], thus placing the electrodes in the soil with those hydrocarbons enables increase in the rate of degradation of toluene, benzene and naphthalene present in the environment.

MFC is also proposed as a device for monitoring contamination of wastewater with toxic compounds. Its operation is based on the inhibition of biological activity when in delivered liquid waste there are toxic substances, resulting in a decrease in the amount of energy generated by the MFC. Thanks to the dependence between the degree of inhibition of production of energy and the degree of contamination of the substrate there are ideas to use it as a preliminary warning device (indicator) from the toxic contamination of wastewater [21, 22].

Modifications of microbial fuel cells led to their application in the desalination of sea water. Moreover, recent modifications to these systems allowed for obtaining the simultaneous energy recovery from salt water [23]. The process of reverse electrodialysis is used for the direct production of energy from gradient of salinity created by freshwater and saline water. The electrodialysis cell uses many pairs of membranes to exchange anions or cations located between two electrodes. This membrane system is indispensable for the effective use of salinity gradient and energy production. But by that cost of construction of such cells increases significantly [23].

More advanced and innovative applications of MFC are biosensors, that means systems using biological reactions for detection of different compounds. The presence of the compound in the anode chamber activates the current flow which is recorded with electronic methods. It has been proposed to use biosensors for detection of compounds such as: glucose (with *Gluconobacter suboxidans* and *G. industrius*), glycerol (with *G. industrius*), ethanol (with *G. suboxidans* and *Acetobacter aceti*) [1], lactates (with *S. putrefaciens*) [25]. MFC are also used as biosensors for measuring pollutants in the environment, for example determination of BOD (biological oxygen demand). This parameter indicates the content of biologically degradable organic material in the sewage or water tanks [26]. Other proposed precise applications is use of miniature MFC to supply medical implants dosing medication for patients [44]. Such miniature MFC may be located directly in the blood vessel using glucose from blood as a fuel [2].

Another group of applications are maintenance-free telemetry stations, for example meteorological or monitoring the environment. An example of such devices is the EcoBotII - the device for monitoring of environment with temperature sensor transmitting information via radio powered by dead organic matter (e.g. dead flies) [33].

Conclusions

Development in field of knowledge concerning microbial fuel cells is growing fast. Year by year more researchers are concentrated on this topic. There are lots of ideas related to innovative applications of MFC in different sectors of industry - from wastewater treatment to biomedical processes. Therefore it is very important to conduct research about modifications and optimizations of these devices, because this technology could be breakthrough in many areas of our lives.

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SMART CITIES IN UKRAINE - THE EVOLUTION, STATE AND CHALLENGES OF SMART SOLUTIONS IN THE AREA OF GOVERNANCE

Abstract
Comparatively new in the field of urban development, the concept of “Smart city” is considered to be a crucial tool to overcome urban challenges faced by the citizens in XXI century. The article discusses the basics of the concept, analyzing its key dimensions. An overview of digital market in Ukraine and its positions in the world rankings are provided along with the evolution of e-governance in Ukraine, as one of the components in “Smart city” concept.
We have outlined the most interesting smart solutions presented in Ukrainian cities and built a comparative table for those among 4 cities. Based on the analysis conducted we have created a list of challenges faced by Ukraine on its way to “smartization”.

Key words
Smart city, e-governance, ICTs, urban development, digital society.

Introduction

Cities have always been crossroads of culture, and today urban areas are the driving forces of development and globalization [1]. During the last years of the twentieth century two important interrelated processes have greatly intensified, namely, urbanization and active development of information and communication technologies (ICTs). According to the United Nations Population Fund, 2008 was the year when more than 50% of the population (3.3 million) were living in urban areas. It is expected that by 2050 this figure will increase to 70% [2].

Cities grow and, as a result, most resources are consumed today in cities. This emphasizes economic, social and environmental importance of the last. Around 75% of world energy reserves are consumed in cities and around 80% of greenhouse gas emissions are produced by cities [3].

People move to cities looking for new opportunities, hoping to get a better job, more profound education and as a result to improve their standards of living. But along with opportunities, urbanization brings a number of challenges (congestion, increasing demand for scarce resources, pollution, etc.). This raises a crucial question of whether it is possible to make cities more sustainable and what are the tools. “Smart city” concept holds an enormous promise here.

Related work

The concept is being studied and developed by academics, civil servants and private sector representatives, which makes it truly unique, allows to consider it comprehensively and to study all the aspects from different points of view. The first academic work on the topic of "Smart cities" was published in 1992 [4]. While the label "Smart city" itself got its popularity starting from 2005, thanks to a number of technology companies like Cisco [5], Microsoft [6], IBM [7], Siemens [8]. The term was applied to complex information systems integrated into the urban infrastructure (transport, water supply, security, etc.).

In 2010 IBM launched the Smart Cities Challenge programme [9], deploying top IBM experts to 100 cities around the globe to help them to address their most critical challenges. During the 18th annual session of the United Nations Commission on Science and Technology for Development (CSTD), Smart Cities and Infrastructure, was selected as one of the priority themes for the 2015-16 period [10]. The topic was actively studied and developed by many prominent academics Cohen B. [11], Giffinger R.[12], Lombardi P.[13], Schaffers H.[14], Murray A., Minevich M. and Abdoullaev A. [15] and others. Many renown organizations have contributed to the topic, for example, The United Nations Educational, Scientific and Cultural Organization (UNESCO) [16], The European Innovation Partnership on Smart Cities and Communities (EIP) [17]; European Parliament [18]; National Intelligence Council [19]; World Bank [20]; Intentional Communication Union (ICU) [21], etc.

Objective and method

The objective of this article is to give an overview of "Smart city" concept and to reveal the evolution of smart solutions applied in Ukraine, particularly in the area of governance. We have started with a short review of the "Smart city" concept components, discussed digital market in Ukraine and finally outlined the latest trends in e-government process along with the key challenges presented in Ukraine.

We have used a method of theoretical, logical and systemic analysis of literature (scientific papers, policy documents, media channels and statistical sources) to study various views on "Smart city" concept and outline recent trends in Ukraine. Also methods of comparative analysis (to compare various ICTs indexes for selected countries) along with descriptive and structural analysis were applied in the article.

"Smart city" concept

There are many sources that aim to describe the concept, but till now there is no standardized, commonly accepted set of terminologies that would help to work with a "Smart city" concept. So first we have to deal with numerous different definitions, indicators and indices [21].

Academics use many terms that connect ICTs with different economic, political and social changes. Among the most widespread are "Digital city", "Smart city", "Intelligent city", "Creative city", "Sustainable city" etc. According to Pardo and Nam "Smart city concept" can be reviewed within 3 dimensions: Technology, Human and Institutional dimensions [22]:

Firstly, technology dimension. It focuses on mobile and smart technologies, physical infrastructure and digital networks. The dimension presupposes commercial application of smart products and solutions. For example, smart houses that are filled with sensors, mobile terminals, smart grids etc. The target is to build a high-tech intensive city that successfully connects and maintains the links between people, information and city elements. Corresponding concepts: digital city, information city, ubiquitous city.

Secondly, human dimension. Concepts where this component dominates assume that creativity and creative class [23] are key elements for the urban development. Since all the innovative/smart solutions are generated by the creative class, the main target for cities is to attract and "grow" this creative class as well as exploit human potential to the fullest. Corresponding concepts: creative city, knowledge city, learning city.

Thirdly, institutional dimension. Under it we understand smart governance and policy to build a smart community where each actor (government, business, citizens) understands the potential of ICTs and is willing to use them to make the environment around a better place for living and developing. Basically institutional preparations and smart governance are crucial to building a smart community. The concept assumes that the interests of peripheral and less developed districts also should be taken into account, with inclusion and equality being the important ingredients. The city strives to improve the quality and efficiency of city services, promoting transparency and accountability [24]. Corresponding concepts: smart community, sustainable city, good governance.

The International Telecommunication Union (ITU) has analyzed approximately 116 definitions of smart cities in 2014. They were obtained from a variety of sources including: academical/research communities, government initiatives, international organizations, corporate/company profiles etc. And in result has identified 8 categories

that are believed to be crucial for smart sustainable city: (1) quality of life and lifestyle, (2) infrastructure and services, (3) ICT, communications, intelligence and information, (4) people, citizen and society, (5) environment and sustainability, (6) governance, management and administration, (7) economy and Finance, and (8) mobility. Among these six key factors for further analysis were chosen:

- smart living,
- smart people,
- smart environment and sustainability,
- smart governance,
- smart mobility and smart economy [21].

Based on the performed analysis ITU suggested the following definition for a smart sustainable city: "A smart sustainable city is an innovative city that uses ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects" [21].

We support the necessity and importance of including “sustainability” component into the concept of “Smart city”, since it shifts the main accent from ICTs, showing that technology is just a tool, while the final goal itself is sustainability.

Digitalization of Ukraine

Nowadays “Smart city” concept gains a huge popularity in Ukraine. This happens due to the number of reasons: urgent need in positive changes on the local levels, intensification of decentralization processes and profound amount of specialists coming to power, people that are willing to promote positive changes on the local levels. Unfortunately, right now the concept does not have the required support at the national level. Its elements are developed and implemented by individual cities and results spread rather slowly and in the limited areas. Obviously, a comprehensive “Smart city” concept cannot be implemented in a “non-digital” country. So right now, at best, we can consider only establishment and development of individual “smart clusters” [25]. We think it is important to give a brief overview of the ICTs sector of Ukraine, since ICTs is one of the key components to promote “Smart cities” concept.

Major Ukrainian cities (Kharkiv, Kyiv etc.) have around 4,000 IT companies operating in offshore development centers. They involve around 100,000 programmers, managers and consultants in total. Around 30,000 students graduate every year from the country’s 20 education institutions specializing in IT. Moreover, a significant number of Ukrainian specialists possess international education or job experience abroad [26].

According to ITU, there are 144 mobile-cellular telephone subscriptions per 100 inhabitants in Ukraine and the number keeps growing. But only 43.40% of individuals are using Internet [27]. Comparing to the European countries, Ukraine has a small Internet market, which, however, under certain favorable conditions may offer great opportunities for growth (see Fig.1). But this also means that many people in Ukraine do not have regular access to Internet. Most of them are residents of small villages and thus lack both technical equipment and needed skills.

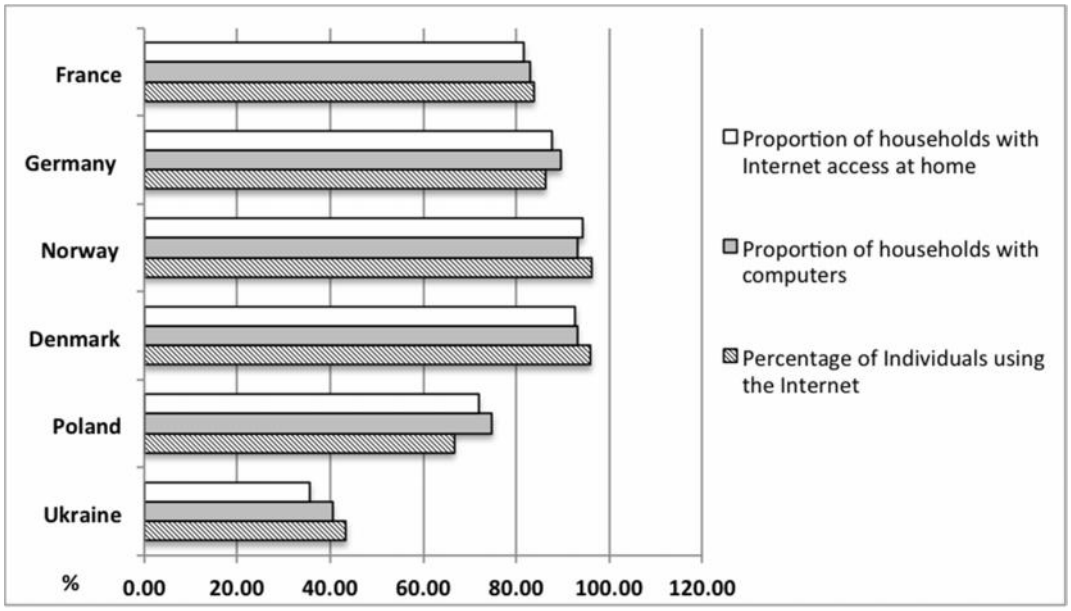

Fig. 1. Availability of ICTs across a number of European countries (2014)
Source: [27]

ITU annually (starting from 2009) publishes reports that feature key ICT data and benchmarking tools to measure the information society, including the ICT Development Index (IDI). The latest report compares the progress within 167 economies worldwide [27]. IDI includes 3 sub-indexes:

First, ICT access (weight in index - 40%)
- Fixed-telephone subscriptions per 100 inhabitants;
- Mobile-cellular telephone subscriptions per 100 inhabitants;
- International Internet bandwidth (bit/s) per internet user;
- Percentage of households with a computer;
- Percentage of households with Internet access.

Second, ICT use (weight in index - 40%)
- Percentage of Individuals using the Internet;
- Fixed-broadband subscriptions per 100 inhabitants;
- Active mobile-broadband subscriptions per 100 inhabitants.

Third, ICT skills (weight in index - 20%)
- Adult literacy rate 100;
- Secondary gross enrolment ratio;
- Tertiary gross enrolment ratio [27].

According to the data (see Table 1.), it is obvious that Ukraine has good positions in terms of human capital readiness but level of networked infrastructure and access to ICTs along with the level of ICTs usage in society leave much to be desired.

Table 1. ICT Development Index and its compounds for selected countries 2010 vs 2015

	2010				**2015**			
	ICT access	ICT use	ICT skills	**Overall**	ICT access	ICT use	ICT skills	**Overall**
Ukraine	5.23	1.27	9.06	**4.41**	6.27	2.17	9.25	**5.23**
Poland	6.85	4.6	9.02	**6.38**	7.15	5.62	9.02	**6.91**
Denmark	8.7	7.2	9.09	**8.18**	8.72	8.83	9.29	**8.88**
Norway	8.33	7.55	9.06	**8.16**	8.24	8.43	9.1	**8.49**
Germany	8.77	5.34	8.17	**7.28**	9.22	6.98	8.69	**8.22**
France	8.15	5.66	8.5	**7.22**	8.77	7.23	8.58	**8.12**

Source: Author's based on [27]

E-government development Index (EGDI) is another interesting index worth studying. According to the report "United Nations E-Government Survey-2014. E-Government For The Future We Want" Ukraine ranked 87 among the 193 member countries of the United Nations in EGDI index and 77 of 193 in e-participation index [28, 29].

EGDI Index includes 3 dimensions:

- Scope and quality of online services (Online Service Index);
- Development status of telecommunication infrastructure (Telecommunication Infrastructure Index);
- Inherent human capital (Human Capital Index).

E-participation Index includes:

- E-information: Enabling participation by providing citizens with public information and access to information without or upon demand;
- E-consultation: Engaging citizens in contributions to and deliberation on public policies and services;
- E-decision-making: Empowering citizens through co-design of policy option and co-production of service components and delivery modalities [29].

Ukrainian positions are rather poor in everything except Human Capital Index (see Table 2). Poland does a little better than Ukraine but is still far from the leading European states.

Table 2. EGDI and E-participation Index for selected countries, 2014

	E-government development Index				**E-participation Index**
	Online Service Index	Telecommunication Infrastructure Index	Human Capital Index	**Overall**	
Ukraine	0.27	0.38	0.86	0.50	0.43
Poland	0.54	0.56	0.83	0.65	0.49
Denmark	0.66	0.87	0.91	0.82	0.55
Norway	0.76	0.81	0.94	0.84	0.68
Germany	0.67	0.8	0.89	0.79	0.70
France	1	0.8	0.88	0.89	0.96

Source: Author's based on [28, 29]

Results prove that developing and providing online services along with supplying the needed infrastructure is the main challenge for Ukraine right now. The study also reveals especially insufficient development of online services for disadvantaged groups and people with disabilities in Ukraine, so "digital inequality" takes place. Digitalization process in Ukraine can be also characterized by the irregular level of development within the regions of Ukraine [30].

E-governance in Ukraine

The scope of the article does not allow us to cover all smart solutions and practices that are applied in our country. So we have decided to focus on governance area only. According to Ukrainian 2020 strategy of the President of Ukraine, eGovernment and the increase of eServices is on top of the agenda [31].

Fig.2 captures the most important events of the recent years that contribute to the development of e-governance in Ukraine. One of the distinctive features in Ukraine is a great contribution of so called "creative class". Active volunteers are the main moving force of the concept in Ukraine. The active stage of development and implementation took place only starting from 2015, when civil society started to take active part in the process.

A major role belongs to ICT Competence Center founded in 2015. It is a non-governmental organization (NGO) that brings together representatives of government, business and individuals with expertise in IT to implement elements of e-governance in Ukraine [32].

The group iGov unites IT volunteers throughout Ukraine. Their major task is conversion of state services into electronic form and maintenance of portal iGov.org.ua. iGov is an open-source project, its code is available on GitHub, so any individual can contribute to the development. It is also a great example of cooperation between government and citizens. Currently 338 administrative services are already available online, while the development of another 723 is being underway [33].

In February 2015 an electronic public procurement system ProZorro was launched in a pilot mode. It allows selling online to government. The platform aims to boost competition and decrease the corruption level in public procurements. Any company can register, find an auction, and apply for it. The tenders are anonymous, only prices and competitors' terms are available. After the winner is chosen based on the results of the tender, the company`s name is revealed. Any user can check on the website what was purchased by the state-owned enterprise and at what price. Participants are required to pay 175 UAH (around $7) for participation but only in cases when the amount of the planned procurement exceeds 35 thousand UAH (around $1410) [34].

Over 20 million dollars have been saved already thanks to the platform, with only 2% of all public tenders being held using ProZorro. All large suppliers, such as ministries, departments and the largest state-owned enterprises should switch to ProZorro on a mandatory basis starting from the 1st of April 2016 [35].

Starting from August 2015 E-petition service has been launched in Ukraine. The main target of this tool is to launch the debates on the issues that are extremely important to people and to reach out to higher authorities. E-petitions tool functions on two levels:

First, state level. The focus is on the issues of the national importance. For example, e-petition to the President of Ukraine is considered in case it gained 25,000 signs within 3 months from the moment the petition was posted [36].

Second, local level. Deals with the issues that are committed to the discretion of local communities. The Unified Local Petitions System (e-dem.in.ua) was developed under the E-governance for Accountability and Participation (EGAP) program, which is funded by the Swiss Confederation. Right now 22 cities are already engaged in the project. Targeted regions of the program are Vinnytsia, Volyn, Dnipropetrovsk and Odessa. However, many more are to join [37].

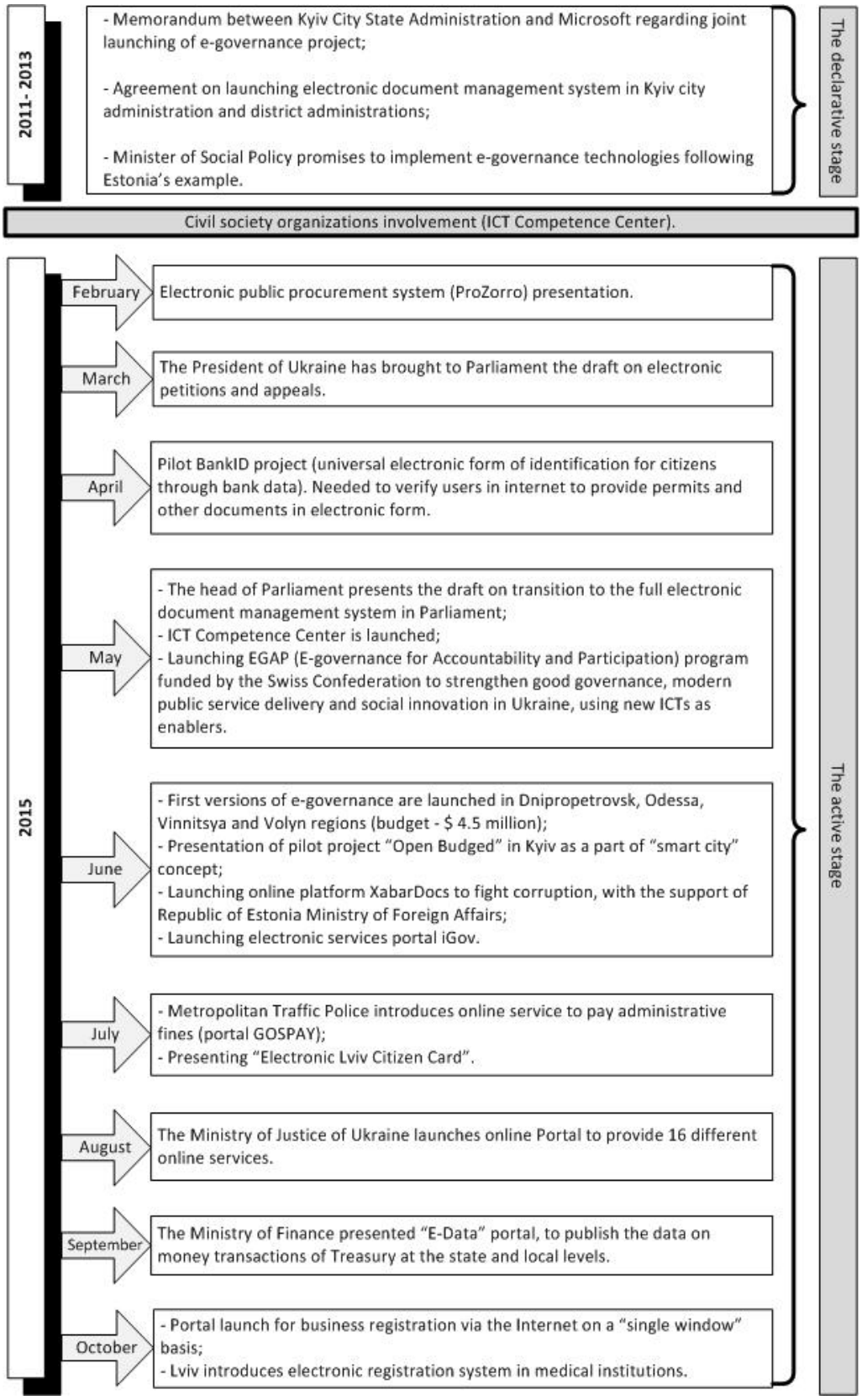

Fig.2 Evolution of e-governance processes in Ukraine
Source: [38, 39]

Among the recent developments, the team of IT volunteer will work on establishment of e-government portal "E-progress". It will represent a platform for e-governance best practices exchange among local authorities, businesses and society. The United States of America will provide a grant for this project [40].

The analysis of "Smart city" initiatives in Ukraine reveals that there are many different smart solutions implemented by Ukrainian cities, aimed at improving quality of life, city management, cost reduction and promotion of sustainable development.

We have built a comparison table (see Table 3) among 4 cities: Vinnytsia, Ternopil, Kyiv, Kharkiv and described below the most successful initiatives presented in Ukrainian cities.

Table 3. Smart solutions comparison among 4 Smart Cities of Ukraine

Services	**Vinnytsia**	**Ternopil**	**Kyiv**	**Kharkiv**
Open Budget	+	+	+	+
Mobile transport schedule	+			
E-petition	+	+	+	+
Map of emergency works	+		+	+
Electronic queue and registration to kindergarten	+	+	+	+
WiFi in public transport	+	+	+	+/-
WiFi in city parks		+	+	+
Remote payment for utility services	+	+	+	+
Electronic citizen card			+	
Video surveillance system		+		+/-
E-procurement system	+	+	+	+
"Open city" platform		+	+	

Source: [41, 42]

"Open Budget" established to promote transparency and free public access to information concerning the planning and execution city budgets [43]. The initiative was implemented in 25 cities already;

Single Public Transport E-Ticket for all public transportation options. The introduction of a single electronic ticket will automate fare collection, increasing revenues by 20-30%, and significantly reduces the costs of public transport services providers (Kyiv) [44];

Mobile applications that allow users to notify local authorities about the ongoing issues (e.g. lack of water, electricity, wastage problem etc.). Citizens are also welcome to share propositions and questions they might have. Service works 24/7. The user gets its number and can check online the status of application. The web site also includes the interactive map of the current repair works (Kyiv, Kharkiv) [42, 44].

Electronic Citizen Card — multifunctional electronic ID Card, which includes user's personal data and supports various applications relating to the provision of social welfare benefits, city services and many other functional options (Lviv, Kyiv) [44];

Medical Portal in Kyiv. It allows citizens to see the availability of particular medicines through the interactive map in different hospitals [45];

Online police portal in Kharkiv that allows to claim the crime, has interactive map of crimes and allows to order certificate of no criminal record [46];

"Open city" platform for effective dialogue with the authorities that was implemented in 27 cities already. It includes 3 sections:

- "Problems and solution", allows to post the problem which will be forwarded to the corresponding

organization;

- "Official information", which includes information about official repair works, the user can also sign up for the updates to be sent to his/her email.
- "Useful facilities", map where users can add hospitals, schools, WiFi free zones, and battery collection zones [47].

Challenges on the way

Local attempts to develop and implement smart initiatives in particular cities allowed us to outline a number of socio-political, economical and executive challenges for Ukraine (see Fig.3).

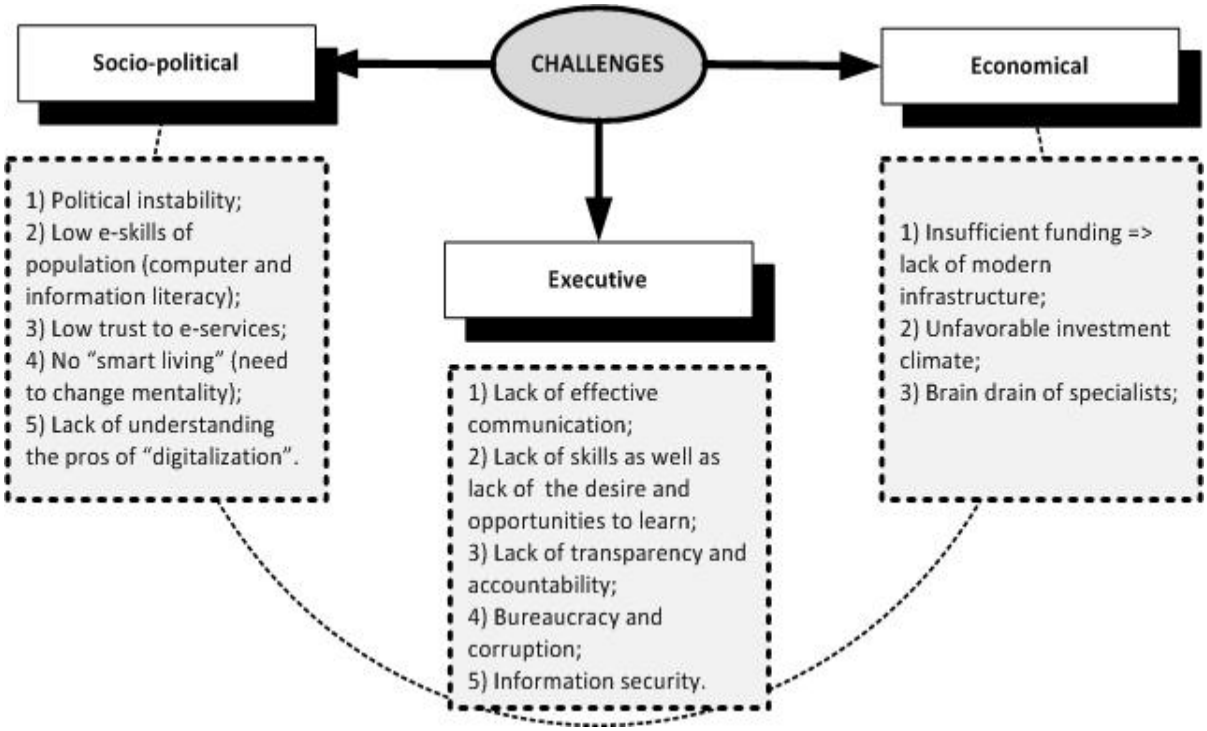

Fig.3 Challenges for Ukraine on the way of implementing "Smart city" concept
Source: Author's

These challenges prove the necessity of the comprehensive government policy and support in the matter. In particular the policy should include:

- Government support for the regional initiatives, aimed at elimination of the "digital gap";
- Steps to increase the quality of the services provided in ICTs sector, their correspondence to the national standards, that are prior to this should be harmonized with international standards;
- Programs and initiatives to increase computer and information literacy of the population;
- Information campaigns to ensure population awareness of the numerous possibilities available, their pros and cons;
- Encouragement of the effective exchange on the national (between the regions) and international levels.

Conclusions

Nowadays reality demands shifting towards a higher and more effective way of ICTs usage for governance improvement, administrative services provision, social support of residents etc. A truly smart and sustainable city needs to possess a "body, mind, and soul". The "body" is the infrastructure, the "mind" is a smart software and the "soul" is the human element making it all work together to meet the needs of present and future generations with respect to economic, social and environmental aspects [48].

In this paper, we have presented a general overview of "Smart city" concept and considered its evolution along with implementation in Ukraine, particularly in the sector of governance. The concept can be considered within three dimensions: Technology, Human and Institutional. But we believe that only systematic integration of these approaches will result in establishment of a truly smart, sustainable and citizens-friendly city. Underdeveloped digital infrastructure (proved by low positions of Ukraine in corresponding international rankings) considered to be the main challenge for Ukraine today. It causes a serious "digital gap" within the country and hampers country's "smartization" process in general.

All the initiatives that are currently developed in Ukraine have a rather bottom-up approach and do not receive a required level of governmental support. While innovations and progress in e-governance are especially valuable for our country, taking into consideration Ukrainian problems with corruption, transparency and accountability in governmental bodies.

Finally, we have considered a list of key challenges (socio-political, economical and executive) on the way to "smartization" along with the possible solutions that hopefully will help to overcome those. And we strongly believe that our first and outmost aim should be not for smart cities themselves but rather for encouragement and development of intelligent behavior and smart citizens that will be able to implement and develop this concept in future. Along with encouragement and support of the active dialogue between government, business and civil society.

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EVALUATION OF QUALITY OF ELECTRIC ENERGY COOPERATING WITH HYDROELECTRIC POWER PLANT - SELECTED FEATURES

Abstract
The article presents evaluation of the quality of electricity in the network cooperating with hydroelectric power plant. The assessment was based on the Decree of the Minister of Economy dated 4 May 2007 on detailed conditions for the operation of the power system and the norm PN-EN 50160: 2010 – Voltage characteristics of electricity supplied by public distribution systems. The analysis was based on actual measurements made by power quality recorder Fluke 1760. The analysis particular emphasis has been to:

- values of higher harmonics and voltage distortion factor (THD_U)
- Power factor cosϕ.
- Active power.

Assessment of quality of electric energy will be discussed based on the analysis of the measurements.

Key words
the quality of electric power, hydroelectric power plant, harmonics, cosϕ, active power

Introduction

Presenting the electric power quality parameters, the attention should be paid to two documents in which they are listed today, i.e. Minister of Economy Decree dated 4 May 2007 on detailed conditions for the operation of the power system [1] and the norm PN-EN 50160: 2010 [2]. In the first position, section 10, the following quality parameters of electricity were mentioned:

- the value of average frequency
- average effective voltage value
- long-term flicker P_{lt}
- symmetrical components for order of symmetric and individual harmonic supply voltage
- distortion factor of higher harmonic voltage THD

The second position specifies an even greater amount of electric energy quality parameters:

- network frequency
- the value of supply voltage
- supply voltage variation
- rapid voltage changes, which include: the value of rapid voltage changes and flicker
- supply voltage dip
- a short power outage
- a long power outage
- casual overvoltage of constant frequency voltage between live conductors and earth
- transient overvoltage between live conductors and earth
- asymmetry of supply voltage
- voltage harmonics
- interharmonics voltage
- voltage signal to transmit information imposed on the supply voltage

Considering all the aforementioned parameters, all kinds of classification can be made. They can be divide them into those which are random (caused by problems with weather, traffic accidents, etc.) and determined (type of receiver, power supply system, etc.). Electromagnetic interference can be divided due to the effect which they cause: disorders that cause immediate effects, e.g. malfunction of protection systems equipment; disorders of the long-term effects, e.g. acceleration of the process of aging and degradation of the insulation of electrical machines and cables.

Taking into account that the quality of electricity is a set of numerical values (quality parameters), the following classification can be made:

- parameters corresponding to normal operating conditions of the power system, e.g. the voltage value and frequency of supply voltage
- parameters related to disorders of normal operating conditions of the system, e.g. overvoltage's flickering lights
- parameters related to supply voltage waveforms, e.g. transient overvoltage's voltage dip

Considering topic quality parameters of electricity must be taken into mind that for the degraded conditions of power supply is not responsible only supplier of electricity but also the recipient of this energy (in figure 1). The most influence on disorders have electrical devices that consume distorted current from the network.

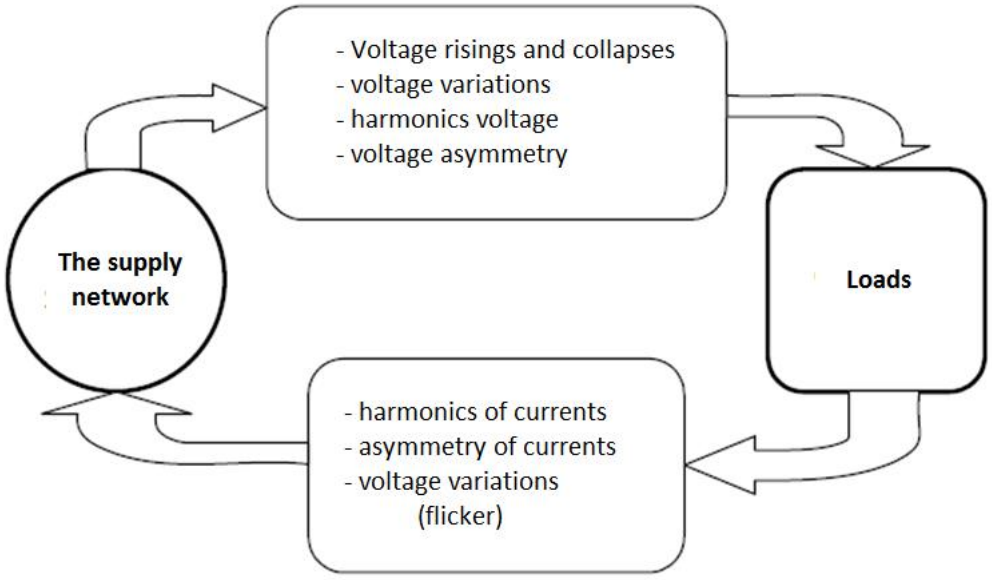


Fig. 1. Sources of typical disturbances in electric power quality
Source: [3]

Place of measurement

The measurements were made by the three-phase power quality recorder Fluke 1760, which is compliant with the class A standard IEC 61000-4-30 (in figure 2). Measurements of electrical energy quality parameters were made in the hydroelectric power plant during its normal operation. The period of observation covered the whole week. The first day of measurement was Friday.

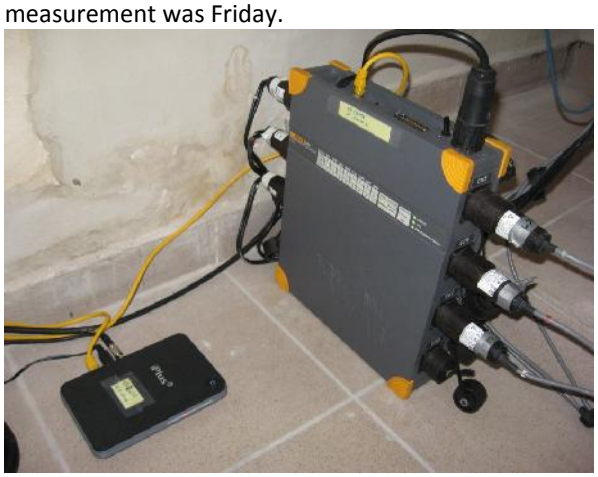


Fig. 2. Connecting measuring instruments
Source: Author's

Analyzed Hydroelectric Power Plant is equipped with two asynchronous generators with a power of 200kW each (in figure 3). Generators are installed on the turbines Francis and Caplan vertically with the transmission

belt. Connected to the network via a transformer 21000/400V, 400kVA the active power delivery. System is equipped with a capacitor batteries - fully automated. Control system (like on and off) of the turbines are fully automated, e.g. in case of power outages on the network side. Sometimes the control is switched to manual control, e.g. the maintenance activities such as cleaning the channel.

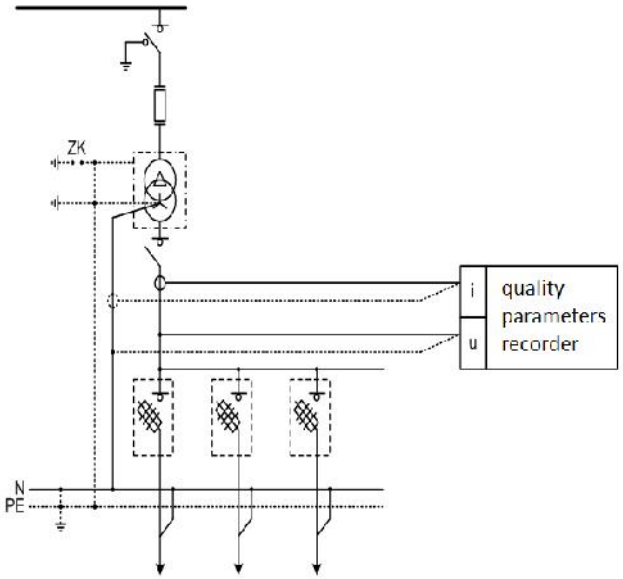


Fig. 3. Wiring diagram of measuring instruments
Source: Author's

The values of higher harmonics and voltage distortion factor (THD_U)

The first parameter of electric energy which has been analysed is the harmonic content in the course of the supply voltage. The harmonics are responsible for distortion sine waves of AC voltage. Even preliminary tables (in Table 1) indicate the patterns in the general factor of voltage waveform distortion (presence of harmonics).

Table 1. Harmonic contents in the voltage waveforms in reference to the time required for 95% of the measurements.

Total harmonic distortion				
Designation	**Tolerance range**	**L1**	**L2**	**L3**
	[%]	[%]	[%]	[%]
THD	0.00 - 8.00	100.00	100.00	100.00
Harmonics				
Order	**Tolerance range**	**L1**	**L2**	**L3**
Nr.	[%]	[%]	[%]	[%]
2	0.00 - 2.00	100.00	100.00	100.00
3	0.00 - 5.00	100.00	100.00	100.00
4	0.00 - 1.00	100.00	100.00	100.00
5	0.00 - 6.00	100.00	100.00	100.00
6	0.00 - 0.50	100.00	100.00	100.00
7	0.00 - 5.00	100.00	100.00	100.00
8	0.00 - 0.50	100.00	100.00	100.00
9	0.00 - 1.50	100.00	100.00	100.00
10	0.00 - 0.50	100.00	100.00	100.00
11	0.00 - 3.50	100.00	100.00	100.00
12	0.00 - 0.50	100.00	100.00	100.00
13	0.00 - 3.00	100.00	100.00	100.00
14	0.00 - 0.50	100.00	100.00	100.00
15	0.00 - 0.50	100.00	100.00	100.00
16	0.00 - 0.50	100.00	100.00	100.00

17	0.00 - 2.00	100.00	100.00	100.00
18	0.00 - 0.50	100.00	100.00	100.00
19	0.00 - 1.50	100.00	100.00	100.00
20	0.00 - 0.50	100.00	100.00	100.00
21	0.00 - 0.50	100.00	100.00	100.00
22	0.00 - 0.50	100.00	100.00	100.00
23	0.00 - 1.50	100.00	100.00	100.00
24	0.00 - 0.50	100.00	100.00	100.00
25	0.00 - 1.50	100.00	100.00	100.00

Source: Author's

The overall Harmonics content in the voltage THD is within the tolerance range, which is 0.00 - 8.00% for 95% of the measurement time (in Table 1). The exact value of this coefficient for each phase (L1, L2, L3) is: 2.71%, 2.99% and 2.89% (in Table 2).

Table 2. Harmonic contents in the voltage waveform - average harmonic content

Total harmonic distortion							
		95%-values			**Maximum values**		
Designation	**Tolerance range**	**L1**	**L2**	**L3**	**L1**	**L2**	**L3**
	[%]	[%]	[%]	[%]	[%]	[%]	[%]
THD	0.00 - 8.00	2.71	2.99	2.89	3.23	3.52	3.36
Harmonics in % of Un							
		95%-values			**Maximum values**		
Order	**Tolerance range**	**L1**	**L2**	**L3**	**L1**	**L2**	**L3**
Nr.	[%]	[%]	[%]	[%]	[%]	[%]	[%]
2	0.00 - 2.00	0.01	0.01	0.01	0.02	0.02	0.02
3	0.00 - 5.00	0.16	0.25	0.16	0.18	0.26	0.17
4	0.00 - 1.00	0.01	0.01	0.01	0.02	0.02	0.02
5	0.00 - 6.00	0.72	0.66	0.60	0.91	0.93	0.90
6	0.00 - 0.50	0.02	0.02	0.02	0.06	0.04	0.06
7	0.00 - 5.00	2.67	2.94	2.87	3.21	3.50	3.29
8	0.00 - 0.50	0.03	0.03	0.03	0.04	0.04	0.05
9	0.00 - 1.50	0.26	0.15	0.18	0.37	0.29	0.27
10	0.00 - 0.50	0.03	0.03	0.03	0.04	0.04	0.05
11	0.00 - 3.50	0.26	0.28	0.29	0.40	0.40	0.43
12	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
13	0.00 - 3.00	0.09	0.09	0.09	0.11	0.13	0.12
14	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
15	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.02
16	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
17	0.00 - 2.00	0.02	0.02	0.02	0.04	0.05	0.05
18	0.00 - 0.50	0.00	0.00	0.00	0.01	0.01	0.01
19	0.00 - 1.50	0.01	0.01	0.01	0.01	0.02	0.02
20	0.00 - 0.50	0.00	0.00	0.00	0.01	0.01	0.01
21	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
22	0.00 - 0.50	0.01	0.01	0.01	0.01	0.01	0.01
23	0.00 - 1.50	0.01	0.01	0.01	0.03	0.03	0.02
24	0.00 - 0.50	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00 - 1.50	0.01	0.01	0.01	0.01	0.01	0.01

Source: Author's

The period of measurement was one week. Fig. 4 shows the course of THD supply voltage, we can deduce at what time Hydroelectric Power Plant worked. Also can be observe the work of the analysed object on the so-called "idle run". The specificity of the test object does not require any work on certain days of the week. Operation of the object depends on the level of flowing water.

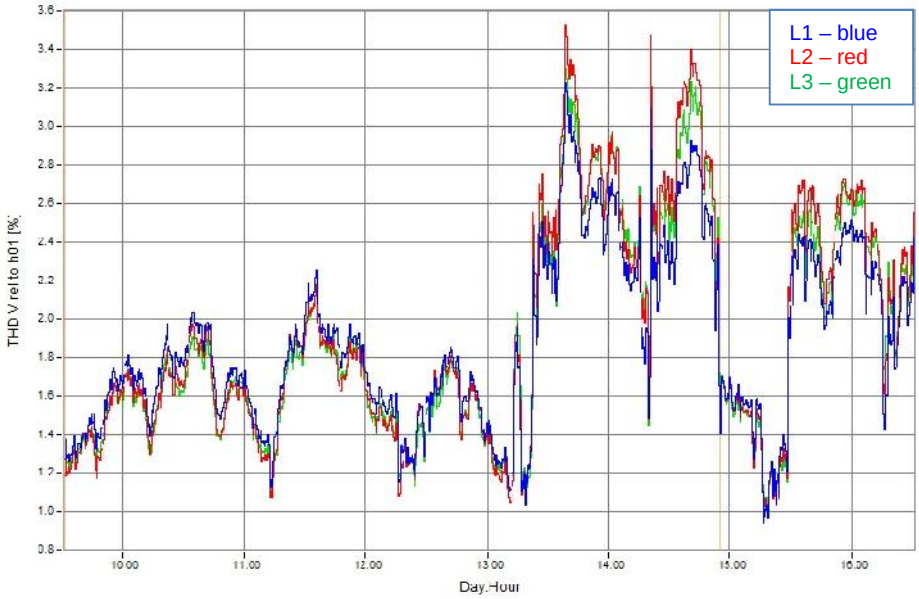


Fig. 4. THDu (relative to the basic harmonic h1 (day:hour))
Source: Author's

Figure 5 shows all of the harmonics of voltage (from the second harmonic h2 to h50 fiftieth). It is clear that with increasing harmonic number decreases its participation in the course of the supply voltage. The highest values take the fifth harmonic h5 and seventh h7.

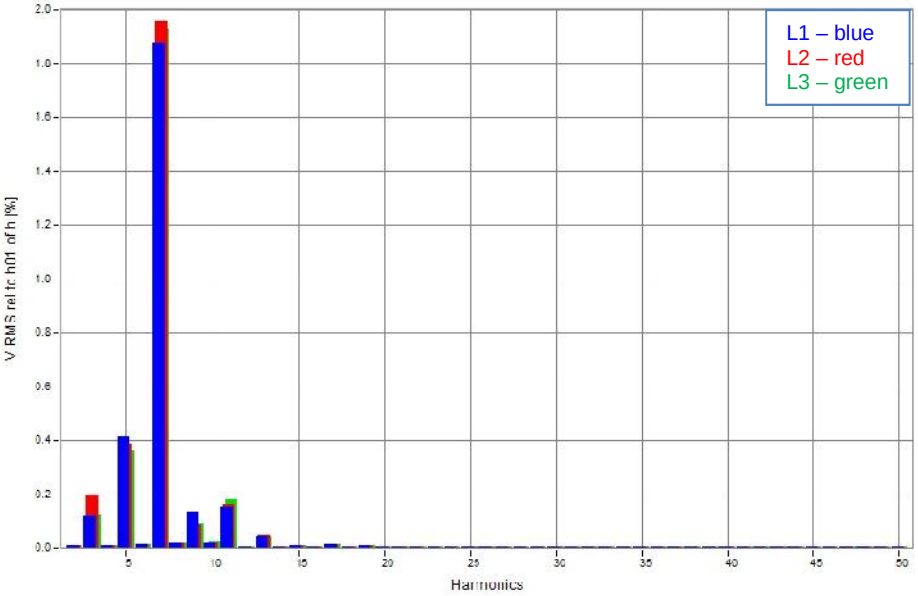


Fig. 5. Spectrum of harmonic
Source: Author's

Analysis of the fifth harmonic H5 (with respect to the fundamental voltage waveform h1) concluded it can be that the examined harmonics (in figure 6) and its value does not come from the analysed object. It is a harmonic, which, based on the preliminary analysis in accordance with norm DIN EN 50160, course does not

coincide with the course of the total THD (in figure 4), it is more aligned. In contrast to the total THD, harmonic fifth h5 have no influence for the work analyzed hydroelectric power.

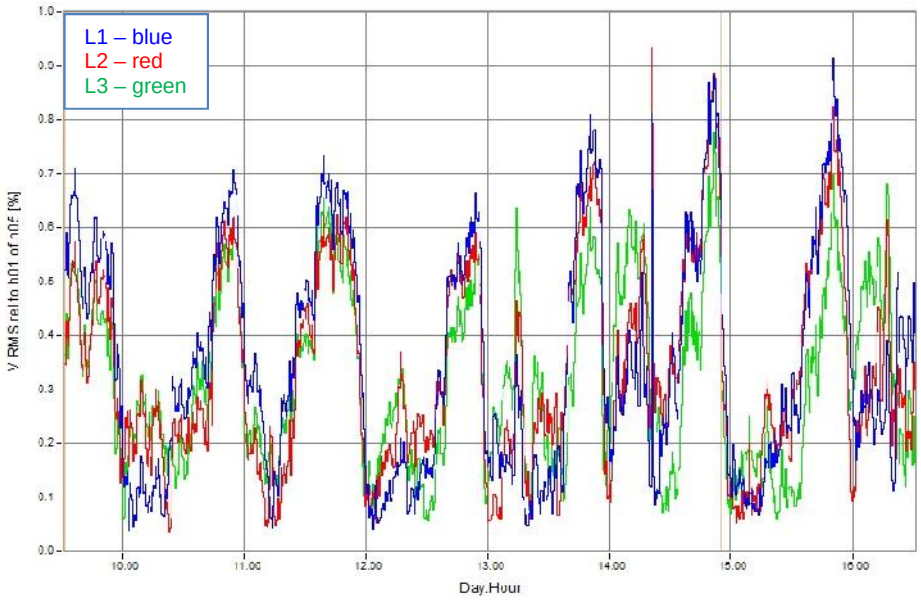


Fig. 6. Higher harmonics (relative to the basic harmonic h1 (day:hour)) - Harmonic 5
Source: Author's

Then was analysed the seventh harmonic h7 (in relation to the basic harmonic voltage waveform h1), for which on the basis of a preliminary analysis in accordance with norm DIN EN 50160 concluded the largest share (in figure 5). In accordance with the norm PN-EN 50160 limit values of 5% (in table 2) has not been exceeded and is 2.67%, 2.94% and 2.87% (corresponding to phase L1, L2 and L3). Number presented in Figure 7 coincides with the total course of THD (in figure 4). Total THD and harmonic seventh h7 reach maximum values in the fifth and sixth day of measurement. It can be also found that all phases of the analysed object are loaded evenly. The time of day did not affect the value of harmonic H7. It can be concluded that the harmonic h7 is directly related to the work of the analysed hydroelectric power.

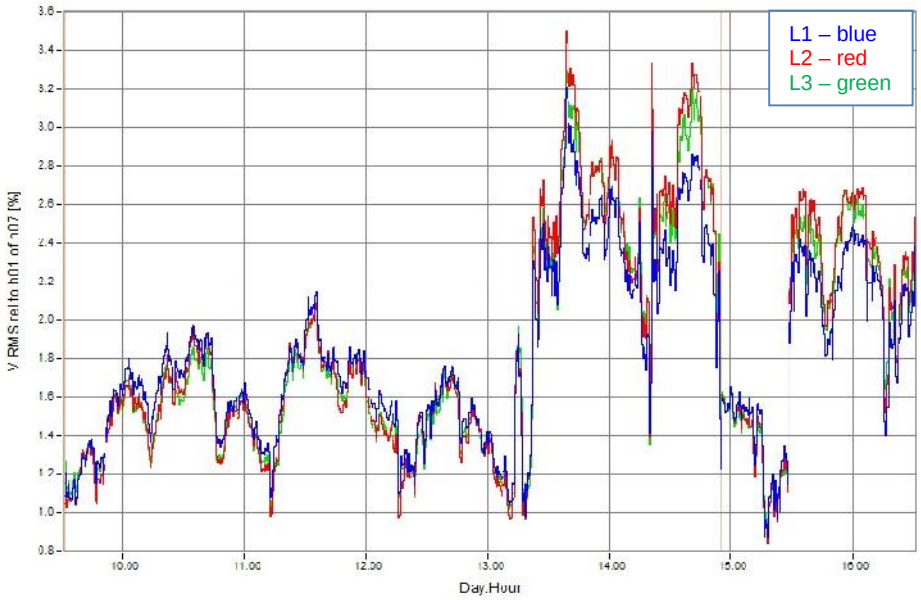
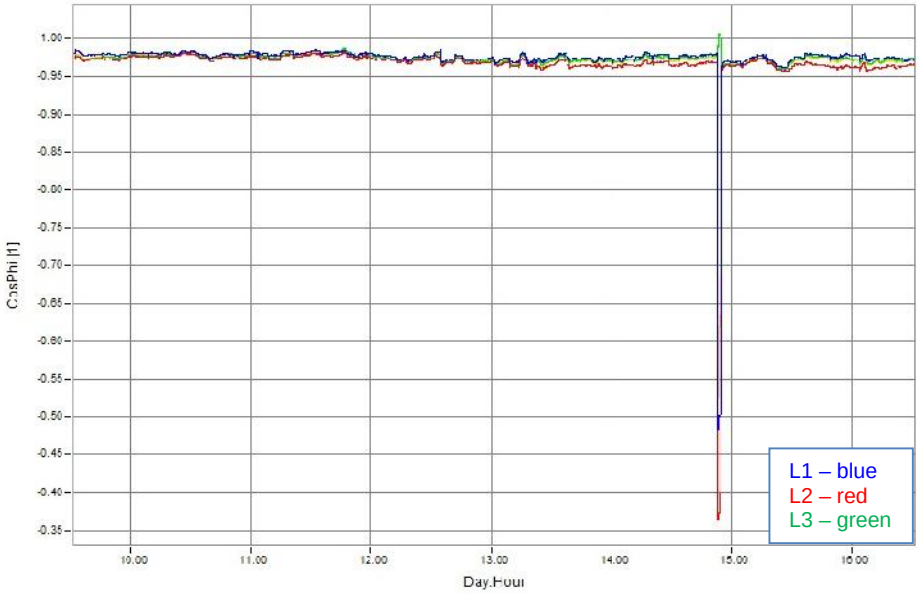


Fig. 7. Higher harmonics (relative to the the basic harmonic h1 (day:hour)) - Harmonic 7
Source: Author's

The power factor cosϕ

The parameter used to characterize objects is a factor cosϕ, the power factor. In the case of a building where took place the measurements of the parameters, this factor is between 0,96-0,99 (in figure 8b). On the presented course (in figure 8a) it can be observed a voltage dip which was registered at the end of the sixth day of the measurement. Voltage collapses occurred in three phases at the same time. The figure 8b clearly shows cyclical changes in the coefficient cosϕ in different times of work and linearity (lower volatility) in the times of stoppage work of the analysed power plant. These changes are dictated by load-associated changes with the normal operation of hydroelectric power plant. There are no variations of the coefficient cosϕ related to the supply system phases.

a)



b)

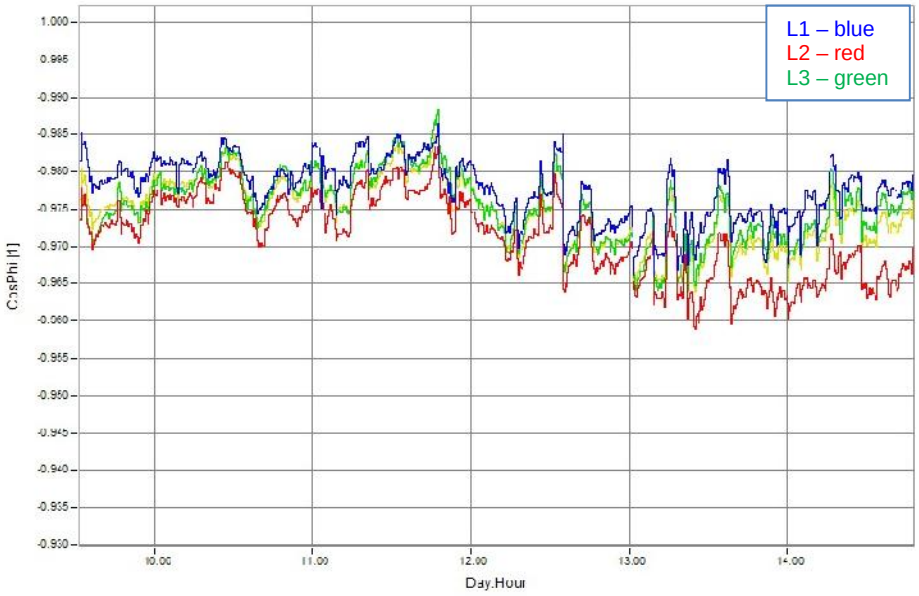


Fig. 8. The power factor cosϕ (day:hour) :
a) the entire measurement period b) the measuring period without voltage dip
Source: Author's

The active power consumption

Analysing the hydroelectric power plant in terms of electric power supply, the power waveforms cannot be ignored. This is the primordial parameter, on the basis of which the analysis of all quality parameters of electricity was carried out. Waveforms of delivered active power are reflected to others waveforms presented in the article. Observing the course of time the power consumed by the supply system (in figure 9) we are able

to tell when the plant is running, i.e. it is used to perform specific tasks which are activated the main consumers of power.

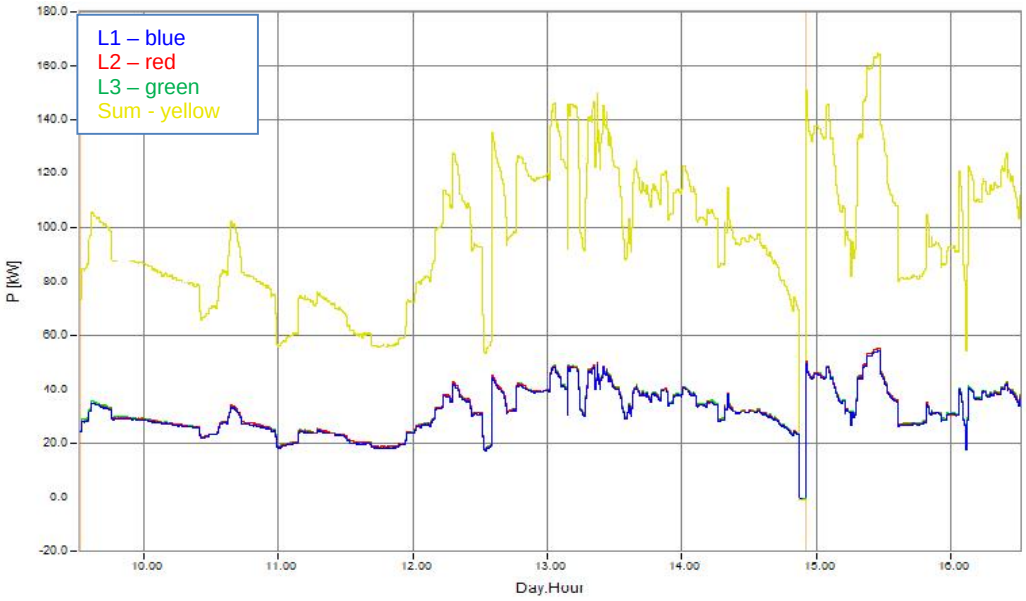


Fig. 9. The active power consumption during the entire measurement period (day:hour)
Source: Author's

Analysing the course of active power, we see the cyclical changes in value relating to the work of the object. The illustrated waveforms are average values of the measurement, the yellow color is the total power consumed by all three phases of the supply. In figure 9 there was observed an occurrence of the sixth day of the voltage dip. The total (max) power demand for electric energy is approx. 160kW (seventh day of the test, in figure 9), while the minimum power falls below 60kW. It can be noticed that the analysed water power plant takes power even outside times at which the normal work is provided. There are also differences between the peak of the day and night valley.

Summary and conclusions

For the analysed actual hydropower the following conclusions can be formulated:

- Research and evaluation of the quality of electricity are becoming more common and are intended to increase the reliability and safety of the electrical installations that are powered by the plant, and energy power supply systems;
- analysis of the results of measurements of electrical power parameters may be useful to locate possible sources of disturbance values of individual parameters in the electrical installation;
- on the basis of measurements there can be created the energy characteristics of the building, which may have an impact on the possible modernization of the structure of the electrical installation or changes in the management of existing loads turned on to this installation in order to balance the load daily.

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ANALYSIS OF COMMERCIALISATION POSSIBILITIES OF BIOPREPARATION „ RHIZOFERTUM" FOR PLANT GROWTH STIMULATION IN UNFAVOURABLE SOIL CONDITIONS

Abstract
The aim of the paper was to discuss commercialisation possibilities of research findings pertaining to the biopreparation for plant growth stimulation in unfavourable soil conditions, which is based on specialized bacterial consortium. The production foundation of the biopreparation is the technology regarding the immobilisation of micro-organisms on mineral-organic media and sodium alginate, taking the form of a capsule. As a result of the conducted analyses, the potential effectiveness of investment in the technology and available solutions on the market were assessed in addition to strengths and weaknesses of the biopreparation. It was also stated that the prospective benefits following from the commercialization of the invention are very high.

Key words: commercialization, biopreparation for plants growth stimulation, fertilisers market

Technology description

The production of the biopreparation for plant growth stimulation is based on the technology regarding the immobilisation of micro-organisms on media. The micro-organisms used in the production of the biopreparation are taken from, inter alia, the strain collection of the Institute of Environmental Engineering: *Pseudomonas fluorescens, Bacillus sp., Azospirillum brasilense , Bacillus subtilis, Bacillus sp. , Bacillus mycoides, Bacillus anthracis, Pseudomonas putida, Pseudomonas sp.* Bacteria were isolated from heavy metals contaminated soil. Endophytic and Rhizobiaceae bacterial strains were isolated from the plants: *Festuca rubra* L., *Agrostis capillaris* L. and *Arabidopsis thaliana* L. Heynh. Isolates were sequenced by 16S rRNA sequence analysis. The micro-organisms are immobilised on the mineral-organic media and sodium alginate, taking the form of a capsule (Fig. 1-2). The used bacteria strains demonstrate the ability to produce indole-3-acetic acid and to decompose 1-aminocyclopropane-1-carboxylic acid, assimilate atmospheric nitrogen, decompose phosphates, and they possess proteolytic and antifungal properties.

Fig. 1. The production of the biopreparation for plant growth stimulation is based on the technology regarding the immobilisation of micro-organisms on media
Source: Author's

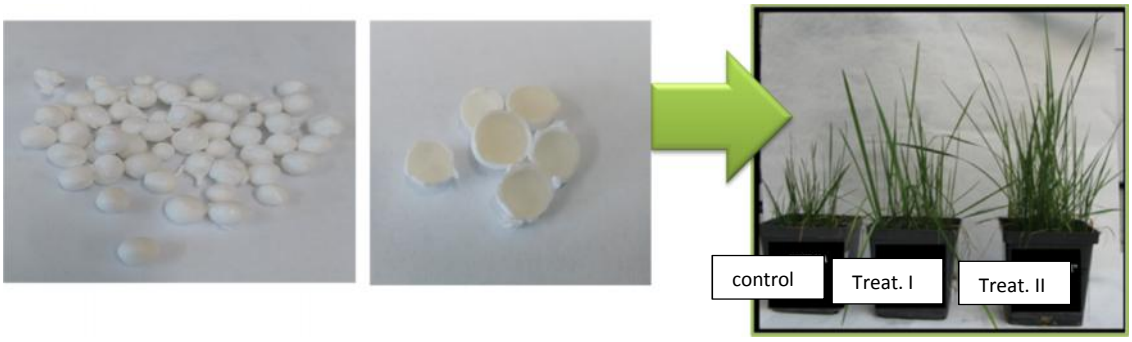

Fig. 2 The micro-organisms are immobilised on mineral-organic media and sodium alginate, taking the form of a capsule (bacteria treatments I,II and control without bacteria with blank capsules)
Source: Author's

The existing achievements within the scope of testing the developed technology covered the following actions [1, 2]:

- bacteria-plant interactions were correlated and better understood – they are essential in order to fully develop the biotechnological prospects of bacteria-plant partnership, and their broad usage,
- higher plant yielding was achieved, including grass as well as rapeseed, in very unfavourable soil conditions (low nutrients content and high heavy metals concentration), with low content of mineral components and considerable soil contamination,
- antifungal metabolites of bacteria were detected in specified strains, especially with respect to fungi *Fusarium* sp. and *Alternaria* sp., which allows us to produce much better yields and to lower the amount of fungicides used in plant cultivation (including rapeseed),
- growth increase of plant biomass (rape, fescue grass) was achieved (30- 60% depending of plants and soil conditions) while cultivating poor soil, which creates the possibility to lower or entirely eliminate the necessity to use mineral fertilisers, including nitrogen and phosphorus,
- the most favourable results were obtained when micro-encapsulation technology with the usage of nano-silica was introduced.

Preparation stages for commercialization

Within the framework of the development, the following stages were carried out:

- market analysis where the technology is applicable,
- analysis of attractiveness of the technology/product based thereon with respect to the existing substitutes,
- competitiveness assessment, including strengths and weaknesses of the product, chances and threats,
- the list of main success factors and potential risks,
- defining the effective path of technology commercialization.

As a result of the conducted analyses, the potential effectiveness of the investment in the technology and available solutions on the market, and also strengths and weaknesses of the biopreparation for plant growth stimulation in unfavourable soil conditions (low nutrient content and high heavy metals content), it has been stated that prospective benefits following from the commercialization of the invention are very high.

While choosing the optimal path of technology transfer, it is to be assumed that the most crucial element of the effectiveness evaluation is above all the capital effect, i.e. raising capital for research and organization development, returns on investment and income. The most essential problems in the transfer of technology pertain to the issues: whether the technology should be sold directly, whether and how licenses should be granted and whether and how intellectual property should be contributed to the enterprise. Granting a license or contributing intellectual property to a company depends, above all, on the readiness to take risks, occurring while running a company and selling technology, on resources and personal competences of employees of the enterprise (the purchaser of the license or intellectual property) and on the influence of the shareholder, contributing intellectual property, on the decisions of the company and on the amount of the expected dividend contingent upon the amount of company shares [3]. The main conditions that underlie the granting of licenses as an alternative with respect to the commercialization through establishing a new company are:

- licensing income,
- venture profitability,

- the level of risk associated with running a business activity,
- competence in technology development,
- influence on decision making (shares in the company, representation in the management board and the board of directors).

The selection of the commercialization path is also dictated by the current aims of the university and the possibilities of further engagement in the process of creation of an innovative product. As it is confirmed by Trzmielak [3], while analysing the cooperation between the entrepreneur and scientists in order to implement research findings, it is necessary to mainly pay attention to different aspects of the functioning of these entities.

Due to the aspiration of the European Union to introduce organic farming and the promotion of organic food [4], the developed preparation fits in the policy of the European Union. One advantage of this biopreparation is that it virtually covers the entire biopreparation market in the context of their properties (Fig. 3-4) – it may fix nitrogen and transform phosphorus into forms assimilable for plants [2].

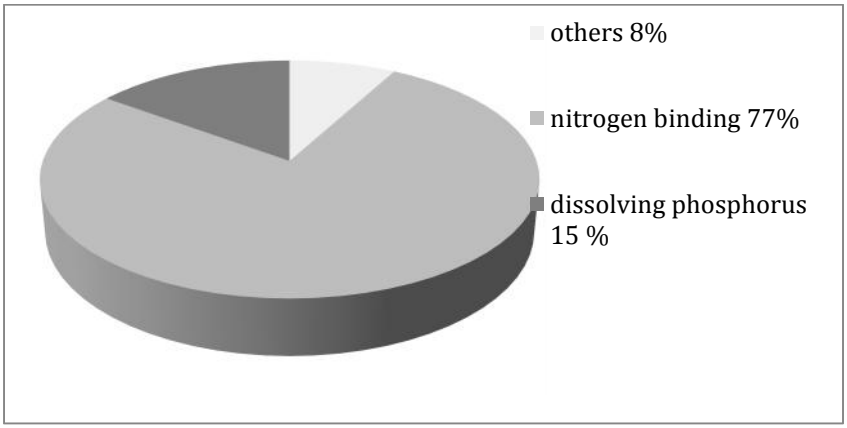

Fig. 3 Biopreparation global market
Source: Author's

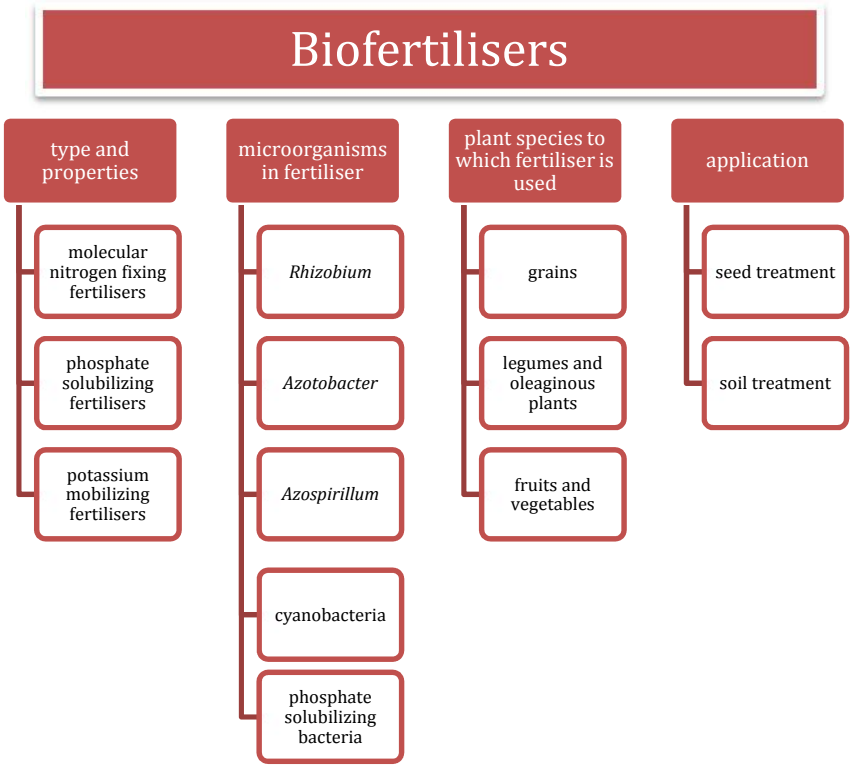

Fig. 4. Biopreparation market – the division into properties, micro-organisms, plants and application
Source: Author's

The offered product complies with the latest market needs, inter alia, due to its "environmental performance" and increased efficiency. Additionally, it limits its potential costs resulting from the necessity to repeat application procedures. It is estimated that from 2014 to 2019 there will be a biofertiliser market growth of up to over USD 1.6bn, with an average annual growth at around 13% [5]. The growth of this market is connected with the growth of the organic food industry, the increased rate of consumption thereof and an increase in awareness of the society with respect to health and threats resulting from the application of chemicals in agriculture. Fertilisers fixing molecular nitrogen, biofertilisers used in seed treatment and biofertilisers for grains, fruits and vegetables are dominant on the biofertiliser market. In the EU states there is no legal definition of biofertilisers or specific legal provisions defining their properties. There are, however, legal regulations within the scope of organic farming. The analysed biopreparation may be also applied on the market of soil improvers, whose production in the EU is estimated at around EUR 1.13bn and 3.37 tonnes. The next market is the market of biostimulants driven by the policy emphasizing the popularization of organic products. The largest development of organic farming, which is strictly connected with the application of biofertilisers and biostimulants, is observed in Spain, Italy, Germany, Great Britain and Poland. It should be indicated that in many reports there is information on high biofertiliser market saturation in the European Union which may constitute a problem in entering the market with new products. The key matter may also be price competitiveness [5].

SWOT analysis of the technology

The SWOT analysis of the technology was carried out. The strengths include: having a good product concept, potentially high profitability of activity, proecological solutions – beneficial impact of the solution on soil quality that is directly used by the final consumer of the product. Additionally, the product is based on bacteria appearing in the natural environment in Europe, which results in higher efficiency and sustainability of the solution in our climatic conditions. Moreover, the form of the solution has positive influence on the application over smaller areas, slow releasing, longer activity, potential favourable impact of solutions on the profitability of recipients, innovative technologies, combining experiences from different industries [5, 6].

The SWOT analysis (Tab. 1) also reveals the weaknesses: start-up project: the lack of knowledge on the industries, the lack of established business relations, limited financial resources, future dependencies on key recipients, employees and suppliers, the necessity to conduct further research on the developed solutions requires substantial funding, the necessity to broaden the possibilities of application through the development of alternative product forms (hard shell, or liquid form).

Table 1. The SWOT analysis of the studied solution

Strengths	**Weaknesses**
▪ Having a good product concept, ▪ Potentially high profitability of the activity, ▪ Proecological solutions – the positive impact of the solution on soil quality which is directly used by the final consumer of the product, ▪ The product is based on bacteria appearing in the natural environment in Europe, ▪ Higher efficiency of the solution, ▪ Sustainability of the solution, ▪ The granular form of the solution has positive influence on the application over smaller areas, ▪ Slow releasing, longer activity, ▪ Potential favourable impact of the solutions on recipient profitability, ▪ Innovative technologies.	▪ Start-up project: the lack of knowledge on industries, the lack of established business relations, ▪ Limited financial resources, ▪ Future dependency on key recipients, ▪ Future dependency on key employees, ▪ Future dependency on suppliers, ▪ The necessity to conduct further research on the developed solutions requires substantial funding, ▪ The necessity to broaden the possibilities of application through the development of alternative product forms (hard shell, or liquid form), ▪ Difficult production of biopreparation, ▪ Poor microbiological knowledge of potential users, ▪ High cost of product ▪ Lower efficiency than chemical agents.

Opportunities	Threats
▪ Prospective, niche market, ▪ Limited competition on the market of products for bioremediation in Poland, ▪ Favouring proecological solutions by legislature, ▪ "Bio" product lobby by the media, ▪ The possibility to obtain Union funds for the implementation of proecological solutions.	▪ Strong competition with respect to foreign players, especially on the fertiliser and plant protection product market, ▪ Stronger competition after the launch of innovative solutions, ▪ The lack of knowledge as to the market reaction time of waiting with reference to the developed solutions, ▪ The lack of interest in the product offer.

Source: Author's

Market analysis

For efficiency purposes, understood as a potential profitability of commercialization of research findings, it is recommended that the path based on the establishment of a spin-off company and the commercialization of research findings on the basis of licence sales be applied. The market analysis indicated that in the case of biopreparations for agriculture, the largest amount of patents is in the possession of the Swiss company Syngenta AG, specializing in the production of agrochemicals. If there is a wish to expand the scope of invention protection, there is a high probability to obtain a European patent in EPO. It is, however, not recommended to cooperate on the basis of know-how sales due to the risk of knowledge acquisition on the technological specification. The conducted analysis of companies acting on the fertiliser and plant protection product market results in the observation that there are many enterprises characterized by the proecological approach, offering preparations that have positive influence on the natural environment [5, 7] .

Currently, the growth of the global biofertiliser market is observed as it is driven by, above all, the growth of the organic food industry. A different factor is connected with the promotion of organic food and farming by government agencies. According to Grand View Research, the key factors for the development of the market and the growth of demand for biofertilisers till 2020, especially in the USA and the European Union, are legal regulations. A global fertiliser market growth is estimated from 2014 to 2019 up to USD 1.65bn in 2019 (CAGR at the level of 13.9%). Transparency Market Research estimates a growth with a slightly lower CAGR (13%) up to USD 1.03bn in 2019 [5].

The conducted analysis of technology application proves that the potential of generating revenues from product sales with the application of biofertiliser production technology is relatively high. Basically, the main limitation of generating revenues from the developed technology is the accessibility of funding sources of investment outlays. The product may be dedicated to bulk consumers, large agricultural, horticulture and fruit farms [8]. Large entities also possess the potential to alternatively mass produce the developed solution. Bulk customers, large agricultural, horticulture, and fruit farms will be interested in the product, which may be relatively easy in application over a vast area by means of agricultural machinery. This functionality is guaranteed by preparations developed, e.g., in hard shell or liquid form. The aim of further research and development activities will be connected with working on a product form which will be competitive for bulk customers. It should be noted that currently available products on the biofertiliser market are present in the formula of easy-to-apply products. The existing product forms is, therefore, an essential factor limiting the application of the product in the area of bulk customers, but it does not limit the sales of the preparation to non-bulk customers, including, above all, small agri-horticultural farms, households. First of all, investors should be sought among:

Firstly, national entities – they may consist of both the domestic enterprises from markets characteristic for the analysed investments, as a rule they have small and medium scale of operation, as well as trading companies, operating within the frames of large industry corporations, dealing with the distribution of products on the Polish market (they always facilitate the process of reaching out to the parent company in contrast to the direct reaching out to holding companies).

Secondly, companies with small and medium scale of operation – i.e. entities generating at least several million from trade and achieving profitability of the operation – as these companies have limited research resources,

and they are characterized by a higher tendency to invest in "foreign" technology, and it is easier to reach them.

With the aim of achieving efficiency understood as a potential profitability of the commercialization of research findings, it is recommended that the path based on the establishment of a spin-off company be introduced. When founding this company, it is necessary to take actions that are to attract investors to the venture, who will ensure funding of the project and limit the risk level. It should be noted that licensing and the sale of invention rights will apply, most of all, after laboratory work has been finished, full product characteristics has been developed and which has been at least in part verified from the practical perspective. In the case of the analysed technology, three crucial research and development works are to be conducted in the next two years. Only after they are commenced and when they are significantly advanced, it will be possible to start searching for investors interested in purchasing the license of the technology or rights thereto. It can, however, be expected that establishing full cooperation with an investor will be possible after this stage is finished or when the investor will seek to link the remuneration on the account of technology licensing with the results of these works to which the university will be obliged. The sale of the rights before the end of this stage is unlikely. The data analysis of the funded companies of the studied sector indicated that the average EBITDA margin is equal to approximately 17%, and the net profitability is 13% (median 11%). These value are only of informative nature as: i). the test of companies in the analysis is relatively small which results from limited access to data and a relatively low number of companies typically dealing with bioproduction in these sectors, ii). the structure of profit generation in the analysed enterprises is not known in detail. The preliminary economic forecast, conducted for the years 2019 – 2021, indicated that prospective introduction of the developed technology in a business activity has large potential. Key areas of competitive advantage have also been defined.

Key factors of the potential success of the developed venture pertaining to the production of the analysed preparations are:

- high qualifications of technology creators which translates into the quality of the developed solution,
- two alternative possibilities of product application lowering the effects of the lack of unfavourable product reception by one of the sectors for an effective investment,
- positive effect of the products on the natural environment:
- rising significance of proecological products in different areas of economy ,
- rising awareness of the society regarding the necessity to protect the environment and the possibility to substitute chemicals with proecological preparations
- linking the offered products with segments seen as attractive from the investment point of view facilitates access to funding sources,
- access to a laboratory centre and team,
- proecological policy of legislature,
- high efficiency of the developed solutions in comparison to substitutes,
- production based on modern but relatively easy equipment base,
- innovative technologies,
- potential connection of experiences from different industries.

Summary and conclusions

The conducted analysis on the application of the technology states that the potential of revenue generation from the sale of products involving the technology of biofertiliser production is very high. The financial analysis proves that only the construction of a company characterized by a large scale of operation leads to the generation of a positive return on equity. The main barrier connected with entering the market of biopreparation production is the development of a concept of producing such preparation, and the commercialization of research findings in the area of biofertilisers is possible. The conducted analysis of sector companies indicated that the production of these preparations is profitable. The offered product is consistent with the recent market demand, inter alia, due to its "environmental performance" and an increased efficiency. It is therefore essential to take action to obtain financing, at the initial stage in the creation of a production installation and to carry out very costly marketing activities and the construction of a sales network. The analysed solution provided grounds to state that the commercialization of research findings in the area of biofertilisers is possible.

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ASSESSMENT OF MANAGEMENT PATHWAYS OF BY-PRODUCTS FROM BIOMASS COMBUSTION USING BATNEEC OPTIONS

Abstract
The paper presents a methodology for evaluating the Best Available Techniques Not Entailing Excessive Costs (BATNEEC) options for the management of by-products from biomass combustion - ash. Biomass ash BA was collected from Green Energy Block in Połaniec (Poland). Four variant of BA disposal were analysed: 1st - the storage of BA on conventional municipal waste landfills; 2nd, 3rd, 4th - use of BA for fertilisers production (2nd – 70% of BA, 3rd - 45% of BA, 4th - 90% of BA). Technical, environmental and economic consequences of the actions in the field of waste management technology were considered. BATNEEC evaluation indicated that the collected BA on dump (1st variant) is technical, environmental and economic inefficient, this solution has received lowest score - 29 points. The 2nd, 3rd and 4th variants have received 124, 113 and 30 points, respectively. This indicates that there are quantitative restrictions on substitution of nutrients in mineral fertilisers. Due to the possibility of secondary pollution during waste usage in agriculture, the use of BA in fertiliser products requires compliance with environmental rules - only the nutrient rich and rather heavy metal poor fractions of BA shall be used for fertilising and soil improvement purposes.

Key words
renewable energy sources (RES), biomass ash (BA), Best Available Techniques Not Entailing Excessive Costs (BATNEEC)

Introduction

One of the primary objectives of a country's economy is providing energy security, guaranteeing no risk of interruption of fuel and energy supplies. Such activities are mainly based on the supply diversification of imported fuel (alternative sources) and the development of production capacity from deposits located on own territory. The fulfilment of this objective leads to enable the economic and civilization development. Moreover, the environmental requirements and the European Union (EU) decision to decrease the share of the imported fuels in the Europe's energy balance promote the possibilities in the usage of local energy sources in accordance with the best practice of the environmental protection technologies [1].

In Poland, according to current legislation, energy policy is defined in the Act on Energy Law [2], which specifies it as a rules of energy policy, a terms and conditions for supply and fuels and energy usage, including heat, and activities of energy companies, an indication of the authorities responsible for fuel and energy (Journal of Laws 2006. No 89, item 625). In recent years, an expert team (representatives of science, economic chambers, businesses and consumers) has developed a draft "Polish Energy Policy until 2050" (PEP 2050). In the energy balance, an increase in percent of the energy usage coming from renewable sources: 15% in 2020 and 20% in 2030 is indicated.

Renewable energy sources (RES) are becoming popular worldwide [3]. Currently, energy from renewable sources in Poland comes mainly from solid biofuels (80.03%), liquid biofuels (8.20%), wind energy (6.05%) water energy (2.46%) and biogas (2.12%) [4]. Under the Polish conditions, one of the most important and promising RES is biomass. According to European Union (EU) legalisation [5], biomass is a biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste (Directive

2001/77 / EC 2001). In recent years, constant growth in the use of biomass for energy purposes is observed. Permanent renewable sources (wood and other solid biomass) are increasingly used in conventional power plants, mainly in the regions of Northern and Eastern Europe, thanks to the extensive district heating network, combined with the relatively high demand for heat in the winter period and a sufficient supply of biomass. The main advantage of biomass compared to other RES is the availability of it. Despite wind and solar which their availability depends on weather, environmental, technological conditions, biomass is local RES that using its energy does not need any complex technology. Moreover, biomass is compatible with most of current fossil fuel power plants [6]. The use of biomass as energy sources has some other advantages, like [7]:

- disposal of a huge amount of organic waste and recovering energy from it;
- animal manure could also be utilized as fertilizer in agriculture;
- political issues related to fuel dependency of countries;
- decrease of the odour problem;
- economic and social development in rural areas;
- provides new job opportunities.

It should be noted that a consequence of increasing biomass combustion is an increase in the amount of waste generated during this process - combustion residues, mainly in the form of biomass ash (BA). The properties of ash from the biomass combustion, if they are well understood, allow for BA usage for industrial purposes or agricultural [8]. Therefore, an important problem is the analysis and development of modern technologies of BA handling [9], with particular reference to its natural usage. BA is a valuable source of nutrients for plants and it could be an alternative to mineral fertilisers.

In Poland, an example of the power plant fired in 100% by biomass in Green Energy Block (ZBE) in Połaniec. However, there are 35 other installations for thermal conversion of biomass, which generated more than 200 thousand tons of BA per year. This is a huge potential feedstock for use it in the fertiliser industry, according to assumptions of circular economy (CE) model (COM 614, 2015) [10] and 'A zero waste programme for Europe' (COM 398, 2014) [11]. Research and development of sustainable utilisation paths for BA, focused on an optimization and expansion of ash utilisation techniques are required in this area.

This paper presents a methodology for evaluating the Best Available Techniques Not Entailing Excessive Costs (BATNEEC) options for the management of by-products (BA) from biomass combustion in a dedicated fluidized bed boiler from Green Energy Block in Power Plant Połaniec (eastern Poland).

Innovative technology for biomass ash (BA) disposal

In June 2013, power plant Green Energy Block in 100% fired by biomass was opened in Połaniec, eastern Poland. Currently the energy produced in the boiler with power 250 MW is 25% of the total national production of electricity from biomass fuel. It should be emphasized that during the energy production, a large amount of by-products from biomass combustion in a dedicated fluidized bed boiler is generated. The main product of biomass combustion is biomass ash with code 10 01 01 (Journal of Laws 2014, item 1923) [12]. According to the EU [13] and polish regulations [14, 15] that waste must subsequently be disposed of. In view of this fact, there is a large and pressing need for the development of innovative technology for the management of BA. Due to the possibility of disposal of this waste for agriculture purposes, fertiliser production technology based on combustion by-products of biomass was invented in ZBE. Under the project, one production line with following components was created:

- feeding system - belt conveyors, feeders;
- preparatory system - mixer buffer grinder, a homogenizer;
- agglomerating system: granulator with conditioner;
- stabilization system: cooler with a sieve shaker;
- receiving system: belt conveyors, scales and packaging machine.

Technological scheme of the analyzed system is shown in Figure 1.

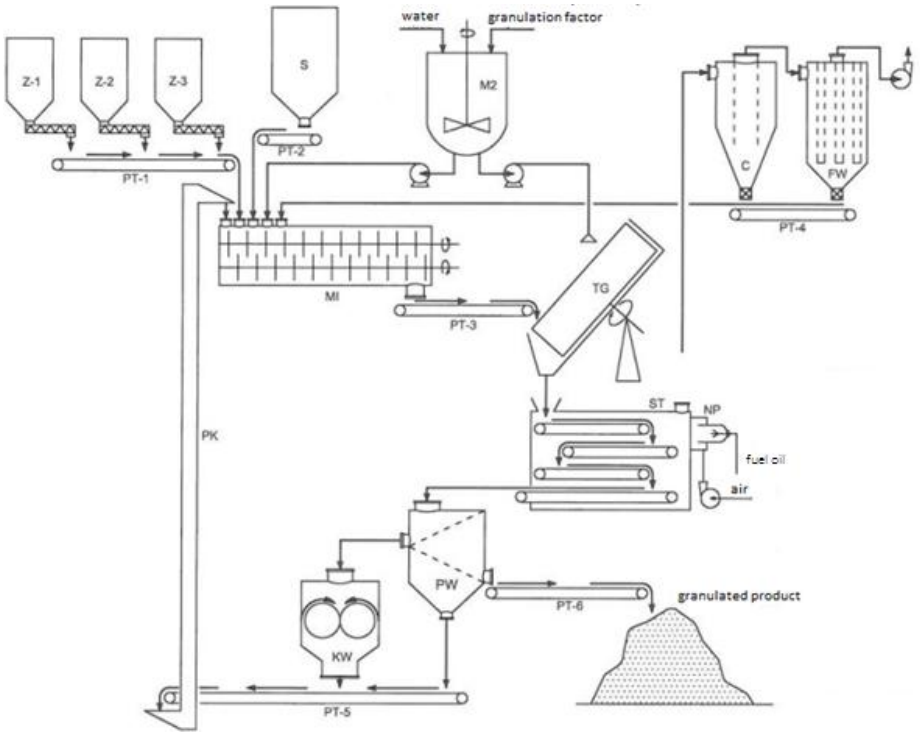

Fig. 1. Technological scheme for the production of fertilizers based on BA (Z-1, Z-2, Z-3 - reservoirs of raw materials, S – silo, MI - intensive mixer, P-1, P-2, P-3, P-4, P-5, P-6 - belt conveyors, PK – bucket conveyor, TG – granulation plate, ST – belt dryer, NP - air heater, PW - vibrating sieve, KW - roll crusher, C – cyclone, FW - bag filter, M2 - mixer of granulation liquid)
Source: Author's

The construction stage of a prototype production line was preceded by performing computer simulations using the application to engineering design CAD (SolidWORKS, AutoCAD, Inventor). The main target of such activities was the elimination of errors and complications, which could have a negative impact on the design of the prototype and the real production process.

Methodology

In order to evaluate methods of BA management, Best Available Techniques Not Entailing Excessive Costs (BATNEEC) options was used. Best Available Techniques (BAT) is most commonly selected and evaluated at the level of the production system and evaluated using expert methods in which the criteria most frequently applied are the technical feasibility of implementation, environmental benefits and economic profitability [16]. BAT include:

- "techniques" - both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- "available" means those developed on a scale which allows implementation in the relevant industrial sector;
- "best" means most effective in achieving a high general level of protection of the environment as a whole.

As BAT plays a key role in industrial sustainability improvement through an increase in energy efficiency, pollution reduction and increasing economic and environmental benefits [17], BATNEEC (which is connected with BAT) methodology was chosen for the assessment of fertilisers production technologies [18]. BATNEEC are the best technologies that represent the minimum hazard for the natural environment, while at the same time maintaining the economic profitability of production, i.e. emissions from installations to the environment should be reduced as much as possible and in the most economically efficient way. The evaluated management technology should be the best in the field of pollution prevention and possible usage for the industrial purposes. Generally BATNEEC concerns the balance between environmental benefits and the incurred costs. In the current study, the technical, environmental and economic consequences of the actions in the field of waste management technology for BA disposal were considered. The methodology for evaluating the technical, environmental and economic effects of new production process with BATNEEC options included: preparing the

topics and areas for action, creation of a problem-approach team, identifying feasible options that can be implemented, defining their specifications, and the evaluation of proposed technological variants according to evaluated options [16].

The first step of the research was to define the criteria for the evaluation of the selected options: technical, environmental and economic consequences. In second step, fourteen evaluation criteria options were indicated:

- Reducing the cost of processing and/or storage of waste;
- Reducing the amount of waste;
- Consistency with the objectives of sustainable development,
- Consistency with the programs of the national economy;
- Consistency with EU programs;
- The degree of adaptation to local conditions;
- Improved relations with consumers;
- Improved relations with the public;
- The investment volume;
- Time and ease of implementation;
- The required legal permits;
- Availability of technologies;
- Ecological assessment method of analysis of the process in terms of cumulative account;
- Assessment of quality technology.

Taking into account the professional knowledge about waste management technologies, an evaluating team of four experts was selected. The experience of BATNEEC evaluation team is presented in Figure 2.

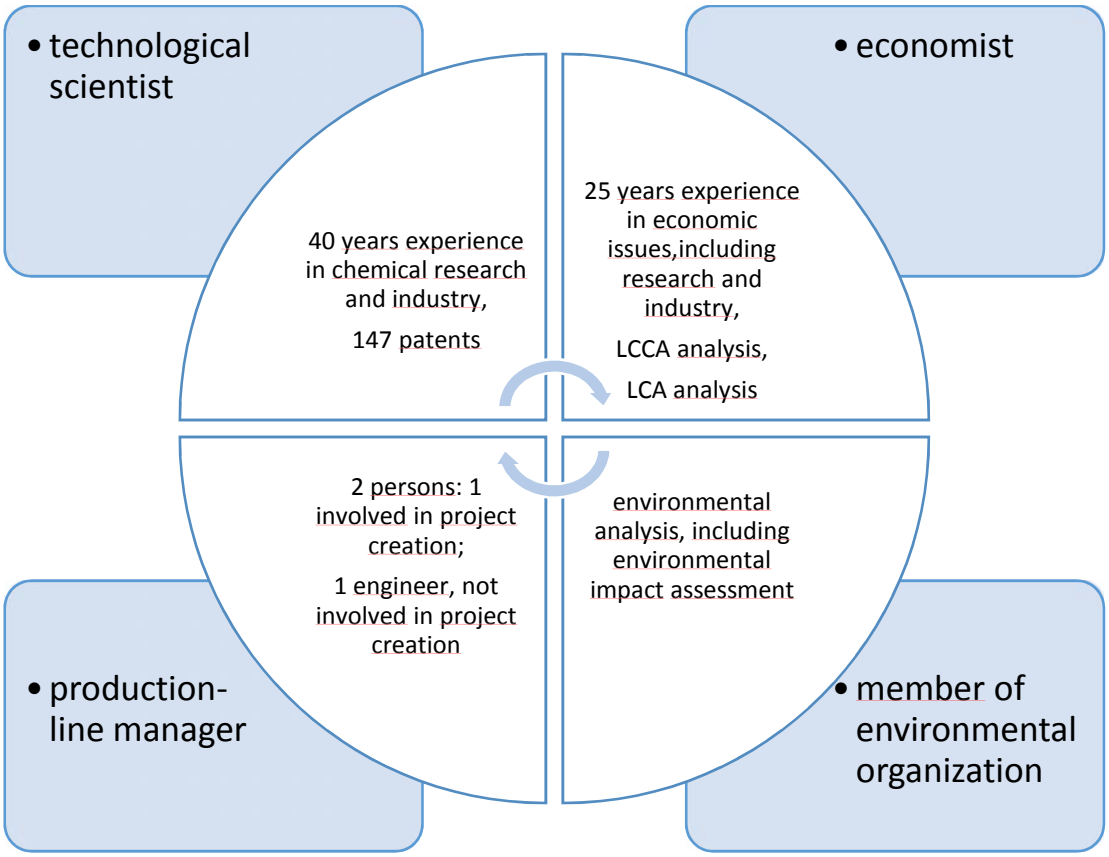

Fig. 2. BATNEEC evaluating team
Source: Author's

The evaluating team included one technological scientist, an economist, a production-line manager, and a representative from an environmental organization. The options studied were scored by the experts on a scale of 0 to 10 points within a given criterion. The maximum rating of one analysed options was 140 points. To facilitate the evaluation, the scoring system was divided into five levels of effect: no effect (0 points), small

effect (1–2 points), medium effect (3–5 points), large effect (6–8 points) and very large effect (9–10 points). From the total score, the an average score was calculated for each criterion (summing up the points and dividing the sum by the number of members awarding points). Total scores of the criteria allowed evaluating and ranking the variants. Ranking of fertiliser production variants permits a proper evaluation and ranking of the technologies used.

The paper presents a methodology for evaluation of the BATNEEC options for the management of by-products from biomass combustion in a dedicated fluidized bed boiler. The main objective of this work was to compare base situation - lack of production with three variants of fertilisers production based on BA. The control situation (disposal of BA on dump) was compared to three variants of fertiliser production, with varying content of nutrients in manufactured products. The following variants were taken into account:
1st variant - a management of BA on conventional municipal waste landfill;
2nd variant – a fertilisers production based on BA: 70% of BA in mass of fertiliser product;
3rd variant – a fertilisers production based on BA: 45% of BA in mass of fertiliser product;
4th variant – a fertilisers production based on BA: 90% of BA in mass of fertiliser product.

Results and discussion

This paper presents the methodology for evaluating the options BATNEEC storage of ashes from the biomass burning and production fertiliser based on BA. The scope of work included the selection of options and criteria for their evaluation. This methodology of assessing of BA management variants with use the BATNEEC options provided the basis for the selection of the options and defined the criteria for their evaluation. The BATNEEC options for the assessment of the BA storage and fertilisers production are described in Table 1.

Table 1. The waste management solutions for biomass ash criteria and evaluation of each option BATNEEC

		Consequences		
Variant	**Solutions**	**Technical**	**Environmental**	**Economic**
1st	Storage of ash from biomass combustion (BA)	A non-refundable loss of raw materials	Storage of BA. The negative impact on the local environment	High costs of BA storage
2nd	Production of fertiliser no. 1 based on ash from biomass combustion (BA)	Use all the products of biomass combustion. Recovery - recycling of raw materials from the BA	Out-of-process recycling of combustion products. Recycling and re-use of raw materials from combustion products. The substitution of natural resources by waste. Elimination of BA storage	Elimination of the high cost of storage. Reduction of energy costs. Income from the sale of fertiliser product
3rd	Production of fertiliser no. 2 based on ash from biomass combustion (BA)	Use all the products of biomass combustion. Recovery - recycling of raw materials from the BA	Out-of-process recycling of combustion products. Recycling and re-use of raw materials from combustion products. The substitution of natural resources by waste. Elimination of BA storage	Elimination of the high cost of storage. Reduction of energy costs. Income from the sale of fertiliser product
4th	Production of fertiliser no. 3 based on ash from biomass combustion (BA)	The use of micro-elements affects a higher solubility in water. Irretrievable loss of raw materials	An adverse impact on the environment through BA storage	Minimizing the cost of BA transport and storage

Source: Author's

The next step in the procedure was the selection of criteria for the evaluation of selected options. This evaluation has a qualitative character. In order to facilitate the assessment of the options, the scoring division on five levels including the zero effects (0 points), small effects (1-2 points), medium effects (3-5 points), large effects (6-8 points) and very large effects (9-10 points) was introduced. The maximum score for each option can reach 140 points. This criteria are universal and can be used after appropriate adaptation to the needs of any process. The results for 1st and 2nd variants are shown in Table 2.

Table 2. Criteria and evaluation of BATNEEC options for analysed variants

		Variants			
No.	**Criteria ratings**	1st	2nd	3rd	4th
1	Reducing the cost of processing and/or storage of waste	0	9	10	0
2	Reducing the amount of waste	0	10	10	0
3	Consistency with the objectives of sustainable development	0	10	10	2
4	Consistency with the programs of the national economy	0	10	10	0
5	Consistency with EU programs	0	10	10	4
6	Degree of adaptation to local conditions	1	9	9	2
7	Improved relations with consumers	1	9	9	2
8	Improved relations with the public	1	9	9	2
9	The investment volume	10	4	4	0
10	Time and ease of implementation	3	4	4	10
11	The required legal permits	3	4	4	0
12	Availability of technologies	10	10	10	4
13	Ecological assessment method of analysis of the process in terms of cumulative account	0	8	7	2
14	Quality technology assessment	0	8	7	2
Total score [points]		**29**	**124**	**113**	**30**

Source: Author's

The highest rated options refer to solutions with very high environmental and economic efficiency, consistent with the objectives of sustainable development (SD). The 2nd and 3rd variants related to the fertiliser production based on biomass ashes have received 124 and 113 points, respectively. This two variants can be regarded as the best available techniques from the analysed solutions. The 4th variant received only 30 points. This indicates that there are quantitative restrictions on substitution of nutrients in mineral fertilisers. The evaluation indicated that the collected biomass ashes on dump (1st variant) is technical, environmental and economic inefficient, this solution has received lowest score - 29 points. It should be also mentioned that due to the possibility of secondary pollution, as in the case of sewage sludge usage in agriculture, the use of BA in fertiliser products requires compliance with environmental rules. That's including the monitoring of heavy metals content - only the nutrient rich and rather heavy metal poor fractions of BA shall be used for fertilising and soil improvement purposes. Moreover, the technology of BA management must comply with legal requirements and be economically viable for the producer of fertilisers. Potential investors should use the BATNEEC options results for evaluation of technological solutions in waste management, especially as the results obtained conform to those proposed in the EU waste hierarchy (Directive 2008/98/EC) [13] and circular economy model (COM 614, 2015) [10].

The proposed technology of BA management could be considered as eco-innovativeness. In EU countries for years there have been grants or loans for environmental project available from the national funds (such as the

National Fund for Environmental Protection and Water Management in Poland), and, recently, also from the EU funds (e.g. Structural Funds) [19], the business operators fund the majority of such projects with their own resources. Supporting eco-innovative projects designed to reduce negative environmental impacts, at every stage of the product life cycle, requires the development and implementation of rules for their evaluation, taking into account the technical feasibility, economic and ecological efficiency, and consideration to social aspects [20] potential beneficiaries which will take into account whole life cycle in the investments projects, in accordance with the 'zero waste' strategy will be in the first place supported by European funds at the national and international level in new programming period 2014-2020.

The results obtained in study are easy to interpret and could be used as a tool for communicating with the public, supporting Corporate Social Reasonability (CSR) of the company. However, due to the fact that the ash from the combustion of biomass is a waste, its safety application in agricultural industry requires extensive knowledge based on the results of experimental research, taking into account environmental and technical aspects as well as legal regulations.

Conclusions

BATNEEC option methodology is a useful tool for comparing the methods of waste management, including biomass ash (BA). The result of BATNEEC analysis was the ranking of the alternative types of waste management technologies analysed, from the most to the least favourable variants, taking into account technical, environmental and economic aspects.

All studied variants (2^{nd}, 3^{rd}, 4^{th}) related to the production of fertilisers based on BA were selected as much more beneficial than collection biomass ashes on dump (1^{st} variant). Among the assessed variants, two options (2^{nd} and 3^{rd}) related to the production of fertilizers (respectively 89% and 81% of the maximum 140 points) were highest rated. This two variants can be regarded as the best available techniques from the analysed solutions.

The assessment of 1^{st} variant related to the BA storage on dump was the lowest (21% of maximum score) - this solution should be avoided. Due to the possibility of secondary pollution of environment, the use of BA for fertiliser purposes requires compliance with environmental rules. The disposal of BA is a problem of secondary waste treatment and there is a large and pressing need for the development of methods for the disposal of this waste.

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